Essays in pension underfunding

The case of the U.S. state pension funds

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Zina Lekniūtė

Essays In Pension Underfunding: The Case Of The U.S. State Pension Funds

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ESSAYS IN PENSION UNDERFUNDING: THE CASE OF THE U.S. STATE PENSION FUNDS

ACADEMISCH PROEFSCHRIFT

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October 2019, Amsterdam.

Contents

Chapter 1

Introduction

The crisis that shattered financial markets in the U.S. and around the globe a decade ago brought much more media attention to the financial situation of the U.S. pension plans. The pension funding, calculated as the ratio of pension assets to liabilities, dropped to levels such as 70% (and in many cases lower) even when calculated at generous discount rates of expected returns. Several cities, Detroit being the most infamous case, filed for bankruptcy protection attempting to also lower their pension obligations in the process. Suddenly the underfunded pension systems seemed like a much more immediate problem.

U.S. public pension plans are in underfunding because of recent financial shocks, but also various political agendas interfering with good pension management. The political interests manifest in suboptimal investment returns (Andonov et al. 2018), oftentimes poor and inadequate contributions (policymakers failing to pay both the full base actuarial contribution and the additional contributions required to cover adverse financial shocks), as well as the generosity of benefits being shortsightedly increased in good times without having the option to bring the generosity back in case of adverse investment outcomes or in the face of increased longevity.

The second chapter of this thesis, "U.S. municipal yields and unfunded state pension liabilities", is based on Lekniūtė, Beetsma, and Ponds (2019) and provides an overview of the funding situation across the U.S. states. Plans in some states are doing fairly well, whereas in others they have already gotten into trouble, like the infamous Detroit bankruptcy case where pensioners had to take a cut along with the bondholders. Yet even the best performing plans might deserve some concern given their high discount rates that make the situation look better than what it would look like if the risk-free rates were used. Given the substantial aggregate mismatch between the plans' assets and liabilities, the chapter continues with an investigation of how this implicit pension debt affects the state's costs of borrowing. It is well established in the literature that investors require higher compensation for lending to entities that have a higher outstanding debt. We show that the relationship also holds for the implicit debt accumulated in pension plans, as states with more underfunded pension plans have higher yields, all else constant. Curiously, however, this relationship is only visible for the time period starting with the financial crisis, suggesting that the experience of such a financial turmoil might have made investors more aware of the underfunding problem.

Many states, very well aware of the future challenges of fulfilling the current pension promises, have implemented changes in their policies meant to curb the underfunding. Most have focused on increasing the contributions or limiting the cost of living adjustments, which are easier to defend if legally challenged. In the third chapter of this thesis, "A value-based assessment of alternative US state pension plans", which is based on Lekniūtė, Beetsma, and Ponds (2018), we explore the financial and redistributive aspects of such pension reforms meant to deal with the underfunding within the defined benefit framework. We find that measures such as increasing the proportion of required amortization amount paid, shortening the amortization horizon, increasing the participants' contribution, halving indexation ambition or making indexation funding ratio dependent, are unlikely to ensure a long-term stability of the pension system, though they slow down the deterioration of the fund's financial health.

In contrast to the parametric reforms covered in the third chapter, the fourth chapter, "This plan is different? Transitioning from underfunded DB plans", explores structural pension system reforms, which is another way of addressing the underfunding problem. One such reform is closing the existing defined benefit plan and starting up an alternative defined contribution system instead. While it is not a mainstream solution, some states have already chosen for such a way forward, resembling somewhat the course that pension plans of private companies took in recent decades. As an alternative to the defined contribution plan we also explore a notional defined contribution solution. This is an alternative that lies in between the current defined benefit plans and the defined contribution plans which some states already pursued, in a sense that pension accrual resembles DC but returns are notional and the asset buffer is collective like in the current DB. If we view this NDC system as a pay-as-you-go system, this allows us to convert the funding deficit from the underfunded DB system to an asset buffer in the NDC system. We also look at how different levels of closing the DB system – whether closing it only for new entrants or for new accrual of existing members too – affects the balance between the tax payers and participants. Each such transition causes intergenerational transfers among tax payers and plan participants.

In the end there is no free lunch. Policymakers might be able to continue with inadequate contributions for a while without an immediate problem – if circumstances allow, pensions can still be paid from the existing reserves for many years. However, it comes at the cost of the future tax payers who will have to fulfill pension promises when reserves are depleted, and, as the second chapter shows, also at the cost of current taxpayers in the form of more expensive debt. This also keeps the often unaware plan participants at risk of unexpected severe cuts. Concrete measures taken in a transparent way could help prevent this from happening.

Chapter 2

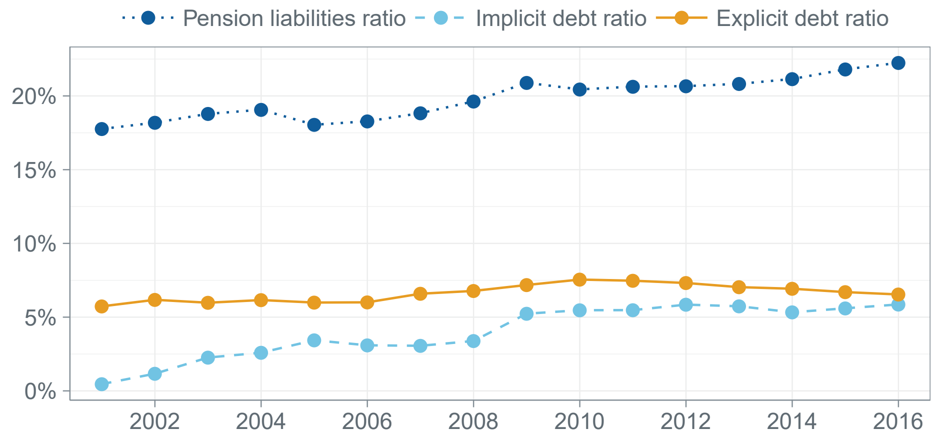
U.S. municipal yields and unfunded state pension liabilities

2.1 Introduction

Both theory and empirical evidence (e.g., Ardagna et al. (2007)) suggest that interest rates rise with public indebtedness. However, the empirical evidence refers primarily to the effect of central or general government debt on sovereign borrowing yields. Evidence on how U.S. state level debt affects borrowing yields is relatively sparse, and this is even more so for the unfunded pension liabilities, i.e. the difference between pension liabilities and pension assets, of U.S. states towards their civil servants, even though these unfunded liabilities tend to be of a magnitude comparable to the explicit public debt (see Figure 2.1), and their legal protection is allegedly high (Munnell et al. (2014a)). Henceforth, we will refer to the former as the "explicit debt" and to the unfunded pension liabilities as the "implicit debt". The implicit debt arises from the defined benefit character of the state civil servants' pensions. Over their working life civil servants accumulate entitlements to future pension benefits. However, the value of these entitlements tends to exceed the accumulated pension capital, thereby resulting in unfunded pension liabilities. Depending on their degree of legal protection, high unfunded pension liabilities may threaten the full repayment of the state's explicit debt as well as the provision of public goods.

In this paper we explore how U.S. states' implicit debt affects yields on explicit municipal debt. We compare the effect of higher implicit debt with that of an increase in the

Figure 2.1: Median state debt and (unfunded) pension liabilities



Note: The figure shows the development over time of three debt measures expressed as a percentage of gross state product: actuarial pension liabilities aggregated over the state pension funds (the "pension liabilities ratio"), unfunded actuarial pension liabilities (the "implicit debt ratio"), calculated as the difference between the actuarial pension liabilities and actuarial pension assets, aggregated over the state pension funds, and the explicit state debt (the "explicit debt ratio"). Actuarial liabilities are the liabilities calculated on the basis of the fund's actuarial assumptions. Reported actuarial assets smooth out fluctuations in the market values of the assets. The dots represent the median values over the states in each year. Data source: Public Plans Database of the Center for Retirement Research at Boston College (2018).

explicit debt. Our sample is dictated by the availability of data on state pension funds, and comprises a panel of all U.S. states over the period 2001 - 2016.

In line with what cross-country empirical analyses usually find, we confirm the positive link between the state explicit debt ratio and municipal debt yields.[1] Moreover, controlling for the state explicit debt ratio, we find that an increase in the implicit debt ratio also exerts a significant positive effect on state municipal yields. However, the effect of a one-percentage point increase in the implicit debt ratio is significantly smaller than the effect of an equal increase in the explicit debt ratio. Further, the positive yield effects of both a higher explicit and implicit debt burden are concentrated in the period since the start of the global financial crisis, which may have triggered an awareness of potential default

[1]Unless explicitly stated otherwise, a "ratio" stands for the share of the gross domestic product or the gross state product, whichever is relevant.

losses, and persist throughout this period, also when the crisis is over.[2] This finding is in line with what tends to be found in other financial markets, such as that for euro area public debt, where spreads between the core and periphery countries went up dramatically since the eruption of the crisis.[3] We use a number of variations on our baseline regression to confirm the robustness of our findings. These leave the baseline estimated effects of the implicit and explicit debt ratios on municipal yields unaffected.

Our findings are of potential importance, because recent years have witnessed a steady across-the-board increase in unfunded state pension liabilities. Because there is often no obvious seniority ranking between the explicit and implicit municipal debt, it is a priori not always clear what the eventual consequences are of a rising implicit pension debt for other state expenditures, such as public consumption and investment. However, the estimates suggest that since the start of the crisis an increase in the implicit debt ratio does reduce the room for other state expenditures, but the effect is less than that of an equal increase in the explicit debt ratio. This likely reflects the perception of market participants that when fiscal pressure gets sufficiently high, ways will be found to curb the state pension debt. The careful documentation by Brainard and Brown (2018) of the state-sector pension reform measures over the period 2007 - 2018 supports this hypothesis. Among the possible instruments are reduced cost-of-living adjustment, higher contributions, reduced benefits and raising the retirement age.

Closest in spirit to our paper is Novy-Marx and Rauh (2012). They estimate the effect of a change in unfunded pension liabilities by regressing municipal bond yields on reductions in the value of pension assets during the last quarter of 2008 when asset markets were most shocked by the global financial crisis. They find a 7 - 15 basis points positive effect on municipal yields for an increase in unfunded pension liabilities equal to 10 percent of state revenues. Using a different dataset and methodology we find an implicit debt effect of roughly the same order of magnitude as in Novy-Marx and Rauh (2012). However, our data allow us to explore important aspects of the implicit pension debt that are not addressed by Novy-Marx and Rauh (2012).[4] The first is the explicit comparison of the

[2] Aubry et al. (2017) suggest that only after the start of the crisis unfunded pension liabilities started to matter for spreads (relative to Treasuries) of state and local debt, and indicate that a likely explanatory factor has been the increased attention of credit rating agencies to unfunded pension liabilities.

[3] For example, see Beetsma et al. (2013), Mohl and Sondermann (2013), Bhanot et al. (2014), Santis (2014) and Monfort and Renne (2014).

[4] In some dimensions our data is less detailed than theirs. The debt instruments included in our yield index contain pre-refunded and non-prerefunded bonds, as well as bonds that may or may not be called before maturity date. As the index is based on a large fraction of the outstanding state debt, effectively we estimate, for given composition of the outstanding debt, the effect of an increase in the implicit debt ratio on a state's average marginal borrowing cost. The latter includes the effect of changes

effect on municipal yields of equal increases in the implicit and explicit debt, which helps us to assess the relative importance of the two sources of debt for other state spending. The second is that we can show that their positive yield effects are present only after the start of the crisis and persist after the crisis has vanished. Novy-Marx and Rauh (2012) instead provide a picture of the effect of the implicit pension debt only during the early stages of the crisis.

Our paper also connects to other strands of the literature. First, while evidence on the relationship between explicit state debt and municipal yields is relatively rare - an early exception being Hastie (1972), there is more evidence on the analogous relationship between the yield on national debt and its size. Examples are Ardagna et al. (2007) and Beetsma et al. (2017) for panels of OECD countries and Baldacci and Kumar (2010) for a panel of advanced and emerging market economies. Other recent contributions are Aisen and Hauner (2013) and Poghosyan (2014). A second strand is that on budgetary transparency, pioneered by Alt et al. (2006) at the U.S. state level and Alt and Lassen (2006) and Alt et al. (2014) for the OECD and Europe. Reck and Wilson (2006) establish that municipal bond prices incorporate relevant information when it becomes available.[5] Further, in spite of the seemingly low transparency about the implicit pension debt (see Ponds et al. (2011)), Bohn and Inman (1996) fail to find evidence that tighter budgetary restrictions encourage states to substitute deficits with higher implicit debt. A third strand focuses on the financial health of the U.S. state pension sector. Novy-Marx and Rauh (2011), Munnell et al. (2013), Novy-Marx and Rauh (2014b) and Lekniūtė et al. (2018) focus on funding gaps in the sector. Other contributions include Munnell et al. (2008a) and D'Arcy et al. (1999). A final strand explores the degree of legal protection of pension liabilities (e.g., see Munnell and Quinby (2012) and Monahan (2012)).

The remainder of this paper is organized as follows. Section 2.2 presents a descriptive analysis of the dataset, while Section 2.3 turns to the empirical results. Section 2.4 discusses the potential mechanisms behind our main results. Finally, Section 2.5 concludes the paper.

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in the expected cost of default as well as potential changes in the liquidity premium. Disentangling these effects is beyond the scope of this paper, as it would require data on actively-traded credit default swaps, which, according to information directly obtained from Bloomberg, are not available for our full sample of states and years.

[5]Analogously, Jin et al. (2006) find that equity risk reflects the risk of a firm's pension plan.

2.2 Data sources, variables and key statistics

2.2.1 Data sources

Our data are obtained from several sources. First, we use the Public Plans Database (PPD) of the Center for Retirement Research at Boston College (2018) to obtain historical time series on assets, liabilities, unfunded liabilities and funding ratios of pension plans in each U.S. state. The funding ratio is defined as the ratio of pension assets over liabilities. The data are annual and run from 2001 until 2016. They cover over 150 public pension plans, representing 90 percent of aggregate assets and plan membership of the civil servants' pension sector in the U.S. For our analysis, we select only state level pension plans, thus excluding local plans. This leaves us with a sample of 114 plans, which covers around 90% of the aggregate assets and liabilities of the PPD. Hence, our empirical analysis captures roughly 80% of the U.S. civil servants' pension sector. A priori there is no reason to believe that the excluded funds are systematically different from those retained in the sample, except that they are usually very small.[6] Given that the database covers almost the entire public pension sector, in the sequel we take all the quantities calculated at the state level as representative of the entire state. Second, we obtain historical time series on gross state products (GSP) and state debt from Chantrill (2018).[7] Third, and finally, we obtain monthly financial data, in particular Treasury and municipal bond yields, for each state from Barclays (2017). The time period and frequency underlying our empirical analysis are determined by the available data on state pension plans.

2.2.2 Main variables and their definitions

Many states feature more than one civil servants pension fund. Hence, in calculating our various measures of a state's pension assets and liabilities, we aggregate the assets and liabilities across all the funds at the level of a given state. A state's funding ratio is then obtained as the ratio of the state's pension assets over its liabilities, and the unfunded liabilities are calculated as the difference between the state's pension liabilities and assets.

Unless explicitly stated otherwise, for all variables we use their end-of-fiscal-year values. The main variables (almost) directly obtained from our data sources are:

[6] A sensitivity analysis in which we include also the local pension plans leaves the results unchanged.
[7] These data were gathered from reports from official government sources. Some data points were randomly checked by us to confirm their reliability.

- YM_{it} = municipal yield. The Barclays Municipal Bond Index for each state is a broad-based benchmark, which is designed to reflect the entire market and which measures the investment grade, US dollar-denominated, fixed-interest tax-exempt municipal bond market. It is a market-value weighted index engineered for the long-term tax-exempt bond market, with an average maturity of 14 years. To address potential liquidity concerns it only includes bonds that have at least $7 million outstanding, are issued as part of transaction of at least $75 million and have at least one year remaining until maturity. Taxable municipals, floating rate bonds and derivatives are excluded. The yield index we use is calculated as "yield-to-worst", which is the default (and only) type published, and which is the minimum of the "yield-to-maturity", i.e. the yield calculated assuming the bond is kept until maturity, and the "yield-to-call", i.e. the yield assuming the bond is called by the issuer at the first possible call date;

- YT_{it} = yield on federal Treasury debt. We consider public obligations of the U.S. federal government with a remaining maturity of one year or more. The average remaining maturity is nine years. The state dimension in the subscript arises, because we take end-of-the-fiscal-year yields, while the fiscal year end varies across the states. Of course, the year-t Treasury yield is the same for states with identical fiscal years;

- FRa_{it} = the state's "actuarial pension funding ratio" as reported in the PPD, calculated as the state's actuarial pension assets over the state's actuarial liabilities. Actuarial pension assets depend on their own lagged value, net money flows (contributions minus benefit payments) and the returns on the existing assets. Essentially, they smooth over time the fluctuations in the market values of the assets. The actuarial liabilities are calculated as the present value of the future pension payments projected on the basis of the fund's actuarial assumptions;

- $IDRa_{it}$ = the "actuarial implicit debt ratio", i.e. the state's pension plans' unfunded actuarial liabilities, calculated as the difference between the state's actuarial liabilities and the state's actuarial assets, divided by its gross state product (GSP);

- EDR_{it} = the state's "explicit debt ratio", i.e. the state's outstanding explicit debt as a ratio of its GSP. Explicit debt is defined as the face value of the outstanding debt in current dollars, i.e. the amounts outstanding reflect the value when issued, less current and prior year retirements. In particular, the debt is not adjusted for price level changes. See U.S. Bureau of the Census (2006), Subsection 6.2.2.[8]

2.2.3 Making liabilities comparable across states

The liabilities reported in the PPD are the actuarial liabilities. A potentially important issue is the imperfect comparability of the financial health of the state pension funds when the financial health is measured by the officially reported figures. Therefore, to maximize comparability we recalculate ("uniformize") the pension fund liabilities on the basis of some common assumptions.

Pension funds have substantial discretion regarding their actuarial assumptions and, in particular, regarding the rate at which they can discount their future benefit payments. The latter is usually based on the expected return on their assets. However, because expected returns are unobservable, assumptions about the expected returns differ widely, so that naturally there is leeway in the choice of the discount rate to calculate the fund's liabilities.[9] Hence, different plans may apply different discount rates to calculate their liabilities. However, from a theoretical perspective applying different rates to discount future benefit payments would only be justifiable if the risks associated with the pension benefits are different. A priori we have no good reason to assume that the various states' pension promises differ in terms of their legal hardness. In our re-calculation of the pension liabilities, we therefore apply the same discount rate across all the states.

Brown and Pennacchi (2015) argue that the correct discount rate is the risk-free rate as future pension promises can be considered to be hard obligations. Accordingly, Novy-Marx and Rauh in their articles (Novy-Marx and Rauh (2009; 2011)) calculate the pension promises using the Treasury yield instead of the actuarial discount rate. Hence, below we will report estimates based on using the Treasury yield to uniformize pension liabilities. However, we will also report estimates based on liabilities calculated using a fixed discount rate of 8%. In practice, this is approximately the median of the expected portfolio returns assumed by pension funds and used to calculate their actuarial liabilities.

[8] U.S. Bureau of the Census (2006) is the U.S. Census Bureau's Government Finance and Employment Classification Manual. It contains the statistical classification categories and definitions that are applicable to the Census Bureau's statistical programs covering government finances and public employment. The actual data is gathered by Chantrill (2018).

[9] In fact, Andonov et al. (2017) find that more poorly funded pension plans tend to take more investment risk, because this allows them to increase the rate at which they can discount future benefit payments, thereby optically improving the plan's financial health.

Using these two alternative discount rates, we obtain a range for the plausible effect of the implicit pension debt on the municipal yield. Hence, our analysis provides us with an order of magnitude of the potential effect rather than some specific point estimate. This approach seems the more appropriate one in view of the fact that we do not know the true amount of risk associated with current and future pensions, which we implicitly allow to range from zero to that on the typical fund's asset portfolio. In fact, many experts would nowadays consider an expected return of 8% on the pension fund's assets to be too high, which suggests that the range we consider for estimated effect on the municipal yield is comfortably wide.

Concretely, to make the liabilities comparable across all states we uniformize the liabilities of each fund as $L^* = L(1 - (r_d - r_a)DUR)$,[10] where L are the fund's GASB liabilities reported in the PPD, L^* are the fund's uniformized liabilities, r_d is the discount rate that we apply to all the pension funds, r_a is the actuarial discount rate applied by the fund and DUR is the duration of its liabilities.[11,12] The discount rate r_d is either the actuarial median of 8 percent or the Treasury yield associated with the bucket for which the maturity range contains the value of the duration of the fund's liabilities.[13] We use the estimates of the durations of the pension liabilities obtained from Rauh (2016). For a small number of plans for which this information is missing we set the duration to 10.4 years, which is the average in Rauh's sample. The liability adjustment means that funds that use an actuarial discount rate higher (lower) than the discount rate r_d will have uniformized liabilities that exceed (fall below) their reported liabilities.

Pension funds use the actuarial value of their assets to report on their funding situation. However, investors are likely to be more interested in the market value of the pension

[10] We use the first-order approximation of the interest rate effect on the liabilities, as this level of precision should be sufficient for our purposes.

[11] The data on the actuarial discount rates in the PPD database are not complete due to some missing observations for certain years in a number of plans. However, across all the cases for which this information is available, the actuarial discount rate is found to be very stable over time for a given plan. Hence, we impute the missing values for the actuarial discount rates with the observations before or after the years for which an actuarial discount rate is missing.

[12] By duration we refer to the modified duration measure which captures the price sensitivity to interest rates.

[13] If all the future pension benefit payments were to take place at the same moment, the maturity and duration of the liabilities would be identical. Obviously, this is not the case. Unfortunately we do not avail of the time profiles of the benefit payments of the pension plans included in our dataset, in which case we could discount benefit streams against the Treasury yields with the corresponding maturities. Hence, our reconstruction of the funds' liabilities is necessarily inaccurate. However, the results are unlikely to be sensitive to this inaccuracy, as applying the same Treasury yield when uniformizing the liabilities irrespective of their duration leaves our results unchanged. Below we also show that our results are unaffected by making counterfactual assumptions about the duration.

assets.[14] Therefore, analogously to FRa_{it} and $IDRa_{it}$, we define:

- FRm_{it} = the state's pension funding ratio obtained by dividing the market value of the state's pension assets by the state's uniformized liabilities as calculated above;
- $IDRm_{it}$ = the state's unfunded pension liabilities calculated as the difference between the state's uniformized liabilities as calculated above and the market value of the state's pension assets, divided by its gross state product (GSP).

2.2.4 Descriptive statistics

Our sample consists of all the 50 U.S. states over the period 2001-2016, although for a couple of states not all financial figures are available for the years 2001-2005. In what comes, it proves useful to not only consider the full sample period, but also the "pre-crisis period" consisting of the years 2001-2006 and the "(post-) crisis period" comprised of the years 2007-2016. This split is motivated by the global financial crisis, the start of which is usually located in the second half of 2007. Table 2.1 summarizes the data pooled across all the observations in our sample. Average annual nominal GSP growth is 3.8 percent over the full sample, which falls in between the substantially higher growth rate of 5.5 percent before the crisis and the 2.8 percent during the (post-) crisis period. The average annual growth rate of building permits, which we include in our analysis because it is generally considered a leading variable for economic activity, is 0.6 percent. Average public spending as a share of GSP is 10.2 percent, while average public revenues as a share of GSP are 9.8 percent. The average municipal yield of 3.5 percent is slightly below the average Treasury yield of 3.9 percent. This likely is the net result of differences in default risk and liquidity, as well as potential differences in the tax treatment of the two types of assets. Going from the period before the crisis to that since the start of the crisis, we see that average Treasury and municipal yields have fallen. The mean GSP share of pension assets is about 16 percent, which is almost constant between the before crisis period and the period after that. This is below the mean share of pension liabilities of 20 percent when measured against an 8 percent discount rate. Liabilities rise from 19 to 21 percent on average, when going from the first to the second sub-period. The increase is substantially larger when liabilities are measured using the Treasury yield, which is explained by its fall going from the first to the second subperiod. The average state level

[14] Market values of pension assets are not always available during the initial years of the sample. In those cases we use actuarial asset values instead. However, this concerns only a total of seven observations.

pension funding ratio of 79 percent based on a common 8 percent discount rate already indicates a substantial average degree of underfunding, but still creates a picture that is far more optimistic than when liabilities are uniformized using the Treasury yield. In this case the average funding ratio is only slightly over 50 percent. The average explicit debt ratio of 7.2 percent exceeds the average implicit debt ratio of 4.6 percent based on a common discount rate of 8 percent, but is lower than the average implicit debt ratio of 16.0 percent based on the Treasury yield. These figures hide substantial variation across the states. The maximum implicit debt ratio of 16.5 percent using 8 percent discounting is close to the maximum of 19.3 percent for the explicit debt ratio,[15] while the maximum implicit debt ratio based on the Treasury yield is more than twice as high. However, there are also instances of substantial overfunding, as indicated by funding ratios substantially above one or negative implicit debt ratios. These instances are concentrated in the pre-crisis period before 2007.

Table 2.1: Key statistics for full sample and sub-periods

	N	St. Dev	Min	Max	Mean (full sample)	Mean before crisis	Mean (post-) crisis
GSP change	787	0.034	-0.135	0.244	0.038	0.055	0.029
Building permits change	787	0.210	-0.610	0.662	0.006	0.056	-0.022
Spending to GSP	787	0.028	0.050	0.219	0.102	0.097	0.105
Revenues to GSP	787	0.028	-0.001	0.255	0.098	0.096	0.099
Municipal yield	787	0.010	0.013	0.064	0.035	0.041	0.032
Treasury yield	787	0.012	0.016	0.059	0.039	0.049	0.033
FR (market assets, 8% disc.)	787	0.180	0.412	1.648	0.790	0.850	0.756
FR (market assets, Tr. disc.)	787	0.137	0.261	1.057	0.512	0.596	0.465
IDR (market assets, 8% disc.)	787	0.042	-0.078	0.165	0.046	0.031	0.054
IDR (market assets, Tr. disc.)	787	0.084	-0.004	0.450	0.160	0.111	0.189
EDR	787	0.035	0.016	0.193	0.072	0.069	0.074
Liabilities (8% disc.)	787	0.067	0.043	0.412	0.202	0.188	0.210
Liabilities (Tr. disc.)	787	0.113	0.068	0.710	0.317	0.269	0.344
Market assets	787	0.056	0.052	0.368	0.156	0.157	0.155

Note: Abbreviations: 8% disc. = uniformized liabilities obtained by discounting against 8% yield, and Tr.disc. = uniformized liabilities obtained by discounting against Treasury yield.

Figure 2.2 depicts for each state and each key variable the difference between its value in 2016 and that in 2001. We observe that municipal yields have fallen everywhere, although by varying amounts. The smallest is a fall by 1.8 percentage points in New Jersey and the largest a fall by 3.7 percentage points in Idaho, Arkansas and New Hampshire. The pattern regarding the explicit debt ratios is more mixed, with changes ranging from a fall by 5 percentage points to a rise by 4 percentage points. The financial health of the state pension sectors, when measured by a funding ratio based on 8 percent discounting, has deteriorated in most of the states, although some states saw an improvement. Changes range from a rise by 30 percentage points in West Virginia to a fall by 67 percentage points in Washington State, which had a high funding ratio to start with. However, when

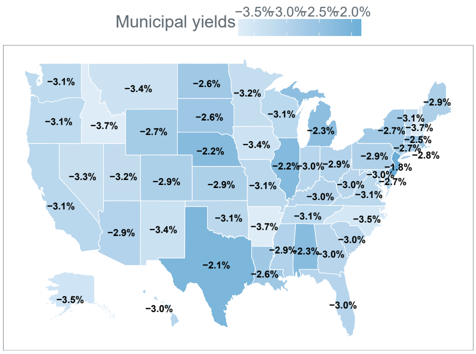
[15]This is still substantially lower than the average general government debt ratio of OECD countries. However, the revenue base at the U.S. state level is also smaller than the general government revenue base of OECD countries.

measured against the Treasury yield, all states but West Virginia experienced a fall in the funding ratio. This is to a large extent due to the fall of the Treasury yield over the sample period. The maximum decrease in the funding ratio is by 65 percentage points in Washington State. Finally, we see that the changes in the implicit debt ratio based on 8 percent discounting range from a fall by 5 percentage points in West Virginia to an increase by 14 percentage points in Alaska and Kentucky. The far majority of the states experienced a rise in the implicit debt ratio, though. Based on Treasury yield discounting the picture is even more pessimistic: all the states saw their implicit debt ratio rise, with a maximum increase by 34 percentage points in Alaska.

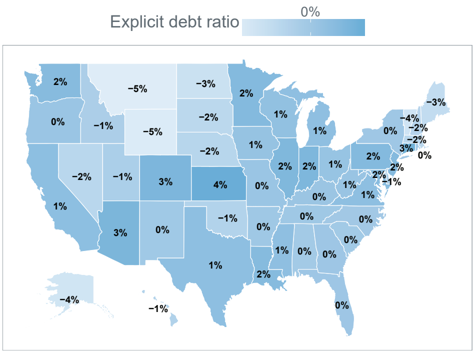
Figure 2.3 depicts how municipal yields and the Treasury yield have developed over time. In most of the years the median municipal yield across the states was lower than the Treasury yield, which is most likely explained by the fact that interest earnings on municipal bonds are tax exempt, whereas those on Treasury debt are not. However, the difference between the Treasury yield and the median municipal yield is generally smaller after the start of the financial crisis than before. Treasury yields may have become relatively more attractive in terms of default risk or liquidity.

Table 2.2 reports the correlations between a number of key variables. First, not surprisingly, municipal and Treasury yields exhibit a high positive correlation. Second, pension funding ratios are positively correlated with both Treasury and municipal yields, while implicit debt ratios are negatively correlated with both yields. The correlations of the funding ratios and implicit debt ratios with the municipal yield may seem paradoxical if we expect that a weaker financial health of the state pension sector pushes up municipal yields on the state's explicit debt. However, the correlation patterns are explained by the fact that since the start of the crisis yields on both state and federal debt have been on a downward trend following the Fed's expansionary monetary policy measures, while at the same time the financial health of the state pension sector has been declining. Hence, the correlations merely seem to be picking up the co-movement of two trends that are not directly related with each other. The trends also explain the positive correlation between the implicit and explicit debt ratios and the negative correlation between the latter variable and the funding ratio. Finally, as expected, implicit debt ratio and the funding ratio are highly negatively correlated for both discounting rates.

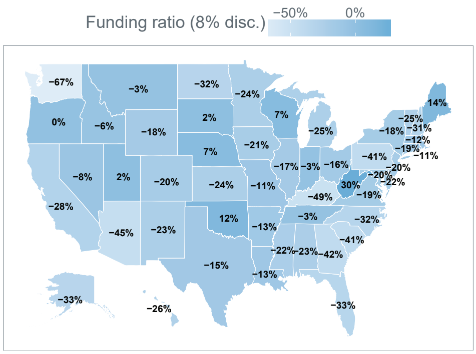
Figure 2.2: Percentage point changes in the key variables over the period 2001-2016



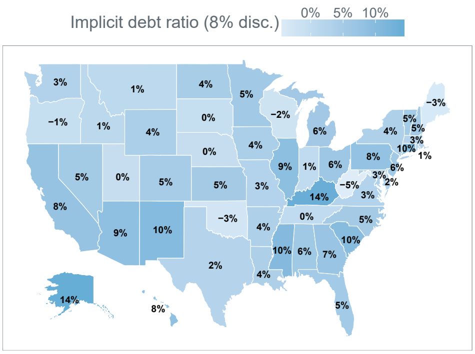
(a) Municipal yields



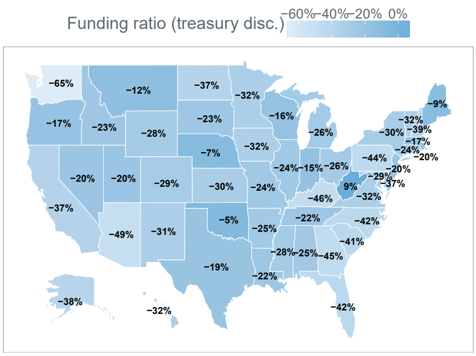
(b) Explicit debt ratio



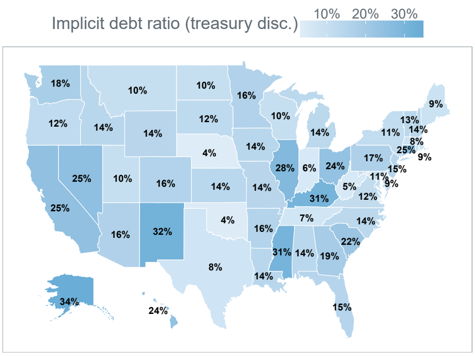
(c) Funding ratio (8% discounting)



(d) Implicit debt ratio (8% discounting)



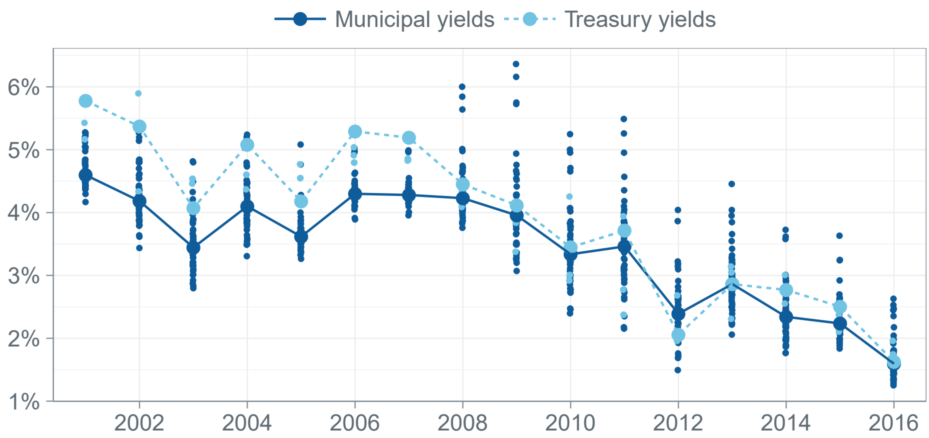
(e) Funding ratio (Treasury discounting)



(f) Implicit debt ratio (Treasury discounting)

Note: Darker shades indicate larger numbers. Alaska and Hawaii have been rescaled and moved for a more compact display. For some states the data are not available for the first couple of years. In those cases changes are calculated for the period during which the data are available. The changes are reported in percentage points.

FIGURE 2.3: Municipal and Treasury yields over the sample period



Note: The small dots represent observations for each individual state, while the large connected dots show the median rates over the states for each sample year. Note that each year features multiple observations for the Treasury yield corresponding to the different ends of the state fiscal years.

TABLE 2.2: Correlation matrix of key variables over all observations

	YM	YT	FRm (8% disc.)	FRm (Tr.disc.)	IDRm (8% disc.)	IDRm (Tr.disc.)	EDR	yoyGSP	yoyB.Permits
YM	1	0.85	0.18	0.45	-0.20	-0.46	0.05	0.16	-0.38
YT	0.85	1	0.27	0.60	-0.28	-0.57	-0.01	0.20	-0.35
FRm (8% disc.)	0.18	0.27	1	0.89	-0.90	-0.64	-0.33	0.22	0.04
FRm (Tr. disc.)	0.45	0.60	0.89	1	-0.83	-0.75	-0.25	0.26	-0.11
IDRm (8% disc.)	-0.20	-0.28	-0.90	-0.83	1	0.84	0.33	-0.26	-0.05
IDRm (Tr. disc.)	-0.46	-0.57	-0.64	-0.75	0.84	1	0.23	-0.28	0.11
EDR	0.05	-0.01	-0.33	-0.25	0.33	0.23	1	-0.08	-0.04
yoyGSP	0.16	0.20	0.22	0.26	-0.26	-0.28	-0.08	1	0.32
yoyB.Permits	-0.38	-0.35	0.04	-0.11	-0.05	0.11	-0.04	0.32	1

Note: Abbreviations: FR = funding ratio, EDR = explicit debt ratio, IDR = implicit debt ratio, yoyGSP = year-on-year percentage growth in GSP, yoyB.Permits = year-on-year percentage growth in building permits, m = based on market assets, 8% disc. = uniformized liabilities obtained by discounting against the 8% yield, and Tr.disc. = uniformized liabilities obtained by discounting against the Treasury yield. The correlations are calculated over all observations in the sample. Sample period is 2001–2016. The funding ratio and the implicit debt are based on the market values of the assets.

2.3 Results

In this section we explore the following hypotheses. First, we explore for the full sample period and for sub-sample periods the hypothesis that increases in explicit and implicit debt raise municipal yields. Second, we test whether these effects of a given increase in explicit and implicit debt are equally large.

2.3.1 Baseline results

The dependent variable in our regressions is the municipal yield based on the Barclays Municipal Bond Index. We stay as close as possible to the existing literature that explores how debt-to-GDP ratios affect sovereign borrowing yields. Hence, in the regression for the municipal yield we include state-specific fixed effects, the Treasury yield on the federal debt in maturity bucket 10 - 20 years,[16,17] and the explicit debt ratio. The state-specific effects are intended to capture all the unobserved differences among the states leading to systematic differences in the municipal yields. The Treasury yield is included to control for general movements in interest rates primarily caused by monetary policy. We extend the regression framework by including measures of the financial health of the civil servants' pension sector in each state. The explicit and implicit debt ratios may not be sufficient statistics for the expected loss associated with default on the explicit debt. In particular, the latter may also be affected by the economic prospects of the state. Hence, in our regressions we control for the GSP growth rate and the growth rate in the number of building permits. Growth rates in economic activity tend to exhibit persistence, hence higher growth now suggests higher growth in the near future, while the volume of building permits is often seen as a leading indicator of future activity. Therefore, these controls may provide a signal of the future capacity to repay the explicit debt. Hence, our baseline regression equation reads:

$$YM_{it} = \alpha_i + \beta_1 YT_{it} + \beta_2 EDR_{it} + \beta_3 FR_{it} + \beta_4 IDR_{it} + \beta_5 X_{it} + \epsilon_{it},$$

[16]This is the range that contains the average maturity of 14 years underlying our municipal bond index.

[17]The alternative is to use the spread between the municipal yield and the Treasury yield as the dependent variable. However, spreads may be driven by various factors unrelated to changes in the explicit or implicit debt, such as changes in monetary policy, changes in the demand for liquidity, etcetera. Figure 2.3, which exhibits a general fall of the Treasury yield relative to municipal yields, is indicative of the role of such factors. The formulation below, in which we allow the coefficient on the Treasury yield to differ from one, allows for more flexibility and, hence, enables us to capture the presence of these factors.

where subscripts i and t indicate the state and the year, respectively, FRm and $IDRm$ are the funding ratio and the implicit debt ratio, respectively, based on the market value of the assets and uniformized liabilities using a common 8 percent discount rate or the Treasury yield, α_i denotes the state i fixed effect that accounts for all the time invariant differences among the states, and the vector X_{it} contains the abovementioned controls. While municipal yields are expected to depend strongly on Treasury yields, they may differ from the latter to the extent that investors perceive them as carrying higher default risk (one reason being that states cannot print money to pay off their debt), more liquidity risk or for other reasons, such as a difference in the tax treatment of their returns. We would expect the repayment risk of municipal debt to depend on the volume of the outstanding explicit debt as well as the financial health of the civil servants' pension funds, because the state is liable for the provision of the pensions of its civil servants. Unless all the pension benefit payments would take place after all of the outstanding explicit debt is redeemed, a higher implicit debt raises the expected default losses on the explicit debt.

In our baseline regressions we include measures of the pension sector's financial health based on the market value rather than the actuarial value of the pension assets, because a priori we expect market values to be a better indicator of the capacity to cover the future pension benefits. We will never include measures of the funding ratio and the implicit debt ratio simultaneously as explanatory variables, because the two are highly (negatively) correlated alternative measures of the financial health of the pension sector. A priori, we would expect the implicit debt ratio to be the more relevant variable for the municipal yield, because a low funding ratio in a state with a relatively small civil servants' pension sector would in itself carry no repayment threat for the explicit debt. The other advantage of using the implicit debt variable is that it is measured in the same units as the explicit debt ratio and, hence, the magnitudes of their estimated effects on the municipal yield can be directly compared.

Table 2.3 reports the estimates for the baseline regression specification.[18] Column (1) presents the estimates when only the explicit debt ratio, but no measure of the pension sector's financial health, is included. A one-percentage point increase in the Treasury yield raises the municipal yield by almost 0.7 percentage points. A one-percentage point increase in a state's explicit debt ratio raises the municipal yield by 8 basis points, an

[18]We report the within R^2 and "Arellano" standard errors that are robust against potential heteroskedasticity and serial correlation in the errors for a given state. We also calculate standard errors adjusted for cross-sectional correlation. The results, in particular the significance levels of our debt measures, are unchanged. However, because we have fewer years than states, this adjustment is strictly speaking not applicable and, therefore, we stick to reporting our heteroskedasticity and serial correlation consistent standard errors.

Table 2.3: Baseline regressions for municipal yields

	Dependent variable:				
	Municipal yield				
	(1)	(2)	(3)	(4)	(5)
Treasury yield	.664***	.701***	.746***	.698***	.725***
	(.017)	(.017)	(.023)	(.017)	(.026)
EDR	.079***	.062***	.060***	.063***	.066***
	(.018)	(.018)	(.018)	(.019)	(.018)
Building permits growth rate	−.004***	−.004***	−.004***	−.004***	−.004***
	(.001)	(.001)	(.001)	(.001)	(.001)
GSP growth rate	−.004	.001	.001	.002	.001
	(.008)	(.008)	(.008)	(.008)	(.008)
FRm (8% disc.)		−.009***			
		(.003)			
FRm (Tr. disc.)			−.012***		
			(.003)		
IDRm (8% disc.)				.036***	
				(.010)	
IDRm (Tr. disc.)					.016**
					(.006)
Observations	787	787	787	787	787
R^2	.871	.880	.881	.878	.874
Adjusted R^2	.862	.871	.872	.869	.865
F-test (EDR = IDR)				.252	.015

Note: Abbreviations: FR = funding ratio, EDR = explicit debt ratio, IDR = implicit debt ratio, m = based on market assets, 8% disc. = uniformized liabilities obtained by discounting against 8% yield, and Tr.disc. = uniformized liabilities obtained by discounting against Treasury yield.
* is p-value <0.1; ** is p-value <0.05; *** is p-value <0.01.
All regressions include state-fixed effects. Sample period is 2001–2016.

effect that is significant at the 1% level. Further, a higher growth rate in building permits, presumably signaling better growth prospects for the state's economy, is associated with a fall in the municipal yield. This is also the case for a higher GSP growth rate, although the effect is not significant. The ensuing regressions include a measure of the financial health of the state pension sector.

Columns (2) and (3) show that, while the explicit debt ratio remains significant at the 1 percent level, the state level funding ratio is significant at this level too. However, the coefficient on the explicit debt ratio is slightly smaller now, and suggests a 6 basis points rise in the municipal yield for a one-percentage point increase in the explicit debt ratio. A one-percentage point reduction in the funding ratio raises the municipal yield by nearly one basis point in the case of discounting against an 8 percent fixed rate and by 1.2 basis points when the Treasury yield is used. The coefficient is larger in absolute terms in the latter case, because the Treasury yield is always lower than 8 percent, implying uniformly lower funding ratios when the Treasury yield is used. Overall, even though the funding ratio may be a less-than-perfect indicator of the difficulty to repay the explicit debt, it still exerts a significant effect on the municipal yield.

Columns (4) and (5) replace the funding ratio with the implicit debt ratio. Both the explicit and the implicit debt ratio are significant, irrespective of the discount rate used to calculate the latter. However, the point estimates of the coefficient on the implicit debt ratio are smaller than of the coefficient on the explicit debt ratio. In the case of 8 percent discounting of future pension benefits, a one-percentage point increase in the implicit debt ratio raises the municipal yield by 3.6 basis points as opposed to 6.3 basis points for a one-percentage point increase in the explicit debt ratio. For discounting against the Treasury yield, the difference is even larger. Now, a one-percentage point increase in the implicit debt ratio raises the municipal yield by 1.6 basis points, one-fourth of the effect of an equal increase in the explicit debt ratio. The smaller effect of the implicit debt ratio in this case results from the fact that implicit debt ratios tend to be substantially larger because the Treasury yield is always (substantially) lower than 8 percent in our sample. The wide range spanned by the rather extreme choices for the discount rate strengthens the hypothesis that the effect of a given increase in the explicit debt ratio on municipal yields is stronger than for a given increase in the implicit debt ratio.

2.3.2 Subperiods

The recent economic and financial crisis has potentially caused large shifts in economic relationships. Figure 2.3 suggests that the relationship between municipal yields and the Treasury yield has changed since the start of the crisis. This indicates that there might have been a broader change in the relationships among economic variables. Therefore, in this subsection we split the full sample into the pre-crisis subperiod 2001-2006 and the (post-) crisis subperiod 2007-2016. Table 2.4 reports the regressions for the period before the crisis, whereas Table 2.5 reports the results for the (post-) crisis period. The format of the two tables is identical to that of Table 2.3. GSP loses its significance in the pre-crisis period, while both GSP and growth in building permits lose their significance during the (post-) crisis period. The pre-crisis estimates are always insignificant for the explicit debt ratio. They are significant for the funding ratio at the 5 percent level for discounting against the Treasury yield, but with an unexpected positive sign, and they are also significant with an unexpected negative sign for the implicit debt ratio calculated with Treasury yield discounting. The coefficient estimates are small, though. By contrast, the coefficients on the explicit debt ratio, the implicit debt ratio and the funding ratio are of the expected sign and highly significant during the (post-) crisis period. Compared to the full-sample estimates, the point estimates of the coefficient on the explicit and implicit debt ratio increase. The estimates in Column (4) of Table 2.5 suggest that a one-percentage point increase in the explicit debt ratio during the (post-) crisis period raises the municipal yield by 10 basis points, while an increase in the implicit debt ratio based on a common 8% discount rate raises the municipal yield by 6 basis points. When liabilities are calculated using the Treasury yield (Column (5)), these effects become 11 and 3 basis points, respectively. We also test formally whether the coefficients on the explicit and implicit debt are equal, finding that equality cannot be rejected for the pre-crisis period, while it can be rejected at the 1 percent level for the (post-) crisis period when liabilities are measured using the Treasury yield and almost rejected at the 10 percent level when liabilities are measured using a common 8 percent discount rate.

In order to see whether the crisis caused a more long-lasting change in the effects of explicit and implicit debt, Table 2.6 repeats the regressions for the period after the crisis, i.e. the "post-crisis period", covering the years 2011–2016. This period excludes the violent (stock-)market gyrations after the demise of Lehman Brothers that took the form of a deep fall followed by a strong recovery of markets. We see that the estimates of the coefficients on both the explicit and implicit debt remain highly significant. In fact, for the explicit debt in particular, they increase quite a bit compared to the estimates for the (post-) crisis period. Also, the coefficients on the funding ratio remain highly significant and become even slightly larger in absolute magnitude. Somewhat surprisingly, the coefficients on GSP growth and building permits growth have become significantly positive. We do not have an obvious explanation for these findings. They may be picking up some movement in municipal yields that is caused by other unrelated factors. Since these coefficients are not the focus of our analysis, we will not investigate this finding further. Tests for the equality of the coefficients on the explicit and the implicit debt reject at the 10 percent level when implicit debt is calculated using a common 8 percent discount rate and at the 1 percent level when it is calculated using the Treasury yield.

Summarizing, our baseline results suggest that both the explicit and implicit debt ratios only become relevant for municipal yields after the start of the global financial crisis. Moreover, during this (post-) crisis period the effect of the explicit debt on municipal yields appears to be stronger than that of the implicit debt. In Section 2.4 we will discuss potential mechanisms behind these findings. There we will argue that the smaller role for municipal yields of the implicit than of the explicit debt is likely explained by the variety of possibilities to renege upon the pension promises when the public finances come under pressure.

We can make a back-of-the-envelope calculation of the long-run effect on a state's public expenditures of a one-percentage point increase in the implicit debt ratio, assuming that the explicit debt ratio is held constant. The full effect on the state's expenditures of the yield increase on the explicit debt will only gradually materialize, as the yield increase only gets incorporated in higher interest payments on debt that is being rolled over. In the long run, all the existing explicit debt will have been rolled over and, hence, by then the yield effect of the rise in the implicit debt will have been fully incorporated. We base our calculation on the average numbers and coefficient estimates for the (post-) crisis period. Using the average implicit debt ratio of 5.4 percent from Table 2.1 and the estimated 6.0 basis points yield increase for each percentage point increase in the implicit debt ratio (assuming pension liabilities are computed using a fixed 8 percent rate) from Table 2.5, we calculate a yield increase that can be attributed to the average implicit pension deficit of (5.4 minus 0) times 6.0 is approximately 32 basis points.[19] Given that the average municipal yield is 3.2 percent, states would face a 0.32/3.2 is 10 percent rise in interest payments (assuming that the municipal yield at the start of the experiment equals the average interest payment on the outstanding debt). When Treasury yield discounting is used, our estimates translate into a yield increase of 18.9×2.9 is approximately 55 basis

[19]These calculations neglect potential non-linear effects in the yield response when the implicit debt ratio is raised by a large amount.

TABLE 2.4: Baseline regressions – pre-crisis period (2001–2006)

	Dependent variable:				
	Municipal yield				
	(1)	(2)	(3)	(4)	(5)
Treasury yield	.617***	.610***	.585***	.612***	.587***
	(.024)	(.025)	(.029)	(.025)	(.030)
EDR	−.021	−.021	−.021	−.020	−.018
	(.022)	(.023)	(.023)	(.023)	(.023)
Building permits growth rate	−.003**	−.003*	−.002	−.003*	−.002*
	(.001)	(.001)	(.001)	(.001)	(.001)
GSP growth rate	.002	.001	−.0001	.001	−.001
	(.008)	(.008)	(.008)	(.008)	(.008)
FRm (8% disc.)		.002			
		(.002)			
FRm (Tr. disc.)			.005**		
			(.002)		
IDRm (8% disc.)				−.010	
				(.008)	
IDRm (Tr. disc.)					−.011*
					(.007)
Observations	287	287	287	287	287
R^2	.838	.840	.842	.839	.841
Adjusted R^2	.802	.803	.805	.802	.804
F-test (EDR = IDR)				.655	.789

Note: Abbreviations: FR = funding ratio, EDR = explicit debt ratio, IDR = implicit debt ratio, m = based on market assets, 8% disc. = uniformized liabilities obtained by discounting against 8% yield, and Tr.disc. = uniformized liabilities obtained by discounting against Treasury yield.
* is p-value <0.1; ** is p-value <0.05; *** is p-value <0.01.
All regressions include state-fixed effects.

Table 2.5: Baseline regressions – (post-) crisis period (2007–2016)

	Dependent variable:				
	Municipal yield				
	(1)	(2)	(3)	(4)	(5)
Treasury yield	.761***	.838***	.915***	.829***	.876***
	(.017)	(.022)	(.029)	(.023)	(.032)
EDR	.156***	.092***	.085***	.099***	.110***
	(.026)	(.020)	(.018)	(.022)	(.024)
Building permits growth rate	−.001	.001	.0004	.0003	−.0005
	(.001)	(.001)	(.001)	(.001)	(.001)
GSP growth rate	−.004	.003	.004	.004	.002
	(.008)	(.007)	(.007)	(.008)	(.008)
FRm (8% disc.)		−.016***			
		(.002)			
FRm (Tr. disc.)			−.022***		
			(.003)		
IDRm (8% disc.)				.060***	
				(.011)	
IDRm (Tr. disc.)					.029***
					(.007)
Observations	500	500	500	500	500
R^2	.877	.896	.899	.891	.885
Adjusted R^2	.862	.883	.886	.878	.871
F-test (EDR = IDR)				.125	.002

Note: Abbreviations: FR = funding ratio, EDR = explicit debt ratio, IDR = implicit debt ratio, m = based on market assets, 8% disc. = uniformized liabilities obtained by discounting against 8% yield, and Tr.disc. = uniformized liabilities obtained by discounting against Treasury yield.
* is p-value <0.1; ** is p-value <0.05; *** is p-value <0.01.
All regressions include state-fixed effects.

Table 2.6: Baseline regressions – post-crisis period (2011–2016)

	Dependent variable:				
	Municipal yield				
	(1)	(2)	(3)	(4)	(5)
Treasury yield	.706***	.763***	.835***	.763***	.792***
	(.023)	(.030)	(.037)	(.030)	(.050)
EDR	.234***	.183***	.167***	.190***	.200***
	(.041)	(.041)	(.040)	(.043)	(.046)
Building permits growth rate	.004***	.004***	.004***	.004***	.004***
	(.001)	(.001)	(.001)	(.001)	(.001)
GSP growth rate	.032***	.026***	.025***	.031***	.033***
	(.008)	(.009)	(.009)	(.009)	(.009)
FRm (8% disc.)		−.024***			
		(.005)			
FRm (Tr. disc.)			−.040***		
			(.007)		
IDRm (8% disc.)				.088***	
				(.024)	
IDRm (Tr. disc.)					.033**
					(.016)
Observations	300	300	300	300	300
R^2	.827	.849	.855	.842	.833
Adjusted R^2	.790	.816	.823	.808	.796
F-test (EDR = IDR)				.078	.003

Note: Abbreviations: FR = funding ratio, EDR = explicit debt ratio, IDR = implicit debt ratio, m = based on market assets, 8% disc. = uniformized liabilities obtained by discounting against 8% yield, and Tr.disc. = uniformized liabilities obtained by discounting against Treasury yield.
* is p-value <0.1; ** is p-value <0.05; *** is p-value <0.01.
All regressions include state-fixed effects.

points, or around 17 percent of the interest cost. Hence, an underfunded pension system may lead to a non-negligible increase in the debt-servicing costs.

We can also compare the size of the estimated effect of an increase in the implicit debt ratio with that found by Novy-Marx and Rauh (2012). For a loss in the value of a state's pension assets equivalent to 10 percent of state own revenue, they estimate a 7 to 15 basis points rise in municipal yields. Based on Table 2 of Novy-Marx and Rauh (2012) we estimate the average GSP ratio of state own revenue at 8.1 percent (the ratio of average own revenue in fiscal year 2008 divided by average state GSP of 2007). Hence, 10 percent of state own revenue equals 0.81 percent of GSP, implying (1/0.81) times 7 to 15 basis points, i.e. 8.6 to 18.5 basis points, higher municipal yields if the market value of a state's pension assets falls by the equivalent of one percent of GSP. This range exceeds the range of 2.9 - 6.0 basis points that, based on the two common discount rates we consider, we estimate for a one-percentage point of GSP increase in the implicit debt ratio.

Because the effect of an increase in the implicit debt ratio on municipal yields appears to be confined to the (post-) crisis period, the remainder of our analysis will focus on this period only. To save space, we no longer report regressions with the funding ratio, but only with the implicit debt, which theoretically is the more relevant measure and which allows for a direct comparison with the effect of an increase in the explicit debt ratio.

2.3.3 Robustness and extensions

This subsection explores in a variety of ways the robustness of the baseline estimates for the (post-) crisis period, confirming that, while the implicit debt ratio generally exerts a positive effect on municipal yields, this effect is smaller than that exerted by explicit debt.

2.3.3.1 Reporting lag

In our baseline regressions all the yields correspond to the end of the state's fiscal year. However, pension funds may take some time to report their figures. Hence, the more relevant moment to measure the effect of the pension sector's financial health on municipal yields could potentially be the reporting moment. Reporting moments differ across the pension funds. In Table 2.7 we therefore rerun our baseline regressions, while taking both municipal and Treasury yields corresponding to the end of the fiscal year plus 1 or 2 months. For easier comparison, Columns (1) and (2) repeat regressions (4) and (5) from

Table 2.5. We observe that the coefficients on the implicit debt ratio remain significant in only two cases and that their magnitude is smaller than when the end of the fiscal year is used as the reporting moment. This may not be surprising as the market values of the pension funds' assets and liabilities can be monitored continuously and, hence, the relevant information of the pension sector's financial health should be available by the end of the fiscal year.

TABLE 2.7: Reporting lag – (post-) crisis period (2007–2016)

	Dependent variable:					
	Municipal yield					
	(1)	(2)	(3)	(4)	(5)	(6)
Treasury yield	.829***	.876***	.856***	.876***	.915***	.951***
	(.023)	(.032)	(.021)	(.029)	(.022)	(.033)
EDR	.099***	.110***	.115***	.118***	.145***	.137***
	(.022)	(.024)	(.025)	(.027)	(.028)	(.029)
Building permits growth rate	.0003	−.0005	.001	.001	.002**	.001**
	(.001)	(.001)	(.001)	(.001)	(.001)	(.001)
GSP growth rate	.004	.002	.014**	.014**	.022***	.023***
	(.008)	(.008)	(.006)	(.006)	(.005)	(.005)
IDRm (8% disc.)	.060***		.023**		.014	
	(.011)		(.010)		(.011)	
IDRm (Tr. disc.)		.029***		.011		.015*
		(.007)		(.008)		(.008)
Observations	500	500	450	450	450	450
R^2	.891	.885	.897	.896	.873	.874
Adjusted R^2	.878	.871	.882	.881	.856	.857
F-test (EDR = IDR)	.125	.002	.001	.000	.000	.000

Note: Columns (1) and (2) repeat the baseline estimates, Columns (3) and (4) report the estimates for a one-month reporting lag, while Columns (5) and (6) report the estimates for a 2-month reporting lag. Abbreviations: FR = funding ratio, EDR = explicit debt ratio, IDR = implicit debt ratio, m = based on market assets, 8% disc. = uniformized liabilities obtained by discounting against 8% yield, and Tr.disc. = uniformized liabilities obtained by discounting against Treasury yield.
* is p-value <0.1; ** is p-value <0.05; *** is p-value <0.01.
All regressions include state-fixed effects.

2.3.3.2 The treatment of the fiscal years

The state fiscal years do not correspond to the calendar year. In most states the fiscal year ends on June 30, whereas it ends on March 31 in New York, August 31 in Texas and September 30 in Alabama and Michigan. Since our pension plan data are generally recorded at the end of the fiscal year, for each state we have so far taken the end-of-the-fiscal-year municipal and Treasury yields corresponding to the fiscal year for that state.

However, seventeen plans in our sample report their figures at a different moment than the end of the state fiscal year. For most states these plans constitute a minority in terms of liabilities, but there are four states in which all the plans report at the end of the calendar year as opposed to the end of the state's fiscal year. Table 2.8 shows the regression outcomes if we use yields corresponding to the end of the own reporting year adopted by the majority of the plans in a state. The equality of the coefficients on the explicit and implicit debt continues to be firmly rejected when implicit debt is measured using the Treasury yield. However, for implicit debt measured using 8 percent discounting the p-value rises. Because the estimates are quite close to those reported in Table 2.5, in the sequel we continue to use the yields at the end of the states' fiscal years.

2.3.3.3 Alternative liability estimates

This subsection explores the robustness of our results for different assumptions underlying the uniformization of the liabilities from the original reported values. Since using the duration data of Rauh (2016) leaves us with several missing observations for which we impute the average duration in that sample, we want to explore the sensitivity of our results to the durations we use. As an alternative we impose common durations of 7.5, 10 or 15 years on the funds. Hence, in the baseline regression we replace the implicit debt ratios based on the plan-specific durations with the corresponding ratios based on one of these common durations. Table 2.9 reports the results. We observe that our results are robust with respect to the assumed liability duration. Obviously, assuming a longer duration blows up the liabilities and, hence, results into coefficient estimates of the implicit debt ratio that are somewhat smaller. Because our results remain robust for such a wide range of common durations, this strengthens our comfort with the baseline results.

Table 2.8: Yields based on the end of the own reporting year – (post-) crisis period (2007–2016)

	Dependent variable:		
	Municipal yield		
	(1)	(2)	(3)
Treasury yield	.726***	.814***	.864***
	(.024)	(.027)	(.034)
EDR	.168***	.098***	.113***
	(.031)	(.023)	(.026)
Building permits growth rate	−.003**	−.001	−.002*
	(.001)	(.001)	(.001)
GSP growth rate	.018	.028*	.026
	(.017)	(.017)	(.017)
IDRm (8% disc.)		.074***	
		(.013)	
IDRm (Tr. disc.)			.035***
			(.007)
Model	FE	FE	FE
Observations	500	500	500
R^2	.840	.860	.850
Adjusted R^2	.821	.843	.832
F-test (EDR = IDR)		.336	.003

Note: Abbreviations: FR = funding ratio, EDR = explicit debt ratio, IDR = implicit debt ratio, m = based on market assets, 8% disc. = uniformized liabilities obtained by discounting against 8% yield, and Tr.disc. = uniformized liabilities obtained by discounting against Treasury yield.
* is p-value <0.1; ** is p-value <0.05; *** is p-value <0.01.
All regressions include state-fixed effects.

2.3.3.4 Actuarial values

So far, we have used the market values of the assets and the uniformized values of the liabilities. However, pension funds report the actuarial values of the assets and the liabilities and, therefore, the setting of their policy instruments is based on these actuarial values. Using actuarial liabilities implies the use of liabilities calculated with the fund's assumed discount rate, which tends to be based on the return that the fund expects to make on its assets.

Table 2.10 reports the regression results for the (post-) crisis period 2007 – 2016 when

TABLE 2.9: Liabilities based on alternative common durations – (post-) crisis period (2007–2016)

	Dependent variable:					
	Municipal yield					
	(1)	(2)	(3)	(4)	(5)	(6)
Treasury yield	.833***	.877***	.830***	.879***	.823***	.879***
	(.023)	(.030)	(.023)	(.032)	(.022)	(.034)
EDR	.100***	.106***	.099***	.107***	.097***	.111***
	(.022)	(.023)	(.022)	(.024)	(.022)	(.024)
Building permits growth rate	.0003	−.0003	.0003	−.0004	.0003	−.001
	(.001)	(.001)	(.001)	(.001)	(.001)	(.001)
GSP growth rate	.004	.003	.004	.003	.004	.002
	(.008)	(.008)	(.008)	(.008)	(.008)	(.008)
IDRm (DUR = 7.5) (8% disc.)	.060***					
	(.011)					
IDRm (DUR = 7.5) (Tr. disc.)		.037***				
		(.008)				
IDRm (DUR = 10) (8% disc.)			.060***			
			(.011)			
IDRm (DUR = 10) (Tr. disc.)				.032***		
				(.007)		
IDRm (DUR = 15) (8% disc.)					.059***	
					(.011)	
IDRm (DUR = 15) (Tr. disc.)						.024***
						(.006)
Observations	500	500	500	500	500	500
R^2	.891	.886	.891	.885	.891	.884
Adjusted R^2	.877	.873	.878	.872	.878	.870
F-test (EDR = IDR)	.110	.008	.122	.004	.128	.001

Note: Abbreviations: FR = funding ratio, EDR = explicit debt ratio, IDR = implicit debt ratio, m = based on market assets, 8% disc. = uniformized liabilities obtained by discounting against 8% yield, Tr.disc. = uniformized liabilities obtained by discounting against Treasury yield, DUR = 7.5 (DUR = 10, DUR = 15) is common duration is set to 7.5 years (10 years, 15 years).
* is p-value <0.1; ** is p-value <0.05; *** is p-value <0.01.
All regressions include state-fixed effects.

in our measures of the financial health of the state pension sector we replace the market values of the assets with the actuarial values and/or we replace the uniformized liabilities with their original actuarial values. For easier comparison, in Columns (1) and (2) we repeat the baseline regressions (Columns (4) and (5) from Table 2.5). Column (3) differs from the previous two columns by replacing the uniformized liabilities with their actuarial values. Unsurprisingly, because the latter are usually based on an 8 percent discount rate or a discount rate close to this value, the coefficient on the implicit debt ratio is very close to that in Column (1). Replacing the market values of the assets with the actuarial values (Columns (4) and (5)) has more substantial implications, because the coefficient on the implicit debt ratio shrinks and loses significance. As a final step, in Column (6) we use the implicit debt ratio based on the actuarial values of both the assets and the liabilities. The coefficient on the implicit debt ratio is insignificant and lower than under the baseline regression. The overall conclusion remains unaltered that a marginal increase in the explicit debt ratio exerts a stronger effect on the municipal yield than the implicit debt ratio. However, in case of the latter, it seems that, in their assessment of the state pension sector's financial health, investors pay more attention to the market values of the pension assets than to their actuarial asset values. The insignificance of the implicit debt ratio when actuarial assets are used is, therefore, not surprising.

2.3.3.5 Non-linear effects of the pension funds' financial health

It is conceivable that investors react differently to an improvement in the funding situation of the pension sector when it is very unfavorable than when it is favorable. The reason is that an improvement in an already healthy funding situation has only little effect on the chance that the government at some point in the future will need to supply additional resources to honor the pension obligations at the expense of its explicit debt-servicing obligations. The opposite is the case when the funding situation is weak to start with. To investigate this possible non-linearity in the relationship between the pension sector's financial health and the municipal yield, we explore whether the coefficient on the implicit debt ratio is larger in absolute value when the funding ratio is relatively low than when it is relatively high. Hence, we interact the implicit debt ratio with a dummy D_{LF}, which equals one (zero) if the funding ratio is below (above) its median value across all states and years in our subsample 2007-2016. Both the implicit debt ratio and the dummies underlying funding ratio within a given interaction term are based on the same uniformizing discount rate. Table 2.11 reports the results. Compared to the baseline the

Table 2.10: Actuarial versus market values – (post-) crisis period (2007–2016)

	Dependent variable:					
	Municipal yield					
	(1)	(2)	(3)	(4)	(5)	(6)
Treasury yield	.829***	.876***	.840***	.776***	.801***	.774***
	(.023)	(.032)	(.023)	(.019)	(.031)	(.020)
EDR	.099***	.110***	.106***	.147***	.144***	.152***
	(.022)	(.024)	(.023)	(.025)	(.025)	(.025)
Building permits growth rate	.0003	−.0005	.0002	−.001	−.001	−.001
	(.001)	(.001)	(.001)	(.001)	(.001)	(.001)
GSP growth rate	.004	.002	.003	−.003	−.003	−.004
	(.008)	(.008)	(.008)	(.008)	(.008)	(.008)
IDR (market assets, 8% disc.)	.060***					
	(.011)					
IDR (market assets, Tr. disc.)		.029***				
		(.007)				
IDR (market assets, act.liab.)			.058***			
			(.011)			
IDR (act. assets, 8% disc.)				.021		
				(.015)		
IDR (act. assets, Tr. disc.)					.011	
					(.008)	
IDR (act. assets, act.liab.)						.014
						(.015)
Observations	500	500	500	500	500	500
R^2	.891	.885	.890	.878	.878	.877
Adjusted R^2	.878	.871	.876	.863	.863	.862
F-test (EDR = IDR)	.125	.002	.056	.000	.000	.000

Note: Abbreviations: FR = funding ratio, EDR = explicit debt ratio, IDR = implicit debt ratio, m = based on market assets, 8% disc. = uniformized liabilities obtained by discounting against 8% yield, Tr.disc. = uniformized liabilities obtained by discounting against Treasury yield, act. assets = actuarial assets, act.liab. = actuarial liabilities.

* is p-value <0.1; ** is p-value <0.05; *** is p-value <0.01.

All regressions include state-fixed effects.

coefficients on the implicit debt ratio are virtually unaltered, while the interaction term is insignificant in both regressions.

TABLE 2.11: Adding the interaction with the funding ratio dummy – (post-) crisis period (2007–2016)

	Dependent variable:	
	Municipal yield	
	(1)	(2)
Treasury yield	.828***	.875***
	(.023)	(.032)
EDR	.099***	.110***
	(.022)	(.024)
Building permits growth rate	.0003	−.0005
	(.001)	(.001)
GSP growth rate	.004	.002
	(.008)	(.008)
IDRm (8% disc.)	.056***	
	(.015)	
IDRm × D_{LF} (8% disc.)	−.004	
	(.009)	
IDRm (Tr. disc.)		.029***
		(.008)
IDRm × D_{LF} (Tr. disc.)		.0003
		(.002)
Observations	500	500
R^2	.891	.885
Adjusted R^2	.877	.870

Note: Abbreviations: FR = funding ratio, EDR = explicit debt ratio, IDR = implicit debt ratio, m = based on market assets, 8% disc. = uniformized liabilities obtained by discounting against 8% yield, and Tr.disc. = uniformized liabilities obtained by discounting against Treasury yield.
* is p-value <0.1; ** is p-value <0.05; *** is p-value <0.01.
All regressions include state-fixed effects.
D_{LF} is a dummy equal to one if the funding ratio is below the median. The funding ratio is based on market assets and uniformized liabilities. Both IDRm and D_{LF} in a given interaction term are based on the same uniformizing discount rate.

TABLE 2.12: Adding the interactions with the public revenue base and credit ratings – (post-) crisis period (2007–2016)

	Dependent variable:			
	Municipal yield			
	(1)	(2)	(3)	(4)
Treasury yield	.832***	.895***	.830***	.878***
	(.022)	(.031)	(.023)	(.031)
EDR	.101***	.110***	.097***	.106***
	(.022)	(.023)	(.022)	(.024)
Building permits growth rate	.001	.001	.0004	−.0004
	(.001)	(.001)	(.001)	(.001)
GSP growth rate	.006	.005	.003	.001
	(.007)	(.008)	(.008)	(.008)
IDRm (8% disc.)	.067***		.068***	
	(.010)		(.013)	
IDRm × D_{HREV} (8% disc.)	−.017***			
	(.004)			
IDRm × D_{HRAT} (8% disc.)			−.014	
			(.018)	
IDRm (Tr. disc.)		.034***		.035***
		(.006)		(.008)
IDRm × D_{HREV} (Tr. disc.)		−.009***		
		(.002)		
IDRm × D_{HRAT} (Tr. disc.)				−.011
				(.008)
Observations	500	500	500	500
R^2	.891	.885	.891	.885
Adjusted R^2	.877	.871	.878	.871

Note: Abbreviations: FR = funding ratio, EDR = explicit debt ratio, IDR = implicit debt ratio, m = based on market assets, 8% disc. = uniformized liabilities obtained by discounting against 8% yield, and Tr.disc. = uniformized liabilities obtained by discounting against Treasury yield.
* is p-value <0.1; ** is p-value <0.05; *** is p-value <0.01.
All regressions include state-fixed effects.
D_{HREV} is a one-zero dummy indicating high revenues. D_{HRAT} is a one-zero dummy indicating a high credit rating.

2.3.3.6 Capacity to repay the explicit debt

Our next extension of the baseline specification includes interactions of the implicit debt ratio with dummies that provide information on the ability to repay the explicit state debt. The first dummy variable is D_{HREV}, which is one for states with higher-than-average ratios of public revenues to GSP (measured by taking the state's average over the (post-) crisis period). The idea is that states with a more narrow revenue base may find it harder to raise the revenue needed to honor the pension entitlements and, hence, the danger that the explicit debt cannot be paid off in full is larger. Columns (1) and (2) of Table 2.12 report the results. We find indeed that for states with a higher-than-average revenue base the effect of a one-percentage point increase in the implicit debt on municipal yields is 1.7 basis points lower when measured at the 8% discount rate, and 0.9 basis points lower when discounted against the Treasury yield, than for states with a lower-than-average revenue base. Hence, we observe that, irrespective of which group a state belongs to, the effect of the explicit debt ratio on municipal yields exceeds that of the implicit debt ratio. The second dummy is D_{HRAT}, which is one for states with a relatively high credit rating of AAA or AA+ in 2016, and zero otherwise.[20] The idea is that states with a relatively low credit rating might be under tighter scrutiny from investors, so that a given deterioration of the pension sector's financial health has a stronger effect on the municipal yield. These regression results are found in Columns (3) and (4) of Table 2.12. Now, the interaction terms are insignificant, while the significance and order of magnitude of the other coefficient estimates are unaffected.

2.3.3.7 Further investigation into robustness and extensions

We investigated some further variants of our baseline regression for the (post-) crisis period for which the results are not explicitly reported in tables, but are available upon request. First, we estimated the baseline regression also with state-specific coefficients on the Treasury yield. Again, the estimates of the coefficients on the explicit and implicit debt and their significance levels are unchanged. Second, because the discount rate used to calculate the liabilities is usually based on the asset return expected by the fund, the actuarial liabilities may reflect the riskiness of the assets (see Andonov et al. (2017)). Hence, a given amount of actuarial liabilities would be associated with higher expected pension pay-outs when the asset portfolio is riskier. The higher asset return would be

[20] Here, we deviate from Novy-Marx and Rauh (2012), who regress bond yields on their own rating. We instead use the states' credit ratings. In regressions of the yield spread between local debt and Treasuries, Aubry et al. (2017) control for the state credit rating.

expected to pay for these higher pay-outs. However, with a more risky asset portfolio it is also more likely that the pension claims cannot be fulfilled and, hence, that the state will be liable for those pensions. Hence, it is conceivable that, for a given implicit debt ratio, a more risky asset portfolio would translate into a higher municipal yield. Therefore, we also tried to estimate an extension of the baseline in which we add the interaction of the actuarial discount rate with the implicit debt. However, because the actuarial discount rate shows very little variation over the sample, the interaction term is highly correlated with the implicit debt and due to multicollinearity the results are not meaningful.

States face not only pension obligations, but also liabilities concerning other post-employment benefits (OPEB). These state obligations are mostly health care, life insurance and deferred compensation (PEW (2016)). Similarly to pension liabilities, the OPEB liabilities can potentially also affect state bond yields. Unfortunately, we do not have quantitative data on the development of these liabilities over the sample period. However, there are a number of reasons why we would not expect the OPEB to play a major role in determining municipal yields. First, and most importantly, pension obligations are considered senior to OPEB obligations. Seider and Williamson (2005) state that OPEB obligations generally represent unsecured claims against the debtor, and that they are not viewed by credit rating agencies as debt, because they are generally modifiable or cancellable in the case of a bankruptcy. Second, OPEB obligations have a very minimal degree of funding, if any, and, hence, only limited exposure to financial assets. Combined with the lack of changes in the underlying liabilities (except for some inflation expectation adjustments), there is only limited variability of the net OBEP debt over time. Hence, we would expect the OBEP to be irrelevant in the context of panel data model with state-fixed effects. Nevertheless, we tried to estimate an extension of our baseline regression in which we included unfunded OPEB liabilities to the extent that such data were available. In particular, we gathered the most recent figures for the unfunded OPEB liabilities per state.[21] We split the set of states on the basis of the GSP shares of their unfunded OPEB liabilities and defined a dummy with a value of one for those that have higher-than-median unfunded OPEB liabilities. We added the interaction of the dummy with the implicit debt as an explanatory variable. The idea behind the regression is that if OPEB liabilities play a role in shaping the standing of a state with its creditors then a given rise in the implicit debt should make it harder to honor the explicit debt when the OPEB are higher. The coefficients on the implicit and the explicit debt are not too far from their baseline values and continue to be significant. However, somewhat surprisingly, with discounting against

[21] In most states the OPEB liabilities are substantially smaller than the pension liabilities and in many instances they are completely negligible.

a common 8 percent discount rate the coefficient on the aforementioned interaction term is significantly negative, although only at the 10 percent level. Since we do not have an obvious explanation for this finding, we will not investigate it further.

2.4 Discussion of the mechanisms

Two key conclusions have emerged from our empirical analysis. First, the results of the sub-period analysis suggest that, while there is no evidence of an effect of a state's indebtedness on municipal yields before the crisis, this changes after the start of the crisis. Second, during this (post-) crisis period an increase in the explicit debt appears to exert a stronger upward effect on municipal yields than does the implicit debt.

The first main result is in line with experience in other financial markets, such as those for euro-area public debt, where the crisis triggered substantial increases in the spreads between higher- and lower-rated financial assets. The increased responsiveness of municipal yields to higher explicit and implicit debt after the start of the crisis may be caused by an increase in investor awareness of potential losses, or an actual increase in the expected losses associated with a higher debt ratio. Support for this latter hypothesis is found in the fact that there was a structural break in bond wrapping starting with the crisis. Bond insurance, which was rather common before the crisis, became nearly non-existent due to the downgrading of several insurers, as shown very clearly in Aubry et al. (2017). This likely has raised investors' expected losses from default. The drop in bond insurance has persisted after the crisis. Because bond insurance does not apply to the implicit debt, it is unlikely that it can explain that implicit debt also became a significant determinant of municipal yields after the start of the crisis. However, there is also evidence that the crisis triggered the awareness of risks that were already present, thereby causing municipal yields to become responsive to increases in both explicit and implicit debt. Aubry et al. (2017) suggest that the growing burden of pensions on state and local budgets has led credit rating agencies to take these explicitly into account in their ratings. Finally, it may not be possible to see the declining bond insurance hypothesis as independent from the hypothesis on growing awareness if the latter itself has undermined the bond insurance market.

As regards to our second main result, there are several potential explanations for the smaller yield effect of the implicit than of the explicit debt since the start of the crisis. First, there may be systematic differences in the timing of the fulfillment of creditor claims.

If all pension benefit payments were scheduled to take place after all outstanding debt is repaid, then a priori we would expect no effects of the size of the implicit debt on the municipal yield. However, this is not true. For example, Display 4 in Alliance Bernstein (2010) depicts a frequency diagram of municipal debt by years to maturity showing that the maturity distribution is very evenly spread over the coming two decades. Except for the short debt of up to one year, which is slightly over 5 percent of the total, all yearly buckets are on the order of between 3 to 4 percent of the outstanding debt. (The diagram does not provide information further than two decades ahead.)

Second, investors may view pension promises as legally easier to renege upon than explicit debt obligations. Munnell and Quinby (2012) provide a concise overview of the legal protection of state pension plans. The legal protection of these plans is the responsibility of the state itself and, hence, it varies across the states. Various degrees of protection are possible, ranging from pensions being viewed as a gratuity that can be withdrawn at any time to protection embedded in the state constitution. Some states protect only benefits accrued to date, while others protect also future accrual. One also needs to separate these core benefits from the cost-of-living-adjustments (COLAs) that generally feature less legal protection. The overview by Brainard and Brown (2018) suggests that states are able to reform their pension plans when the fiscal pressure is high enough, although similar measures sometimes meet with different legal success in different states. In the widely-reported case of the Detroit bankruptcy of 2013 also retirees faced benefit cuts, in spite of the fact that this was ruled out by the Constitution of the State of Michigan.[22] In fact, federal law did allow bankruptcy judges to renegotiate the pensions. The overview by Brainard and Brown (2018) counts a total of 116 state pension reforms over the period 2007 - 2018. The largest number of reforms took place in 2010 (18 reforms) and 2011 (27 reforms). A guiding principle for such reforms is the need to balance the objectives of the different stakeholders, i.e. the employees, the employers and the tax payers. Even when the pensions arrangement is viewed as a contract, a court might determine that its impairment is justified by reasonable and necessary public interest (Munnell and Quinby (2012)). As Brainard and Brown (2018) document, most reforms involve a combination of reduced benefit levels, including reduced or abolished COLAs, higher employee contributions, and reduced eligibility for retirement, which includes longer vesting periods, longer working lives and a higher minimum age for a benefit to be drawn. Also, risks were shifted from employers to employees, for example by making benefit levels

[22] Article IX, Section 24 of the Constitution of the State of Michigan of 1963 reads "The accrued financial benefits of each pension plan and retirement system of the state and its political subdivisions shall be a contractual obligation thereof which shall not be diminished or impaired thereby."

and employee costs dependent on the financial situation of a fund or an increased reliance on individual savings plans.

2.5 Concluding remarks

Recent years have seen a steady decline in the funding situation of U.S. state pension plans. As a result the implicit pension debt associated with the states' civil servants pension funds is rising. This paper has explored how the implicit pension debt affects municipal debt yields. In so doing it has made two specific contributions, in particular in comparison with Novy-Marx and Rauh (2012). First, both the implicit and the explicit pension debt only affect municipal yields since the start of the global financial crisis. This in line with the break experienced in other financial markets, such as that for euro-area public debt, where spreads between the core and periphery countries went up dramatically since the eruption of the crisis. Second, while the implicit debt exerts a positive effect on municipal yields, its effects are significantly smaller than the effect of explicit debt on municipal yields. While further investigation of the driving factors behind these findings is needed, it is likely that the crisis triggered an increase in the awareness of investors and rating agencies of potential credit losses, which in turn may have undermined the insurance possibilities against such losses. The difference in municipal yield responses to explicit versus implicit debt is unlikely attributable to differences in the timing of the claims, but may well reflect a perception that pensions can more easily be adjusted or reneged upon than explicit debt contracts. Indeed, some states have already started to address their civil servant pension underfunding problems in a variety of ways (e.g. Munnell et al. (2014a)).

Chapter 3

A value-based assessment of alternative U.S. state pension plans

3.1 Introduction

In the past decades the U.S. has witnessed a trend away from defined benefit (DB) towards defined contribution (DC) pension plans. However, an exception to this trend are the plans that manage the pensions of state civil servants. Despite the aging of the population, these plans still largely operate on a DB basis, although it is clear that in many cases the financial situation of the pension fund is too weak to fully honor the pension promises made to its participants. However, these promises cannot so easily be reneged upon (see Brown and Wilcox (2009)). In fact, pension beneficiaries may even get priority over the states' debt holders when a state goes bankrupt. Hence, in many instances existing pension promises to state civil servants threaten the financial health of the state, possibly resulting in large claims on its tax payers and/or the crowding out of public services.

This paper explores the redistributive features of a typical U.S. state defined benefit pension plan under unchanged fund policies and under alternative policies in terms of contributions, benefits and indexation aimed at alleviating the financial burden on the tax payer. We also explore changes in the fund's investment mix. We assume that pension promises cannot be defaulted upon. We quantify the amount of redistribution among the different stakeholders of the fund, i.e. the various cohorts of plan participants and tax payers, under the baseline plan, under which current policies are continued, and alternative plans using the so-called method of value-based asset-liability management (value-based

ALM). It differs from standard or "classic" ALM in that it values redistribution at market prices. While the classic ALM model is based on simulation of the actual probability distribution of asset returns and inflation, value-based ALM is based on simulations using the risk-neutral probability distribution. Pension plan changes are always a zero-sum game, implying that the total value of the contract to all the stakeholders together is unchanged and that a plan change can only shift value among groups of stakeholders. To the best of our knowledge, our paper is the first attempt at applying value-based ALM to the study of reform-induced redistribution within U.S. state pension funds. In addition, we use a classic ALM analysis to explore the financial health of U.S. state pension plans in the long run.

We simulate a representative pension fund over a period of three quarters of a century. This is a common planning horizon for the U.S. social security scheme. Over this horizon we explore the financial health and redistributive features of the U.S. state funded pension system. Regarding financial health, the classic ALM results show that under our benchmark parameter setting based on recent financial markets forecasts from the Survey of Professional Forecasters (SPF), there is a high chance that the fund's assets are fully depleted at the end of our evaluation horizon. This is the case for our baseline plan, which captures the policies most commonly followed by U.S. state pension funds, as well as the alternative policies we consider. These include raising the share of the amortization cost that is contributed (to close the gap between the fund's liabilities and assets), speeding up the amortization payment, halving indexation to consumer-price inflation, introducing indexation conditional on the funding ratio (the ratio of fund's assets over liabilities) and changing the fund's investment mix. While these policies may help in slowing down the fund's asset depletion, they still lead to a close-to-zero chance of averting full asset depletion in the long run. A substantial shortening of the amortization period performs relatively best in this respect. Also, of some interest is a conditional indexation policy, which has become popular lately among Dutch pension funds. Such a policy reduces the speed of asset depletion by limiting the build-up of entitlements, especially when the fund's financial health deteriorates. A shift away from the benchmark parameter setting by basing projections on the financial market performance over the past 25 years instead of on SPF forecasts mitigates the expected speed of asset depletion, especially under some of the alternative plans we consider, although the chances of a fully depleted fund at the end of our 75-years horizon are still substantial under the various plans. The broader conclusion is that even a substantially more optimistic outlook for financial markets than the current one does not solve the long-run financial sustainability problems of the U.S. state pension sector.

Regarding redistribution, our value-based ALM results show that the current pension contract yields a substantial net benefit to all cohorts of fund participants, which in turn implies a substantial financial burden on all cohorts of tax payers. In present (i.e., year 2015) value terms, over the 75-years horizon under the baseline plan the fund participants receive almost 14 trillion dollars in net benefit, of which the tax payers have to contribute almost 11 trillion dollars. Increasing the amortization contribution rate and speeding up amortization without addressing the benefit level harms the current tax payers at the benefit of the future tax payers.

A doubling of the contribution rate by the participants affects their net benefit from the pension contract. The cohorts that have not yet entered the labor force at the start of the simulation horizon experience a value loss equal to more than half the fund's initial assets, while the value loss of the older participants equals one-third of the fund's initial assets. The benefit to both old and young tax payers exceeds 40% of the fund's initial assets. The overall shift from participants to tax payers is about 2.5 trillion dollars. Reducing benefits by cutting indexation can be quite effective too. Halving the indexation to CPI inflation shifts over one trillion from participants to tax payers, while making indexation conditional on the funding ratio shifts more than two trillion dollars from the former to the latter group. Changes in the pension fund's investment portfolio do not affect the participants' values, but cause value shifts among cohorts of tax payers. An increase in the riskiness of the portfolio benefits the future tax payers at the expense of the current tax payers, because there is a higher chance of fund's assets being depleted and, consequently, the sponsor having to pay support payments in the short run.

The remainder of this paper is structured as follows. Section 3.2 relates it to the relevant literature. Section 3.3 provides a description of the model, discussing the calculation of the pension fund's benefits, contributions and liabilities. Sections 3.4 and 3.5, respectively, describe our economic scenario generator and the valuation of the cash flows following from the pension contract. Sections 3.6 and 3.7 summarize the data (sources) and the benchmark settings, respectively, while Section 3.8 presents the various alternative pension plans we will consider. Section 3.9 discusses the simulation results for the classic ALM and the value-based ALM. It also considers some variations on the benchmark setting. Finally, Section 3.10 concludes the main text of this paper. Technical details have been relegated to the Appendices. Appendix 3.A gives the details on pension plan modeling that were left out in the main text. Appendices 3.B-3.E lay out the simulation details, while Apendix 3.F reports the results of the robustness analysis.

3.2 Relationship with the literature

A recent overview by Munnell et al. (2013) illustrates the urgency of the financial condition of many U.S. state pension funds. For a sample of 109 state plans and 17 locally-administered plans, the paper estimates the aggregate funding ratio (i.e., the ratio of assets over liabilities) for 2012 at 73%. Almost a quarter of the plans have a funding ratio below 60%, while only a small fraction of 6% have a funding ratio above 100%. The funding ratios are calculated on the basis of standards that prescribe that assets are reported on an actuarially-smoothed basis, while the discount rate for the liabilities is typically set at around 8 percent, reflecting the expected long-term investment return on the fund's assets.[1] These standards have been criticized by economists (Novy-Marx and Rauh (2009) and Bader and Gold (2003)), who claim that the future streams of benefit payments should be discounted at a rate reflecting their riskiness. As the state pension benefits are protected under most state laws, these payments can be seen as guaranteed and so this would plead for discounting them against the risk-free interest rate. In fact, Brown and Pennacchi (2015) argue that for calculating a pension plan's funding ratio, liabilities should always be discounted against the default-free term structure, no matter what the actual default risk of the plan is. Doing so would lead to a severe fall in the already-low average funding ratios of the state plans. In fact, a precise assessment of the riskiness of state pension promises likely remains elusive for the foreseeable future. For example, the recent default of the city of Detroit on its obligations may be an instructive case of whether pensions should be seen as a contractual obligation that cannot be diminished or impaired, or whether the holders of pension rights should be treated like other creditors, so that benefit cuts cannot be ruled out. Indeed, a U.S. bankruptcy judge declared in December 2013 that legally pensions can be cut (Bomey and Priddle (2013)).

The value-based ALM approach that we apply in this paper to U.S. state pension funds has its roots in the pioneering papers of Sharpe (1976) and Sharpe and Treynor (1977) in utilizing derivative pricing to value contingent claims within pension funds. More recent applications of derivative pricing to pension plans are, among others, Blake (1998), Exley et al. (1997), Chapman et al. (2001), Ponds (2003), Bader and Gold (2007), Hoevenaars and Ponds (2008) and Ponds and Lekniūtė (2011). Our paper is closest in spirit to Biggs (2010), which also employs an option-based approach to value the market price of pension liabilities of U.S. state pension plans. However, it does not address reform plans and the associated redistribution effects. Value-based ALM has also been employed in the

[1] In 2014 the new GASB standards were proposed, but Munnell et al. (2014c) estimate that their effects would be minimal.

Dutch discussion on the redesign of the second-pillar pension funds offering DB plans. In particular, the CPB Netherlands Bureau for Economic Policy Analysis (2012) applies it to investigate the generational fairness of various pension reform plans, while Platanakis and Sutcliffe (2015) apply it to quantify the redistribution associated with the 2011 reform of the UK pension plan for universities (USS).

Our paper is complementary to related contributions studying the degree of underfunding of U.S. state pension plans, the causes of the underfunding and the measures that could be taken to solve plan deficits. Novy-Marx and Rauh (2011) conduct a careful analysis of the value of the pension promises made by U.S. state pension funds under different assumptions about the riskiness of state pension plans and their seniority relative to state debt in the case of default. Several papers explore the extent of underfunding and the question of what should be the appropriate target for the funding ratio (compare D'Arcy et al. (1999), Lucas and Zeldes (2009) and Bohn (2011)). Brown et al. (2011) argue that adequate funding requires 100% funding of the liabilities.

Regarding the causes of the underfunding of state pension plans some papers point at the implications of what may be called the "accounting game". The accountability horizon of politicians and public sector union leaders is much shorter than the horizon over which pension promises have to be met by adequate funding. Hence, union leaders and politicians tend to downplay the long-term costs of pension promises in favor of higher short-term wages and benefits (Mitchel and Smith (1994) and Schieber (2011)), as well as higher state spending in the short run. Shnitser (2013) stresses the role of the institutional design of pension plans in explaining the large variation in funding discipline. Institutional rules facilitating transparency and pre-commitment to expert-based financial and actuarial advice, in particular, appear to be conducive to mitigating underfunding and limiting the shift of costs to future tax payers. Kelley (2014) and Elder and Wagner (2015) apply a public choice perspective to explaining underfunding issues.

Essentially, the literature has explored three broad directions of solutions to the underfunding problem: higher contributions, lower benefits and higher investment returns. Novy-Marx and Rauh (2014b) explore by how much contributions need to be raised to reach full funding in 30 years time. They compute a necessary increase of the order of 2.5 times the prevailing contribution level. The option of reducing benefits has long been seen as virtually impossible, as in many states public pensions are interpreted as hard contractual obligations, protected by civil law and state constitutions (Monahan (2012)). However, several states have already enacted benefit cuts and other measures to scale back the generosity of pensions. Further, as documented by Munnell et al. (2014a), in response to the economic and financial crisis, many public plan sponsors have reduced or eliminated cost-of-living adjustments in one way or another. Munnell et al. (2014a) report that between 2010 and 2013 this has been done by 17 states and conclude that benefits are no longer as secure as they were perceived to be before the financial crisis. Novy-Marx and Rauh (2014a) explore performance-linked indexation rules comparable to the one in the Wisconsin Retirement System or the conditional indexation rule in the Netherlands (Ponds and van Riel (2009) and Beetsma and Bucciol (2010; 2011a;b)). Shnitser (2013) stresses that simply scaling back generosity or imposing higher contribution rates will not be enough. She claims that foremost the institutional design has to be reframed to practices and rules that have proven to be successful in promoting funding discipline. A third route proposed to solve funding deficits is to raise expected investment returns. This option is already being exploited by U.S. state pension funds, as many of them have high portfolio shares in equity, substantially higher than of pension funds outside the U.S. (Andonov et al. (2017) and OECD (2011)). However, finance-based papers (Black (1989), Peskin (2001), Bader and Gold (2003), Lucas and Zeldes (2009) and Pennacchi and Rastad (2011)) recommend that the strategic asset allocation should be set in line with the perspective of the tax payers as the party bearing the residual risk, which suggests to limit mismatch risk between the funds' assets and the market value of their liabilities. This may imply no equity investment at all when one aims at full protection of accrued benefits in the short run. Lucas and Zeldes (2009), employing a long-term perspective, suggest that the optimal portfolio should include some equity holdings as future pension liabilities are related to future wage growth and this growth is to some extent correlated with the equity returns.

3.3 The model

This section briefly sketches the model. The full details of the model are found in Appendix 3.A. It first describes the demography, then the wage developments and, finally, the pension fund. The participant population of the pension fund consists of individuals of ages 25 to 99 years. Individuals enter the fund at the age of 25 and remain with the fund for the rest of their life. We distinguish between males and females and apply projections of survival probabilities to calculate the size of these cohorts in the future. The survival probabilities are deterministic, hence there is no longevity risk. Crucial for the calculation of the pension liabilities are the wage developments. We assume a uniform wage level within each cohort, while over one's life the wage level follows a certain career profile that is constant over time (i.e., the relative wage between two cohorts of specific ages is constant over time). Because we do not have gender-specific age-wage profiles, we set the wage levels of males and females equal. The economy-wide wage growth rate is stochastic and will be modelled as explained in Section 3.4 below.

State pension funds can differ in many respects from each other. Some of the differences are parametric, such as the value of the discount rate to be applied when calculating the liabilities, while other differences are more fundamental. We model a pension fund based on the most common features across the entire population of pension funds available to us from the Public Plans Database of the Center for Retirement Research at Boston College (2015). In doing so, we try to stay as close as possible to the actual practice of GASB accounting employed by pension funds, and use their most common actuarial assumptions to calculate their financial health *in actuarial terms*, which is the basis for their instrument settings (contributions, indexation and benefits). However, our simulations of the fund over time, and the valuation of the cash flows, will be based on an economic scenario set and a term structure constructed from actual and survey projections of economic and financial data.

3.3.1 The calculation of the actuarial assets and liabilities

As inputs for policy decisions, we need to calculate the *actuarial assets* A_t^{act} and *actuarial liabilities* L_t^{act} to the participants of the fund. These consist of the retired and the workers. Compared to the market value of the assets, the dynamics of the actuarial assets are smoothed, because each period they change only by expected investment income plus a fraction of the difference between realized and expected investment income. The actuarial liabilities are calculated as the present value of the future benefit payments to all current fund participants, taking into account the survival probabilities, and based on the *actuarial* assumptions typically used by pension funds. The actuarial liabilities should be distinguished from what we will term the *economic liabilities*, the projected benefits based on the economic developments expected by the market participants and discounted against a proper market interest rate. The economic liabilities will be discussed in more detail below.

To calculate the actuarial liabilities, we need to calculate the projected future benefits of both the retirees and the workers. The projected future benefits equal the current pension rights adjusted for the *actuarially projected* future cost-of-living adjustments (COLAs),[2]

[2]In practice, COLAs are only included in the calculation of the liabilities to the pensioners if there exists an explicit policy rule on how the indexation is awarded. COLAs are not taken into account if indexation is determined on an ad-hoc basis.

intended to protect the retirees' living standards and calculated on the basis of the fund's own future inflation projection. The *current* pay-out to a retiree equals their current pension rights, which equals their pension rights at the moment of retirement compounded by the *realized* COLA since retirement. In turn, pension rights at retirement are the product of the annual accrual rate, the number of years in the workforce and the average over the latest (usually one to five years) wages earned by the individual.

Thus, we need to distinguish the actuarial projection of the COLA and the realized COLA. The latter covers a certain share of realized inflation and is often capped at a predetermined level (Center for Retirement Research at Boston College (2015)). Hence, under our baseline plan and most alternative plans we model the *realized* COLA as

$$COLA_t = \max\left[\min\left(\xi \cdot cpi_t, cap\right), 0\right] \tag{3.1}$$

where cpi_t stands for actual consumer-price inflation in period t, ξ is the fraction that is compensated and cap is the maximum indexation rate. Here, both cpi and cap are expressed as a fraction of unity. The minimum indexation rate is bounded from below at zero, hence benefit payments are prevented from declining in nominal terms. In reality, ξ is often below one. However, in order to avoid an arbitrary parametrization, under our baseline pension plan we will set $\xi = 1$, while we will consider an alternative plan in which ξ is below one.

In contrast to the retirees, active participants are expected to continue working and, hence, accrue additional years of service. Therefore, there are various ways in which the liabilities associated with the worker's current pension rights can be recognized. Under the *Accrued Benefit Obligation (ABO) method*, only the pension rights accrued up to now are taken into account, while future wage rises are not taken into account. The *Projected Benefit Obligation* (*PBO) method* also takes into account the effect of actuarially projected salary increases on the rights accrued up to now. Finally, the *Projected Value of Benefits (PVB) method* in addition takes into account the rights that the employees will acquire in the future if they continue working in their current job until retirement. As a result, a cohort that has just entered the labor force already has a stake in the fund's liabilities based on the PVB method, as opposed to the ABO or PBO method. For people of working age PVB liabilities would normally exceed PBO liabilities, which, in turn would exceed ABO liabilities. However, all three measures converge for a given individual at the moment of retirement.

The PVB method is of particular relevance here since state civil service jobs are relatively secure. We use the PVB method to calculate our liability measures and the associated pension contributions. The calculations are done under the assumption that individuals spend their full career as fund participants. We make this assumption, because the Public Pensions Database has no information on the entry and exit likelihoods at different ages at the individual fund level or at the aggregate level. Given the upward-sloping age-wage profiles, ignoring entry at later age biases all the liability measures downward, while ignoring job exits that take place before retirement produces an upward bias in our PBO and PVB measures, because the projected salary increases of the quitters would drop out of these measures. In view of the absence of the appropriate data, we have chosen to ignore entries later in working life and premature exits, rather than making arbitrary assumptions about the age distribution of the people entering and leaving the fund.

3.3.2 The funding ratio

The evaluation of a pension fund's financial health and its policies, including indexation decisions, is usually based on a funding ratio that is calculated on the basis of the fund's actuarial assumptions. We refer to this funding ratio as the *policy funding ratio* (FR_t^P), defined as the ratio of the fund's actuarial assets and actuarial liabilities:

$$FR_t^P = \frac{A_t^{act}}{L_t^{act}}. \tag{3.2}$$

However, the policy funding ratio often gives an overly optimistic picture of the financial health of the pension fund, in particular due to the use of an unrealistically high discount rate for the calculation of the actuarial liabilities. Therefore, we also calculate an *economic funding ratio* (FR_t^E) defined as the ratio of the market value of the assets A_t and the *economic liabilities* L_t:

$$FR_t^E = \frac{A_t}{L_t}. \tag{3.3}$$

The economic liabilities are computed by discounting against the (default-free) nominal term structure the projected future benefits based on the expected price and nominal wage developments implied by our model of the dynamics of the state variables, conditional on their values in period t (see Section 3.4 below).

Brown and Pennacchi (2015) provide a number of arguments for using the default-free nominal term structure for DB pension plans if the funding ratio is intended to measure the fund's financial health. First, the funding ratio thus calculated is independent of the investment portfolio, in contrast to when the liabilities are calculated on the basis of the expected investment return. Second, the funding ratio calculated in this way immediately shows how much more a plan sponsor needs to contribute in the case of underfunding (or would receive back in the case of overfunding) for an insurance company to take over the pension obligations and guarantee the DB payments. Note that the floor and the cap on the indexation rate prevent accumulated entitlements from fully keeping up with inflation. Appropriate account of the floor would shift the term structure for the discounting down, while the opposite is the case when appropriate account is taken of the cap. However, incorporating the effects of the floor and the cap in a fully consistent way is so complicated that we decide to apply the nominal term structure without any further adjustments.

3.3.3 Benefits and contributions

The total amount of benefits B_t paid out by the fund is the sum over all retirement ages of the number of retirees at each age times the current pension rights at that age. The *total contribution rate* c_t is total contributions C_t divided by the aggregate wage sum. We have that

$$\begin{aligned} c_t &= c_t^{NC} + c_t^{Amort} + c_t^{SS} \\ &= c_t^{act} + c_t^{SS}, \end{aligned} \tag{3.4}$$

where c_t^{NC}, c_t^{Amort} and c_t^{SS} are the so-called *normal cost* payment, the (actual) *amortization* payment and the *sponsor support* payments, respectively, all as fractions of the aggregate wage sum. Finally, we refer to $c_t^{act} = c_t^{NC} + c_t^{Amort}$ as the *actuarial contribution rate*.

The normal cost equals the value of the additional pension rights earned in a given year. The amortization payment is based on the so-called *unfunded actuarial accrued liability* ($UAAL$), which, in turn, is the difference between the *actuarial accrued liability*, $L_{accr,t}^{act}$, and the actuarial value of the assets, i.e. $UAAL_t = L_{accr,t}^{act} - A_t^{act}$. We assume a smoothing period of u years for the amortization of the $UAAL_t$. The amortization payment cannot be negative. If there is a funding surplus, i.e. $UAAL_t < 0$, the actuarial contribution is kept at the normal cost covering contribution c_t^{NC}, hence $c_t^{Amort} = 0$. Munnell et al. (2008a) show that in only about half of all the pension plans the required amortization contribution is paid. In our simulations we thus allow for only a fraction of the required amortization payment to be *actually* paid.

Forecasting the development of a pension fund over a long horizon implies that there exist scenarios in which the fund's assets get depleted.[3] We assume that, whenever the fund's assets A_t become insufficient to finance the net cash outflow $B_t - C_t$, the employer, i.e. the tax payer,[4] provides sponsor support SS_t. Hence, $SS_t = (B_t - C_t) - A_t$, if this is positive. Otherwise, $SS_t = 0$. Once the sponsor support becomes positive, the fund effectively continues to be run on a pay-as-you-go basis. Both the policy and economic funding ratios remain at zero from that moment onwards.

The actuarial contribution rate can be split into a contribution rate c_t^P paid by the plan participant and a contribution rate c_t^T paid by the tax payer (as employer):

$$c_t^{act} = c_t^P + c_t^T. \tag{3.5}$$

Typically, as we will also assume in our simulations, the contribution rate paid by the worker is fixed, i.e. c_t^P is constant, while the tax payer as employer pays the remainder.

3.4 The economic scenario generator

We estimate a quarterly vector autoregression (VAR) model on historical data for the U.S. and use this model to generate a set of economic scenarios.[5] It is generally not known which scenario will occur in reality. Hence, we evaluate the performance of an object of interest under all the scenarios that we generate. For our purposes, there is no need for a very refined model specification. Hence, we simply use a first-order VAR model linking the state vector in quarter $q+1$ to that in quarter q:

$$X_{q+1} = \begin{bmatrix} y_{q+1} \\ xs_{q+1} \\ cpi_{q+1} \\ w_{q+1} \end{bmatrix} = \alpha + \Gamma X_q + \varepsilon_{q+1}, \tag{3.6}$$

[3]There is no record of depleted fund assets in the Pension Plan Database. Indeed, the funding problems are a relatively recent problem that has become more acute over the recent years. Of course, we cannot exclude the possibility that there may have been some small plan in the past that is not included in the database and that has run out of assets. However, we are not aware of any.

[4]Henceforth, we will refer to the employer as the "tax payer".

[5]Kim (2009) discusses the limitations of basing the pricing model on an economic scenario generator using observable macro variables, pointing in particular to the problem that in practice these variables are partly driven by "unspanned volatility" and, hence, their realisations do not necessarily correspond to the state variables underlying the pricing kernel. Nevertheless, we stay with most of the literature, and continue under the assumption that those "unspanned volatility" shocks are absent.

where y_{q+1} is the short-term quarterly interest rate, xs_{q+1} is the excess return on stocks, cpi_{q+1} is consumer price inflation and w_{q+1} is real wage growth. The first two variables are calculated by taking the natural logarithm of the gross rate. The latter two variables are calculated as changes in the logarithm of the relevant index. The error terms ε_{q+1} are independently and identically distributed and follow a multivariate normal distribution with mean zero and variance-covariance matrix Σ. Further, $\alpha = (I - \Gamma)\mu$, where I denotes the identity matrix and μ is the unconditional mean of the vector X_q for all q. The estimates $\hat{\alpha}$ and $\hat{\Gamma}$ of α and Γ, respectively, are obtained by estimating equation (3.6) using OLS. We obtain $\hat{\Sigma}$ as the variance-covariance estimate of the error terms.[6] Given $\hat{\Gamma}$ and $\hat{\alpha}$, the estimate of μ is:

$$\hat{\mu} = (I - \hat{\Gamma})^{-1}\hat{\alpha}. \tag{3.7}$$

The parameter estimates associated with (3.6) are used to price the cash flows implied by the pension arrangement.

3.5 Valuation

A pension plan can be seen as a financial contract. If we perceive this contract as a combination of contingent claims, we can value the pension deal using the derivative pricing techniques of risk-neutral valuation introduced by Black and Scholes (1973). Below, we explain how we calculate the value of the pension contract for all pension fund stakeholders, i.e. for the individual cohorts of participants and the individual cohorts of tax payers. Aggregating over the individual cohorts we obtain the contract value for all participants as a group and all the tax payers as a group.

To value the contract we use the scenarios for the underlying state vector produced by our scenario generator. The scenarios are generated at the quarterly frequency. We draw both real-world ("P world") scenarios for the classic ALM model and risk-neutral ("Q world") scenarios for the value-based ALM model. Under the classic ALM we generate paths for the state vector drawing shocks from a zero-mean normal density function, while under value-based ALM we generate these paths using risk-neutral sampling, which effectively amounts to a negative shift in the means of the components of the original shock vector.

The path for the state vector thus gives us a path for the stock returns. Also, for each quarter into the simulation, we determine the term structure using an affine model based

[6] The Breusch-Godfrey test for serial correlation in the errors shows that with a 1% significance level we cannot reject the null hypothesis that there is no autocorrelation.

on the state variables (e.g., see Dai and Singleton (2000), Ang and Piazzesi (2003), Ang et al. (2008) and Le et al. (2010)). This allows us to calculate the return on the fixed income part of the fund's portfolio, so that we now have the return on the entire fund's portfolio. Using the path of the state vector generated under the risk-neutral sampling, as well as the returns on the fund's portfolio based on this same path of the state vector, allows us to generate the annual cash flows associated with the pension contract under the value-based ALM. These are then discounted against the risk-free rate of interest. Appendix 3.B shows the details of the pricing of the cash flows and Appendix 3.C of the transformation to the risk-neutral scenarios needed to calculate the value of the pension contract to the various stakeholders.

We aim at valuing the pension contract to the different stakeholders of the fund. Therefore, we will calculate the value of the net benefits to each cohort of fund participants and each cohort of tax payers. We will value the cash flows over a horizon of T years. Recall that the scenarios are simulated at the quarterly frequency, while the cash flows materialize at the annual frequency.

The value $V_0^{P,a}$ of the pension contract to plan participants of the cohort aged a at $t = 0$ is:

$$V_0^{P,a} = \mathrm{E}_0^Q \left[\sum_{t=1}^{T} \left(\prod_{q=1}^{4t-2} (Y_q)^{-1} \right) NB_t^a + \left(\prod_{q=1}^{4T-2} (Y_q)^{-1} \right) \tilde{L}_T^a \right], \tag{3.8}$$

where E_0^Q is the risk-neutral expectation under the Q measure of the cash flows discounted against the quarterly gross risk-free rate Y_q, obtained through the simulation of the state vector, and q denotes the quarter. NB_t^a is the net benefit of the cohort aged a in period t, which for workers is their contribution and for pensioners is the pension benefit they receive. Hence, NB_t^a is negative for workers and positive for retirees. Because NB_t^a occurs in the middle of time period t, it is discounted only for half of year t. Further, $\tilde{L}_T^a$ is the final value of the economic liabilities to the cohort of age a. Since the working participants accrue pension entitlements in exchange for their contributions, we add the discounted final value of the economic liabilities to the discounted value of the net benefits to arrive at the value of the contract for each cohort. Unlike benefits and contributions, the outstanding pension entitlements at the end of the simulation period are not actual cash flows that materialize during the simulation. Rather, they form an estimate of the outstanding pension promises that have been given in exchange for contributions paid earlier. To sum up, the contract value to a cohort is defined as the present value of the benefits they receive, minus present value of their contributions, plus the present value of the pension entitlements accrued by the end of the simulation horizon in exchange for the contributions made earlier. The contract value to all participants is the sum of the contract values for each cohort participating in the fund during the evaluation horizon, i.e. $V_0^P = \sum_a V_0^{P,a}$.

The value of the contract to the tax payer cohort of age a in period 0 is:

$$V_0^{T,a} = -\,\mathrm{E}_0^Q \left[\sum_{t=1}^{T} \left(\prod_{q=1}^{4t-2} (Y_q)^{-1} \right) \left(C_t^{T,a} + SS_t^a \right) - V_0^{R,a} \right], \tag{3.9}$$

where $C_t^{T,a}$ is the tax-payers' contribution in dollars, i.e. the normal cost plus the actual amortization payment minus the contribution by the employees, and SS_t^a the sponsor support. The contract value to the total population of tax payers is $V_0^T = \sum_a V_0^{T,a}$. The final term in (3.9) is the part of the so-called *residual value* of the pension fund absorbed by the cohort of age a. The residual value is the difference between the present value of the assets remaining at the end of the evaluation horizon and the aggregate of the final values of the economic liabilities:

$$V_0^R = \mathrm{E}_0^Q \left[\prod_{q=1}^{4T-2} (Y_q)^{-1} (A_T - \tilde{L}_T) \right]. \tag{3.10}$$

Therefore, it is what is left over in present value terms for the tax payers at the end of the simulation horizon after redeeming their obligations to the fund participants still alive at that moment. Since the contributions associated with these accrued liabilities by the tax payers as employers have already been made, we can view the residual value as the amount of resources that the tax payers alive at the end of the horizon would still need to provide to (if the residual is negative) or receive from (if the residual is positive) the fund participants. We therefore distribute the residual value over all cohorts of tax payers alive at the end of the horizon.

The cohort-specific plan participant values are immediately available, as participants always contribute a certain part of their cohort-specific salary and receive cohort-specific benefit payments. Determining the cohort-specific tax payers' values is not completely straightforward. The aggregate cash flows in a year from all the tax payers together are immediately available. However, calculating the contract values for the individual cohorts of tax payers aged a in period 0 requires an assumption about the allocation of the aggregate cash flows across the cohorts of tax payers. We assume that the demographic structure of the tax payers' population and the age-wage profiles of the tax payers are identical to those of the participant population. The cash flows assigned to a specific tax payer cohort are then proportional to the share of this specific cohort in aggregate income. For tax payers of working age, the relative contribution of each cohort is fixed over time through the age-wage profile, because the latter is constant over time. The relative contribution of a cohort of retired tax payers is proportional to the average income of the participant cohort (i.e., the retirement benefit) relative to average aggregate income, where average income is the average over all scenarios in a specific year under the baseline plan. When allocating the residual value, we assume that it is absorbed by the different cohorts of tax payers alive at the end of the horizon in proportion to the present value of their projected remaining lifetime income.

3.6 The data

All our data are for the U.S. Our dataset comprises macroeconomic data, data from financial markets, data on state pension funds and demographic data. The economic scenario generator described earlier is based on historical data spanning the first quarter of 1990 up to and including the second quarter of 2015.

We use historical time series of the short interest rate, stock returns, price inflation and wage inflation. We obtain the real wage growth rate by adjusting the nominal wage growth rate by the growth rate in the nominal price index. The short interest rate is the 3-month treasury rate series and is obtained from the Board of Governors of the Federal Reserve System (2015). For the stock returns we use the NYSE/Amex/Nasdaq value-weighted return with dividends, which is available from the Center for Research in Security Prices (2015). For price inflation we use the CPI index provided by the Bureau of Labor Statistics (2015). Finally, wage inflation is obtained from the compensation of employees, wages and salary accruals and is retrieved from the US. Bureau of Economic Analysis (2015). These data are all quarterly or of higher frequency and transformed into quarterly data. The U.S. treasury nominal yield curve for maturities from 1 to 10 years is retrieved from the Federal Reserve Board (2015). We obtain the treasury real yield curve rates for maturities 5, 7 and 10 from the US Department of the Treasury (2015). However, they are only available starting from 2003. Finally, we obtain pension plan data from the Public Plans Database of the Center for Retirement Research at Boston College (2015).

As far as the demography is concerned, we use the National Population Estimates for 2010 by single year of age and sex provided by the United States Census Bureau (2014). Further, we use the survival rates derived from the Cohort Life Tables for the Social Security Area by Year of Birth and Sex provided by the U.S. Social Security Administration (2014). These life tables are available for birth years with 10 years intervals. Therefore, we linearly interpolate the survival rates for the birth years in between the ones directly available.

3.7 Benchmark settings for our U.S. state plan

We set the benchmark simulation horizon to 75 years, which is a commonly-used horizon for pension policy evaluation in the U.S. and which allows us to take into account a large number of cohorts that enter the fund after the start of the evaluation horizon. Hence, we evaluate the pension contract for cohorts born up to fifty years from now, in effect assuming that for cohorts born later contributions will be set such that their net contract value is zero. Extending the simulation horizon, we observe that the present values of both the end-of-the-horizon assets and economic liabilities fall and, hence, become less relevant relative to the present value of the benefits paid out over the horizon. In Subsection 3.9.3.3, we show that extending the horizon to 100 years has no qualitative and only limited quantitative effect on our results.

The demographic structure of our fund at the start of the simulation horizon, $t = 0$, is assumed to be identical to that of the U.S. population in 2010. Hence, the relative sizes of the cohorts are equal to those for the U.S. in 2010. We set the population of our pension fund at $t = 0$ equal to the aggregate number of participants in 2012 of all the state plans covered by the data from the Center for Retirement Research at Boston College (2015). As a result, our pension fund initially has approximately 26 million participants. While these data do not include all the U.S. public pension plans, they do include a very substantial share of the U.S. public sector workers at the sub-national level. Hence, the magnitude of the net burden on the tax payers that we will expose below provides a good indication of the seriousness of the public sector pension underfunding problem for the U.S., although it may only be a lower bound to the problem. This is not only because a number of public plans have not been included in our dataset – and a priori there is little reason to assume that these plans are healthier than those that are part of our dataset –, but also because the lion's share of the cost to the tax payers will be in the most underfunded, riskiest plans, since tax payers' guarantees are increasing and convex in risk.[7] Obviously,

[7]While beyond the scope of the current paper, it would be interesting in future research to obtain a more accurate assessment of the aggregate underfunding of the U.S. public pension system by simulating all individual funds in our sample over the set of scenarios.

when financial pressure accumulates, the subnational authorities will start shifting new participants into DC plans. However, we aim at assessing the underfunding problem under current plans and plausible alternatives, so here we ignore other potential policy reactions to the problem.

The fund's demography over the simulation horizon evolves as follows. Throughout the simulation horizon new cohorts aged 25 enter the labor market and become participants of the pension fund. Hence, for the first 25 years of the simulation horizon we determine the sizes of the 25-year old cohort by taking the sizes of the cohorts younger than 25 in the U.S. population initially and projecting the size of each such cohort when it reaches the age of 25 by using the officially projected (gender-specific) survival probabilities. The number of new entrants for the remaining 50 years of a simulation run is calculated by extending over time the trend in the size of the 25-year old cohort, i.e. by calculating the average annual growth rate of the 25-year old cohort over the first 25 years of the simulation horizon and taking this as the annual growth rate for the next 50 years. At the start of the simulation there are about 280 thousand 25-year old males and about 270 thousand 25-year old females entering the fund. During the first 25 years the number of new 25-year olds decreases on average by 0.34% per year. Extrapolating this trend over the next 50 years yields roughly 210 thousand new male entrants and 200 thousand new female entrants in the final simulation year.

Our simulations are based on the most common characteristics of the U.S. state pension plans. The liabilities are computed by using the entry age normal (EAN) actuarial method for liability recognition and are based on the following assumptions. Individuals retire at the age of 65. Hence, a full career means that they work for 40 years. The career (age-wage) profile is obtained from Bucciol (2012). Because the shape of this profile does not change over time, the wage earned at a given age increases each year with the common wage growth rate in the economy. The $t = 0$ average wage rate is set such that the fund's initial liabilities L_0 are equal to 3,900 billion dollars, which is the aggregate amount of liabilities in 2012 over all pension funds in the Public Plans Database of the Center for Retirement Research at Boston College (2015).[8] The benefit factor, or accrual rate, is 2% for each additional year of service, while the earnings base for the retirement benefit is the average of the final three years of pay during the career. During retirement there is full

[8]Effectively, this implies that we have to scale down the wage relative to the actual average U.S. wage. Implicitly, this rescaling corrects for the potential presence of vesting periods, which are not explicitly included in our model of the pension fund, and the difference between average state sector and economy-wide wages.

indexation for consumer price inflation when inflation is non-negative, while indexation is set at zero when inflation is negative.

The *actuarial* assumptions by our pension fund are based on the median assumptions used by the funds in the Public Plans Database of the Center for Retirement Research at Boston College (2015) in 2012 (the most recent year for which there is a full sample available). As a result, projected benefits are heightened up with a projected nominal salary increase of 3.75% for each working year and a projected annual rate of price inflation of 3.16% for each year in retirement, while the future retirement benefits are discounted at a fixed rate of 7.75% a year. We assume the initial accrued pension rights, B_0^a, to have been fully indexed up to time $t = 0$.

Contributions to the fund are calculated as follows. The annually required contribution is set to the normal cost plus the required amortization payment, which we assumed to be fixed at zero in the case of a fund surplus (one-sided policy). The normal cost is calculated as a percentage of the projected career salary based on the EAN actuarial method. The amortization payment is determined by spreading the unfunded actuarial accrued liability $UAAL$ in equal annual payments over the next 30 years, with a moving 30-years window. Hence, we use the so-called *open amortization period*. Employees pay a fixed 6% contribution of their salary, while the tax payer as employer pays the remainder of the required contribution.

Our sample data show that in 2012, assuming that the normal cost is paid in full, the actual amortization payment is on average just slightly more than half of the required amortization payment. Because of the lack of potentially more representative data we assume that the actual contribution is set to 100% of the normal cost, plus 50% of the required amortization payment. However, because our estimate of the share of required amortization paid varies substantially across plans and because of the importance of this parameter to the funding situation of the plan, we will also examine variations on the baseline plan in which less or more of the required amortization payment is paid in a year.

We set the initial actuarial funding ratio FR_0 equal to 71%, which is the median funding ratio of the pension funds in our database in 2012. Based on FR_0 and the initial liabilities, which are thus both matched to our data, we obtain the initial actuarial assets of the fund:

$$A_0^{act} = FR_0 L_0. \tag{3.11}$$

The actuarial funding position of the pension fund in the subsequent periods is calculated as the ratio of the actuarial assets and liabilities.[9]

We assume that under the baseline plan the fund invests 50% of its assets in fixed income (with an average annual return of 4.7%) and the other 50% in risky assets (with an average annual return of 5.5%). This implies an average annual return on the fund's portfolio of 5.1%. We thus abstract from investments in assets other than these two classes.[10]

3.8 The alternative plans

We consider a number of variations on the baseline plan, which we refer to as Plan 0, to explore what various policy changes imply for the contract values of the different stakeholders. This can give us leads about the effectiveness of different measures in reducing the likelihood that the pension fund's assets get depleted and, hence, in reducing reliance on the support from the tax payers.

We consider three groups of measures, which we summarize in Table 3.1. The first set of measures, Plans 1.1-1.4, addresses the contribution rate. Plans 1.1 and 1.2 vary the fraction of the required amortization payment actually paid, Plan 1.3 shortens the period over which the amortization payment is spread, while Plan 1.4 doubles the contribution payment by the participants from 6% to 12% of their salary, but leaves the total contribution rate and, hence, the fund's financial health unchanged.

The second set of alternatives addresses the degree of indexation. Under all plans, including the baseline plan, there is a 0% floor on indexation. Plan 2.1 halves indexation when CPI inflation is positive. Under Plan 2.2, if CPI inflation is positive, then indexation to CPI inflation is conditional on the level of the *policy* funding ratio FR^P. Specifically, if $cpi \geq 0$ and $FR^P < 0.5$, indexation is 0, while if $cpi \geq 0$ and $FR^P \geq 0.5$, it equals $(2FR^P - 1)cpi$. Therefore, if CPI inflation is positive, indexation is zero for funding ratios below one half, while it increases linearly with the funding ratio for funding ratios of at least one half. Hence, a funding ratio above unity implies more than full indexation. This way of providing conditional indexation is closely related to the way most Dutch pension

[9] The computation of the actuarial assets makes use of a 5-year smoothing period of realized investment income in excess of expected investment income – see Appendix 3.A.

[10] As we will explain in more detail later, the expected fixed-income and stock returns are based on the 2015Q1 ten-year forecasts from the Survey of Professional Forecasters (Federal Reserve Bank of Philadelphia (2015)).

TABLE 3.1: Summary of the alternative plans

Plan	**Description**
0	Baseline
Contribution policy	
1.1	0% amortization paid
1.2	100% amortization paid
1.3	Amortization spread over 10 years
1.4	Participants' contribution rate doubled to 12%
Indexation policy	
2.1	Indexation at 0.5 *cpi*
2.2	Conditional indexation
Portfolio composition	
3.1	100% stocks
3.2	0% stocks

funds index their pension rights – see Ponds and van Riel (2009) and Beetsma and Bucciol (2011b).

We continue to set contributions on the basis of the normal cost that was calculated under the assumption of full indexation. We do this in order to see the isolated effect of a change in indexation. Otherwise, the comparison with the baseline plan would be contaminated by a fall of the normal cost when indexation is reduced, which through lower contributions would in turn dampen the beneficial effect of less indexation on the fund's financial health.

The third group of measures concerns the composition of the fund's asset portfolio, which we vary from zero to 100% stocks.

3.9 Results

Appendix 3.E reports the quarterly frequency estimates of $\hat{\mu}$ and $\hat{\Sigma}$ of the VAR model (3.6) over the period 1990Q1 - 2015Q2. It also computes the correlation matrix of the vector of state variables. Not surprisingly, the shocks to the excess stock return are most volatile. Also not surprisingly, the correlation between the short-interest rate and CPI inflation is positive, while the correlation between CPI inflation and real wage growth is negative. If the nominal wage is sticky, then positive shocks to inflation have a negative effect on real wage growth. Finally, real wage growth is positively correlated with the excess stock returns, which is, for example, in line with the prediction of the standard neoclassical macroeconomic model driven by total factor productivity shocks.

The economic outlook nowadays differs substantially from the average economic situation over our sample period 1990Q1 - 2015Q2. Because historically observed values are unlikely to provide the best estimate of expected future values, in the simulation of our benchmark scenario set we replace the estimated vector of means $\hat{\mu}$ with the medians of the 10-year-ahead forecasts taken from the SPF in 2015Q1 as provided by the Federal Reserve Bank of Philadelphia (2015). Hence, we impute an annual average of 5.5% for the stock returns, 2.7% for the short interest rate and 2.1% for consumer price inflation. The SPF does not report projections for real wage growth. Hence, to impute SPF projections for the entire $\hat{\mu}$-vector, we replace the average real wage growth estimate with the SPF projection of productivity growth, which is 1.7%. Actually, this gives a scenario set that is very similar to the one we get if we would not replace the average real wage growth estimate. We properly transform these annual values into quarterly values. We continue to work with the original variance-covariance matrix $\hat{\Sigma}$ estimated above.

As a robustness check on our main findings, in Subsection 3.9.3 we discuss the results based on a scenario set in which we do not impute the SPF forecasts, but use the original $\hat{\mu}$-vector estimate for the means of the state variables. Our benchmark results leave the inflation risk premium free to be determined along with the parameters of the yield curve. In Subsection 3.9.3 we show that the numerical results are close to their benchmark values if we exogenously impose an inflation risk premium at specific values in line with findings elsewhere. There, we also show that extending the evaluation horizon to 100 years has no qualitative and only limited quantitative impact on our findings.

The inputs for our calculations come from different years. Because the financial market projections are based on data for the year 2015, in the sequel we assume that the beginning of the evaluation period $t = 0$ corresponds to the year 2015. Obviously, the implicit assumption is that the funding ratios and demography of the funds have not changed too much over the past couple of years.

3.9.1 The "classic" ALM benchmark results

This subsection discusses the "classic" (i.e., not applying market-based valuation) ALM simulation results under the baseline plan and the alternative plans. Here, and in the sequel, we simulate the pension fund's performance for a set of 5000 economic scenarios over a horizon of 75 years.

Table 3.2a reports for the various plans the 5%, 50% and 95% percentiles after 25 years for the total contribution rate c and its components, the normal cost payment c^{NC}, the amortization payment c^{Amort} and the sponsor support payment c^{SS}, all in percentages of the wage sum. For the normal cost payment we present only one column, because the normal cost depends only on the assumptions made by the fund and is therefore constant across scenarios. Table 3.2b reports the numbers for the policy funding ratio FR^P, the economic funding ratio FR^E and the pension result PR after 25 years. The pension result is defined as the ratio of the cumulative granted indexation to the cumulative price inflation, i.e. $PR_t = \prod_{\tau=0}^{t}(1 + COLA_\tau)/(1 + cpi_\tau)$. Hence, the lower it is, the larger the deterioration in the purchasing power of the benefits. Table 3.3 reports all the corresponding numbers after 75 years.

Consider first the results for the baseline Plan 0. The normal cost contribution at $t = 0$ is 12% and the total contribution is 14%. After 25 years, the respective median values are 12% and 20%, while the median amortization contribution is 8% (note that generally the median total is not the sum of the other two medians, as they likely correspond to different scenarios). The median sponsor support is 0%. After 75 years, the median total contribution has risen to 41%. The median sponsor support contribution is now of the same order of magnitude as the median amortization contribution. After 25 years the median value of the policy funding ratio is only 28%, while after 75 years the median has fallen to zero. After 75 years even the 95th percentile of the policy funding ratio is zero. The economic funding ratio, which provides a more accurate assessment of the fund's financial health, is even lower than the policy funding ratio as long as the latter is positive. Once the assets have been depleted and consequently the policy funding ratio has fallen to zero, the fund is effectively run on a pay-as-you-go basis, with benefits on a period-by-period basis financed through the various payments by the employees and the tax payers. The gradual run-down of the fund's assets can no longer be used as a cushion against the drastic increase in the total contribution rate. The bleak long-run financial outlook for the fund is not surprising in view of the fact that the expected return on its asset portfolio falls short of its discount rate, while only 50% of the required amortization costs is paid when the fund's financial health is poor (and, given its rolling window of 30 years, the required amortization itself adjusts only slowly to a financial deterioration of the fund). The pension result exceeds 100% after 75 years at the three reported percentiles, because full indexation is always granted when inflation is positive and zero in the case of deflation. Table 3.4 reports the probability that all assets are fully depleted within the 75-year simulation horizon. This probability is 97% for the baseline plan, while, conditional on a full depletion taking place, the median year in which this happens is 41 years from the start of the simulation.

TABLE 3.2: Classic ALM results under different plans after 25 years

(A) Contributions

Case	Description	c			c^{NC}	c^{Amort}			c^{SS}		
		5%	50%	95%	-	5%	50%	95%	5%	50%	95%
Baseline											
0	baseline plan	15%	20%	23%	12%	3%	8%	11%	0%	0%	0%
Contribution											
1.1	0% amortization paid	12%	12%	37%	12%	0%	0%	0%	0%	0%	25%
1.2	100% amortization paid	16%	25%	30%	12%	4%	13%	18%	0%	0%	0%
1.3	amortization 10 years	15%	27%	34%	12%	3%	15%	22%	0%	0%	0%
Indexation											
2.1	indexation is 0.5 CPI	14%	19%	22%	12%	2%	7%	10%	0%	0%	0%
2.2	conditional indexation	14%	19%	21%	12%	2%	6%	9%	0%	0%	0%
Portfolio composition											
3.1	100% stocks	12%	21%	36%	12%	0%	9%	12%	0%	0%	13%
3.2	0% stocks	20%	21%	21%	12%	8%	9%	9%	0%	0%	0%

(B) Funding ratios and pension result

Case	Description	FR^P			FR^E			PR		
		5%	50%	95%	5%	50%	95%	5%	50%	95%
Baseline										
0	baseline plan	6%	28%	69%	4%	20%	51%	100%	102%	106%
Contribution										
1.1	0% amortization paid	0%	7%	53%	0%	4%	38%	100%	102%	106%
1.2	100% amortization paid	23%	44%	81%	15%	31%	62%	100%	102%	106%
1.3	amortization in 10 years	36%	55%	90%	23%	39%	70%	100%	102%	106%
Indexation										
2.1	indexation is 0.5 CPI	11%	35%	79%	7%	24%	59%	73%	80%	89%
2.2	conditional indexation	15%	39%	80%	9%	27%	59%	58%	69%	84%
Portfolio composition										
3.1	100% stocks	0%	23%	148%	0%	15%	110%	100%	102%	106%
3.2	0% stocks	17%	23%	30%	13%	16%	19%	100%	102%	106%

Note: classic ALM results after 25 years for the 5%, 50% and 95% percentiles of (a) the total contribution rate (c), which is the sum of the normal cost (c^{NC}), amortization (c^{Amort}) and sponsor support payment (c^{SS}), all in percentages of the wage sum, and (b) the policy funding ratio (FR^P), the economic funding ratio (FR^E), and the pension result (PR) for the baseline Plan 0 and alternative contribution (Plans 1.1-1.3), indexation (Plans 2.1-2.2) and investment (Plans 3.1-3.2) policies. Note that the median values of the components of c do not necessarily add up to the median value of c. The policy funding ratio is defined as actuarial assets over actuarial liabilities, the economic funding ratio as market value of assets over economic liabilities, and the pension result as the ratio of cumulative granted indexation to cumulative price inflation.

Table 3.3: Classic ALM results under different plans after 75 years

(a) Contributions

Case	Description	c 5%	c 50%	c 95%	c^{NC} -	c^{Amort} 5%	c^{Amort} 50%	c^{Amort} 95%	c^{SS} 5%	c^{SS} 50%	c^{SS} 95%
Baseline											
0	baseline plan	35%	41%	47%	13%	12%	13%	14%	9%	15%	20%
Contribution											
1.1	0% amortization paid	36%	41%	48%	13%	0%	0%	0%	23%	28%	34%
1.2	100% amortization paid	27%	37%	45%	13%	14%	24%	28%	0%	0%	4%
1.3	amortization 10 years	21%	36%	44%	13%	7%	23%	31%	0%	0%	0%
Indexation											
2.1	indexation is 0.5 CPI	23%	36%	43%	13%	10%	13%	14%	0%	10%	16%
2.2	conditional indexation	20%	31%	38%	13%	7%	12%	13%	0%	6%	12%
Portfolio composition											
3.1	100% stocks	18%	41%	47%	13%	5%	13%	14%	0%	15%	20%
3.2	0% stocks	36%	41%	48%	13%	13%	13%	14%	10%	15%	20%

(b) Funding ratios and pension result

Case	Description	FR^P 5%	FR^P 50%	FR^P 95%	FR^E 5%	FR^E 50%	FR^E 95%	PR 5%	PR 50%	PR 95%
Baseline										
0	baseline plan	0%	0%	0%	0%	0%	0%	102%	106%	112%
Contribution										
1.1	0% amortization paid	0%	0%	0%	0%	0%	0%	102%	106%	112%
1.2	100% amortization paid	0%	11%	46%	0%	8%	34%	102%	106%	112%
1.3	amortization in 10 years	25%	43%	81%	16%	30%	61%	102%	106%	112%
Indexation										
2.1	indexation is 0.5 CPI	0%	0%	23%	0%	0%	15%	41%	49%	59%
2.2	conditional indexation	0%	0%	38%	0%	0%	27%	18%	25%	39%
Portfolio composition										
3.1	100% stocks	0%	0%	62%	0%	0%	42%	102%	106%	112%
3.2	0% stocks	0%	0%	0%	0%	0%	0%	102%	106%	112%

Note: classic ALM results after 75 years for the 5%, 50% and 95% percentiles of (a) the total contribution rate (c), which is the sum of the normal cost (c^{NC}), amortization (c^{Amort}) and sponsor support payment (c^{SS}), all in percentages of the wage sum, and (b) the policy funding ratio (FR^P), the economic funding ratio (FR^E), and the pension result (PR) for the baseline Plan 0 and alternative contribution (Plans 1.1-1.3), indexation (Plans 2.1-2.2) and investment (Plans 3.1-3.2) policies. Note that the median values of the components of c do not necessarily add up to the median value of c. The policy funding ratio is defined as actuarial assets over actuarial liabilities, the economic funding ratio as market value of assets over economic liabilities, and the pension result as the ratio of cumulative granted indexation to cumulative price inflation.

Table 3.4: Likelihood of full depletion of assets

Case	Description	Probability	Year, 5%	Year, 50%	Year, 95%
Benchmark					
0	baseline plan	97.0%	28	41	64
Contribution					
1.1	0% amortization paid	99.7%	20	28	45
1.2	100% amortization paid	13.2%	52	68	75
1.3	amortization in 10 years	0.0%	-	-	-
Indexation					
2.1	indexation is 0.5 CPI	88.8%	32	49	70
2.2	conditional indexation	71.6%	36	56	73
Portfolio composition					
3.1	100% stocks	90.1%	21	35	64
3.2	0% stocks	100.0%	36	39	42

Note: the first column reports the probability that the fund's assets are fully depleted within the 75-year simulation horizon. The following columns show the quantiles for the distribution of the years of full depletion, conditional on scenarios in which depletion takes place within the simulation horizon. As an example, under the baseline Plan 0, conditional on depletion taking place, 27 is the maximum number of years in which this happens in less than 5% of the cases. Therefore, the quantile is attained at 28.

It is important to realize that extreme outcomes, like a full depletion of the fund's assets, are unlikely to occur in reality, because before such an extreme outcome materializes, policymakers would have undertaken some action to avoid it. However, we want to see what the consequences of adhering to the baseline Plan 0 are. The high likelihood that this leads to full asset depletion is precisely the reason why we explore whether specific alternatives to the baseline plan can mitigate the deterioration of the long-run financial health of the fund, as well as the rise in tax payer contributions.

When no amortization payments are made (Plan 1.1), initially the total contribution rate is equal to the normal cost. However, this leads to an even more dramatic expected deterioration of the policy funding ratio than under the baseline plan. Already after 25 years the median policy funding ratio is only 7%, while the economic funding ratio is only 4%. Again, after 75 years the funding ratios at all percentiles we consider are zero. This eventually leads to the same total contribution rate as under the baseline plan, but this time via a different route, namely, the sponsor support instead of the amortization payments. A shift to 100% amortization under Plan 1.2 provides slightly better protection of the fund's financial health, leaving the median policy funding ratio after 75 years at 11%. The shift from 0% to 100% amortization contribution implies a shift away from sponsor support contribution, because it reduces the likelihood of complete asset depletion. In this case the median total contribution rate after 75 years is 37%, while the median amortization contribution is 24% and the median sponsor support contribution is zero. A shift to an amortization period of 10 years has a similar effect. The plans 1.1 to 1.3 are sorted in terms of how well the plan's underfunding reflects in the amortization payments. The stricter the amortization policy, the higher the amortization payments (hence also total contributions) are in the short term, but the lower the total contributions in the longer term. The numbers for the funding ratios, total contributions and amortization contributions under Plan 1.4 are identical to those under the baseline plan. Hence, we do not separately report them in the tables. However, the component of the normal cost paid by the participants has been doubled.

The second set of alternative measures introduces changes in the indexation rate. Plan 2.1 always yields lower indexation when CPI inflation is positive, implying that in the not too distant future the funding ratio holds up better than under the baseline plan (the median policy funding ratio after 25 years is now 35% versus 28% under the baseline plan). This is even more so the case under conditional indexation (Plan 2.2), because indexation becomes particularly low when the policy funding ratio is low. However, after 75 years, both the median policy funding ratio and median economic funding ratio are zero under both alternatives. Not surprisingly, the alternative indexation policies affect the pension result negatively. Its median value after 75 years drops to less than 50% when indexation is halved and it drops to only a quarter under conditional indexation. Reduced generosity in terms of indexation favors the tax payers who benefit from a reduction in amortization contributions and, in particular, from a reduction in sponsor support contribution.

Our third set of measures looks at changes in the pension fund's asset portfolio. Not surprisingly, because of the increased riskiness, a policy of investing 100% of the asset portfolio in stocks, Plan 3.1, produces an increase in the spread of the funding ratio compared to the baseline plan after 25 years. The 5th percentile of the policy funding ratio is zero and the median is 23%. However, the 95th percentile is 148%. Nevertheless, in the long run, after 75 years, the median policy funding ratio is still zero, because the overoptimistic actuarial projection of the portfolio return exceeds the actual average return on the portfolio. There is some chance that stocks do on average extremely well over the full horizon and, hence, that the burden on the tax payers turns out to be low. Indeed the 5th percentile of the amortization contribution is 5% and of the sponsor support contribution is 0%. However, the medians of these components are the same as under the baseline plan. A switch to 100% bonds compresses the spread in the policy funding ratio in the shorter run, so that even its 5th percentile is still positive after 25 years. However, in the long run even the 95th percentile has fallen to zero. The quantiles of the amortization and sponsor support contributions are very much in line with the corresponding quantiles under the baseline plan.

Overall, it can be concluded that under many of the settings studied here the chances of the pension fund ending the 75-year horizon with positive assets are low. The only exception is the alternative of a 10-year amortization period. An important factor is the high actuarial discount rate used by the fund, which exceeds the lower average return on the investment portfolio and thus leads to inadequate contributions to keep the fund financially healthy. With such a discrepancy between the actuarial discount rate and the average performance of the asset portfolio even a substantially less generous indexation policy may not be enough to prevent the fund from running out of assets. The other important factor concerns the tax payers' discipline in paying the normal cost and the amortization payments fully. Once the amortization is paid fully, or even better, the amortization period is shortened, the funding situation may improve substantially.

3.9.2 The value-based ALM benchmark results

In the previous subsection we have used a classic ALM analysis to explore to what extent alternatives to the baseline plan can reduce the likelihood that the pension fund's assets get depleted. Value-based ALM is useful to assess changes in the market value of the pension contract to its various stakeholders when shifting from the baseline plan to another plan.

We evaluate at $t = 0$ the baseline plan, as well as alternatives to the baseline. In value terms, reforms are zero-sum games across the fund's stakeholders (plan participants and tax payers):

$$\Delta V_0^P + \Delta V_0^T = 0, \tag{3.12}$$

where V_0^s is the contract value for stakeholder s ($= P$ or T) under the baseline plan and $\Delta V_0^s \equiv \tilde{V}_0^s - V_0^s$ is the change in value from the baseline plan, where $\tilde{V}_0^s$ is the value under the alternative plan. The fund's initial assets do not appear in this expression, as we start with the same value of initial assets under all plans, hence the change in its value is always zero. We are also interested in the *relative change* ΔRV_0 in the values of the various stakeholders, computed as:

$$\Delta RV_0^s = \frac{\tilde{V}_0^s - V_0^s}{A_0} \times 100\%. \tag{3.13}$$

We express the relative change as a fraction of a common denominator, which we choose to be the value of the initial assets A_0. This way we obtain an impression of the importance of the relative change compared to the scale A_0 on which the fund operates.

We report contract values for the entire group of participants, the entire group of tax payers, individual cohorts of participants and individual cohorts of tax payers.

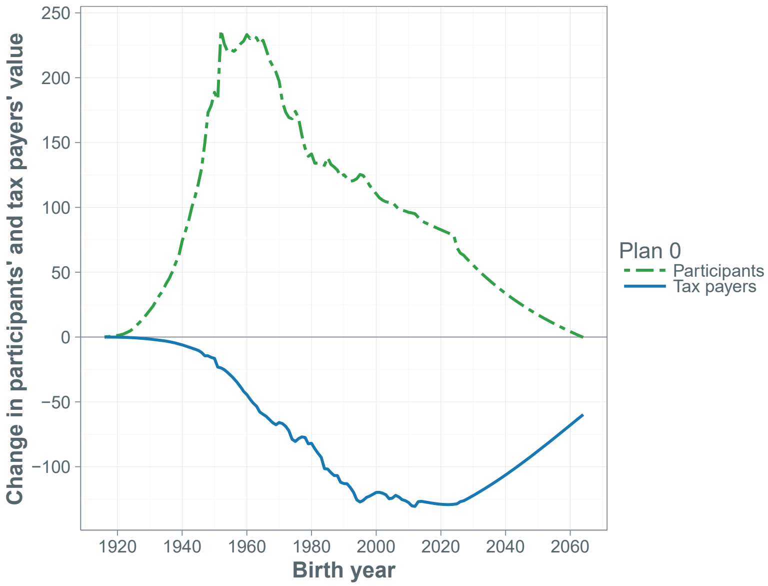
3.9.2.1 The baseline plan

Figure 3.1 shows for the baseline Plan 0 the value of the contract $V_0^{P,a}$ and $V_0^{T,a}$ in billions of dollars for the various cohorts of fund participants and tax payers, respectively. The youngest generation is the one to be born in 50 years from $t = 0$ (it has age -50 at $t = 0$, i.e. the year 2015), whereas the oldest is 99 years old at the start of the simulation period. Here, $t = 0$ is the year 2015. The figure gives an impression of the order of magnitude of the aggregate amounts at stake for the various cohorts of stakeholders in the state civil service pension funds. In present value terms, under the baseline plan over the 75-year simulation horizon, the value of the aggregate net benefit plus the final economic liabilities to all participant cohorts is approximately 14 trillion dollars, while the value of the aggregate contribution over all tax payer cohorts minus the value of the final assets is approximately 11 trillion dollars.[11] The difference equals the fund's initial assets. These are sizable numbers and, as indicated earlier, they likely form a lower bound on the actual amount of redistribution from tax payers to fund participants. We see that the value of the contract is positive for all participant cohorts. This is mostly due to the fact that participants pay only a part of total contribution. Also, for the older cohorts that are in the fund initially, the contributions are sunk, while their benefits are still ahead of them. For the current elderly the contract value starts falling steeply with age, as the amount of remaining future benefits to be received is shrinking with age.

For the cohorts of age 25 and younger at $t = 0$, the positive contract value needs more explanation, because in a completely actuarially-neutral system, those who have not yet been contributing would experience zero value from their pension contract: the value of their future benefits must be offset by the value of their future contributions. However, this value is only zero for the cohort born at $t = 50$ (i.e., the year 2065), because over the evaluation horizon this cohort will pay zero contributions and thus build up zero rights. For future generations that will be born before $t = 50$, the value of the benefits they

[11] In our discussion of these numbers we ignore the fact that part of the tax payer population are also participants in the fund. Thus, we focus on the gross redistribution between the groups and not on the net redistribution, which would require more information to construct reliable numbers.

FIGURE 3.1: Stakeholder contract values under the baseline plan



Note: participants' and tax payers' contract values by age cohort under the baseline Plan 0, in billions of dollars.

will receive over the evaluation horizon plus the value of the accrued rights at the end of the evaluation period exceeds the value of the contributions to be made during the evaluation period. This net benefit must be financed out of the fund's initial assets or through contributions from the tax payers. From the figure we observe that the value of the plan $V_0^{T,a}$ is negative for all the cohorts of tax payers.

3.9.2.2 Outcomes of the alternative plans

We report changes in dollar values and in relative values for groups of cohorts of participants and tax payers resulting from alternative plans. The results are reported in Table 3.5a (for changes in dollar values) and Table 3.5b (for changes in relative values) for two groups of participants and two groups of tax payers. Negative relative values denote a deterioration compared to the baseline plan for the particular stakeholders under consideration. The group of the "young"(superscript Y) comprises all the cohorts younger than 25 or yet unborn at $t = 0$, while the group of the "old"(superscript O) comprises all the cohorts of age 25 or older at $t = 0$, hence all the active or retired participants at $t = 0$. As explained above, theoretically, for each alternative plan, the sum of value changes must be zero, i.e. $\Delta V_0^{P,Y} + \Delta V_0^{P,O} + \Delta V_0^{T,Y} + \Delta V_0^{T,O} = 0$. However, due to numerical inaccuracies small deviations from zero may be possible.

Table 3.5: Effects of plan changes on stakeholders

(a) Contract values to stakeholders

Case	Description	$V_0^{P,Y}$	$V_0^{P,O}$	$V_0^{T,Y}$	$V_0^{T,O}$
Baseline					
0	baseline plan ($ level)	4564	9209	-8126	-2853
Contribution ($ change)					
1.1	0% amortization paid	0	0	-348	342
1.2	100% amortization paid	0	0	636	-630
1.3	amortization 10 years	0	0	1181	-1170
1.4	part. contr. rate doubled	-1549	-978	1290	1237
Indexation ($ change)					
2.1	indexation is 0.5 CPI	-394	-955	1100	253
2.2	conditional indexation	-720	-1657	1980	403
Portfolio composition ($ change)					
3.1	100% stocks	0	0	169	-145
3.2	0% stocks	0	0	-70	51

(b) Relative effects

Plan	Description	$\Delta RV_0^{P,Y}$	$\Delta RV_0^{P,O}$	$\Delta RV_0^{T,Y}$	$\Delta RV_0^{T,O}$
Contribution					
1.1	0% amortization paid	0%	0%	-13%	12%
1.2	100% amortization paid	0%	0%	23%	-23%
1.3	amortization 10 years	0%	0%	43%	-42%
1.4	part. contr. rate doubled	-56%	-35%	47%	45%
Indexation					
2.1	indexation is 0.5 CPI	-14%	-34%	40%	9%
2.2	conditional indexation	-26%	-60%	72%	15%
Portfolio composition					
3.1	100% stocks	0%	0%	6%	-5%
3.2	0% stocks	0%	0%	-3%	2%

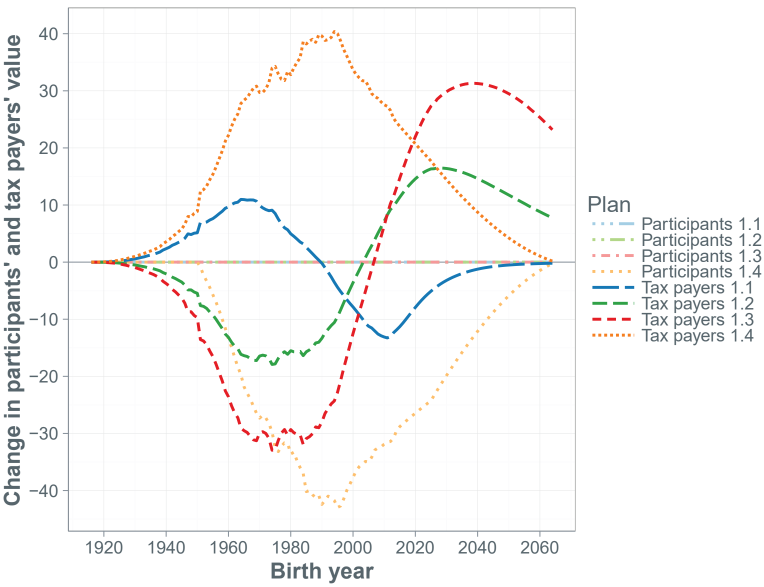
Note: the table reports the effects of switching from baseline Plan 0 to Plans 1.1-3.2 on future plan participants ($\Delta V_0^{P,Y}$, $\Delta RV_0^{P,Y}$), current plan participants ($\Delta V_0^{P,O}$, $\Delta RV_0^{P,O}$), future tax payers ($\Delta V_0^{T,Y}$, $\Delta RV_0^{T,Y}$) and current tax payers ($\Delta V_0^{T,O}$, $\Delta RV_0^{T,O}$). Panel (a) reports the value of the baseline plan and the change in value of switching from the baseline to an alternative plan in billions of dollars. Panel (b) reports relative changes as percentages of the fund's initial assets A_0. Negative numbers imply a deterioration of the value for that stakeholder.

Under Plans 1.1-1.3 neither the contributions made by the plan participants nor the indexation rules are changed, so $\Delta V_0^{P,Y} = \Delta V_0^{P,O} = 0$. A reduction in the amortization payment (Plan 1.1) benefits current tax payers, because they see their amortization contribution rate fall. However, it affects future cohorts of tax payers negatively, as they have to cover the deficit with sponsor support payments once assets get completely depleted, which now happens earlier. An increase in the amortization payment, Plan 1.2, has the opposite effect and benefits the young tax payers, while the old tax payers lose out. A similar conclusion holds for a shortening of the period over which the amortization takes place, Plan 1.3. A doubling of the contribution rate by the participants, Plan 1.4, reduces the total contribution paid by the tax payers and, thus, shifts value from both groups of participants to the tax payers. The aggregate value shift exceeds 2.5 trillion dollars. In percentage terms the older participants lose one-third of the contract value, while the younger participants lose more than half of their value.

Changes in indexation policy shift value between the participants and the tax payers. Halving indexation, Plan 2.1, lowers the plan value to the participants and raises the plan value to the tax payers, who have to pay smaller amortization and sponsor support contributions. The aggregate value loss to the participants is about 1.4 trillion dollars, or 14% of initial fund assets for the younger participants and one-third of initial fund assets for the older participants. Especially the young tax payers benefit, the reason being that the reduction in indexation reduces the tax payer support most when the fund's assets are depleted or almost depleted. Conditional indexation, Plan 2.2, produces qualitatively similar, but quantitatively even larger value shifts across the stakeholders. In fact, the loss of the older participants is 60% of initial fund assets, while that of the younger participants is more than a quarter of initial fund assets. Older tax payers gain 15% of initial fund assets, while young tax payers even gain 72% of initial fund assets.

Our third set of changes concerns changes in the composition of the asset portfolio of the pension fund. In all of the previous plans the asset mix was kept constant at 50% fixed income and 50% risky assets. When the portfolio allocation is the same across the plans, the total amount of risk remains unchanged, but it is shifted among stakeholders due to policy changes, like changes in the contribution or indexation rules. Changing the asset mix changes the riskiness of the pension fund's asset portfolio itself. Since neither indexation policy, nor the participant contribution rules have changed, the fund participants are unaffected by changes in the composition of the fund's asset portfolio. However, there are shifts in value across the tax payers. A shift to 100% stocks (Plan 3.1) affects older tax payers negatively, but younger tax payers positively. Older tax payers suffer, because in the shorter run the increased riskiness of the fund raises the chance that the fund completely runs out of assets. This makes it more likely that the older tax payers need to support the pension benefits on a pay-as-you-go basis. For the younger tax payers, this would be the overwhelmingly likely prospect in any case. An increase in riskiness of the asset portfolio raises the likelihood of positive assets in the longer run, thereby lowering the chance that the current younger tax payers have to pay the benefits on a pay-as-you-go basis later in working life. So the states of the world with earlier fund depletion under the riskier strategy do not hurt the younger tax payers, while they benefit from the possible states of the world where these riskier asset strategies perform well. In the case of de-risking (Plan 3.2), we observe the opposite effects. Obviously, these and other policy changes that redistribute across cohorts of tax payers could in principle be undone through an appropriate combination of public debt and tax policies.

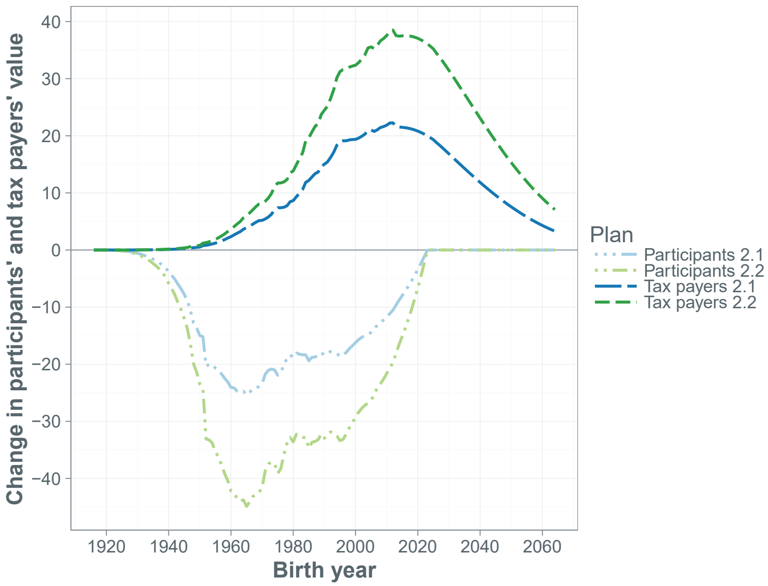
FIGURE 3.2: Changes in stakeholder contract values from contribution reforms



Note: this figure depicts by age cohort the change in the stakeholder contract value (in billions of dollars) when policy is changed from the baseline Plan 0 to plans with no amortization payment (Plan 1.1), full amortization payment (Plan 1.2), 10 years amortization smoothing (Plan 1.3) and a doubling of the contribution rate by employees (Plan 1.4).

Figures 3.2 - 3.4 depict the value consequences of contract changes for all individual cohorts of participants and tax payers. In line with the numbers reported in the above tables, we see indeed that moving from the baseline plan to Plan 1.1 with zero amortization (see Figure 3.2) the older tax payers are better off, as part of the contribution burden is shifted

FIGURE 3.3: Changes in stakeholder contract values from indexation reforms

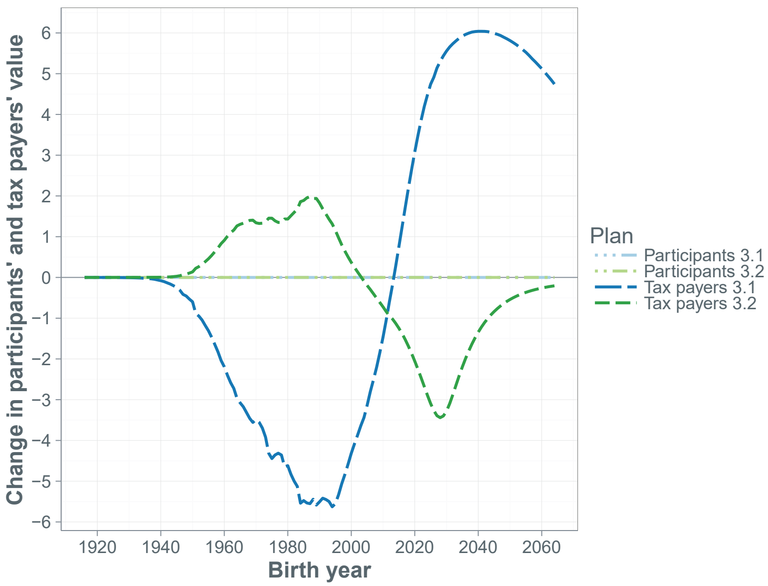


Note: this figure depicts by age cohort the change in the stakeholder contract value (in billions of dollars) when policy is changed from the baseline Plan 0 to plans with half CPI indexation (Plan 2.1) and conditional indexation (Plan 2.2).

to the future, while younger cohorts of tax payers have to contribute more to make up for the losses of the fund. Contributions are shifted from amortization to sponsor support. However, in contrast to amortization, sponsor support only needs to be provided when the fund's assets are depleted, which generally takes place some decades after the start of the evaluation period. Moving to 100% amortization, Plan 1.2, works in the opposite direction and, hence, reduces the value for the older tax payers, but benefits the younger tax payers. The same is the case when amortization is speeded up (Plan 1.3), which has even stronger negative effects on the older tax payers and stronger positive effects on the younger tax payers. Finally, a doubling of the contribution by the workers affects all the workers' values negatively and all the tax payers' values positively. The retired participants are unaffected.

Not surprisingly, a shift from full indexation to compensation of only half of the CPI, i.e. a shift from Plan 0 to Plan 2.1 (see Figure 3.3), lowers the contract value to all participant cohorts currently alive and born up to 10 years from the start of the simulation horizon. All cohorts that enter the fund later see no change in value, because they will not receive

FIGURE 3.4: Changes in stakeholder contract values from changes in the fund's asset portfolio composition



Note: this figure depicts by age cohort the change in the stakeholder contract value (in billions of dollars) when policy is changed from the baseline Plan 0 to plans with 100% risky assets (Plan 3.1) and 100% fixed income assets (Plan 3.2).

any pension benefit over the simulation horizon, while their contributions are unchanged. Recall that under all the plans that we consider, including Plan 2.1, the calculation of the contributions and the economic liabilities at the end of the simulation horizon, based on the expected price and nominal wage developments implied by our estimated VAR model, is done as if indexation is full. Only the actual indexation in retirement is adjusted. Hence, cohorts that do not reach retirement within the simulation horizon are not affected by this plan. All cohorts of tax payers benefit from the shift to Plan 2.1. Similarly, since indexation tends on average to be lower under conditional indexation, also Plan 2.2 affects the value for all participants that are already retired or reach retirement during the simulation horizon negatively, while all tax payer cohorts are better off. Again, those participant cohorts born more than 10 years into the future are unaffected. Quantitatively, the effects on all the cohorts of tax payers and participants, except those that will not reach retirement during the simulation horizon, are larger than under Plan 2.1. This is the result of tendency for the funding ratio to sharply deteriorate over the simulation horizon, implying that there will be very little or no indexation when indexation is made conditional. Finally, looking at an increase in risk of the pension fund's portfolio (see Figure 3.4), we observe that all the participating cohorts are unaffected, while young tax payers benefit from a more risky portfolio and old tax payers lose, as explained above. The opposite is the case when the portfolio is made less risky.

3.9.3 Robustness analysis

3.9.3.1 More optimistic assumptions about the asset returns

There is substantial uncertainty surrounding the expected returns on financial variables. Hence, in reality there is a good chance that the realisations of our state vector deviate quite substantially from the benchmark expected values underlying our scenario set. For our benchmark scenario set, we found that it is highly likely that the fund's assets will be depleted over the simulation horizon. In this subsection we show that the likelihood of a severe asset deterioration of the fund will still be high even under substantially more optimistic assumptions about the asset returns. In particular, in this subsection we base the means of the state vector in our scenario set on the originally-estimated $\hat{\mu}$ vector, i.e. we do not adjust the means according to the SPF forecast. In particular, investment returns will be higher under this alternative setting: the average annual portfolio return will be 7.7%, based on 50% in fixed income with an average annual return of 4% and 50% in risky assets with an average annual return of 11.3%.

Because only the means of state vector are changed, the scenario set under risk-neutral sampling is unchanged and, hence, the value-based ALM results are unaffected. Therefore, we do not discuss them further and we focus here on the changes in the classic ALM results. To save space, we report only the quantiles of the relevant variables after 75 years – see Table 3.6. Because of the higher portfolio returns, assets tend to fall at a slower pace and, hence, amortization and sponsor support contributions tend to be smaller. As a result, the median total contribution rate of 21% under Plan 0 is much lower than the median of 41% under the benchmark scenario set. The same holds for the other plans, except for Plan 1.1 (0% amortization paid) and Plan 3.2 (0% stocks). Except for these two plans, the median amortization contribution rate has become much lower. This is also the case for the median sponsor support contribution rate under the baseline Plan 0, Plan 1.4 (doubling of the participants' contribution rate), Plans 2.1 and 2.2 involving reduced indexation and Plan 3.1 involving 100% stocks.

Turning to the funding ratios, we observe that under the baseline Plan 0 the median policy funding ratio is 37%, which still implies that there is a substantial chance of a severe deterioration of the fund's financial position over our horizon. Extreme outcomes in both directions are possible. At the fifth percentile, the policy funding ratio is 0%, while at the 95th percentile it is close to 900%, which reflects the possibility of stocks doing very well over extended periods of time. Obviously, such extreme funding ratios are very unlikely to materialize, because long before policy adjustments, such as a reduction in contribution rates, would have been implemented. However, we want to report the consequences of consistently sticking to a given plan. Increasing or speeding up amortization (Plans 1.2 and 1.3) or reducing indexation (Plans 2.1 and 2.2) are now much more effective at protecting the policy funding ratio in the longer run. The economic funding ratios are always below the policy funding ratios, reflecting the fact that the latter ones are based on actuarial assumptions that do not reflect the risk-free nature of the benefits. The figures for the pension results do not differ much from those under the benchmark scenario set, which reflects the fact that the lower portfolio returns under the benchmark scenario set are primarily the problem of the tax payer. The exception is Plan 2.2 of conditional indexation, under which also the participant substantially benefits from the higher portfolio returns: the higher policy funding ratio under the alternative scenario set allows for more indexation on average.

Table 3.7 reports the likelihood and speed of asset depletion over our 75-year horizon. Under the base Plan 0, the likelihood of full depletion has fallen to less than 40%. While this is still substantial, it is much lower than the near-certainty of full depletion under the benchmark scenario set. Increasing or speeding up amortization (Plans 1.2 and 1.3) brings the likelihood of full depletion to zero or nearly zero, while making indexation much less generous (Plans 2.1 and 2.2) substantially lowers the likelihood of full depletion. Conditional on full depletion occurring during the simulation horizon, we observe that it tends to occur later than under the benchmark scenario set. For example, under the baseline Plan 0 the median year in which this occurs rises from 41 to 57 from the start of the simulation.

3.9.3.2 Alternative exogenous inflation risk premia

While our benchmark analysis leaves the inflation risk premium to be determined as part of the parameter optimization procedure, there is little consensus about the size of the inflation risk premium in the literature and, a priori, there is no reason to believe that our estimate is more accurate than estimates reported elsewhere in the literature. Hence, it

Table 3.6: Classic ALM results under different plans after 75 years (sensitivity scenario set)

(a) Contributions

Case	Description	c			c^{NC}	c^{Amort}			c^{SS}		
		5%	50%	95%	-	5%	50%	95%	5%	50%	95%
Baseline											
0	baseline plan	13%	21%	47%	13%	0%	8%	14%	0%	0%	19%
Contribution											
1.1	0% amortization paid	13%	40%	48%	13%	0%	0%	0%	0%	27%	35%
1.2	100% amortization paid	13%	13%	35%	13%	0%	0%	22%	0%	0%	0%
1.3	amortization in 10 years	13%	13%	32%	13%	0%	0%	19%	0%	0%	0%
Indexation											
2.1	indexation is 0.5 CPI	13%	13%	40%	13%	0%	0%	13%	0%	0%	14%
2.2	conditional indexation	13%	14%	34%	13%	0%	1%	13%	0%	0%	8%
Portfolio composition											
3.1	100% stocks	13%	13%	45%	13%	0%	0%	14%	0%	0%	18%
3.2	0% stocks	37%	42%	48%	13%	13%	14%	14%	11%	16%	21%

(b) Funding ratios and pension result

Case	Description	FR^P			FR^E			PR		
		5%	50%	95%	5%	50%	95%	5%	50%	95%
Baseline										
0	baseline plan	0%	37%	867%	0%	25%	595%	102%	106%	114%
Contribution										
1.1	0% amortization paid	0%	0%	694%	0%	0%	477%	102%	106%	114%
1.2	100% amortization paid	20%	112%	1001%	13%	76%	704%	102%	106%	114%
1.3	amortization in 10 years	53%	160%	1101%	34%	110%	777%	102%	106%	114%
Indexation										
2.1	indexation is 0.5 CPI	0%	107%	1122%	0%	71%	787%	43%	51%	62%
2.2	conditional indexation	0%	92%	325%	0%	62%	240%	26%	66%	1439%
Portfolio composition										
3.1	100% stocks	0%	1149%	25065%	0%	779%	19147%	102%	106%	114%
3.2	0% stocks	0%	0%	0%	0%	0%	0%	102%	106%	114%

Note: classic ALM results after 75 years for the 5%, 50% and 95% percentiles of (a) the total contribution rate (c), which is the sum of the normal cost (c^{NC}), amortization (c^{Amort}) and sponsor support payment (c^{SS}), all in percentages of the wage sum, and (b) the policy funding ratio (FR^P), the economic funding ratio (FR^E), and the pension result (PR) for the baseline Plan 0 and alternative contribution (Plans 1.1-1.3), indexation (Plans 2.1-2.2) and investment (Plans 3.1-3.2) policies. Note that the median values of the components of c do not necessarily add up to the median value of c. The policy funding ratio is defined as actuarial assets over actuarial liabilities, the economic funding ratio as market value of assets over economic liabilities and the pension result as the ratio of cumulative granted indexation to cumulative price inflation.

Table 3.7: Likelihood of full depletion of assets (sensitivity scenario set)

Case	Description	Probability	Year, 5%	Year, 50%	Year, 95%
Baseline					
0	baseline plan	38.1%	36	57	73
Contribution					
1.1	0% amortization paid	70.6%	25	40	68
1.2	100% amortization paid	0.4%	54	69	74
1.3	amortization in 10 years	0.0%	-	-	-
Indexation					
2.1	indexation is 0.5 CPI	18.4%	39	60	74
2.2	conditional indexation	8.8%	42	62	74
Portfolio composition					
3.1	100% stocks	18.5%	24	43	70
3.2	0% stocks	100.0%	36	39	42

Note: the first column reports the probability that the fund's assets are fully depleted within the 75-year simulation horizon. The following columns show the quantiles for the distribution of the years of depletion, conditional on scenarios in which depletion takes place within the simulation horizon. As an example, under the baseline Plan 0, conditional on depletion taking place, 35 is the maximum number of years in which this happens in less than 5% of the cases. Therefore, the quantile is attained at 36.

is important to explore whether our findings are sensitive to the size of the inflation risk premium. Therefore, in this subsection we impose an exogenous inflation risk premium that deviates from the inflation risk premium that was endogenously determined under the benchmark. The annual inflation risk premium that follows endogenously from the optimization equals minus 62 basis points. We consider an inflation risk premium of zero, which may be a natural choice in the absence of any prior knowledge about its size, and one of plus 20 basis points annually. The latter choice is motivated by Brown and Pennacchi (2015) who find an annual inflation risk premium of 21 basis points over 2004 - 2014 for the U.S. Because their estimate refers to 10-year debt and ours to short-run 3-month debt, the two cases are not entirely comparable. However, the sensitivity of our results to the inflation risk premium seems to be too low for this to be a relevant mismatch.

The numerical results for these variants are reported in Appendix 3.F. We observe that the classic ALM results are close to the original results. The most important consequence of a higher inflation risk premium is that the frequency distribution of the funding ratios tends to shift to the right. The reason is that an increase in the inflation risk premium raises the required return on nominal debt and the resulting increase in the average portfolio return of the fund mitigates the decline in its assets. However, the effect is so marginal that the chance that the fund is out of assets at the end of the evaluation horizon is still overwhelming. As far as the value-based ALM results are concerned, the contract values of the different groups of stakeholders tend to be quite close to the original ones, though a bit larger in absolute size. The relative effects also tend to become slightly larger in absolute size, especially for the alternative inflation indexation plans.

3.9.3.3 Extending the evaluation horizon to 100 years

In our final robustness experiment we extend the evaluation horizon to 100 years. The numerical results of this variant are also reported in Appendix 3.F. Obviously, the frequency distributions of the funding ratios at the end of the horizon shift further to the left, and the chances that the system survives such a long period are close to zero. As regards to the value-based ALM results, we expect no effect on the groups that are alive at the start of the evaluation period: they were all dead at the end of the 75 year horizon, so nothing changes for them. However, as we should expect, the positive (negative) contract value of the young participants (tax payers) increases in size. The reason is that young cohorts benefit over a longer period from the contributions by the tax payers. Hence, the shift in relative values for these groups also increases in absolute magnitude for deviations from the baseline Plan 0.

3.10 Concluding remarks

This paper has explored the financial and redistributive aspects of a typical U.S. state DB pension fund under unchanged policies. The results confirm what is generally feared, namely that continuing current pension policies leads to the depletion of the fund's assets. Even a substantially more optimistic outlook for financial markets than that under our benchmark parameter setting does not solve the long-run financial sustainability issues of the U.S. state pension sector. In fact, the magnitude of the problem exposed in this chapter may well form a lower bound to its true extent, because our dataset did not include all civil servants' pension funds. A priori, there is little reason to assume that the funds that have not been included are financially healthier than the funds that were part of our dataset. Hence, a continuation of current pension policies is likely to confront the tax payers with an enormous bill, because in principle they have to guarantee the accumulated entitlements of the funds' participants. Even rather substantial shifts in the structure of the pension contributions or substantial reductions in inflation indexation are unlikely to resolve the long-run financial issues of the U.S. state pension sector, although they may slow down the deterioration of its financial health somewhat.

The looming financial burden on tax payers and the prospective deterioration of public services may discourage individuals of working age from working in states where the pension funding problems are worst. An outcome with falling spending on public goods and rising taxes merely to finance civil servants' retirement schemes may become politically unsustainable and result in states defaulting on their pension obligations. This could well cause larger value losses to fund participants than those associated with orderly reforms backed by a majority of the population.

The analysis in this paper can be extended into various directions, for example by exploring the consequences of closing the fund to new participants or closing it even for contributions from current participants. Also, by applying our method of value-based asset-liability management, we can study value shifts between tax payers and participants for individual state funds and explore which states face the most urgent need for pension reform.

3.A The model

3.A.1 The population

The participant population of the pension fund consists of individuals of ages 25 to 99 years. Individuals enter the fund at the age of 25 and remain with the fund for the rest of their life. Further, we assume that they retire at age a_R. The number of male and female participants of age a at time t is denoted as M_t^a and F_t^a, respectively, where $a \in [25, 99]$. Using projections of survival probabilities we can calculate the size of these cohorts in the future. Concretely, $M_{t+n}^{a+n} = q_{a,t}^{m,n} M_t^a$ and $F_{t+n}^{a+n} = q_{a,t}^{f,n} F_t^a$, where $q_{a,t}^{m,n}$ and $q_{a,t}^{f,n}$ are the probabilities that respectively a male and female person aged a in period t will survive another n years. The survival probabilities are deterministic. Hence, there is no longevity risk.

3.A.2 Wages

The wage level of the cohort of age a at time t is W_t^a and it is updated each time period. We assume a uniform wage level within each cohort, while over one's life the wage level follows a certain career profile. We set the wage levels of males and females equal. The nominal wage level evolves as follows:

$$W_t^a = W_{t-1}^{a-1} w_{t-1}^{a-1},$$

where w_{t-1}^{a-1} is the gross wage growth rate from period $t-1$ to t for a cohort aged $a-1$ in period $t-1$. This factor is the product of the economy-wide gross wage growth rate w_{t-1} and a component $\tilde{w}_{t-1}^{a-1}$ attributable to the progression of the career of someone of age $a-1$ in period $t-1$:

$$w_{t-1}^{a-1} = w_{t-1} \tilde{w}_{t-1}^{a-1}. \tag{3.14}$$

We refer to $\tilde{w}_{t-1}^{a-1}$ as the (gross) promotion rate from period $t-1$ to t for someone aged $a-1$ in period $t-1$. Note that $\tilde{w}_{t-1}^{a-1}$ is always greater than one if the career profile has an upward sloping shape. We assume that the career profile remains constant over time, which implies that $\tilde{w}_{t-1}^{a-1} = \tilde{w}^{a-1}$ in all periods. The economy-wide wage growth rate w_{t-1} is stochastic and is modelled as explained in Section 3.4.

3.A.3 The pension fund

Market value of the assets. The market value of the fund's assets at the beginning of the next year, A_{t+1}, is equal to the asset value A_t at the beginning of this year, multiplied by its gross rate of return R_t, plus the net money inflow times the gross return over the half year over which it is on average invested:

$$A_{t+1} = A_t R_t + (C_t - B_t) R_t^{1/2}, \tag{3.15}$$

where C_t is the total amount of contributions received (calculated below) and B_t the total amount of benefits paid out. Since the benefits and contributions are (usually) paid on a monthly basis, while our model runs on a yearly basis, we assume that the payment of the benefits and contributions takes place in the middle of the calendar year and, hence, the net money inflow is invested on average for half a year until the beginning of the next year.

Calculation of the actuarial assets. Pension fund assets in the U.S. are not measured at their market value when they are used as an input for pension policy. Rather, pension funds in the U.S. apply a smoothing procedure to come up with an actuarial value of their assets A_t^{act} in period t. Define the Investment Income Amount Of Immediate Recognition

($IIAOIR$) as a target investment income based on the *expected* gross return $\bar{R}_t$:

$$IIAOIR_t = A_t(\bar{R}_t - 1) + (C_t - B_t)(\bar{R}_t^{1/2} - 1). \tag{3.16}$$

The so-called Investment Income Market Total ($IIMT$) denotes the actual realization of investment income, i.e. the difference between the market value of the assets at the end of the year and the market value of the assets at the beginning of the year, less the net cash inflow associated with the contributions and the benefits. From equation (3.15) we get:

$$IIMT_t = A_{t+1} - A_t - (C_t - B_t) = A_t(R_t - 1) + (C_t - B_t)(R_t^{1/2} - 1). \tag{3.17}$$

Finally, the Investment Income Amount For Phased In Recognition ($IIAFPIR$) is realized investment income in excess of expected investment income:

$$IIAFPIR_t = IIMT_t - IIAOIR_t.$$

Hence, $IIAFPIR_t$ is positive when the actual investment return exceeds its expected value, and vice versa. The usual smoothing procedure to calculate actuarial assets involves taking the average of the excess investment incomes over the past. We define the Total Recognized Investment Gain ($TRIG$) as the average of $IIAFPIR$ over a smoothing horizon of v years:

$$TRIG_t = \frac{1}{v}\sum_{i=0}^{v-1} IIAFPIR_{t-i}.$$

Then, the actuarial value of the assets at the beginning of year $t+1$ will be determined by adding to the actuarial value of the assets at the beginning of year t the net money inflows (contribution payments minus the benefit pay-outs), investment income of immediate recognition and the smoothed value of the excess investment income over the past v years:

$$A_{t+1}^{act} = A_t^{act} + (C_t - B_t) + IIAOIR_t + TRIG_t. \tag{3.18}$$

In short, the actuarial value of the assets at the end of the current year is equal to the actuarial value at the end of previous year, plus the net cash flows into the fund, plus the projected return on the assets, and a recognition of the smoothed difference between actual and expected investment income. In the special case that the initial actuarial assets equal the initial market value of the assets, $A_0^{act} = A_0$, and the smoothing period is shrunk to a single period, one has that $A_t^{act} = A_t$, for all $t \geq 0$. Hence, in this specific case the process of the actuarial assets coincides with that of the market value of the assets.

Calculation of the actuarial liabilities. This subsection sketches the calculation of the actuarial liabilities, closely following Munnell et al. (2008b) and Novy-Marx and Rauh (2011). This requires the calculation of the (projected) benefits of the pension fund participants. The group of pension fund participants comprises the employees and the retired.

The fund's actuarial liabilities are the sum of the actuarial liabilities $L_t^{act,m}$ and $L_t^{act,f}$ to the male and female participants. The actuarial liabilities to each gender, in turn, are calculated by multiplying the individual actuarial liability $L_t^{act,a,\zeta}$ to an age-a and gender-ζ individual by the number of gender-ζ individuals in this cohort and then summing over the cohorts. Hence, the fund's actuarial liabilities are calculated as:

$$\begin{aligned} L_t^{act} &= L_t^{act,m} + L_t^{act,f} = \sum_{a=25}^{99} \left(M_t^a L_t^{act,a,m} + F_t^a L_t^{act,a,f} \right), \\ L_t^{act,a,\zeta} &= \sum_{i=\max(a_R-a,0)}^{99-a} \left(\tilde{R}_t^{(i)} \right)^{-i} q_{a,t}^{\zeta,i} K_{t,t+i}^{a+i}, \end{aligned} \tag{3.19}$$

where $K_{t,t+i}^{a+i}$ is the projection at time t of the pension pay-out i years ahead for a participant of age a and $\tilde{R}_t^{(i)}$ is the gross interest rate that the *pension fund* uses to discount to period t the cash flows materializing i periods into the future. It will be based on the median discount rate used by the pension funds in our dataset. The discount rate used by U.S. public pension plans is usually flat over the entire projection horizon and equal to the expected asset portfolio return. We notice that $\tilde{R}_t^{(0)} = 1$ and $q_{a,t}^{\zeta,0} = 1$. Summarizing, the liabilities to an individual of a particular cohort depend on the number of years he/she will (still) receive benefits, the level of the benefits, the discount rate and the survival probabilities.

Calculation of the pensioners' benefits. The current pay-out to a retiree equals the current pension rights, B_t^a, while the projected pay-out i periods from now equals the current pension rights adjusted for projected future indexation:

$$\begin{aligned} K_{t,t}^{a} &= B_t^a, \forall a \in [a_R, 99], \\ K_{t,t+i}^{a+i} &= B_t^a \prod_{j=1}^{i} \left(1 + \pi_{t,t+j}^p\right), \forall i \in [1, 99-a], \forall a \in [a_R, 98], \end{aligned}$$

where $\pi_{t,t+j}^p$ is the projection in period t of the COLA in period $t+j$. It is based on the average *actuarial* annual inflation projection used by the pension funds in our dataset.

Current pension rights B_t^a equal the pension rights at the moment of retirement increased by the past *realized* indexation since then:

$$B_t^a = B_{t-(a-a_R)}^{a_R} \prod_{j=0}^{a-(a_R+1)} (1 + COLA_{t-j}), \forall a \in [a_R + 1, 99].$$

For example, the pension rights of a 70-year old person, who retired at the age $a_R = 65$, are equal to the benefit calculated when that person reached the age of 65, plus the indexation that has been awarded over the 5 years since then.

A common feature of the state pension plans in the U.S. is that benefits at the moment of retirement are based on the average wage preceding the moment of exit from the workforce. Concretely, the benefit of somebody retiring in year $t - (a - a_R)$ can be calculated as the product of the accrual rate ε, the number of years in the workforce (here, 40), and the average wage level over the past z years:

$$B_{t-(a-a_R)}^{a_R} = \frac{40\varepsilon}{z} \sum_{l=1}^{z} W_{t-(a-a_R)-l}^{a_R-l}, \forall a \in [a_R, 99].$$

The averaging period z varies from one to five years, with the majority of public plans applying a three–year average (Munnell et al. (2012)).

Calculation of the workers' benefits. The projected (at time t) pay-out to someone of age a is given by its current pension rights B_t^a adjusted for the actuarially-projected COLAs during retirement:

$$K_{t,t+i}^{a+i} = B_t^a, i = a_R - a, \forall a \in [25, a_R - 1],$$
$$K_{t,t+i}^{a+i} = B_t^a \prod_{j=a_R+1-a}^{i} \left(1 + \pi_{t,t+j}^p\right), \forall i \in [a_R + 1 - a, 99 - a], \forall a \in [25, a_R - 1],$$

where the first equation gives the projected benefit during the first year of retirement, while the second equation gives the projected benefit during the ensuing years in retirement, which thus takes into account the projection of the COLAs during retirement.

Methods for recognizing liabilities. The value of a worker's pension rights B_t^a depends on the method used to recognizing liabilities. Under the ABO method only the pension rights accrued until time t are taken into account:

$$B_t^{25} = 0,$$
$$B_t^a = \frac{(a-25)\varepsilon}{\min(a-25,z)} \sum_{l=1}^{\min(a-25,z)} W_{t-l}^{a-l}, \forall a \in [26, a_R].$$

The youngest cohort of age 25 has just entered the fund and has no rights accrued yet. The rights of the other young cohorts who do not yet have z years in service are based on the average of the available wage history. For the cohorts that have at least z years of service, the pension rights are the product of the years in the workforce, the accrual rate and the average pay over the past z years. Hence, for an individual worker the ABO pension rights increase with each additional year of service.

Under the *PBO method*, we also take into account the effect of expected future salary increases on the rights accrued up to now. Hence, under this method B_t^a is the projected benefit level at retirement when the *actuarially-projected* salary advances are taken into account:

$$B_t^{25} = 0,$$
$$B_t^a = \frac{(a-25)\varepsilon}{z} \sum_{l=1}^{z} W_{t,t+(a_R-a)-l}^{p,a_R-l}, \forall a \in [26, a_R - 1].$$

where $W_{t,t+(a_R-a)-l}^{p,a_R-l}$ is the period-t actuarial projection of wage $W_{t+(a_R-a)-l}^{a_R-l}$ of someone aged $a_R - l$ in period $t + (a_R - a) - l$. The actuarial projection of the wage growth that took place in the past or the current wage growth (e.g., if $a = a_R - 1$ and $l = 1$), is equal to the realized wage growth. Again, the youngest cohort, the 25 years old, has no accrual yet and, hence, it has no pension rights in terms of the PBO. However, for a given age and a positive nominal wage growth projection, the pension rights of the other working cohorts are higher under the PBO method than under the ABO method.

Finally, state civil service jobs are relatively secure, so that the pension fund might in addition consider the rights that the employees will acquire in the future if they continue working in their job until retirement. The *PVB method* takes this into account. Therefore, it defines the pension rights B_t^a including future accrual due to new service:

$$B_t^a = \frac{40\varepsilon}{z} \sum_{l=1}^{z} W_{t,t+(a_R-a)-l}^{p,a_R-l}, \forall a \in [25, a_R - 1]. \quad (3.20)$$

This measure is therefore based on the accrual over a full working life.

The total amount of pension benefits to be paid out in year t is:

$$B_t = \sum_{a=a_R}^{99} (M_t^a + F_t^a) B_t^a.$$

3.A.4 Inputs for calculating the contributions

3.A.4.1 The entry-age normal costing method

The most common method for calculating the normal cost in public plans is the so-called *entry-age normal costing* (EAN) method. Under the EAN method, the employer's annual normal cost associated with an individual participant is calculated as a contribution throughout the projected years of service needed to finance the PVB obligation. Due to salary growth pension rights increase more than linearly over time. Hence, the method implies a component of front-loading, because the employer is pre-paying some of the future accrual (Munnell et al. (2008b)).

The so-called *normal cost rate* (NCR) of an active participant is calculated at the entry age as the ratio of the actuarial (i.e., using the fund's discount rate) present values of the actuarially-projected benefits and career salary levels:

$$NCR_t^{25,\zeta} = \frac{L_t^{25,\zeta}}{PVW_t^{25,\zeta}}, \quad \zeta \in \{f; m\},$$

where $L_t^{25,\zeta}$ is the actuarial liability to someone of gender ζ who enters the labor force in period t as calculated in (3.19) on the basis of the PVB method, i.e. based on pension rights as calculated in (3.20), and $PVW_t^{25,\zeta}$ is the actuarial present value of all future wages throughout the participant's career as projected at entry. Hence, the normal cost rate is the percentage payment of a worker's projected career salary needed to cover the cost of the projected pension benefits for that worker at entry into the fund.

Further, the actuarial present value of actuarially-projected wages of a worker of age a and gender ζ is calculated as:

$$PVW_t^{a,\zeta} = \sum_{i=0}^{a_R-1-a} \left(\tilde{R}_t^{(i)}\right)^{-i} q_{a,t}^{\zeta,i} W_{t,t+i}^{p,a+i},$$

which takes account of the survival probabilities.

Finally, the (actuarial) *present value of the future normal cost* ($PVFNC$) of a worker of age a are the normal costs that will be recognized throughout the remaining years of service:

$$PVFNC_t^{a,\zeta} = PVW_t^{a,\zeta} \times NCR_{t-(a-25)}^{25,\zeta}.$$

Hence, this is the product of the actuarially discounted value of projected wages and the normal cost rate determined at the time when the worker entered the fund.

3.A.4.2 The actuarial accrued liability

The actuarial accrued liability (L_{accr}^{act}) of a participant is the difference between the actuarial liabilities to this participant and the actuarial present value of the future normal cost:

$$L_{accr,t}^{act,a,\zeta} = L_t^{act,a,\zeta} - PVFNC_t^{a,\zeta}.$$

If we follow an individual worker over time, we will see that the actuarial present value of the future normal cost will decrease, as there will be fewer remaining years to pay the normal cost. Therefore, the actuarial accrued liability associated with an individual worker increases over time.

The actuarial accrued liability of pensioners is simply equal to the actuarial liabilities, since they should have paid the whole normal cost before reaching the retirement age. Therefore,

$$PVFNC_t^{a,\zeta} = 0 \Rightarrow L_{accr,t}^{act,a,\zeta} = L_t^{act,a,\zeta}, \forall a \in [a_R, 99].$$

Finally, the fund's actuarial accrued liability is the sum of the individual actuarial accrued liabilities over genders and cohorts:

$$L_{accr,t}^{act} = L_{accr,t}^{act,m} + L_{accr,t}^{act,f} = \sum_{a=25}^{99} \left(M_t^a L_{accr,t}^{act,a,m} + F_t^a L_{accr,t}^{act,a,f} \right). \tag{3.21}$$

3.A.5 Contributions

The aggregate volume of actuarial contributions by all the participants and the employer in year t is:

$$C_t^{act} = \sum_{a=25}^{a_R-1} \left(NCR_{t-(a-25)}^{25,m} M_t^a W_t^a + NCR_{t-(a-25)}^{25,f} F_t^a W_t^a \right) + \lambda AMORT_t,$$

where

$$AMORT_t = \begin{cases} \frac{1}{u} UAAL_t & \text{if } UAAL_t \geq 0, \\ 0 & \text{if } UAAL_t < 0, \end{cases}$$

and λ is the fraction of the required amortization payment *actually* paid. Notice that the first component of C_t^{act} is the sum over all working life ages and over the genders of the product of the gender-specific normal cost rate times the aggregate wage volume earned by each gender. The actuarial contribution rate c_t^{act} is expressed as a percentage of the total wage sum in year t:

$$c_t^{act} = \frac{C_t^{act}}{\sum_{a=25}^{a_R-1} (M_t^a + F_t^a) W_t^a}. \tag{3.22}$$

3.A.6 The sponsor support

We define the sponsor support contribution rate as:

$$c_t^{SS} = \frac{SS_t}{\sum_{a=25}^{a_R-1} (M_t^a + F_t^a) W_t^a}, \tag{3.23}$$

where

$$SS_t = \begin{cases} 0 & \text{if } A_t \geq B_t - C_t, \\ (B_t - C_t) - A_t & \text{if } A_t < B_t - C_t. \end{cases}$$

Notice that the sponsor support is included in the calculation of the actuarial assets.

3.B Simulation procedure

This appendix provides the details on the simulation of both the classic ALM and the value-based ALM model. In both cases we draw a set of economic scenarios. Each scenario involves drawing a path of 300 quarters (for the 75 years horizon) of our state vector. Below we first discuss the pricing framework, followed by the calculation of the fund's portfolio returns. Finally, we discuss the risk-neutral sampling procedure used for the risk-neutral valuation.

3.B.1 Pricing framework

Consider some derivative with a pay-off of Z_τ at time τ, which is a function of the path $X_1, X_2, ...$ of the state vector. The price of the derivative at time q[12] is then given by:

$$P_q = \sum_{\tau=q+1}^{\infty} \mathrm{E}_q \left[Z_\tau \exp \sum_{s=q+1}^{\tau} m_s \right],$$

where $-m_{q+1}$ is the stochastic discount rate for the real-world scenarios. In line with the literature (Campbell et al. (1996)), we assume that the stochastic discount rate $-m_{q+1}$ in period $q+1$ for the real-world scenarios is given by the following function of the state vector generated by our VAR model and the shocks to this state vector:

$$-m_{q+1} = e_y' X_q + \tfrac{1}{2}(\beta_0 + \beta_1 X_q)' \Sigma (\beta_0 + \beta_1 X_q) + (\beta_0 + \beta_1 X_q)' \varepsilon_{q+1}, \tag{3.24}$$

where β_0 and β_1 are respectively a vector and a matrix of parameters and e_y indicates the position of the short rate in the state vector:

$$e_y = (1, 0, 0, 0)'.$$

In a complete market it is possible to sell the derivative at time $q+1$ for its price P_{q+1}. Hence the following must hold:

$$P_q = \mathrm{E}_q \left[P_{q+1} \exp \left(m_{q+1} \right) \right], \tag{3.25}$$

[12] Here, we index time by q to indicate that we now count time in terms of quarters (running from 1 to 300).

where P_{q+1} is the total price based on the total return index where any pay-off is reinvested in the same index. If we use lower-case letters to denote log-values so that

$$p_q = \log P_q,$$

knowing that X_{q+1} has a normal distribution, and using the properties of the log-normal distribution, we can derive from equation (3.25):

$$\begin{aligned}\exp p_q &= \mathrm{E}_q\left[\exp p_{q+1} \exp m_{q+1}\right] = \mathrm{E}_q\left[\exp(p_{q+1} + m_{q+1})\right] \\ &= \exp\left(\mathrm{E}_q\left[p_{q+1} + m_{q+1}\right] + \tfrac{1}{2}\operatorname{Var}_q\left[p_{q+1} + m_{q+1}\right]\right).\end{aligned}$$

Hence,

$$p_q = \mathrm{E}_q\left[p_{q+1} + m_{q+1}\right] + \tfrac{1}{2}\operatorname{Var}_q\left[p_{q+1} + m_{q+1}\right]. \tag{3.26}$$

Note that

$$\mathrm{E}_q\left[m_{q+1}\right] = -e_y' X_q - \tfrac{1}{2}(\beta_0 + \beta_1 X_q)'\Sigma(\beta_0 + \beta_1 X_q), \tag{3.27}$$

$$\operatorname{Var}_q\left[m_{q+1}\right] = (\beta_0 + \beta_1 X_q)'\Sigma(\beta_0 + \beta_1 X_q). \tag{3.28}$$

In what follows, this pricing framework is applied to the various assets that are relevant for us.

3.B.1.1 Nominal bonds

We determine the term structure using an affine model based on the state variables (e.g., see Dai and Singleton (2000), Ang and Piazzesi (2003), Ang et al. (2008) and Le et al. (2010)). Denote by $p_q^{(n)}$ the quarter-q log price of a zero coupon nominal bond that matures at time $q+n$ and pays one unit of currency at maturity date. We assume that it is an affine function of the state variables:

$$p_q^{(n)} = -D_n - H_n' X_q. \tag{3.29}$$

Its nominal yield $Y_q^{(n)}$ satisfies the following relationship:

$$\left(1 + Y_q^{(n)}\right)^{-n} = P_q^n. \tag{3.30}$$

Denote $y_q^{(n)} \equiv \ln(1 + Y_q^{(n)})$. Hence, equations (3.29) and (3.30) imply

$$y_q^{(n)} = -\frac{1}{n} p_q^{(n)} = \frac{1}{n} D_n + \frac{1}{n} H_n' X_q. \tag{3.31}$$

Applying the general pricing equation (3.26) to zero-coupon bonds and using equation (3.29) we get:

$$\begin{aligned} p_q^{(n)} &= \mathrm{E}_q\left[p_{q+1}^{(n-1)} + m_{q+1}\right] + \tfrac{1}{2}\,\mathrm{Var}_q\left[p_{q+1}^{(n-1)} + m_{q+1}\right] \\ &= -D_{n-1} - H_{n-1}'\,\mathrm{E}_q\left[X_{q+1}\right] \\ &+ \mathrm{E}_q\left[m_{q+1}\right] \\ &+ \tfrac{1}{2}\,\mathrm{Var}_q\left[-H_{n-1}'X_{q+1}\right] \\ &+ \tfrac{1}{2}\,\mathrm{Var}_q\left[m_{q+1}\right] \\ &+ \mathrm{Cov}_q\left[-H_{n-1}'X_{q+1}, m_{q+1}\right]. \end{aligned} \tag{3.32}$$

Using (3.27), (3.28) and $\mathrm{E}_q\left[X_{q+1}\right] = (I-\Gamma)\,\mu + \Gamma X_q$, we can rewrite (3.32) as

$$\begin{aligned} p_q^{(n)} &= -D_{n-1} - H_{n-1}'\left((I-\Gamma)\mu + \Gamma X_q\right) \\ &- e_y'X_q - \tfrac{1}{2}(\beta_0 + \beta_1 X_q)'\Sigma(\beta_0 + \beta_1 X_q) \\ &+ \tfrac{1}{2}\left(H_{n-1}'\Sigma H_{n-1}\right) \\ &+ \tfrac{1}{2}(\beta_0 + \beta_1 X_q)'\Sigma(\beta_0 + \beta_1 X_q) \\ &+ H_{n-1}'\Sigma(\beta_0 + \beta_1 X_q), \end{aligned}$$

where the last part follows from

$$\begin{aligned} \mathrm{Cov}_q\left[-H_{n-1}'X_{q+1}, m_{q+1}\right] &= \mathrm{Cov}_q[-H_{n-1}'\left((I-\Gamma)\mu + \Gamma X_q + \varepsilon_{q+1}\right), \\ &\quad - e_y'X_q - \tfrac{1}{2}(\beta_0 + \beta_1 X_q)'\Sigma(\beta_0 + \beta_1 X_q) - (\beta_0 + \beta_1 X_q)'\varepsilon_{q+1}] \\ &= \mathrm{E}_q\left[(-H_{n-1}'\varepsilon_{q+1})(-(\beta_0 + \beta_1 X_q)'\varepsilon_{q+1})\right] \\ &= \mathrm{E}_q\left[(H_{n-1}'\varepsilon_{q+1})(\varepsilon_{q+1}'(\beta_0 + \beta_1 X_q))\right] \\ &= H_{n-1}'\,\mathrm{E}_q\left[\varepsilon_{q+1}\varepsilon_{q+1}'\right](\beta_0 + \beta_1 X_q) \\ &= H_{n-1}'\Sigma(\beta_0 + \beta_1 X_q). \end{aligned}$$

We can further rewrite $p_q^{(n)}$ as

$$\begin{aligned} p_q^{(n)} &= -D_{n-1} - H_{n-1}'(I-\Gamma)\mu - H_{n-1}'\Gamma X_q \\ &- e_y'X_q \\ &+ \tfrac{1}{2}H_{n-1}'\Sigma H_{n-1} \\ &+ H_{n-1}'\Sigma\beta_0 + H_{n-1}'\Sigma\beta_1 X_q \\ &= -D_{n-1} - H_{n-1}'(I-\Gamma)\mu + \tfrac{1}{2}H_{n-1}'\Sigma H_{n-1} + H_{n-1}'\Sigma\beta_0 \\ &- (e_y' + H_{n-1}'\Gamma - H_{n-1}'\Sigma\beta_1)X_q. \end{aligned}$$

The last equation is already of the affine structure as in equation (3.29) with parameters

$$\begin{aligned} D_n = D_{n-1} + H'_{n-1}(I-\Gamma)\mu - \tfrac{1}{2}H'_{n-1}\Sigma H_{n-1} - H'_{n-1}\Sigma\beta_0, \\ H_n = e_y + (\Gamma - \Sigma\beta_1)' H_{n-1}. \end{aligned} \tag{3.33}$$

For $n = 0$ we have that:

$$p_q^{(0)} = \ln P_q^{(0)} = \ln 1 = 0,$$

which is given by equation (3.29) with parameters

$$\begin{aligned} D_0 &= 0, \\ H_0 &= 0. \end{aligned} \tag{3.34}$$

Using (3.34) in (3.33) we get

$$\begin{aligned} D_1 &= 0, \\ H_1 &= e_y. \end{aligned} \tag{3.35}$$

This implies

$$p_q^{(1)} = -e'_y X_q = -y_q^{(1)}. \tag{3.36}$$

The deflator is calibrated to the short rate so that this constraint is satisfied.

3.B.1.2 Real bonds

Denote by $P_{s,q}^{r(n)}$ the price of a real bond at time q issued at time $s \leq q$ and maturing at time $q+n$. Such a bond pays Π_{q+n}/Π_s at maturity, where Π_q is the price index at time q. This implies that:

$$P_{q-1,q}^{r(n)} = \frac{\Pi_q}{\Pi_{q-1}} P_{q,q}^{r(n)}, \tag{3.37}$$

which can be expressed in terms of logarithms as:

$$p_{q-1,q}^{r(n)} = \pi_q + p_{q,q}^{r(n)}. \tag{3.38}$$

At maturity the nominal pay-off of the real bond is equal to the inflation during the bond's life, so in real terms the pay-off is equal to one. The real n-period yield is thus:

$$Y_q^{r(n)} = \left(\frac{1}{P_{q,q}^{r(n)}} \right)^{\frac{1}{n}}, \tag{3.39}$$

which in logarithmic terms is:

$$y_q^{r(n)} = -\frac{1}{n} p_{q,q}^{r(n)}. \tag{3.40}$$

Analogously to (3.29), we assume that $p_{q,q}^{r(n)}$ is of affine structure:

$$p_{q,q}^{r(n)} = -D_n^r - H_n^{r\prime} X_q. \tag{3.41}$$

For $n = 0$ we have that:

$$p_{q,q}^{r(0)} = \ln P_{q,q}^{r(0)} = \ln 1 = 0, \tag{3.42}$$

which by equation (3.41) always holds if

$$\begin{aligned} D_0^r &= 0, \\ H_0^r &= 0. \end{aligned} \tag{3.43}$$

We will assume that (3.41) is valid for n and deduce its validity for $n+1$.

According to the general pricing formula (3.25), and using (3.38):

$$P_{q,q}^{r(n+1)} = \mathrm{E}_q \left[P_{q,q+1}^{r(n)} \exp m_{q+1} \right] = \mathrm{E}_q \left[\exp(\pi_{q+1} + p_{q+1,q+1}^{r(n)} + m_{q+1}) \right]. \tag{3.44}$$

Applying (3.41) we get:

$$\begin{aligned} p_{q,q}^{r(n+1)} &= \mathrm{E}_q \left[\pi_{q+1} + p_{q+1,q+1}^{r(n)} + m_{q+1} \right] + \tfrac{1}{2} \mathrm{Var}_q \left[\pi_{q+1} + p_{q+1,q+1}^{r(n)} + m_{q+1} \right] \\ &= \mathrm{E}_q \left[\pi_{q+1} \right] \\ &- D_n^r - H_n^{r\prime} \mathrm{E}_q \left[X_{q+1} \right] \\ &+ \mathrm{E}_q \left[m_{q+1} \right] \\ &+ \tfrac{1}{2} \mathrm{Var}_q \left[\pi_{q+1} - H_n^{r\prime} X_{q+1} \right] \\ &+ \tfrac{1}{2} \mathrm{Var}_q \left[m_{q+1} \right] \\ &+ \mathrm{Cov}_q \left[\pi_{q+1} - H_n^{r\prime} X_{q+1}, m_{q+1} \right]. \end{aligned} \tag{3.45}$$

Let e_π indicate the position of the inflation in the state vector:

$$e_\pi = (0, 0, 1, 0)', \tag{3.46}$$

so that

$$\pi_{q+1} = e_\pi' X_{q+1}. \tag{3.47}$$

Using (3.47), (3.27), (3.28) and $\mathrm{E}_q[X_{q+1}] = (\mathrm{I} - \Gamma)\mu + \Gamma X_q$, we can rewrite (3.45) as

$$\begin{aligned} p^{r(n+1)}_{q,q} &= \mathrm{E}_q\left[\pi_{q+1} + p^{r(n)}_{q+1,q+1} + m_{q+1}\right] + \tfrac{1}{2}\mathrm{Var}_q\left[\pi_{q+1} + p^{r(n)}_{q+1,q+1} + m_{q+1}\right] \\ &= e'_\pi\left((I-\Gamma)\mu + \Gamma X_q\right) \\ &- D^r_n - H^{r\prime}_n\left((I-\Gamma)\mu + \Gamma X_q\right) \\ &- e'_y X_q - \tfrac{1}{2}(\beta_0 + \beta_1 X_q)'\Sigma(\beta_0 + \beta_1 X_q) \\ &+ \tfrac{1}{2}(e'_\pi - H^{r\prime}_n)\Sigma(e_\pi - H^r_n) \\ &+ \tfrac{1}{2}(\beta_0 + \beta_1 X_q)'\Sigma(\beta_0 + \beta_1 X_q) \\ &+ (H^{r\prime}_n - e'_\pi)\Sigma(\beta_0 + \beta_1 X_q). \end{aligned} \tag{3.48}$$

where the last part follows from

$$\begin{aligned} \mathrm{Cov}_q\left[\pi_{q+1} - H^{r\prime}_n X_{q+1}, m_{q+1}\right] &= \mathrm{Cov}_q\left[(e'_\pi - H^{r\prime}_n)X_{q+1}, m_{q+1}\right] \\ &= \mathrm{Cov}_q[(e'_\pi - H^{r\prime}_n)\left((I-\Gamma)\mu + \Gamma X_q + \varepsilon_{q+1}\right), \\ &- e'_y X_q - \tfrac{1}{2}(\beta_0 + \beta_1 X_q)'\Sigma(\beta_0 + \beta_1 X_q) - (\beta_0 + \beta_1 X_q)'\varepsilon_{q+1}] \\ &= \mathrm{E}_q\left[((e'_\pi - H^{r\prime}_n)\varepsilon_{q+1})(-(\beta_0 + \beta_1 X_q)'\varepsilon_{q+1})\right] \\ &= \mathrm{E}_q\left[((H^{r\prime}_n - e'_\pi)\varepsilon_{q+1})(\varepsilon'_{q+1}(\beta_0 + \beta_1 X_q))\right] \\ &= (H^{r\prime}_n - e'_\pi)\,\mathrm{E}_q\left[\varepsilon_{q+1}\varepsilon'_{q+1}\right](\beta_0 + \beta_1 X_q) \\ &= (H^{r\prime}_n - e'_\pi)\Sigma(\beta_0 + \beta_1 X_q). \end{aligned} \tag{3.49}$$

We can further rewrite $p^{r(n+1)}_{q,q}$ as

$$\begin{aligned} p^{r(n+1)}_{q,q} &= -D^r_n + (e'_\pi - H^{r\prime}_n)(I-\Gamma)\mu + (e'_\pi - H^{r\prime}_n)\Gamma X_q \\ &- e'_y X_q \\ &+ \tfrac{1}{2}(e_\pi - H^r_n)'\Sigma(e_\pi - H^r_n) \\ &+ (H^{r\prime}_n - e'_\pi)\Sigma\beta_0 + (H^{r\prime}_n - e'_\pi)\Sigma\beta_1 X_q \\ &= -D^r_n + (e'_\pi - H^{r\prime}_n)(I-\Gamma)\mu + \tfrac{1}{2}(e_\pi - H^r_n)'\Sigma(e_\pi - H^r_n) + (H^{r\prime}_n - e'_\pi)\Sigma\beta_0 \\ &+ ((e'_\pi - H^{r\prime}_n)\Gamma - e'_y + (H^{r\prime}_n - e'_\pi)\Sigma\beta_1)X_q. \end{aligned} \tag{3.50}$$

The last equation is already of the affine structure as in equation (3.29) with parameters

$$\begin{aligned} D^r_{n+1} &= D^r_n + (H^r_n - e_\pi)'(I-\Gamma)\mu - \tfrac{1}{2}(H^r_n - e_\pi)'\Sigma(H^r_n - e_\pi) - (H^r_n - e_\pi)'\Sigma\beta_0, \\ H^r_{n+1} &= e_y + (\Gamma - \Sigma\beta_1)'(H^r_n - e_\pi). \end{aligned} \tag{3.51}$$

3.B.1.3 Stocks

The excess return on stocks is defined as follows and can be rearranged using (3.36):

$$r^s_{q+1} - y^{(1)}_q = \ln\left(\frac{P^s_{q+1}}{P^s_q}\right) - y^{(1)}_q = p^s_{q+1} - p^s_q + p^{(1)}_q \tag{3.52}$$

$$\Longrightarrow p^s_{q+1} = r^s_{q+1} - y^{(1)}_q + p_q - p^{(1)}_q, \tag{3.53}$$

where P^s_q is the stock price and r^s_q is its return. Note that both r^s_{q+1} and $y^{(1)}_q$ are returns going from period q to period $q+1$, with $y^{(1)}_q$ known in period q. Using (3.34) in (3.32) we get

$$p^{(1)}_q = \mathrm{E}_q\left[m_{q+1}\right] + \tfrac{1}{2}\,\mathrm{Var}_q\left[m_{q+1}\right]. \tag{3.54}$$

From (3.26), (3.52) and (3.54) it follows that

$$\begin{aligned}
\mathrm{E}_q\left[r^s_{q+1} - y^{(1)}_q\right] &= \mathrm{E}_q[p^s_{q+1}] - \left(\mathrm{E}_q\left[p^s_{q+1} + m_{q+1}\right] + \tfrac{1}{2}\,\mathrm{Var}_q\left[p^s_{q+1} + m_{q+1}\right]\right) \\
&\quad + \mathrm{E}_q\left[m_{q+1}\right] + \tfrac{1}{2}\,\mathrm{Var}_q\left[m_{q+1}\right] \\
&= \mathrm{E}_q[p^s_{q+1}] - \left(\mathrm{E}_q\left[p^s_{q+1}\right] + \tfrac{1}{2}\,\mathrm{Var}_q\left[p^s_{q+1}\right] + \mathrm{Cov}_q\left[p^s_{q+1}, m_{q+1}\right]\right) \\
&= -\tfrac{1}{2}\,\mathrm{Var}_q\left[p^s_{q+1}\right] - \mathrm{Cov}_q\left[p^s_{q+1}, m_{q+1}\right].
\end{aligned}$$

Using (3.53) and the fact that p^s_q and $p^{(1)}_q$ are known at time q, so that

$$\mathrm{Var}_q[p^s_{q+1}] = \mathrm{Var}_q[r^s_{q+1} - y^{(1)}_q + p^s_q - p^{(1)}_q] = \mathrm{Var}_q[r^s_{q+1} - y^{(1)}_q], \tag{3.55}$$

we get

$$\mathrm{E}_q\left[r^s_{q+1} - y^{(1)}_q\right] = -\tfrac{1}{2}\,\mathrm{Var}_q\left[r^s_{q+1} - y^{(1)}_q\right] - \mathrm{Cov}_q\left[r^s_{q+1} - y^{(1)}_q, m_{q+1}\right]. \tag{3.56}$$

The excess return on stocks can also be written as

$$r^s_{q+1} - y^{(1)}_q = e'_{xs}X_{q+1} = e'_{xs}\left((\mathrm{I} - \Gamma)\mu + \Gamma X_q + \varepsilon_{q+1}\right), \tag{3.57}$$

where $e_{xs} = (0,1,0,0)'$ is a unit vector representing the location of the excess return on stocks in the state vector. Hence,

$$e'_{xs}\left((\mathrm{I} - \Gamma)\mu + \Gamma X_q\right) = \mathrm{E}_q\left[r^s_{q+1} - y^{(1)}_q\right]. \tag{3.58}$$

It follows from equation (3.24), (3.56), (3.57) and (3.58) that

$$\begin{aligned} e'_{xs}\left((\mathrm{I}-\Gamma)\mu + \Gamma X_q\right) &= -\tfrac{1}{2}\,\mathrm{Var}_q\left[e'_{xs}\varepsilon_{q+1}\right] - \mathrm{Cov}_q\left[e'_{xs}\varepsilon_{q+1}, -(\beta_0+\beta_1 X_q)'\varepsilon_{q+1}\right] \\ &= -(\tfrac{1}{2}e'_{xs}\Sigma e_{xs}) - \mathrm{E}_q\left[(e'_{xs}\varepsilon_{q+1}-0)(-(\beta_0+\beta_1 X_q)'\varepsilon_{q+1}-0)\right] \\ &= -(\tfrac{1}{2}e'_{xs}\Sigma e_{xs}) - \mathrm{E}_q\left[-e'_{xs}\varepsilon_{q+1}\varepsilon'_{q+1}(\beta_0+\beta_1 X_q)\right] \\ &= -(\tfrac{1}{2}e'_{xs}\Sigma e_{xs}) + e'_{xs}\Sigma(\beta_0+\beta_1 X_q). \end{aligned}$$

Hence,

$$\begin{aligned} & e'_{xs}\left((\mathrm{I}-\Gamma)\mu + \Gamma X_q + \tfrac{1}{2}\Sigma e_{xs} - \Sigma\beta_0 - \Sigma\beta_1 X_q\right) = 0 \\ \Leftrightarrow\ & e'_{xs}\left(\left((\mathrm{I}-\Gamma)\mu - \Sigma\beta_0 + \tfrac{1}{2}\Sigma e_{xs}\right) + (\Gamma - \Sigma\beta_1)X_q\right) = 0. \end{aligned}$$

This is satisfied for all values of X_q if:

$$\begin{aligned} e'_{xs}\left((\mathrm{I}-\Gamma)\mu - \Sigma\beta_0\right) + \tfrac{1}{2}e'_{xs}\Sigma e_{xs} &= 0, \\ e'_{xs}\left(\Gamma - \Sigma\beta_1\right) &= 0. \end{aligned} \tag{3.59}$$

The first equation yields one condition, whereas the second equation yields as many conditions as there are state variables. It follows that the conditions in (3.59) must be satisfied for stocks. These conditions determine the parameters β_0 and β_1 of the discount factor.

3.B.1.4 The inflation risk premium

We follow Grishchenko and Huang (2012) and assume that the inflation risk premium $RP_q^{\pi(n)}$ is defined by the following equation:

$$y_q^{(n)} - y_{q,q}^{r(n)} = \frac{1}{n}\sum_{i=1}^{n}\mathrm{E}_q[\pi_{q+i}] + \frac{1}{2}e'_{\pi}\Sigma e_{\pi} + RP_q^{\pi(n)}, \tag{3.60}$$

where on the left-hand side we have the difference between the nominal and the real yield. The first term on the right-hand side is n-period expected inflation and the second term is the so-called Jensen's correction - a convexity term that has little impact on the results.

Iterating (3.6) backwards and taking an expectation we get:

$$\begin{aligned}
\mathrm{E}_q[X_{q+i}-\mu] &= \mathrm{E}_q[\Gamma(X_{q+i-1}-\mu)+\varepsilon_{q+i}] \\
&= \mathrm{E}_q[\Gamma(\Gamma(X_{q+i-2}-\mu)+\varepsilon_{q+i-1})+\varepsilon_{q+i}] \\
&= \mathrm{E}_q\left[\Gamma^i(X_q-\mu)+\sum_{j=0}^{i-1}\Gamma^j\varepsilon_{q+i-j}\right] \\
&= \Gamma^i(X_q-\mu),
\end{aligned} \tag{3.61}$$

and therefore:

$$\mathrm{E}_q[X_{q+i}] = \mu + \Gamma^i(X_q-\mu). \tag{3.62}$$

It follows then that the expected inflation is

$$\mathrm{E}_q[\pi_{q+i}] = \mathrm{E}_q[e'_\pi X_{q+i}] = e'_\pi\mu + e'_\pi\Gamma^i(X_q-\mu), \tag{3.63}$$

and

$$\begin{aligned}
\frac{1}{n}\sum_{i=1}^{n}\mathrm{E}_q[\pi_{q+i}] &= \frac{1}{n}\sum_{i=1}^{n}e'_\pi\mu + \frac{1}{n}\sum_{i=1}^{n}e'_\pi\Gamma^i(X_q-\mu) \\
&= e'_\pi\mu + \frac{1}{n}e'_\pi(\sum_{i=1}^{n}\Gamma^i(X_q-\mu)) \\
&= e'_\pi\mu + \frac{1}{n}e'_\pi((X_q-\mu)(\mathrm{I}-\Gamma^{n+1})(\mathrm{I}-\Gamma)^{-1}-(X_q-\mu)) \\
&= e'_\pi\mu + \frac{1}{n}e'_\pi\Gamma(\mathrm{I}-\Gamma^n)(\mathrm{I}-\Gamma)^{-1}(X_q-\mu).
\end{aligned} \tag{3.64}$$

Inserting

$$y_q^{(n)} = \frac{1}{n}D_n + \frac{1}{n}H'_nX_q, \tag{3.65}$$

$$y_{q,q}^{r(n)} = \frac{1}{n}D^r_n + \frac{1}{n}H^{r\prime}_nX_q, \tag{3.66}$$

and (3.64) into (3.60), and multiplying by n, we obtain:

$$D_n + H'_nX_q - D^r_n - H^{r\prime}_nX_q = ne'_\pi\mu + e'_\pi\Gamma(\mathrm{I}-\Gamma^n)(\mathrm{I}-\Gamma)^{-1}(X_q-\mu) + \frac{n}{2}e'_\pi\Sigma e_\pi + nRP_q^{\pi(n)}, \tag{3.67}$$

or

$$\begin{aligned}
0 = {} & D^r_n - D_n + ne'_\pi\mu - e'_\pi\Gamma(\mathrm{I}-\Gamma^n)(\mathrm{I}-\Gamma)^{-1}\mu + \frac{n}{2}e'_\pi\Sigma e_\pi + nRP_q^{\pi(n)} \\
& + (H^{r\prime}_n - H'_n + e'_\pi\Gamma(\mathrm{I}-\Gamma^n)(\mathrm{I}-\Gamma)^{-1})X_q.
\end{aligned} \tag{3.68}$$

Note that the risk premium is constant over time, hence $RP_q^{\pi(n)} = RP^{\pi(n)}$ for all q. Assuming that this expression holds for all X_q, we can write for $n = 1$:

$$
\begin{aligned}
RP^{\pi} &= D_1 - D_1^r - e_\pi'\mu + e_\pi'\Gamma\mu - \tfrac{1}{2}e_\pi'\Sigma e_\pi, \\
H_1^{r\prime} &= H_1' - e_\pi'\Gamma.
\end{aligned}
\tag{3.69}
$$

where we have defined $RP^{\pi} = RP^{\pi(1)}$. Using (3.35) and (3.51),

$$
\begin{aligned}
RP^{\pi} &= e_\pi'(I-\Gamma)\mu + \tfrac{1}{2}e_\pi'\Sigma e_\pi - e_\pi'\Sigma\beta_0 - e_\pi'\mu + e_\pi'\Gamma\mu - \tfrac{1}{2}e_\pi'\Sigma e_\pi, \\
e_y - (\Gamma - \Sigma\beta_1)'e_\pi &= e_y - \Gamma' e_\pi.
\end{aligned}
\tag{3.70}
$$

Hence, we have the following constraints associated with the one-period inflation risk premium:

$$
\begin{aligned}
e_\pi'(\Sigma\beta_0) &= -RP^{\pi}, \\
e_\pi'(\Sigma\beta_1) &= 0.
\end{aligned}
\tag{3.71}
$$

Following an analogous procedure, i.e. starting from an expression similar to (3.60) for the difference between the yield on a nominal bond and a bond indexed to real wage growth, we obtain the following constraints associated with the one-period real-wage risk premium:

$$
\begin{aligned}
e_w'(\Sigma\beta_0) &= -RP^{w}, \\
e_w'(\Sigma\beta_1) &= 0.
\end{aligned}
\tag{3.72}
$$

where

$$
e_w = (0,0,0,1)'. \tag{3.73}
$$

3.B.2 Parameter optimization

In this subsection we obtain the model-induced values $\tilde{\beta}_0$ and $\tilde{\beta}_1$ for β_0 and β_1, respectively. First, we obtain empirical estimates $\hat{D}_n$ and $\hat{H}_n$ of D_n and H_n, respectively, through multivariate OLS estimation of equation (3.31) for some specific maturities using the historical time series of zero-coupon yields for those maturities and using the historical time series of the state variables. The estimation is again at the quarterly level from the third quarter of 1990 up to and including the second quarter of 2015. The same procedure is repeated for the real yields, in order to obtain empirical estimates $\hat{D}_n^r$ and $\hat{H}_n^r$. For this purpose we use the historical data of the real yields starting from 2003. The optimal $\tilde{\beta}_0$ and $\tilde{\beta}_1$ are obtained through an optimization procedure exploiting several model-implied restrictions. The optimal values for $\tilde{\beta}_0$ and $\tilde{\beta}_1$ imply specific values $\tilde{D}_n$, $\tilde{H}_n$, $\tilde{D}_n^r$ and

$\tilde{H}_n^r$ for the model parameters D_n, H_n, D_n^r and H_n^r, respectively, by using the recursion in equations (3.33) and (3.51). Specifically, given $H_0 = 0$ and $\tilde{\beta}_1$, we can calculate $\tilde{H}_1$, $\tilde{H}_2$, and so on. Given $D_0 = 0$, $\tilde{\beta}_0$ and the path H_0, $\tilde{H}_1$, $\tilde{H}_2$,..., we calculate $\tilde{D}_1$, $\tilde{D}_2$, ... Similarly, given $H_0^r = 0$ and $\tilde{\beta}_1$, we can calculate $\tilde{H}_1^r$, $\tilde{H}_2^r$, and so on. Given $D_0^r = 0$, $\tilde{\beta}_0$ and the path H_0^r, $\tilde{H}_1^r$, $\tilde{H}_2^r$,..., we calculate $\tilde{D}_1^r$, $\tilde{D}_2^r$, ... The part of the objective function constructed in order to solve for $\tilde{\beta}_1$ aims at matching the historical yield exposures to the state variables to the exposures in the model, i.e. bringing $\tilde{H}_n$ and $\tilde{H}_n^r$ as close as possible to $\hat{H}_n$ and $\hat{H}_n^r$. The part of the objective function constructed in order to solve for $\tilde{\beta}_0$ aims at matching the latest interest rate level in our model to the latest interest rate level in our sample period, i.e. bringing $\tilde{D}_n$ and $\tilde{D}_n^r$ as close as possible to the levels implied by the most recent interest rates and $\tilde{H}_n$ and $\tilde{H}_n^r$. Once we have the series $\tilde{D}_n$ and $\tilde{H}_n$, we have constructed the nominal term structure that we use to calculate the returns on the fixed-income part of pension fund portfolio. Once we have the series $\tilde{D}_n^r$ and $\tilde{H}_n^r$, we have constructed the real term structure.

3.B.2.1 Optimization of β_1 and β_0

In the main analysis we use the $\hat{\mu}$ corresponding to the values indicated by the SPF, so that the simulations generated from the model are based on an outlook for the economy that is as close as possible to the current one. In our robustness analysis we use the direct estimate $\hat{\mu}$ of μ. Further, note that the model constraints in the second lines of (3.59) and (3.71) are expressed in terms of $\Sigma\beta_1$, so it is easier to obtain first an estimate $(\widetilde{\Sigma\beta_1})$ of the combination $\Sigma\beta_1$ than to obtain a direct estimate $\tilde{\beta}_1$ of β_1 itself. Analogously, the model constraints in the first lines of (3.59) and (3.71) are expressed in terms of $\Sigma\beta_0$, so it is easier to obtain an estimate $(\widetilde{\Sigma\beta_0})$ of the combination $\Sigma\beta_0$ than to obtain a direct estimate $\tilde{\beta}_0$ of β_0 itself. Hence, we obtain $\tilde{\beta}_1$ and $\tilde{\beta}_0$ in two steps. First, we obtain all elements of $(\widetilde{\Sigma\beta_1})$ and $(\widetilde{\Sigma\beta_0})$. Then, we obtain $\tilde{\beta}_1$ and $\tilde{\beta}_0$ from

$$\tilde{\beta}_1 = \hat{\Sigma}^{-1}(\widetilde{\Sigma\beta_1}). \tag{3.74}$$

$$\tilde{\beta}_0 = \hat{\Sigma}^{-1}(\widetilde{\Sigma\beta_0}), \tag{3.75}$$

where $\hat{\Sigma}$ is obtained from the estimation of equation (3.6).

Let us move to the determination of $(\widetilde{\Sigma\beta_1})$ and $(\widetilde{\Sigma\beta_0})$. The elements in the $(\widetilde{\Sigma\beta_1})$ row corresponding to the excess returns are predetermined by the constraint (3.59):

$$e'_{xs}(\widetilde{\Sigma\beta_1}) = e'_{xs}\hat{\Gamma}. \tag{3.76}$$

Further, using the second line of the constraint (3.71) and the fact that we impose a zero real wage risk premium, we can set the elements in the row of $(\widetilde{\Sigma\beta_1})$ corresponding to inflation and real wage growth to zeroes. The element of $(\widetilde{\Sigma\beta_0})$ corresponding to the excess stock returns follows straight away from the first line of (3.59):

$$e'_{xs}(\Sigma\beta_0) = e'_{xs}(I - \hat{\Gamma})\hat{\mu} + \tfrac{1}{2}e'_{xs}\hat{\Sigma}e_{xs}, \tag{3.77}$$

where $\hat{\mu}$ is based on imputation from the SPF in the main analysis and is the direct estimate obtained from equation (3.6) in the robustness analysis. $\hat{\Gamma}$ is obtained from the estimation of equation (3.6). Finally, the element of $(\widetilde{\Sigma\beta_0})$ corresponding to real wage growth is set to zero, as we impose a zero real wage risk premium due to a lack of market information on it.

Our optimization procedure can be used to solve for the one-period risk premia associated with inflation and real wage growth. This amounts to solving for the third and fourth elements of $(\widetilde{\Sigma\beta_0})$, alongside the other elements of $(\widetilde{\Sigma\beta_1})$ and $(\widetilde{\Sigma\beta_0})$ that we need to optimize over below. The first lines of (3.71) and/or (3.72) then determine the third and fourth element of $(\widetilde{\Sigma\beta_0})$ directly. However, to the best of our knowledge real-wage indexed bonds do not exist in practice. Hence, it is not possible to match its model-implied term structure to one that is estimated on actual data. Therefore, we directly impose a real wage growth risk premium of zero. This seems reasonable in view of the fact that real wage growth exhibits limited volatility compared to the other elements of the state vector. However, the inflation risk premium is kept as a free parameter in the model.

We obtain the remaining elements of $(\widetilde{\Sigma\beta_1})$ and $(\widetilde{\Sigma\beta_0})$, i.e. the first row of $(\widetilde{\Sigma\beta_1})$ and the first and third element of $(\widetilde{\Sigma\beta_0})$, by minimizing over these elements a criterion function that is the sum of the following four components that will all receive an equal weight in the optimization procedure.

The first component tries to match the model-implied exposures H_n of the nominal yield to the state variables to their empirical values $\hat{H}_n$:

$$\sum_{n\in\tau}\left\|H_n - \hat{H}_n\right\|^2 = \sum_{n\in\tau}\left\|e_y + (\hat{\Gamma} - \Sigma\beta_1)'H_{n-1} - \hat{H}_n\right\|^2, \tag{3.78}$$

where $\tau = \{4, 8, 20, 40\}$. Note that H_{n-1} is a function of $\Sigma\beta_1$ through the recursion in the second line of (3.33).

The second component is constructed analogously for the real yields:

$$\sum_{n\in\tau}\left\|H_n^r-\hat{H}_n^r\right\|^2=\sum_{n\in\tau}\left\|e_y+(\hat{\Gamma}-\Sigma\beta_1)'H_{n-1}^r-e_\pi)-\hat{H}_n^r\right\|^2, \tag{3.79}$$

where $\tau=\{4,8,20,40\}$ and H_{n-1}^r is a function of $\Sigma\beta_1$ through the recursion in the second line of (3.51).

For the remaining components we will make use of the affine structure of the yields:

$$y_q^{(n)}=\frac{1}{n}D_n+\frac{1}{n}H_n'X_q, \tag{3.80}$$

and

$$y_q^{r(n)}=\frac{1}{n}D_n^r+\frac{1}{n}H_n^{r\prime}X_q. \tag{3.81}$$

The third component of the objective function tries to match the intercept D_n that follows from the model to the difference between the last observation of the yields and the model prediction without the intercept, so that the model matches the last interest rates as well as possible:

$$\sum_{n\in\tau}\left\|\Big(D_{n-1}+\tilde{H}_{n-1}'(I-\hat{\Gamma})\hat{\mu}-\tfrac{1}{2}\tilde{H}_{n-1}'\hat{\Sigma}\tilde{H}_{n-1}-\tilde{H}_{n-1}'(\Sigma\beta_0)\Big)-\Big((y_{q_{last}}^{(n)}-\frac{1}{n}\tilde{H}_n'X_{q_{last}})n\Big)\right\|^2 \tag{3.82}$$

where $\tau=\{4,8,20,40\}$, q_{last} indicates the quarter of the last observation and we have used the first line of (3.33).

The fourth component is constructed analogously for the real yields. Let us define:

$$\dot{H}_{n-1}^r=\tilde{H}_{n-1}^r-e_\pi \tag{3.83}$$

$$\sum_{n\in\tau}\left\|\Big(D_{n-1}^r+(\dot{H}_{n-1}^r)'(I-\hat{\Gamma})\hat{\mu}-\tfrac{1}{2}(\dot{H}_{n-1}^r)'\hat{\Sigma}(\dot{H}_{n-1}^r)-(\dot{H}_{n-1}^r)(\Sigma\beta_0)\Big)-\Big((y_{q_{last}}^{r(n)}-\frac{1}{n}\tilde{H}_n^{r\prime}X_{q_{last}})n\Big)\right\|^2 \tag{3.84}$$

where $\tau=\{4,8,20,40\}$ and we have used the first line of (3.51).

Using $H_0=H_0^r=0$ and the optimal value $\tilde{\beta}_1$ in combination with the second lines of (3.33) and (3.51) we can thus calculate $\tilde{H}_1$, $\tilde{H}_2$,... and $\tilde{H}_1^r$, $\tilde{H}_2^r$,..., which we will use further in the model. Using $D_0=D_0^r=0$, the optimal value of $\tilde{\beta}_0$ and the sequences $\tilde{H}_n$ and $\tilde{H}_n^r$ we can thus construct $\tilde{D}_n$ and $\tilde{D}_n^r$ using the first lines in (3.33) and (3.51).

We now have the nominal and real term structures fully constructed.

3.B.3 Calculation of the portfolio returns

The model generates scenarios for the term structure of interest rates. The fixed-income portfolio returns have to be extracted from this information. We assume that the fixed-income component of the fund's asset portfolio consists of zero-coupon bonds with a principal value of one unit of currency to be repaid at maturity, τ years from now.

$$1 = \left(1 + Y_0^{(4\tau)}\right)^{-4\tau},$$

where we have assumed that the bond is priced at par. The interest rate $Y_0^{(4t)}$ is the quarterly interest rate obtained from the construction of the term structure using the affine structure model described above. Hence, the left-hand side is the bond's price at issuance date when it is sold at par value 1, while the right-hand side is the present discounted value of the cash flows associated with the bond, i.e. the repayment of the principal, discounted back to issuance date. The bond return is:

$$\left(1 + Y_1^{(4\tau-1)}\right)^{-(4\tau-1)} - \left(1 + Y_0^{(4\tau)}\right)^{-4\tau} = \left(1 + Y_1^{(4\tau-1)}\right)^{-(4\tau-1)} - 1,$$

divided by the purchase price of the bond, which is one.

With the estimation of β_0 and β_1 we have constructed the term structure of interest rates, so that, given the simulated state vector, we can compute, as just laid out, the return on the fixed-income component of the fund's asset portfolio, which consists of 10-year zero-coupon bonds. Hence, $\tau = 10$. It is rebalanced at the beginning of every time period so that it again consists of 10-year maturity bonds. The return on the stock component of the fund's portfolio is obtained directly from the simulation of the state vector.

3.C Risk-neutral sampling

The price of a derivative paying a cash flow Z (which is a function of the path $X_1, X_2, ...X_\tau$ of the state vector) at time τ is

$$P_0 = \mathrm{E}_0 \left[Z_\tau \exp \sum_{q=1}^{\tau} m_q \right].$$

Using (3.24) this equation can be rewritten as

$$\begin{aligned}P_0 = &\int Z(\boldsymbol{\varepsilon}) \exp\left[-\sum_{q=1}^{\tau} e_y' X_{q-1}\right] \\ &\times \exp\left[-\sum_{q=1}^{\tau} \left(\tfrac{1}{2}(\beta_0 + \beta_1 X_{q-1})'\Sigma(\beta_0 + \beta_1 X_{q-1}) + (\beta_0 + \beta_1 X_{q-1})'\varepsilon_q\right)\right] \\ &\times \frac{1}{(2\pi)^{k\tau/2}|\Sigma|^{\tau/2}} \exp\left[-\sum_{q=1}^{\tau} \tfrac{1}{2}\varepsilon_q'\Sigma^{-1}\varepsilon_q\right] \boldsymbol{d\varepsilon}.\end{aligned}$$

where $\boldsymbol{\varepsilon} = (\varepsilon_1', \varepsilon_2', ..., \varepsilon_\tau')'$ and k is the dimension of the state vector (in our case, 4). Hence,

$$P_0 = \int Z(\boldsymbol{\varepsilon}) \exp\left[-\sum_{q=1}^{\tau} y_{q-1}^{(1)}\right] f(\boldsymbol{\varepsilon})\boldsymbol{d\varepsilon},$$

where

$$f(\boldsymbol{\varepsilon}) = \frac{1}{(2\pi)^{k\tau/2}|\Sigma|^{\tau/2}} \exp\left[-\sum_{q=1}^{\tau} \left(\tfrac{1}{2}\left(\varepsilon_q + \Sigma(\beta_0 + \beta_1 X_{q-1})\right)' \Sigma^{-1} \left(\varepsilon_q + \Sigma(\beta_0 + \beta_1 X_{q-1})\right)\right)\right]. \tag{3.85}$$

Here π is the number "pi" (to be distinguished from our symbol for inflation). We estimate this integral by means of the Monte Carlo integration:

$$\hat{P}_0 = \frac{1}{S}\sum_{s=1}^{S} \exp\left[-\sum_{q=1}^{\tau} y_{q-1}^{(1)}(\boldsymbol{\xi}^{(s)})\right] Z(\boldsymbol{\xi}^{(s)}), \tag{3.86}$$

where $S = 5000$ and every $\boldsymbol{\xi}^{(s)}$ is drawn from the multivariate normal distribution with the density function $f(\boldsymbol{\varepsilon})$.

Observe that by definition it follows that the joint density $f(\boldsymbol{\varepsilon})$ can be decomposed as:

$$f(\boldsymbol{\varepsilon}) = \prod_{k=2}^{\tau} f(\varepsilon_k|\varepsilon_{k-1}, \ldots, \varepsilon_1) f(\varepsilon_1), \tag{3.87}$$

where for each q:

$$f(\varepsilon_q|\varepsilon_{q-1}, \ldots, \varepsilon_1) = \frac{1}{(2\pi)^{k/2}|\Sigma|^{\frac{1}{2}}} \exp\left[-\tfrac{1}{2}\left(\varepsilon_q + \Sigma(\beta_0 + \beta_1 X_{q-1})\right)' \Sigma^{-1} \left(\varepsilon_q + \Sigma(\beta_0 + \beta_1 X_{q-1})\right)\right]. \tag{3.88}$$

We can draw $\xi_1, \xi_2, \ldots, \xi_\tau$ from the distribution $f(\boldsymbol{\varepsilon})$ sequentially, i.e. by first drawing ξ_1 from its marginal distribution, then drawing ξ_2 from the conditional distribution $f(\xi_2|\xi_1)$, and so on. Hence,

$$\xi_q|\xi_{q-1}, ..., \xi_1 \sim \mathbb{N}(-\Sigma(\beta_0 + \beta_1 X_{q-1}), \Sigma). \tag{3.89}$$

3.D Generating scenarios

The economic scenarios are generated using the parameter estimates $\hat{\alpha}$, $\hat{\Gamma}$, $\hat{\Sigma}$, $\tilde{\beta}_0$, $\tilde{\beta}_1$, $\tilde{D}_n$, $\tilde{H}_n$, $\tilde{D}_n^r$ and $\tilde{H}_n^r$.

First, setting the initial value of the state vector at the imputed or estimated value for μ and using (3.6) the path of the vector of state variables is simulated for the chosen horizon length. Then, at each quarter into the horizon, the term structure of the nominal interest rate is constructed using the above parameter estimates.

The same scenario-generating procedure is followed for both the real-world and risk-neutral scenarios. The only difference lies in the mean of the shock vector. For the real-world simulation the error terms are drawn from the mean-zero normal distribution $\varepsilon_{q+1} \sim \mathbb{N}(0, \hat{\Sigma})$. Under the risk-neutral scenarios, the error terms are drawn sequentially as discussed in the previous section (3.89).

3.E Estimates of the VAR parameters

The parameter estimates of the VAR in equation (3.6) are:

$$\hat{\mu} = \begin{bmatrix} 0.0022747 \\ 0.0207877 \\ 0.0047909 \\ 0.0038911 \end{bmatrix}, \hat{\Sigma} = \begin{bmatrix} 0.0000011 & 0.0000212 & 0.0000011 & 0.0000025 \\ 0.0000212 & 0.0072488 & 0.0000434 & 0.0003188 \\ 0.0000011 & 0.0000434 & 0.0000670 & -0.0000548 \\ 0.0000025 & 0.0003188 & -0.0000548 & 0.0001418 \end{bmatrix}.$$

After the imputation with the SPF data we have for the quarterly vector of means:

$$\hat{\mu} = \begin{bmatrix} 0.0066600 \\ 0.0031003 \\ 0.0051621 \\ 0.0041434 \end{bmatrix},$$

while $\hat{\Sigma}$ is kept at its originally estimated value.

The correlation matrix for the state variables is as follows:

	y	xs	cpi	w
y	1.00000000	−0.0103837	0.22675373	0.08041977
xs	−0.0103837	1.00000000	0.03858944	0.31787796
cpi	0.22675373	0.03858944	1.00000000	−0.5327254
w	0.08041977	0.31787796	−0.5327254	1.00000000 .

The parameter estimates of $\tilde{\beta}_0$ and $\tilde{\beta}_1$ are:

$$\tilde{\beta}_0 = \begin{bmatrix} -570.72039 \\ 0.5203232 \\ 57.591303 \\ 31.204703 \end{bmatrix}, \tilde{\beta}_1 = \begin{bmatrix} -21858.11 & -2492.9284 & 29821.855 & 57977.976 \\ -207.71570 & -0.2785189 & 163.94782 & 156.69091 \\ 1739.0937 & 113.08954 & -1937.7378 & -3177.1339 \\ 1526.475 & 88.494231 & -1645.8884 & -2607.3416 \end{bmatrix}.$$

3.F Results of robustness analysis

Here, we provide the results of the simulations of the pension fund's performance for a set of 1000 economic scenarios in order to save the simulation time.

3.F.1 Exogenous inflation risk premium

Tables 3.8-3.10 report the results when an inflation risk premium of zero is imposed, while Tables 3.11-3.13 report the corresponding results for an annual inflation risk premium of 20 basis points.

3.F.2 Extending the evaluation horizon to 100 years

Tables 3.14-3.15 report the results for a horizon of 100 years.

Table 3.8: Classic ALM results under different policies after 75 years – zero inflation risk premium

(a) Contributions

Case	Description	c			c^{NC}	c^{Amort}			c^{SS}		
		5%	50%	95%	-	5%	50%	95%	5%	50%	95%
Baseline											
0	baseline plan	26%	41%	47%	13%	12%	13%	14%	0%	15%	20%
Contribution											
1.1	0% amortization paid	36%	41%	47%	13%	0%	0%	0%	23%	28%	34%
1.2	100% amortization paid	23%	36%	44%	13%	10%	23%	28%	0%	0%	4%
1.3	amortization in 10 years	16%	35%	44%	13%	3%	21%	31%	0%	0%	0%
Indexation											
2.1	indexation is 0.5 CPI	20%	36%	42%	13%	7%	13%	14%	0%	10%	15%
2.2	conditional indexation	18%	31%	38%	13%	5%	12%	13%	0%	6%	12%
Portfolio composition											
3.1	100% stocks	15%	41%	47%	13%	2%	13%	14%	0%	15%	20%
3.2	0% stocks	36%	41%	47%	13%	13%	13%	14%	10%	15%	20%

(b) Funding ratios and pension result

Case	Description	FR^P			FR^E			PR		
		5%	50%	95%	5%	50%	95%	5%	50%	95%
Baseline										
0	baseline plan	0%	0%	1%	0%	0%	1%	102%	106%	112%
Contribution										
1.1	0% amortization paid	0%	0%	0%	0%	0%	0%	102%	106%	112%
1.2	100% amortization paid	0%	14%	61%	0%	11%	48%	102%	106%	112%
1.3	amortization in 10 years	26%	46%	95%	19%	36%	79%	102%	106%	112%
Indexation										
2.1	indexation is 0.5 CPI	0%	0%	44%	0%	0%	36%	41%	49%	59%
2.2	conditional indexation	0%	0%	56%	0%	0%	45%	19%	26%	45%
Portfolio composition										
3.1	100% stocks	0%	0%	80%	0%	0%	66%	102%	106%	112%
3.2	0% stocks	0%	0%	0%	0%	0%	0%	102%	106%	112%

Note: classic ALM results after 75 years for the 5%, 50% and 95% percentiles of (a) the total contribution rate (c), which is the sum of the normal cost (c^{NC}), amortization (c^{Amort}) and sponsor support payment (c^{SS}), all in percentages of the wage sum, and (b) the policy funding ratio (FR^P), the economic funding ratio (FR^E), and the pension result (PR) for the base Plan 0 and alternative contribution (Plans 1.1-1.3), indexation (Plans 2.1-2.2) and investment (Plans 3.1-3.2) policies. Note that the median values of the components of c do not necessarily add up to the median value of c. The policy funding ratio is defined as actuarial assets over actuarial liabilities, the economic funding ratio as market value of assets over economic liabilities and the pension result as the ratio of cumulative granted indexation to cumulative price inflation.

Table 3.9: Likelihood of full depletion of assets – zero inflation risk premium

Case	Description	Probability	Year, 5%	Year, 50%	Year, 95%
Baseline					
0	baseline plan	94.5%	29	43	67
Contribution					
1.1	0% amortization paid	98.8%	21	29	47
1.2	100% amortization paid	11.0%	52	66	74
1.3	amortization in 10 years	0.0%	-	-	-
Indexation					
2.1	indexation is 0.5 CPI	81.8%	32	51	70
2.2	conditional indexation	64.2%	37	58	73
Portfolio composition					
3.1	100% stocks	89.4%	21	35	65
3.2	0% stocks	100.0%	40	44	47

Note: the first column reports the probability that the fund's assets are fully depleted within the 75-year simulation horizon. The following columns show the quantiles for the distribution of the years of depletion, conditional on scenarios in which depletion takes place within the simulation horizon.

TABLE 3.10: Effects of plan changes on stakeholders – zero inflation risk premium

(A) Contract values to stakeholders

Case	Description	$V_0^{P,Y}$	$V_0^{P,O}$	$V_0^{T,Y}$	$V_0^{T,O}$
Baseline					
0	baseline plan	4671	9235	-8239	-2865
Contribution					
1.1	0% amortization paid	0	0	-384	381
1.2	100% amortization paid	0	0	676	-688
1.3	amortization in 10 years	0	0	1221	-1248
1.4	part. contr. rate doubled	-1631	-1007	1367	1270
Indexation					
2.1	indexation is 0.5 CPI	-512	-1231	1453	294
2.2	conditional indexation	-895	-2077	2522	444
Portfolio composition					
3.1	100% stocks	0	0	339	-129
3.2	0% stocks	0	0	-96	43

(B) Relative effects

Plan	Description	$\Delta RV_0^{P,Y}$	$\Delta RV_0^{P,O}$	$\Delta RV_0^{T,Y}$	$\Delta RV_0^{T,O}$
Contribution					
1.1	0% amortization paid	0%	0%	-14%	14%
1.2	100% amortization paid	0%	0%	24%	-25%
1.3	amortization 10 years	0%	0%	44%	-45%
1.4	part. contr. rate doubled	-59%	-36%	49%	46%
Indexation					
2.1	indexation is 0.5 CPI	-18%	-44%	52%	11%
2.2	conditional indexation	-32%	-75%	91%	16%
Portfolio composition					
3.1	100% stocks	0%	0%	12%	-5%
3.2	0% stocks	0%	0%	-3%	2%

Note: the table reports the effects of switching from baseline Plan 0 to Plans 1.1-3.2 on future plan participants ($\Delta V_0^{P,Y}$, $\Delta RV_0^{P,Y}$), current plan participants ($\Delta V_0^{P,O}$, $\Delta RV_0^{P,O}$), future tax payers ($\Delta V_0^{T,Y}$, $\Delta RV_0^{T,Y}$) and current tax payers ($\Delta V_0^{T,O}$, $\Delta RV_0^{T,O}$). Panel (a) reports the value of the baseline plan and the change in value of switching from the baseline to an alternative plan in billions of dollars. Panel (b) reports relative changes as percentages of the fund's initial assets A_0. Negative numbers imply a deterioration of the value for that stakeholder.

Table 3.11: Classic ALM results under different policies after 75 years – inflation risk premium 20 bp

(a) Contributions

Case	Description	c			c^{NC}	c^{Amort}			c^{SS}		
		5%	50%	95%	-	5%	50%	95%	5%	50%	95%
Baseline											
0	baseline plan	25%	41%	47%	13%	12%	13%	14%	0%	15%	20%
Contribution											
1.1	0% amortization paid	36%	41%	47%	13%	0%	0%	0%	23%	28%	34%
1.2	100% amortization paid	23%	36%	44%	13%	10%	23%	28%	0%	0%	4%
1.3	amortization in 10 years	15%	34%	43%	13%	2%	21%	30%	0%	0%	0%
Indexation											
2.1	indexation is 0.5 CPI	19%	36%	42%	13%	6%	13%	14%	0%	10%	15%
2.2	conditional indexation	18%	31%	38%	13%	5%	12%	13%	0%	5%	12%
Portfolio composition											
3.1	100% stocks	15%	41%	47%	13%	2%	13%	14%	0%	15%	20%
3.2	0% stocks	36%	41%	47%	13%	13%	13%	14%	10%	15%	20%

(b) Funding ratios and pension result

Case	Description	FR^P			FR^E			PR		
		5%	50%	95%	5%	50%	95%	5%	50%	95%
Baseline										
0	baseline plan	0%	0%	4%	0%	0%	3%	102%	106%	112%
Contribution										
1.1	0% amortization paid	0%	0%	0%	0%	0%	0%	102%	106%	112%
1.2	100% amortization paid	0%	15%	63%	0%	12%	51%	102%	106%	112%
1.3	amortization in 10 years	27%	47%	97%	19%	37%	83%	102%	106%	112%
Indexation										
2.1	indexation is 0.5 CPI	0%	0%	48%	0%	0%	40%	41%	49%	59%
2.2	conditional indexation	0%	0%	59%	0%	0%	48%	19%	26%	46%
Portfolio composition										
3.1	100% stocks	0%	0%	80%	0%	0%	67%	102%	106%	112%
3.2	0% stocks	0%	0%	0%	0%	0%	0%	102%	106%	112%

Note: classic ALM results after 75 years for the 5%, 50% and 95% percentiles of (a) the total contribution rate (c), which is the sum of the normal cost (c^{NC}), amortization (c^{Amort}) and sponsor support payment (c^{SS}), all in percentages of the wage sum, and (b) the policy funding ratio (FR^P), the economic funding ratio (FR^E), and the pension result (PR) for the base Plan 0 and alternative contribution (Plans 1.1-1.3), indexation (Plans 2.1-2.2) and investment (Plans 3.1-3.2) policies. Note that the median values of the components of c do not necessarily add up to the median value of c. The policy funding ratio is defined as actuarial assets over actuarial liabilities, the economic funding ratio as market value of assets over economic liabilities and the pension result as the ratio of cumulative granted indexation to cumulative price inflation.

TABLE 3.12: Likelihood of full depletion of assets – inflation risk premium 20 bp

Case	Description	Probability	Year, 5%	Year, 50%	Year, 95%
Baseline					
0	baseline plan	93.8%	29	44	67
Contribution					
1.1	0% amortization paid	98.7%	21	29	48
1.2	100% amortization paid	10.7%	52	67	75
1.3	amortization in 10 years	0.0%	-	-	-
Indexation					
2.1	indexation is 0.5 CPI	80.9%	33	51	70
2.2	conditional indexation	62.7%	37	58	73
Portfolio composition					
3.1	100% stocks	89.4%	21	35	65
3.2	0% stocks	100.0%	41	44	48

Note: the first column reports the probability that the fund's assets are fully depleted within the 75-year simulation horizon. The following columns show the quantiles for the distribution of the years of depletion, conditional on scenarios in which depletion takes place within the simulation horizon.

Table 3.13: Effects of plan changes on stakeholders – inflation risk premium 20 bp

(a) Contract values to stakeholders

Case	Description	$V_0^{P,Y}$	$V_0^{P,O}$	$V_0^{T,Y}$	$V_0^{T,O}$
Baseline					
0	baseline plan	5063	9456	-8781	-2936
Contribution					
1.1	0% amortization paid	0	0	-391	388
1.2	100% amortization paid	0	0	701	-713
1.3	amortization in 10 years	0	0	1265	-1294
1.4	part. contr. rate doubled	-1713	-1024	1441	1296
Indexation					
2.1	indexation is 0.5 CPI	-577	-1344	1610	316
2.2	conditional indexation	-1006	-2260	2788	471
Portfolio composition					
3.1	100% stocks	0	0	338	-127
3.2	0% stocks	0	0	-96	42

(b) Relative effects

Plan	Description	$\Delta RV_0^{P,Y}$	$\Delta RV_0^{P,O}$	$\Delta RV_0^{T,Y}$	$\Delta RV_0^{T,O}$
Contribution					
1.1	0% amortization paid	0%	0%	-14%	14%
1.2	100% amortization paid	0%	0%	25%	-26%
1.3	amortization in 10 years	0%	0%	46%	-47%
1.4	part. contr. rate doubled	-62%	-37%	52%	47%
Indexation					
2.1	indexation is 0.5 CPI	-21%	-49%	58%	11%
2.2	conditional indexation	-36%	-82%	101%	17%
Portfolio composition					
3.1	100% stocks	0%	0%	12%	-5%
3.2	0% stocks	0%	0%	-3%	2%

Note: the table reports the effects of switching from baseline Plan 0 to Plans 1.1-3.2 on future plan participants ($\Delta V_0^{P,Y}$, $\Delta RV_0^{P,Y}$), current plan participants ($\Delta V_0^{P,O}$, $\Delta RV_0^{P,O}$), future tax payers ($\Delta V_0^{T,Y}$, $\Delta RV_0^{T,Y}$) and current tax payers ($\Delta V_0^{T,O}$, $\Delta RV_0^{T,O}$). Panel (a) reports the value of the baseline plan and the change in value of switching from the baseline to an alternative plan in billions of dollars. Panel (b) reports relative changes as percentages of the fund's initial assets A_0. Negative numbers imply a deterioration of the value for that stakeholder.

TABLE 3.14: Classic ALM results under different policies – evaluation horizon 100 years

(A) Contributions

Case	Description	c			c^{NC}	c^{Amort}			c^{SS}		
		5%	50%	95%	-	5%	50%	95%	5%	50%	95%
Baseline											
0	baseline plan	37%	43%	50%	13%	13%	14%	15%	11%	16%	21%
Contribution											
1.1	0% amortization paid	38%	43%	50%	13%	0%	0%	0%	24%	30%	36%
1.2	100% amortization paid	33%	40%	49%	13%	19%	27%	30%	0%	0%	6%
1.3	amortization in 10 years	23%	38%	47%	13%	10%	25%	33%	0%	0%	0%
Indexation											
2.1	indexation is 0.5 CPI	32%	38%	44%	13%	13%	13%	14%	6%	11%	16%
2.2	conditional indexation	24%	34%	40%	13%	11%	13%	14%	0%	7%	13%
Portfolio composition											
3.1	100% stocks	27%	43%	49%	13%	13%	14%	15%	0%	15%	21%
3.2	0% stocks	38%	43%	50%	13%	13%	14%	15%	11%	16%	21%

(B) Funding ratios and pension result

Case	Description	FR^P			FR^E			PR		
		5%	50%	95%	5%	50%	95%	5%	50%	95%
Baseline										
0	baseline plan	0%	0%	0%	0%	0%	0%	103%	108%	115%
Contribution										
1.1	0% amortization paid	0%	0%	0%	0%	0%	0%	103%	108%	115%
1.2	100% amortization paid	0%	2%	30%	0%	2%	22%	103%	108%	115%
1.3	amortization in 10 years	24%	41%	77%	15%	28%	59%	103%	108%	115%
Indexation										
2.1	indexation is 0.5 CPI	0%	0%	0%	0%	0%	0%	31%	38%	47%
2.2	conditional indexation	0%	0%	14%	0%	0%	10%	10%	15%	25%
Portfolio composition										
3.1	100% stocks	0%	0%	1%	0%	0%	1%	103%	108%	115%
3.2	0% stocks	0%	0%	0%	0%	0%	0%	103%	108%	115%

Note: classic ALM results after 100 years for the 5%, 50% and 95% percentiles of (a) the total contribution rate (c), which is the sum of the normal cost (c^{NC}), amortization (c^{Amort}) and sponsor support payment (c^{SS}), all in percentages of the wage sum, and (b) the policy funding ratio (FR^P), the economic funding ratio (FR^E), and the pension result (PR) for the base Plan 0 and alternative contribution (Plans 1.1-1.3), indexation (Plans 2.1-2.2) and investment (Plans 3.1-3.2) policies. Note that the median values of the components of c do not necessarily add up to the median value of c. The policy funding ratio is defined as actuarial assets over actuarial liabilities, the economic funding ratio as market value of assets over economic liabilities and the pension result as the ratio of cumulative granted indexation to cumulative price inflation.

Table 3.15: Effects of plan changes on stakeholders – evaluation horizon 100 years

(a) Contract values to stakeholders

Case	Description	$V_0^{P,Y}$	$V_0^{P,O}$	$V_0^{T,Y}$	$V_0^{T,O}$
Benchmark					
0	baseline plan	5681	9209	-9241	-2853
Contribution					
1.1	0% amortization paid	0	0	-349	342
1.2	100% amortization paid	0	0	637	-630
1.3	amortization 10 years	0	0	1180	-1170
1.4	part. contr. rate doubled	-1902	-978	1642	1237
Indexation					
2.1	indexation is 0.5 CPI	-658	-955	1367	253
2.2	conditional indexation	-1195	-1656	2456	403
Portfolio composition					
3.1	100% stocks	0	0	247	-145
3.2	0% stocks	0	0	-71	51

(b) Relative effects

Plan	Description	$\Delta RV_0^{P,Y}$	$\Delta RV_0^{P,O}$	$\Delta RV_0^{T,Y}$	$\Delta RV_0^{T,O}$
Contribution					
1.1	0% amortization paid	0%	0%	-13%	12%
1.2	100% amortization paid	0%	0%	23%	-23%
1.3	amortization 10 years	0%	0%	43%	-42%
1.4	part. contr. rate doubled	-69%	-35%	59%	45%
Indexation					
2.1	indexation is 0.5 CPI	-24%	-34%	49%	9%
2.2	conditional indexation	-43%	-60%	89%	15%
Portfolio composition					
3.1	100% stocks	0%	0%	9%	-5%
3.2	0% stocks	0%	0%	-3%	2%

Note: the table reports the effects of switching from baseline Plan 0 to Plans 1.1-3.2 on future plan participants ($\Delta V_0^{P,Y}$, $\Delta RV_0^{P,Y}$), current plan participants ($\Delta V_0^{P,O}$, $\Delta RV_0^{P,O}$), future tax payers ($\Delta V_0^{T,Y}$, $\Delta RV_0^{T,Y}$) and current tax payers ($\Delta V_0^{T,O}$, $\Delta RV_0^{T,O}$). Panel (a) reports the value of the baseline plan and the change in value of switching from the baseline to an alternative plan in billions of dollars. Panel (b) reports relative changes as percentages of the fund's initial assets A_0. Negative numbers imply a deterioration of the value for that stakeholder.

Chapter 4

This plan is different? Transitioning from underfunded DB plans

4.1 Introduction

The long-term sustainability of the U.S. state pension funds has been a matter of public concern since the severe fall in the funding ratios in the aftermath of the financial crisis. Two types of responses by the state pension funds have been observed (Aubry and Crawford 2017).

The first one concerns contract adjustments within the existing framework of the defined benefit (DB) system. Plans save on newly accrued pension entitlements by reducing benefit generosity for new employees, or by cutting back on benefit indexation (cost-of-living adjustments) for existing retirees. Raising the employees' contributions is also an often implemented option. Lekniūtė et al. (2018) look at measures of this sort to improve the sustainability of the fund in the long run and the generational redistribution stemming from the different measures.

The second type of response is closing the existing DB pension plan by transferring new pension entitlements (be it for new employees only, or even for future accrual of existing employees) to an alternative system. A defined contribution (DC) plan is a common alternative for the existing defined benefit plans (Munnell et al. 2014b). A characteristic of defined contribution plans is that the risks are borne by the plan participants themselves and that the sponsor no longer has any obligations.

This paper explores the second type of response. Some state pension funds have indeed introduced new DC systems, but overall the size of the DC presence in the U.S. public sector pensions is still very modest. This is in contrast to the private sector in the U.S., where most companies have closed their DB plans and replaced them by DC plans. Given the prevailing situation of underfunding, it is not unthinkable that DC plans will become the dominant pension vehicle for U.S. public state plans as well.

In this paper we analyze the effects of pension systems transitioning from full DB to various degrees of DC (in terms of the affected participants' population) in order to improve their long term sustainability. For comparability purposes we assume an unchanged pre-fixed contribution by employers to the individual DC accounts. This contribution replaces the normal cost contribution of the closed DB plan. Motivated by Auerbach and Lee (2011) we also explore notional defined contribution (NDC) systems as alternatives to pure DC. The rationale is that the public pension system in the U.S. can be regarded as a substantially underfunded DB scheme, or, alternatively, as an NDC scheme with a significant buffer. Such an alternative system could prove to be an attractive solution as the usual critique of such a system, namely, the initial buffer accumulation (Auerbach and Lee (2011)), would have already been taken care of.

4.2 Relationship with the literature

There are several strands of relevant literature. The first one relates to pension system changes already implemented in practice. The second one concerns the general global trend of transitioning from defined benefit to defined contribution schemes. The third one covers an alternative notional defined contribution route of reform.

Aubry and Crawford (2017) discuss pension reforms carried out in public state pension plans in the U.S. The majority of plans have introduced policy changes of some sort since the financial crisis. In around a quarter of all plans the reforms affected both the current and the new participants, whereas in other plans only new participants were subject to adjusted terms. While most reforms were DB contract adjustments, be it contributions, cost-of-living adjustment terms or retirement age, some retirement plans also introduced DC or hybrid schemes. This option was much more often applied to only the new plan entrants than to the current participants. Munnell et al. (2014b) elaborate on the latter type of reforms by looking at defined contribution activity in government pensions. They describe two waves of plans moving towards DC: the first one just before the financial crisis and motivated by high investment returns, the second one during the crisis and meant to mitigate the risk of large unfunded liabilities in the future (whether due to investment or longevity risk) and to provide a retirement solution to short-tenured workers.

Munnell et al. (2017) describe a shift in retirement plan coverage from DB to DC and how this negatively affects the retirees due to actuarially unfair annuities and low interest rates. Such a shift, however, has been much more characteristic for plans provided by private companies than for the government sector so far. Broadbent et al. (2006) discuss a global trend of moving from DB to DC and cite pension underfunding as one of the main driving factors behind the shift. They describe several advantages of DC systems over the traditional DB ones, but also acknowledge the fact that investment risk is reallocated from the corporate sector to households. Based on data from Australia, Canada and the U.S. they find that aggregate asset allocation remains similar in DB and DC.

Holzmann (2017) documents extensively the advantages of notional (alternatively called non-financial) DC over traditional DB schemes. They describe NDC as more transparent systems, allowing for automatic adjustments without politically often difficult discretionary decisions, having better aligned incentives for labor market decisions and clearly separated replacement and redistributive functions. They also present NDC schemes as a solution allowing for a smooth transition from DB to DC format avoiding high transition costs. Börsch-Supan (2004) also points out the compelling elements of NDC systems, namely, the transparency and accountability, but argue that this might be achieved in well designed public DB systems as well.

When NDC plans are discussed, the Swedish NDC pension system is often cited as one of the top systems in the world. Auerbach and Lee (2011) discuss risk sharing across generations in alternative pension systems. They explore Sweden's NDC system and conclude it would perform well if not for the fact that the initial buffer has to be accumulated, which affects the cohorts active during the buffer accumulation period. Palmer (2000) describes the Swedish pension reform and identifies two main questions that are relevant for the transition problem: firstly, how the old pension rights are honored in the new system, and secondly, which cohorts will be affected by transition.

4.3 Baseline and alternative pension systems

The analysis is based on a typical public pension plan that is scaled to represent the public pension sector in the U.S. at the macro level. Section 4.3.1 describes how the baseline plan is arranged. Section 4.3.2 lays out the modifications to the system with respect to the baseline that are implemented so that alternative pension systems of interest can be analyzed.

The comparison of the baseline and the alternative pension systems relies on the assumption that under the baseline plan the employer would continue to pay the promised benefits without implementing any substantial reforms no matter how severely underfunded the plan were to become. Even though the employers in the public pension plans are the tax payers, and in this context the terms can be used interchangeably, hereafter we use the term "employer" when we talk about the contributions, and the term "tax payer" when it comes to the total stakeholders' values.

4.3.1 Basis: continuation of the existing DB plan

This section explains the modeling of our baseline public DB pension plan, i.e. it describes the assumptions regarding plan participants' population, salaries, pension contributions and promises, as well as assets, liabilities and funding ratio calculation.

4.3.1.1 Population

The participants' population consists of working cohorts aged 25 to 64 and retired cohorts of ages 65 to 99; thus the retirement age a_R is assumed to be 65. The total number of participants initially matches that of the public pension sector in the U.S. We assume that participants stay in the system for their whole life, i.e. they stay employed in the public sector throughout their careers. There is no longevity risk at the aggregate level as we use deterministic survival probabilities to project the population development over time:

$$\begin{aligned} M_{t+n}^{a+n} &= q_{a,t}^{m,n} M_t^a, \\ F_{t+n}^{a+n} &= q_{a,t}^{f,n} F_t^a, \end{aligned} \tag{4.1}$$

where M_t^a and F_t^a are the number of males and females, respectively, of age a, and $q_{a,t}^{m,n}$ and $q_{a,t}^{f,n}$ are the chances of a male and female, respectively, of age a to survive another n years. The numbers of new entrants to the system each year are expected to develop according to the development of the general U.S. population.

4.3.1.2 Wages

The assumed salary level is age and time dependent but gender neutral. That is, salaries over time are indexed with economy-wide gross wage growth rate w_t and adjusted with the appropriate career development factor per age $\tilde{w}_t^a$:

$$\begin{aligned} W_{t+1}^{a+1} &= W_t^a w_t^a, \\ w_t^a &= w_t \tilde{w}_t^a, \end{aligned} \tag{4.2}$$

where W_t^a is the annual nominal wage of a plan participant of age a at time t. The career growth per age group is assumed to stay constant over time, i.e. relative salary positions of two cohorts of a certain age remain constant throughout the simulation horizon.

4.3.1.3 Liabilities

The pension fund liabilities consist of pension promises to current workers and retirees. The total liabilities are the sum of the present values of pension rights calculated per gender and age group:

$$\begin{aligned} L_t = L_t^m + L_t^f &= \sum_{a=25}^{99} \left(M_t^a L_t^{a,m} + F_t^a L_t^{a,f} \right), \\ L_t^{a,\zeta} &= \sum_{i=\max(a_R - a, 0)}^{99-a} \left(\tilde{R}_t^{(i)} \right)^{-i} q_{a,t}^{\zeta,i} K_{t,t+i}^{a+i}, \end{aligned} \tag{4.3}$$

where $K_{t,t+i}^{a+i}$ is the projection at time t of the pension payout i years ahead for a participant of age a at time t and $\tilde{R}_t^{(i)}$ is the gross interest rate used in time period t by the pension fund to discount the cash flows materializing i periods into the future. The projected pension payout is calculated differently for workers and retirees, since the initial benefit at retirement is already known for pensioners, whereas it has to be projected for the working cohorts. This projection is made using the projected value of benefits (PVB) methodology. This bases the pension rights for the working participants on the projected years of service and projected salary at retirement. Specifically, the projected benefits of current active participants are based on the assumption that they will work until retirement and their salaries will grow as projected. The precise calculation for both groups is laid out below.

Workers. We first present the projected pension benefits of the current workers. For the first year of retirement it is the initial calculated benefit. For the subsequent years in retirement this figure is increased with the cost-of-living adjustment since the start of retirement:

$$\begin{aligned} K_{t,t+i}^{a+i} &= B_t^a, i = a_R - a, \forall a \in [25, a_R - 1], \\ K_{t,t+i}^{a+i} &= B_t^a \prod_{j=a_R+1-a}^{i} \pi_{t+j}^p, \forall i \in [a_R + 1 - a, 99 - a], \forall a \in [25, a_R - 1], \end{aligned} \tag{4.4}$$

where π_t is the cost-of-living adjustment (COLA) at time t. The first equation of (4.4) is the projected benefit at the moment of retirement of a worker of age a at time t. The second equation of (4.4) is the projected benefit after the moment of retirement of a worker of age a at time t.

The projected benefit in the first year of retirement is based on the number of years of accrual representing the full career (i.e., 40) and the expected final salary, which is based on the current salary augmented with projected wage growth over the remaining years until retirement:

$$B_t^a = \frac{40\varepsilon}{z} \sum_{l=1}^{z} \mathrm{E}_t \left[W_{t+(a_R-a)-l}^{a_R-l} \right], \forall a \in [25, a_R - 1], \tag{4.5}$$

where ε is the accrual rate for each year of work and pension benefits are based on the average wage during the last z years before retirement. $W_{t+(a_R-a)-l}^{a_R-l}$ therefore refers to projected salary levels from z years before retirement to the last year before retirement. For the working cohorts that are closer than z years to retirement some or all of these salary levels are realizations rather than expectations.

Pensioners. The projected payouts for pensioners, similarly as in (4.4), are the current pension payouts adjusted for the projected future indexation.

$$\begin{aligned} K_{t,t}^{a} &= B_t^a, \forall a \in [a_R, 99], \\ K_{t,t+i}^{a+i} &= B_t^a \prod_{j=1}^{i} \pi_{t+j}^p, \forall i \in [1, 99 - a], \forall a \in [a_R, 98]. \end{aligned} \tag{4.6}$$

Because the pension rights for the retired are already determined, they are not affected by assumptions regarding future service or salary increases:

$$\begin{aligned} B^{a_R}_{t-(a-a_R)} &= \frac{40\varepsilon}{z}\sum_{l=1}^{z} W^{a_R-l}_{t-(a-a_R)-l}, \forall a \in [a_R, 99]\,, \\ B^{a}_{t} &= B^{a_R}_{t-(a-a_R)} \prod_{j=0}^{a-(a_R+1)} \pi_{t-j}, \forall a \in [a_R+1, 99]\,. \end{aligned} \tag{4.7}$$

The first equation of (4.7) calculates the initial benefit at retirement. It is analogous to (4.5), but the final wage on which the benefit is based is a realization and not an expectation anymore. It concerns the salary levels during the last z years before retirement. The second equation of (4.7) regards the inflation adjustments that have taken place since retirement up till time t.

Accrued actuarial liabilities. The accrued actuarial liabilities $L_{accr,t}$ are used in calculating the required amortization payments and are defined as a difference between the PVB liabilities and the projected value of future normal costs ($PVFNC$), i.e. the projected liabilities at retirement less the accrual to be covered by remaining future contributions until retirement:

$$\begin{aligned} L_{accr,t} = L^{m}_{accr,t} + L^{f}_{accr,t} &= \sum_{a=25}^{99}\left(M^a_t L^{a,m}_{accr,t} + F^a_t L^{a,f}_{accr,t}\right), \\ L^{a,\zeta}_{accr,t} &= L^{a,\zeta}_t - PVFNC^{a,\zeta}_t, \\ PVFNC^{a,\zeta}_t &= PVW^{a,\zeta}_t \times NCR^{25,\zeta}_{t-(a-25)}, \end{aligned} \tag{4.8}$$

where NCR is the normal cost rate and PVW is the present value of projected lifetime salaries, both of which will be explained in section 4.3.1.6.

4.3.1.4 Assets

The pension plan is modeled on an annual basis. Benefits and contributions come in the middle of the year on average and thus the market value of pension fund's assets develops according to the following formula:

$$A_{t+1} = A_t R_t + (C_t - B_t)\sqrt{R_t}, \tag{4.9}$$

where R_t is the gross return on the fund's investment portfolio, C_t is the contribution inflow and B_t is the benefit outflow which is the sum of benefits paid out to each cohort:

$$B_t = \sum_{a=a_R}^{99} (M_t^a + F_t^a) B_t^a. \tag{4.10}$$

4.3.1.5 Measures of the plan's financial position

For actuarial purposes the fund calculates the actuarial asset value A_t^{act} which is a moving average of historic market values. The actuarial assets are used together with the actuarial accrued liabilities in calculating two measures of the fund's financial situation: the funding ratio and the unfunded liabilities. The funding ratio FR_t is the ratio of assets to liabilities:

$$FR_t = \frac{A_t^{act}}{L_t}. \tag{4.11}$$

The unfunded liabilities, $UAAL_t$ (unfunded actuarial accrued liabilities), are the actuarial accrued liabilities that are not covered by the actuarial assets:

$$UAAL_t = L_{accr,t} - A_t^{act}. \tag{4.12}$$

The unfunded liabilities are used in calculating the amortization payments meant to cover the funding deficit.

4.3.1.6 Contributions

The contributions paid to the fund consist of the normal cost payment and, in case of underfunding, the amortization payment.

The normal cost contribution rates are determined based on the entry-age normal costing method, which defines the contribution rate as a share of lifetime salary that would cover the projected lifetime pension accrual. It is calculated as a ratio of entering cohort's PVB liabilities to the present value of projected lifetime salaries at entry into the labor force:

$$\begin{aligned} NCR_t^{25,\zeta} &= \frac{L_t^{25,\zeta}}{PVW_t^{25,\zeta}}, \quad \zeta \in \{f; m\}, \\ PVW_t^{a,\zeta} &= \sum_{i=0}^{a_R-1-a} \left(\tilde{R}_t^{(i)}\right)^{-i} q_{a,t}^{\zeta,i} W_{t+i}^{a+i}. \end{aligned} \tag{4.13}$$

The amortization payment is meant to gradually cover the funding deficit. The required amortization payment is a share of the total unfunded accrued actuarial liabilities ($UAAL$). However, amortization payment is only required if the $UAAL$ is positive, i.e. if the system is underfunded:

$$AMORT_t = \begin{cases} \frac{1}{u} UAAL_t & \text{if } UAAL_t \geq 0, \\ 0 & \text{if } UAAL_t < 0. \end{cases} \tag{4.14}$$

The total contribution amount paid to the pension fund is the sum of cohort specific normal cost payments and the actually paid amortization payment:

$$C_t^{act} = \sum_{a=25}^{a_R-1} \left(NCR_{t-(a-25)}^{25,m} M_t^a W_t^a + NCR_{t-(a-25)}^{25,f} F_t^a W_t^a \right) + \lambda AMORT_t, \tag{4.15}$$

where λ is the fraction of the required amortization payment *actually* paid, which may thus differ from the required payment. Notice that the first component of C_t^{act} is the sum over all working life ages and over the genders of the product of the gender-specific normal cost rate (calculated in the time period when the cohort entered the fund) times the aggregate wage volume earned by each gender.

By expressing the actuarial contribution amount in terms of the pension fund's salary base we obtain:

$$c_t^{act} = \frac{C_t^{act}}{\sum_{a=25}^{a_R-1} (M_t^a + F_t^a) W_t^a}. \tag{4.16}$$

We refer to c_t^{act} as the actuarial contribution rate.

The final contribution rate is the actuarial rate plus the sponsor support rate:

$$\begin{aligned} c_t &= c_t^{NC} + c_t^{Amort} + c_t^{SS} \\ &= c_t^{act} + c_t^{SS}, \end{aligned} \tag{4.17}$$

where c_t^{NC}, c_t^{Amort} and c_t^{SS} are the so-called normal cost payment, the actual amortization payment and the sponsor support payment, respectively, all as fractions of the aggregate wage sum. The actuarial contribution rate can also be split into the sum of employer's and employees' contribution rates:

$$c_t^{act} = c_t^P + c_t^E, \tag{4.18}$$

where c_t^P are plan participant contributions as a share of the wage sum and c_t^E are employer's contributions as a share of the wage sum. We assume that the employees pay a fixed contribution rate and the employer covers the rest of the normal cost.

The sponsor support payment SS_t is the last resort payment that is needed if the fund runs out of money. It is therefore:

$$SS_t = \begin{cases} 0 & \text{if } A_t \geq B_t - C_t, \\ (B_t - C_t) - A_t & \text{if } A_t < B_t - C_t, \end{cases} \tag{4.19}$$

and is expressed as a contribution rate analogously as in (4.16):

$$c_t^{SS} = \frac{SS_t}{\sum_{a=25}^{a_R-1} (M_t^a + F_t^a) W_t^a}. \tag{4.20}$$

4.3.2 Alternative ways of transforming the system

In this section we define the alternative ways of closing the baseline DB pension plan that we will study. We first describe the alternative arrangements qualitatively, and then lay out the resulting modifications in the modeling of the existing DB plan, as well as the modeling of each new plan arrangement.

4.3.2.1 Alternative plan arrangements

The following retirement system arrangements are considered:

Variant 0. The existing DB pension plan continues to run as usual.

Variant 1. In this case, the existing participants (at $t = 0$) continue to pay contributions and accrue benefits in the existing DB pension plan, but there are no new participants entering. New participants accrue their pension entitlements in a DC plan instead. To maintain comparability with variant 0, new participants pay the same contribution into the DC plan as they would have done in the DB plan. Similarly, for each employee the employer pays the same normal cost contribution as under variant 0. Now, these employer's contributions go into the closed DB fund for the existing participants and into the private DC accounts for the new participants. The plan sponsor is still responsible for the risk of DB assets being completely depleted before all obligations to pensioners have been met. The employer therefore pays the amortization and sponsor support payments that are needed to meet the benefit obligations to DB participants. The DC participants bear the risk of low returns themselves.

Variant 2. The existing DB pension plan is completely closed to any new accumulation of pension entitlements. Accumulated entitlements of the existing participants are frozen in the fund at the current number of years of service, although the retirement benefit will be based on the final salary average. As in variant 1, benefits are paid from the fund's reserves, investment returns and additional employer's contributions in the form of amortization payments or sponsor support. New accumulation of entitlements by existing participants and of new participants takes place in a DC plan. Again, to maintain comparability with variant 0, the baseline contributions of both the employer and the employees equals the original normal cost payments under variant 0. However, now these contributions go into the DC fund.

Variant 1ndc. This is the NDC alternative of variant 1. The existing participants remain in the DB plan, while new entrants accrue pension entitlements in an NDC scheme. Existing accumulated assets stay in the DB fund.[1] Hence, the NDC plan is started with an empty buffer, which is incremented each year with the difference between contributions received and benefits paid out, and the investment returns. Unlike in variant 1, the sponsor is still the ultimate bearer of risk in the new scheme, i.e. the sponsor pays the difference between contribution inflows and benefit outflows if the buffer is depleted.

Variant 2ndc. This is the NDC alternative of variant 2. Entitlements and assets accumulated up to now remain in the DB scheme, while any new entitlements of both existing and new entrants will be accumulated in the NDC scheme. Thus the NDC plan starts with an empty buffer. Like in variant 1ndc, the buffer develops over time and the sponsor is ultimately responsible for paying the NDC benefits in case of depleted buffer if contribution inflows are not sufficient to cover benefit outflows.

Variant 3ndc. The complete transformation of the DB scheme into NDC. At the transition, we keep the DB pension rights for both pensioners and working cohorts as they

[1] Hence, new entrants have no stake in what has been accrued by the DB participants up till now.

are, meaning that they are kept in a DB format, but they now live within the NDC plan and therefore get NDC indexation instead of the base plan indexation. For pensioners the only change is effectively the indexation. For the working cohorts the transformation means that their rights now consist of two components. The first one is the heritage DB pension rights (expressed as a promised pension payment) that were accrued up to the moment of conversion and based on the years of accrual and salary at the moment of conversion. The second one is the newly accrued NDC accounts (expressed in dollar value and to be annuitized at retirement). Both components get NDC indexation. The assets accumulated in the DB scheme will become the buffer of the NDC scheme when it starts. The benefits of the current pensioners remain the same in the new scheme, except for potential differences in the future indexation. The pension entitlements of both pensioners and working cohorts are backed by the initial buffer of the NDC scheme and the future contributions, as well as eventual sponsor support if needed.

Some comments are warranted. First, for comparability of the various schemes we assume that the employer sticks to the normal cost approach when granting contributions to individual (N)DC accounts. Each cohort receives an amount equal to its wage base times the normal cost percentage calculated in the baseline plan. Note that because in the base system the employer's share of the normal cost is paid as a lump-sum payment, as opposed to separate contributions for each cohort specifically, it is not directly obvious what the employer's contributions to the individual accounts should be. For example, contributions increasing with age could be an option, reflecting the fact that contributions made at an early age have a longer investment horizon and thus can be lower to achieve the same investment result as a higher contribution later on in life. The way contributions are allocated to cohorts over time might affect the generational results; however, assuming that any alternative allocation is based on a calculation using the same actuarial assumptions, this effect should be limited. Due to the fact that the lump-sum payment in the base system is calculated as the sum of normal cost of all cohorts, maintaining our assumption also means that the employer pays the same aggregate normal cost contribution across all variants, which makes comparison easier.

Second, whereas NDC plans are usually implemented as pay-as-you-go plans with defined contribution features, and returns on plan participants' accounts are notional, the NDC variants we consider here can accumulate assets. This due to the fact that the NDC plans are newly started and there are initially fewer money outflows than inflows, whereas we keep the same contribution levels as in the baseline. This does not directly follow the pay-as-you-go principle and therefore the NDC variants we consider fall in between the funded and pay-as-you-go schemes.

Third, while modifying the pension contract seems doable in many states from a legal point of view for new entrants to the system or for existing members when only new accrual is concerned, adjusting the existing pension rights can prove to be challenging (Aubry and Crawford (2017)). This is in particular a relevant concern in variant 3ndc. Leaving the legal restrictions out of consideration, there are multiple possible approaches of how the pension rights of current pensioners and working cohorts can be transferred to the NDC system. However, in order to avoid analysing options that are politically or legally unattainable, or sensitive to parameter assumptions, we choose a prudent approach that would be most likely to sustain the challenges in court and be politically feasible. This means we keep the up to now accrued pension rights unchanged. Alternatively, accrued pension rights could be converted to an NDC account by calculating the annuity value of the accrued pension entitlements. These accounts would be increased each year with new contributions and return, and the resulting accounts would be annuitized again at retirement. However, this option includes a politically sensitive decision on the discount rate to be used for conversion, which would especially directly affect the pensioners as they have no new accrual in the future to dampen the shock. To prevent this, one could choose to keep the pension rights of pensioners as they are and only convert the rights of working cohorts to NDC asset accounts. This approach, however, would lead to discontinuity between the oldest working cohorts and those just retired, which again would be neither easy nor desirable to implement. We therefore stick to the prudent two-components system approach.

Fourth, in all pension systems we analyze we assume that the asset allocation remains unchanged. It is a reasonable assumption, given that Broadbent et al. (2006) find comparable aggregate asset allocations in DB and DC systems in their sample that covers Australia, Canada and the U.S. We keep out of consideration the potential utility gains that could be achieved by individual participants by being able to select an asset allocation that is optimal for their aggregate portfolio. This is especially the case in DC alternatives where participants usually have a lot of freedom in deciding on asset allocation. Whether people in practice behave in such a rational way is another question, and Broadbent et al. (2006) suggest that "households do not necessarily manage risks in the most appropriate way".

Finally, in all instances we assume that changes in the pension system do not affect the number of participants and their salaries. This ignores potential side effects of pension reform such as making the public sector a less (or possibly more) attractive employer, which would potentially change the labor supply and compensation. However, our assumption makes it easier to analyze and compare alternative reforms. A priori, we would not know how alternative pension plan variants affect the system's demography and factor payments. Careful modeling would be required to avoid introducing arbitrary effects, which would go beyond the scope of the present paper.

4.3.2.2 Modifications of baseline DB plan

Benefits. We assume that the pension plan reform takes place in period 1. When the DB plan is closed for *new* participants only (variants 1 and 1ndc), in terms of pension entitlements nothing changes for the existing participants of the fund at $t = 0$, i.e. for those of age 25 or older at $t = 0$. The first expression in (4.21) below coincides with (4.5), except that it applies only to the existing participants. For new entrants after period 0, pension entitlements are set to 0 (the second equation of (4.21)).

$$\begin{aligned} B_t^a &= \frac{40\varepsilon}{z}\sum_{l=1}^{z}\mathrm{E}_t\left[W_{t+(a_R-a)-l}^{a_R-l}\right], \forall a \in [25+t, a_R-1], \forall t, \\ B_t^a &= 0, \forall a < 25+t, \forall t > 0. \end{aligned} \tag{4.21}$$

When the reform entails the closure of the DB plan for *all* participants (variants 2 and 2ndc), further DB accrual stops for everyone (4.22). Whereas in the initial time period the projected benefits are still based on the projected 40 working years, at the conversion pension entitlements of existing participants at $t = 1$ are frozen at the number of years that these participants have been in service up till that year. For new entrants in period 1 and later DB pension rights are set to 0.

$$\begin{aligned} B_t^a &= \frac{40\varepsilon}{z}\sum_{l=1}^{z}\mathrm{E}_t\left[W_{t+(a_R-a)-l}^{a_R-l}\right], \forall a \in [25+t, a_R-1], t = 0, \\ B_t^a &= \frac{\max(0, a-25-t+1)\varepsilon}{z}\sum_{l=1}^{z}\mathrm{E}_t\left[W_{t+(a_R-a)-l}^{a_R-l}\right], \forall a \in [25, a_R-1], \forall t > 0, \end{aligned} \tag{4.22}$$

where the numerator of the factor before the summation in the second equation reflects the number of years in the system at the moment of DB closure for a given age, times the yearly accrual rate. It also implies that cohorts that enter after the closure have no pension rights in the DB system anymore (the numerator is zero for them). The rest of the expression calculates the expected final average salary before retirement. Note that under all of the abovementioned reform alternatives the benefits to be paid from the DB scheme are based on the projected final average salary before retirement. The latter is assumed to be exogenous, so unaffected by the specific reform. Also, we assume that plan participants continue to work in the same sector until retirement.

In the remaining variant 3ndc all current DB pension entitlements are frozen at the current years of accrual and current salary levels (called accrued benefit obligations, ABO) and transferred to the NDC system. Note that this differs from variants 2 and 2ndc in that current salary levels instead of projected levels at retirement are taken, because these pension rights will get indexation within NDC framework (whereas in the DB scheme benefits are only indexed in retirement, but calculated based on salaries at retirement, thus indexed *implicitly*).

$$\begin{aligned} B_t^a &= \frac{40\varepsilon}{z}\sum_{l=1}^{z} \mathrm{E}_t\left[W_{t+(a_R-a)-l}^{a_R-l}\right], \forall a \in [25+t, a_R-1], t=0, \\ B_t^a &= \frac{\max(0, a-25-t+1)\varepsilon}{\min(a-25, z)} \sum_{l=1}^{\min(a-25,z)} \mathrm{E}_t\left[W_{1-l}^{a-l}\right], \forall a \in [25, a_R-1], \forall t>0. \end{aligned} \tag{4.23}$$

Here the first equation is the same as above and displays the initial situation before closing the DB plan. The second equation shows the DB pension rights after the closure. The numerator of the factor before the summation is the same as in (4.22) and gives the number of years of service up till the moment of closure, times the yearly accrual rate. The rest of the expression calculates the average salary level over the last z years (or fewer years for cohorts that do not have sufficiently long work history).

Contributions. New entrants to the system no longer contribute to the DB scheme, so the normal cost rate associated with these cohorts is zero under any of the reform variants:

$$NCR_t^{25,\zeta} = 0, \zeta \in \{f; m\}, \quad \forall t > 0. \tag{4.24}$$

Because new cohorts do not accrue any new pension entitlements they also do not contribute to the DB plan. We keep c_t^P at the baseline level of 6 percent. The fact that only DB participants who are active at time 0 pay the contribution into the DB plan, implies that in variants 1 and 1ndc

$$C_t^{P,DB} = 0, \forall t \geq (a_R - 25). \tag{4.25}$$

The youngest worker cohort that continues to contribute to DB scheme is 26 at the moment of the reform in period 1. Hence, as of the moment this cohort retires the contributions to the fund become zero. In variants 2, 2ndc and 3ndc contributions to the DB fund fall to zero as of period 1:

$$C_t^{P,DB} = 0, \forall t > 0. \tag{4.26}$$

The employer continues to pay the part of the normal cost payment that belongs to the participants still actively accruing DB pension rights. Similar to the employees' contributions, the employer's contributions terminate when the youngest worker cohort that continues to contribute to the DB scheme retires. Hence, for variants 1 and 1ndc it holds that:

$$C_t^{E,DB} = 0, \forall t \geq (a_R - 25), \tag{4.27}$$

and for variants 2, 2ndc and 3ndc the following is true:

$$C_t^{E,DB} = 0, \forall t > 0. \tag{4.28}$$

Since the DB benefits are guaranteed, the sponsor is ultimately responsible for covering the deficits of the closed plan. This is done via the amortization and sponsor support payments, like in the original open system. However, because the dynamics of the open and closed systems differ in terms of cashflows going in and out, the actual amortization payments and sponsor support payments under the closed system will be different from those in the open system.[2]

4.3.2.3 Individual (N)DC accounts module

Asset accounts and buffers. In variants 1, 1ndc, 2 and 2ndc the assets accrued until the moment of reform remain in the DB plan and the employer's amortization and/or sponsor support payments continue to be made so as to guarantee the remaining entitlements in the DB plan. Under the NDC variations the risks are shared and borne by both the participants (though the risk may be spread across the participant cohorts) and the sponsor via eventual payments to cover the deficits. The risks associated with building up a pension in the DC plan are entirely borne by the participants at the individual level. Hence, with the transition from DB to (N)DC risk is shifted from sponsor to plan participants.

[2] Alternatively, amortization payments could be ignored and the sponsor would pay sponsor support as it becomes necessary. This would somewhat change the distribution of the burden over the various tax payer cohorts.

In variants 1 and 2 each individual has their own asset account (we keep track of the accounts at the cohort level):

$$\begin{aligned} A_0^{(N)DC,a} &= 0, \\ A_{t+1}^{(N)DC,a+1} &= A_t^{(N)DC,a} R_t + C_t^{(N)DC,a} \sqrt{R_t}, \end{aligned} \tag{4.29}$$

where $C_t^{(N)DC,a}$ is the total employer's and plan participants' contribution attributable to cohort of age a in time period t, and R_t is the investment return.

At retirement, the accumulated assets are converted into annuities and the asset account is depleted:

$$A_t^{a_R,(N)DC} = 0. \tag{4.30}$$

Aggregate assets over all accounts at each point in time are:

$$A_t^{(N)DC} = \sum_{a=25}^{a_R-1} A_t^{(N)DC,a}. \tag{4.31}$$

In variants 1ndc, 2ndc and 3ndc there are individual-specific *notional* asset accounts (pension entitlements), but the actual assets are in a collective pool, henceforth referred to as the buffer. The buffer evolves as follows:

$$\begin{aligned} A_0^{(N)DC} &= A_{init}^{(N)DC}, \\ A_{t+1}^{(N)DC} &= A_t^{(N)DC} R_t + (C_t^{(N)DC} - B_t^{(N)DC}) \sqrt{R_t}, \end{aligned} \tag{4.32}$$

where $B_t^{(N)DC}$ are the total benefits paid out to pensioners and $C_t^{(N)DC}$ are the total contributions received from the working cohorts in a given year:

$$\begin{aligned} B_t^{(N)DC} &= \sum_{a=[a_R,99]} B_t^{(N)DC,a}, \\ C_t^{(N)DC} &= \sum_{a=[25,a_R-1]} C_t^{(N)DC,a}. \end{aligned} \tag{4.33}$$

The initial assets are zero in variants 1ndc and 2ndc:

$$A_{init}^{(N)DC} = 0, \tag{4.34}$$

whereas in variant 3ndc they equal the assets of the DB plan in period 1 which are then transferred into the NDC buffer:

$$A_{init}^{(N)DC} = A_1^{DB}. \tag{4.35}$$

Accumulation of pension entitlements. The (N)DC individual entitlement account of a cohort a evolves as:

$$\begin{aligned} (N)DC_0^a &= (N)DC_{init}^a, \\ (N)DC_{t+1}^{a+1} &= (N)DC_t^a R_t^i + C_t^{(N)DC,a} \sqrt{R_t^i}, \end{aligned} \tag{4.36}$$

where the return on the entitlement account in the individual DC setup (variants 1 and 2) is equal to the investment portfolio return:

$$R_t^i = R_t, \tag{4.37}$$

while in the NDC setup (variants 1ndc, 2ndc and 3ndc) the individual entitlement account grows with NDC indexation:

$$R_t^i = ind_t^{NDC}. \tag{4.38}$$

Hence, in the DC plans of variants 1 and 2 the value of the assets is by definition equal to the value of the pension entitlements, i.e. the liabilities, and, hence, the funding ratio of DC plan always equals unity.

In all reform variants participants start accruing (N)DC pension entitlement from zero, hence:

$$(N)DC_{init}^a = 0, \tag{4.39}$$

but NDC plan within variant 3ndc contains the pension rights inherited from the DB system, as shown in (4.23). These pension rights do not grow with new accrual (it is accrued in individual notional accounts instead), but they are increased with NDC indexation. The existing participants in variant 3ndc therefore in effect have two accounts.

Pension payments. At retirement, in both DC and NDC systems the accrued assets are converted to an annuity for the remaining lifetime. The cohort benefits $B_t^{(N)DC,a_R}$ are determined as follows:

$$B_t^{(N)DC,a_R} = \frac{(N)DC_t^{a_R}}{f_t^{ann}}, \tag{4.40}$$

where f_t^{ann} is the annuity factor reflecting a unit payment starting at retirement and continuing while the person is alive. In the individual DC plan it is based on the nominal interest rate:

$$f_t^{ann} = \sum_{i=0}^{99-a_R} \left(R_t^{(i)}\right)^{-i} q_{a,t}^{\zeta,i}, \tag{4.41}$$

while in the NDC plan it is based on expected nominal wage growth:

$$f_t^{ann} = \sum_{i=0}^{99-a_R} (\bar{w}_t)^{-i} q_{a,t}^{\zeta,i}, \tag{4.42}$$

where $q_{a,t}^{\zeta,i}$ is the gender neutral survival probability, calculated as the average weighted by the gender shares of the gender-specific survival probabilities, because we assume that the annuities cannot be made gender specific. This does not have an effect on the final results since in our analysis we look at cohorts rather than individuals.

In the DC plan, the annuity remains constant in nominal terms over the retirement period,

$$B_{t+a-a_R}^{(N)DC,a} = B_t^{(N)DC,a_R}, \forall a > a_R, \tag{4.43}$$

while in the NDC plan it is annually adjusted with the system's wage sum growth combined with a balancing parameter if the funding situation of the plan is unsatisfactory:

$$\begin{aligned} B_{t+1}^{(N)DC,a+1} &= B_t^{(N)DC,a_R} ind_t^{NDC}, a = a_R, \\ B_{t+1}^{(N)DC,a+1} &= B_t^{(N)DC,a} ind_t^{NDC}, \forall a \in [a_R + 1, 99]. \end{aligned} \tag{4.44}$$

Here ind_t^{NDC} is the gross indexation rate of NDC benefits at time t.

NDC indexation. Like Auerbach and Lee (2011), we model our NDC pension plan alternatives following the example of the Swedish NDC pension system. However, we follow a more recent implementation of it as described in the Annual Report of the Swedish Pension System by the Swedish Pensions Agency (2016), which has an updated definition of the balancing mechanism that now involves smoothing of shocks.

The indexation is equal to the system's population's gross nominal wage growth α_t when the system is fully funded, and a fraction of it when the system is underfunded, so as to steer the fund towards a better funding situation. The specifics are explained in the remainder of this section.

Let us define α_t as the growth of the income index II_t:

$$\alpha_t = \frac{II_t}{II_{t-1}}. \tag{4.45}$$

Let b_t denote the balance ratio which reflects the financial outlook of the system. To avoid sudden substantial reductions in pension benefits and entitlements the balancing is smoothed out over time. The dampened balance ratio $\bar{b}_t$ is a smoothed version of the balance ratio b_t (described below in (4.51)), with one third of the shock in b_t reflecting in $\bar{b}_t$:

$$\bar{b}_t = \frac{b_t - 1}{3} + 1. \tag{4.46}$$

Note that we follow the Swedish system in choosing the value for the smoothing parameter, but in practice, depending on the system design, a different number could also be chosen. Once the balance ratio falls below 1, balancing mechanism is activated. The balancing index is then calculated as the income index adjusted for the dampened balance ratio:

$$BI_t = II_t\bar{b}_t, \tag{4.47}$$

which over time evolves as follows:

$$BI_{t+1} = BI_t\frac{II_{t+1}}{II_t}\bar{b}_{t+1} = II_{t+1}\bar{b}_t\bar{b}_{t+1}. \tag{4.48}$$

The balancing mechanism stops when the balancing index reaches the level of the income index again. We then define β_t as the change in the balancing index:

$$\beta_t = \frac{BI_t}{BI_{t-1}}. \tag{4.49}$$

The NDC indexation is then the change in balancing index if balancing mechanism is activated, and the change in the income index otherwise:

$$ind_t^{NDC} = \begin{cases} \beta_t & \text{if balancing activated,} \\ \alpha_t & \text{otherwise.} \end{cases} \tag{4.50}$$

The balance ratio b_t itself depends on the funding situation of the NDC system, defined as follows:

$$b_t = \frac{A_t^{(N)DC}}{\sum_{a=[25,a_R-1]}(N)DC_t^a + PVB_t^{(N)DC}}, \tag{4.51}$$

where the first term in the denominator denotes the sum of the entitlements of the current workers from the NDC scheme and $PVB_t^{(N)DC}$ is the present value of pensioners' benefits from the NDC scheme. The latter is calculated by discounting the pension payments with the discount rate $\tilde{R}_t^{(i)}$ which is equal to the expected wage growth, and summing the annuity values across male and female participants:

$$PVB_t^{(N)DC} = L_t^{(N)DC,m} + L_t^{(N)DC,f} = \sum_{a=a_R}^{99} \left(M_t^{(N)DC,a} L_t^{(N)DC,a,m} + F_t^{(N)DC,a} L_t^{(N)DC,a,f} \right),$$
$$L_t^{(N)DC,a,\zeta} = \sum_{i=0}^{99-a} \left(\tilde{R}_t^{(i)} \right)^{-i} q_{a,t}^{\zeta,i} B_t^{(N)DC,a}, \forall a \in [a_R, 99]. \tag{4.52}$$

Contributions. For a fair comparison among pension arrangements, we assume that the employer continues to pay the same normal cost contribution in all alternative arrangements. This means that the sum of employer's normal cost payments to the closed DB fund and the payments to the (N)DC part of the new arrangement is equal to the total normal cost paid by the employer in the baseline plan. This way we create a fair comparison among the variants and avoid underestimating the employer burden when DB plans are closed. Also politically, it may be hard for public sector employers to completely withdraw from their explicit or implicit obligations towards their employees.

We express the following formulas in dollar amounts instead of contribution rates because the wage bases differ between the DB and (N)DC arrangements. The total normal cost payment in the alternative plan arrangements is equal to the employer's contribution that is split between the DB and (N)DC plans, plus the plan participants' contribution:

$$C_t^{NC} = C_t^{E,DB} + C_t^{E,(N)DC} + C_t^{P}. \tag{4.53}$$

Since the total normal cost payment in all variants is assumed to be the same as in the baseline, the employer's contribution that goes to the (N)DC plan equals the normal cost contribution in the baseline minus the plan participants' contribution and the employer's contribution that goes to the closed DB plan:

$$C_t^{E,(N)DC} = C_t^{NC,baseline} - C_t^{P} - C_t^{E,DB}. \tag{4.54}$$

We thus assume that the normal cost payment by the employer and the plan participants remains the same, independent of which reform is chosen, and denote this amount by $C_t^{NC,baseline}$.

This guarantees unchanged treatment of the employer (at least as far as the normal cost is concerned, because amortization and sponsor support may differ across the variants), but not necessarily the participants. The reason is that the employer's only stake is the contribution, whereas the participants have both contributions and benefits on their balance sheet.

The (N)DC contribution amounts per cohort are defined as each cohort's wage sum times the normal cost rate:

$$C_t^{(N)DC,a} = \sum_{a=25}^{a_R-1} \left(NCR_{t-(a-25)}^{25,m} M_t^{DC,a} W_t^a + NCR_{t-(a-25)}^{25,f} F_t^{DC,a} W_t^a \right). \tag{4.55}$$

While in the DC components of variants 1 and 2 the sponsor completely transfers all risk to participants, in the NDC components of variants 1ndc, 2ndc and 3ndc the sponsor is still responsible for eventual deficits. Similarly to SS_t in the DB plan, the sponsor support payment $SS_t^{(N)DC}$ is the last resort payment that is needed if the plan runs out of money:

$$SS_t^{(N)DC} = \begin{cases} 0 & \text{if } A_t^{(N)DC} \geq B_t^{(N)DC} - C_t^{(N)DC}, \\ (B_t^{(N)DC} - C_t^{(N)DC}) - A_t & \text{if } A_t^{(N)DC} < B_t^{(N)DC} - C_t^{(N)DC}. \end{cases} \tag{4.56}$$

4.4 Results

We compare the different variants under identical economic scenarios. The scenario set covers many possible future developments of stock and bond markets, as well as economic variables, for 75 years ahead and is generated using a vector autoregression model as described in Lekniūtė et al. (2018). The model is calibrated on historical quarterly U.S. data of short-term interest rates, excess returns on stocks, consumer price inflation and real wage growth. The yield curve is defined as an affine term structure model.

4.4.1 Evaluation of the alternative variants

To analyze the differences between reform alternatives we calculate values for stakeholders – employer (tax payers) and plan participants – as well as the residual value of the fund, using risk-neutral valuation. It is not straightforward whether the residual value should be attributed to tax payers or plan participants, so in the tables we report the residual value separately. Because in the baseline variant the residual more naturally belongs to the tax payers given that they are the bearers of the residual risk due to the guaranteed nature of the benefits, for simplicity and ease of comparison in the plots of generational effects we attribute it to tax payers *in all variants*. The final residue of the system is attributed to the tax payer cohorts proportionally to the present value of projected lifetime income of each cohort.

Plan participants. Plan participants' stake in the scheme consists of two elements: the net benefit during the evaluation horizon and the pension liabilities at the end of the evaluation horizon, both explained below.

The first component of the plan participants' stake in the scheme is the lifetime net benefit that each cohort receives. The net benefit of cohort h at time t is denoted by $NB_t^{DB,h}$ for the DB component of the system and $NB_t^{(N)DC,h}$ for the (N)DC component of the system. h refers to the cohort's age at the beginning of the simulation and in our model varies from $25 - T + 1$ to 99, T being the simulation horizon. The net benefit is given by the difference between the benefits received and contributions paid (one of the two is zero at any moment in time):

$$\begin{aligned} NB_t^{DB,h} &= B_t^{DB,h} - C_t^{P,DB,h}, \\ NB_t^{(N)DC,h} &= B_t^{(N)DC,h} - C_t^{P,(N)DC,h}, \end{aligned} \tag{4.57}$$

where the first terms on the right-hand side are the benefits from the two plans. The total net benefit value for participants as a group is the sum of net benefit values for all cohorts over all time periods:

$$\begin{aligned} V_0^{NB,DB,h,t} &= \mathrm{E}_0^Q\left[\left(\prod_{q=1}^{4t-2}(Y_q)^{-1}\right)NB_t^{DB,h}\right], \\ V_0^{NB,(N)DC,h,t} &= \mathrm{E}_0^Q\left[\left(\prod_{q=1}^{4t-2}(Y_q)^{-1}\right)NB_t^{(N)DC,h}\right], \end{aligned} \tag{4.58}$$

$$V_0^{NB} = \sum_{h=25-T+1}^{99} \sum_{t=1}^{T} \left(V_0^{NB,DB,h,t} + V_0^{NB,(N)DC,h,t} \right). \tag{4.59}$$

For cohorts that are still alive at the end of the evaluation horizon, the pension rights accrued up till then are also of importance, as they reflect their expected payouts in the future years that fall outside of the analyzed horizon. The total participants' values per cohort, time and component are therefore the sum of net benefits and the liabilities remaining at the end of the evaluation horizon, and are defined as follows:

$$\begin{aligned}
V_0^{P,DB,h,t} &= V_0^{NB,DB,h,t}, \forall t < T, \\
V_0^{P,DB,h,T} &= V_0^{NB,DB,h,T} + \mathrm{E}_0^Q \left[\left(\prod_{q=1}^{4T-2} (Y_q)^{-1} \right) \tilde{L}_T^{DB,h} \right], \\
V_0^{P,(N)DC,h,t} &= V_0^{NB,(N)DC,h,t}, \forall t < T, \\
V_0^{P,(N)DC,h,T} &= V_0^{NB,(N)DC,h,T} + \mathrm{E}_0^Q \left[\left(\prod_{q=1}^{4T-2} (Y_q)^{-1} \right) \left((N)DC_T^h + P\tilde{V}B_T^{(N)DC,h} \right) \right].
\end{aligned} \tag{4.60}$$

The first equation of (4.60) shows that the values to plan participants in the DB plan in time periods during the simulation are equal to only the net benefit in the respective time period. The second equation shows that the value at the end of the horizon is equal to the value of the net benefit received in the last time period plus the value of the remaining promised pension payments, i.e., the DB liabilities $\tilde{L}_T^{DB,h}$ attributable to cohort h. These are calculated using the expected inflation developments implied by the state variables' dynamics and discounted against the nominal term structure. The third and fourth equations are analogous but concern the (N)DC component. Here the promised pension payments at the end of the horizon are represented as a sum of the (N)DC account value $(N)DC_T^h$ and the present value of the remaining (N)DC annuity payments $P\tilde{V}B_T^{(N)DC,h}$, the former being zero for the retirees and the latter for the working cohorts at the end of the simulation horizon. These are calculated analogously as in (4.52) but using the nominal term structure for discounting. In other words, the values at the end of the horizon include not only the actual payments but also the remaining accrued liabilities, expressed as account values for workers and annuity values for retirees.

The total cohort's value per component is the sum of cohort's values over time:

$$
\begin{aligned}
V_0^{P,DB,h} &= \sum_{t=1}^{T} V_0^{P,DB,h,t}, \\
V_0^{P,(N)DC,h} &= \sum_{t=1}^{T} V_0^{P,(N)DC,h,t}.
\end{aligned}
\tag{4.61}
$$

The benefits come from one or both parts of the system and thus the total participants' value is the sum of DB and (N)DC values:

$$
V_0^{P,h} = V_0^{P,DB,h} + V_0^{P,(N)DC,h}. \tag{4.62}
$$

The total market value for the plan participants' group as a whole is the sum of the values across the current and the future plan participant cohorts:

$$
V_0^{P} = \sum_{h=25-T+1}^{99} V_0^{P,h}. \tag{4.63}
$$

Tax payers. We define the total payments of the tax payers' cohort h as $V_0^{TP,DB,h}$ and $V_0^{TP,(N)DC,h}$ in the DB and (N)DC components of the pension scheme, respectively. These reflect the employer's total payments and the sponsor support:

$$
\begin{aligned}
V_0^{TP,DB,h} &= \mathrm{E}_0^{Q}\left[\sum_{t=1}^{T}\left(\prod_{q=1}^{4t-2}(Y_q)^{-1}\right)\left(C_t^{E,DB,h} + SS_t^{DB,h}\right)\right], \\
V_0^{TP,(N)DC,h} &= \mathrm{E}_0^{Q}\left[\sum_{t=1}^{T}\left(\prod_{q=1}^{4t-2}(Y_q)^{-1}\right)\left(C_t^{E,(N)DC,h} + SS_t^{(N)DC,h}\right)\right], \\
V_0^{TP} &= \sum_{h=25-T+1}^{99}\left(V_0^{TP,DB,h} + V_0^{TP,(N)DC,h}\right).
\end{aligned}
\tag{4.64}
$$

The first equation of (4.64) shows that the value of the tax payers' stake in the DB part of the arrangement is equal to the value of the total contribution payments (employer's share of normal cost and amortization payments made) plus the value of the sponsor support payments that are made to the DB plan, summed over time. The second equation is analogous to the first one but concerns the (N)DC part of the arrangement. The last equation demonstrates that the total tax payers' value is calculated by summing both the DB and the (N)DC stakes over cohorts.

Residual value. The residual value V_0^R is the value of the difference between the final assets and the remaining liabilities at the end of the evaluation horizon.

$$
\begin{aligned}
V_0^{R,DB} &= \mathrm{E}_0^Q\left[\prod_{q=1}^{4T-2}(Y_q)^{-1}(A_T-\tilde{L}_T)\right],\\
V_0^{R,(N)DC} &= \mathrm{E}_0^Q\left[\prod_{q=1}^{4T-2}(Y_q)^{-1}\left(A_T^{(N)DC}-\left(\sum_{a=[25,a_R-1]}(N)DC_T^a+PVB_T^{DC}\right)\right)\right],\\
V_0^R &= V_0^{R,DB}+V_0^{R,(N)DC}.
\end{aligned}
\tag{4.65}
$$

The first equation of (4.65) calculates the residual value of the DB component as the value of the difference between the final assets and the remaining liabilities of the DB plan. The second equation is analogous to the first one, but concerns the NDC system and therefore it is the value of the difference between the final buffer of the NDC system and its liabilities, calculated as a sum of notional account values of the working cohorts and the present values of the remaining promised annuities for pensioners. The total residue is the sum of the DB and (N)DC components.

The total tax payers' value V_0^T is calculated as the value of the total payments they have to make to keep the scheme afloat over the evaluation horizon (which is negative, because it is an outflow), plus the residual value of the scheme at the end of the evaluation horizon:

$$
\begin{aligned}
V_0^{T,DB} &= V_0^{TP,DB}+V_0^{R,DB},\\
V_0^{T,(N)DC} &= V_0^{TP,(N)DC}+V_0^{R,(N)DC},\\
V_0^T &= V_0^{T,DB}+V_0^{T,(N)DC}.
\end{aligned}
\tag{4.66}
$$

4.4.2 Results starting from the economy-wide funding situation

Our baseline results assume that the starting funding ratio of our fund is the median funding ratio among the public pension plans in the U.S.

4.4.2.1 Aggregate value-based results

Table 4.1 shows the total values per stakeholder under each of the reform variants.

Since the alternative variants are implemented in such a way that the employer pays the same normal cost independently of the arrangement, the differences in the total tax payer

Table 4.1: Total values for each variant

variant	V_0^{NB}	V_0^{R}	V_0^{TP}
0	14519	-3180	-8538
1	11288	-11	-8513
1ndc	10792	484	-8513
2	9311	0	-6547
2ndc	9174	147	-6548
3ndc	7664	-1155	-3664

Note: the table reports the total values (in billions of dollars) under variant 0 and alternative variants per stakeholder: V_0^{NB} is the net benefit aggregated over all participant cohorts, V_0^{R} is the final residue of the system and V_0^{TP} are the total tax payers' payments aggregated over all tax payer cohorts.

payments come from amortization and sponsor support payments that are made to the legacy DB system and the NDC system.

The aggregate tax payer payment (to both the DB and the (N)DC schemes) is the largest under the baseline plan variant 0, and decreases with the extent to which the DB plan is closed and new and/or existing liabilities are transferred to the (N)DC alternative.

Closing the DB system to new entrants has only a marginal lowering effect on the total sponsor contribution paid over the evaluation horizon of 75 years – it decreases from 8538 to 8513 billion. Less money comes in as sponsor amortization payments and more as sponsor support, because there are more scenarios where assets become depleted sooner. However, the reform does help to limit the costs in the future by preventing potential further underfunding. Whereas the residual value at the end of the horizon is a deficit of 3180 under the baseline variant 0, resulting from a large stock of outstanding liabilities at the end of the horizon against a small amount of remaining assets, the situation improves substantially in the new system. In the DB plan, even when new pension accrual is fully funded, the costs come due to the guaranteed nature of future pensions, as the risk of eventual future underfunding due to lower than expected returns falls on tax payers alone. Therefore transferring new entrants to alternative plans results in a lower value of future DB liabilities and consequently improves the residual situation in the DB fund.

Closing the plan not only to new participants but also to the new accrual of current participants decreases the sponsor amortization and support payments by an additional 1966 billion. Closing the DB system completely (incorporating the current rights within the NDC system, variant 3ndc) implies by far the largest step in terms of reducing the sponsor's contribution. The remaining expenditure of 3664 billion consists mostly of the normal cost payment, though some sponsor support is needed in the NDC plan too (and probably more would be needed in the coming years, given the negative residue of the system). The difference between this value and the values under the alternative plans indicates the magnitude of the cost of the sponsor's guarantee of the DB pension benefits. Obviously, a reduction in the costs of the sponsor is mirrored in a smaller net benefit of the participants. However, in this case it is also reflected in the negative final residue of the system, since the NDC buffer (initial DB assets) was used up to maintain stable indexation and only after it is depleted does indexation start to react to underfunding, so the underfunding problem is for a part shifted to the future.

Table 4.2 is a more detailed version of Table 4.1, where values are split into their underlying components. The net benefit column is split into benefits, contributions by employees, and outstanding final liabilities for both DB and (N)DC plans. The residue and sponsor contribution columns are split into DB and (N)DC components.

The total employees' contribution amount does not change across variants, but more of it goes into the (N)DC plan when more new pension rights are accrued there. The effects on the net benefit of participants under the alternative reform variants thus come from adjustments in paid out benefits and remaining pension rights. When new entrants are referred to the (N)DC plan under variants 1 and 1ndc, the value of the DB net benefits falls from 14056 to 10480 billion dollars. The lost DB benefits are replaced by pension payouts in the (N)DC system but the value of these makes up only for part of the loss of the DB net benefits as compared to variant 0. Variants 2 and 2ndc exhibit a similar pattern, but of a larger magnitude.

Participants in 3ndc variant gather benefits from two components that both exist in the NDC system. To distinguish between the two we report the benefits from the DB component under the V_0^B even though they are technically in the NDC system. In variant 3ndc participants gather slightly lower NDC benefits than those in 2ndc, which means that incorporating the legacy DB benefits into the NDC system puts a strain on the new system's financial situation and less indexation can be given as a result. The DB part is also somewhat less beneficial for the participants' group as a whole for the same reason.

The values of tax payers' payments also shift from DB to (N)DC with the increasing degree of closing the DB system. The shift is larger when the DB scheme is fully closed to new accrual than when it is only closed to the accrual of new participants. Tax payers' payments to the (N)DC part of the system under variants 1 and 1ndc are 1851 billion dollars and cover only the normal cost of the pension rights accrued by the new entrants to the system. No sponsor support payments are needed in case of 1ndc because the fund only has new entrants and thus collects contributions for a while before any benefits have to be paid out, therefore having positive cash inflows. Variants 2 and 2ndc feature a higher total tax payers' payment of 2827 and 2828 billion dollars, respectively, as they additionally have to cover the new accrual of current participants, as well as a tiny sponsor support contribution needed in variant 2ndc in some scenarios. Variant 3ndc sees a larger total tax payers' payment because a more substantial sponsor support payment is needed to cover the legacy DB pension rights, even with a lower adjusted indexation in the end.

The values of the terminal liabilities of the DB scheme drop to zero under each of the reform variants, because by the end of the horizon none of the participants existing at the moment of the reform are alive any more. The residual values in the DB parts of the reform variants drop to virtually zero, while there are minor positive residual values under the 1(ndc) and 2(ndc) plans. Plan 3ndc builds up a substantial negative residue but it is still a couple of times smaller than the one in the baseline. Incorporating the existing liabilities is a strain on the newly established NDC system because the buffer starts to be eaten up by the underfunded legacy pension rights, whereas indexation, while not guaranteed anymore, is slow to adapt because it first waits for the buffer to be depleted.

While the net benefit loss from the DB plan is only partially made up by net benefits in the new (N)DC system, the positive side of a reform is that the original large deficit of 3180 billion dollars at the end of the evaluation horizon substantially diminishes or even vanishes and is in fact replaced by a small end surplus in the new (N)DC schemes. Although this is not modelled, participants may benefit from the fact that they no longer have to rely on the sponsor's questionable willingness and ability to cover the plan's deficits through amortization payments and additional sponsor support as is the case in the original DB plan.

Table 4.2: Total values per component for each variant

variant	V_0^B	$V_0^{B^{(N)DC}}$	$V_0^{C^P}$	$V_0^{C^{P,(N)DC}}$	$V_0^{L_T}$	$V_0^{L_T^{(N)DC}}$	V_0^R	$V_0^{R^{(N)DC}}$	V_0^{TP}	$V_0^{TP^{(N)DC}}$
0	14056	0	-2737	0	3200	0	-3180	0	-8538	0
1	10480	2001	-1024	-1713	0	1545	1	-12	-6662	-1851
1ndc	10480	1756	-1024	-1713	0	1293	1	483	-6662	-1851
2	6549	3954	-45	-2692	0	1545	2	-1	-3720	-2827
2ndc	6549	4071	-45	-2692	0	1291	2	146	-3720	-2828
3ndc	5525	3645	-45	-2692	0	1231	0	-1155	-64	-3600

Note: the table reports by component the values (in billions of dollars) under variant 0 and the alternative variants. V_0^B and $V_0^{B^{(N)DC}}$ are the participant benefits from the DB and (N)DC plans, $V_0^{C^P}$ and $V_0^{C^{P,(N)DC}}$ the participant contributions, $V_0^{L_T}$ and $V_0^{L_T^{(N)DC}}$ the final liabilities, V_0^R and $V_0^{R^{(N)DC}}$ the residual values, and V_0^{TP} and $V_0^{TP^{(N)DC}}$ the total tax payers' payments under the DB and (N)DC systems, respectively.

4.4.2.2 Cohort value-based results

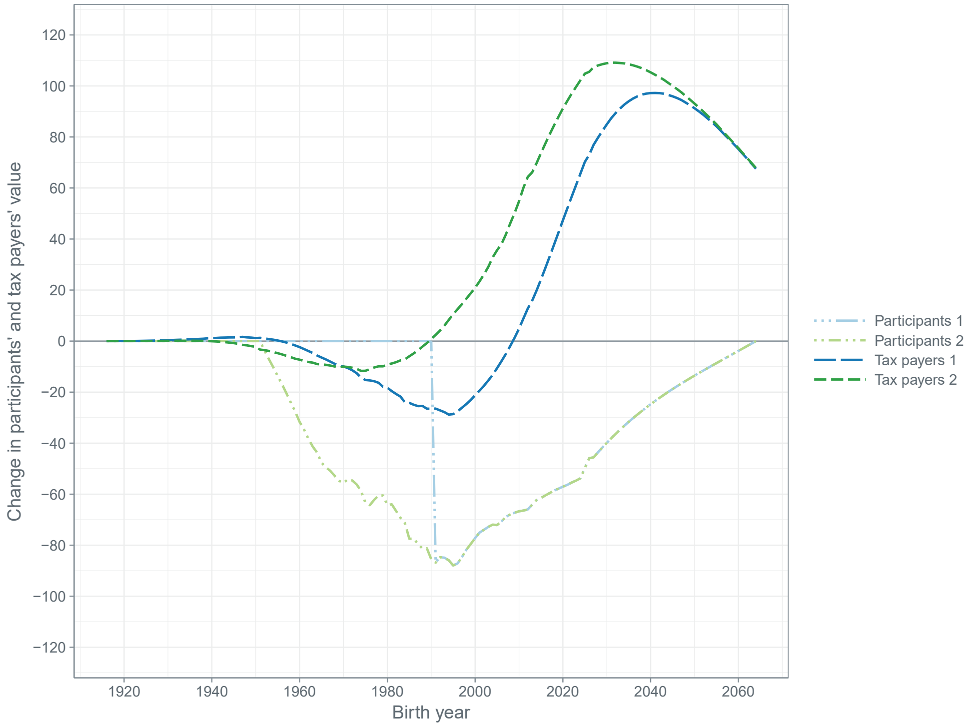
This subsection explores the effects of the reforms on the individual cohorts.

Figure 4.1 shows the changes in value for each cohort of tax payers and pension plan participants when the baseline system is transformed into the DC variants 1 and 2. Since tax payers are not the ultimate risk bearers in the DC arrangements anymore, and the normal cost payments are fixed across arrangements, the value changes show how much more or less tax payers contribute in terms of amortization payments and sponsor support in the closed DB plan as compared to the baseline DB plan. As we saw in the previous subsection, both variants improve the value of taxpayers as a group. However, there are substantial differences in the effects across cohorts, and between the two variants for a given cohort.

Under both new variants, there is an initial slight improvement in the tax payers' position due to the fact that amortization payments are calculated over a lower amount of liabilities. However, the effect on the tax payers' value quickly becomes negative, because sponsor support payments kick in much sooner than under the baseline, due to the fact that cash inflows from new contributions become smaller (variant 1) or vanish altogether (variant 2). Younger tax payers benefit down the road, because there are fewer liabilities left to be covered by sponsor payments. For the tax payers both reform variants exhibit the same qualitative pattern. However, the negative effect on tax payers' value kicks in sooner under variant 2, since contribution payments to the DB plan are completely terminated when DB plan is closed to all new accrual, hence the fund gets depleted faster than under variant 1, where contributions by the existing participants still continue. However, no new cashflows under variant 2 also means no new additional liabilities to cover, hence the value effect on tax payers also turns positive sooner than under variant 1. As we have seen, the aggregate improvement to the tax payers' value is also larger under variant 2. As far as the plan participants are concerned, under variant 1 all new cohorts face a negative value effect compared to variant 0, while all existing participants are unaffected. Under variant 2, all existing and new cohorts are negatively affected. Retired cohorts are not affected under either reform variant, since the two types of closing the DB plan only concern new accrual, while already accrued DB benefits are treated as a hard guarantee.

Figure 4.2 is analogous to Figure 4.1 but compares the NDC alternatives instead. Again, as seen in the aggregate results, the plot shows a clear improvement in value terms for the tax payers at the cost of the plan participants.

FIGURE 4.1: Value changes for DC variants 1 and 2

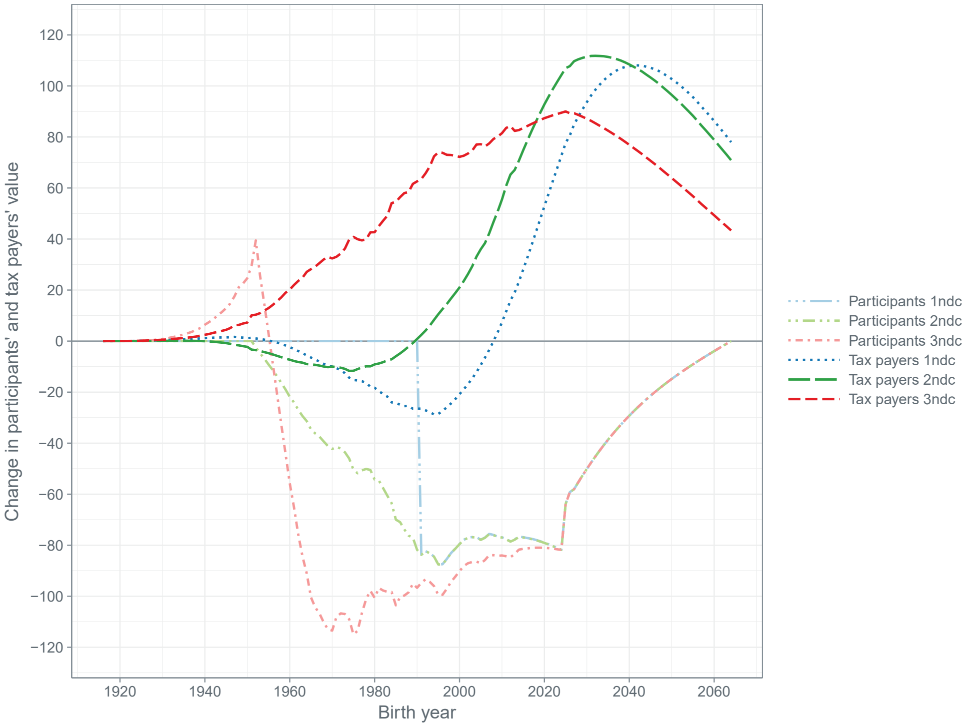


Note: this figure depicts by age cohort the change in the stakeholders' contract value (in billions of dollars) when arrangements are shifted from the baseline variant 0 under which the original DB plan is continued, to alternative variants in which the DB plan is replaced by a DC plan for new entrants to the system (variant 1) and for all new accrual by both new entrants and current participants (variant 2).

All participants can be grouped into four categories: current pensioners, current workers that have already accrued entitlements in the DB system, new entrants that reach the retirement age before the end of the evaluation horizon and new entrants that are still working by the end of the evaluation horizon.

Variant 1ndc only affects new participants. The existing participants stay in the DB plan under the same treatment. Variant 2ndc affects also the existing workers, and the extent to which they are affected varies according to the fraction of lifetime accrual already completed in the DB plan. Older active participants lose less, because they have accrued more – protected – pension entitlements. Variant 3ndc affects both the retired and active participants. The only way the retirees – who do not accrue new pension rights anymore – are affected is via the indexation of their existing DB rights that now live inside the NDC

Figure 4.2: Value changes in NDC variants



Note: this figure depicts by age cohort the change in the stakeholders' contract value (in billions of dollars) when policy is changed from the baseline variant 0 (continuing the DB plan) to alternative arrangements where the DB plan is replaced by an NDC plan for new entrants to the system (variant 1ndc), for all new accrual by both new entrants and current participants (variant 2ndc) and when for all participants the DB plan is transformed into an NDC plan with all accumulated assets transferred from the DB plan to the NDC plan (variant 3ndc).

scheme. They lose the guaranteed nature of DB indexation but are now indexed with the growth of the total wage sum. Pensioners experiencing a positive value change means that the latter effect is dominant. The NDC buffer inherited from the DB system makes sure that indexation can be given rather easily, at least in the beginning. The younger existing active participants experience a negative value shift since they essentially move from a guaranteed final salary system to an average salary system. The older active participants fall in between and their final result depends on how the balance plays out between the two effects playing a role.

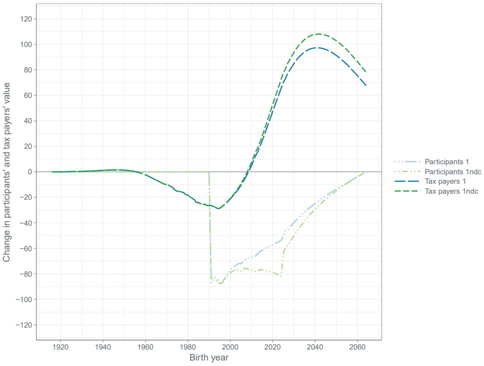
The effects on the new entrants to the system are similar in all NDC variants. There is a minuscule difference in indexation received between plans 1ndc and 2ndc because they both can easily give indexation before they mature. Indexation is significantly lower in plan 3ndc that suffers from having to absorb the legacy DB pension rights. However, the major system change from final salary DB to average salary NDC is a dominant factor in the value loss for these cohorts. This also holds for the new entrants who do not reach the retirement before the end of the evaluation horizon.

Aggregate tax payers' value is positively affected under all three schemes. However, the effects vary across cohorts. Under the 1ndc and 2ndc variants initial tax payer cohorts benefit marginally due to the lower amortization payments, which are calculated over a smaller amount of liabilities. However, since there are fewer (or no) contributions coming into the fund, the tax payers soon start losing when they have to pay more in terms of sponsor support payments. The reason is that the lack of new contribution inflows tends to lead to a faster depletion of assets. The effect of the reform becomes positive for later cohorts, since by then the participant base in the legacy DB scheme and thus the liabilities attributed to them are smaller than under the baseline, which leads to lower sponsor support payments. Under variant 3ndc all tax payer cohorts benefit, since they no longer have to provide amortization and sponsor support payments in the DB plan (even though they do eventually pay some sponsor support in the NDC plan). When compared to 1ndc or 2ndc, the initial cohorts are better off, but the future cohorts benefit less in 3ndc. That is because converting a funded system to a virtually pay-as-you-go system with a buffer allows to pay less (or none) sponsor support in the beginning but more underfunding is shifted to the future. It is still a substantial improvement as compared to the baseline plan.

Figures 4.3 and 4.4 contain the same information as Figures 4.1 and 4.2 but they have been rearranged to facilitate the outcomes for the DC and NDC counterparts. Taxpayers as a group would be nearly indifferent choosing between plans 1 and 1ndc or 2 and 2ndc. There are of course generational differences but they come mostly due to the fact that the DB plan is closed and not that much due to the way the new plan is implemented. From participant's perspective, there is also not a big difference between DC and NDC plans. The effects differ slightly depending how DC returns and NDC indexation play out, but the major effect comes from the new system being an average wage system without a guaranteed indexation.

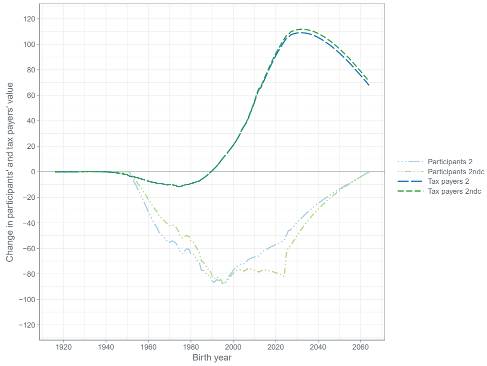
All in all, the future cohorts face a substantial deterioration in their pension rights under all of the alternative systems analysed. However, this conclusion only holds under the assumption that the promises made in the current system would be fulfilled by the tax payers. We have seen multiple examples where that did not happen when states or counties

FIGURE 4.3: Value changes in variants with no new DB entrants



Note: this figure depicts by age cohort the change in the stakeholders' contract value (in billions of dollars) when policy is changed from the baseline variant 0 (continuing DB plan for all new accrual) to alternative arrangements in which the DB plan is replaced by a DC plan (variant 1) or an NDC plan (variant 1ndc) for new entrants to the system.

FIGURE 4.4: Value changes in variants with no new DB accrual



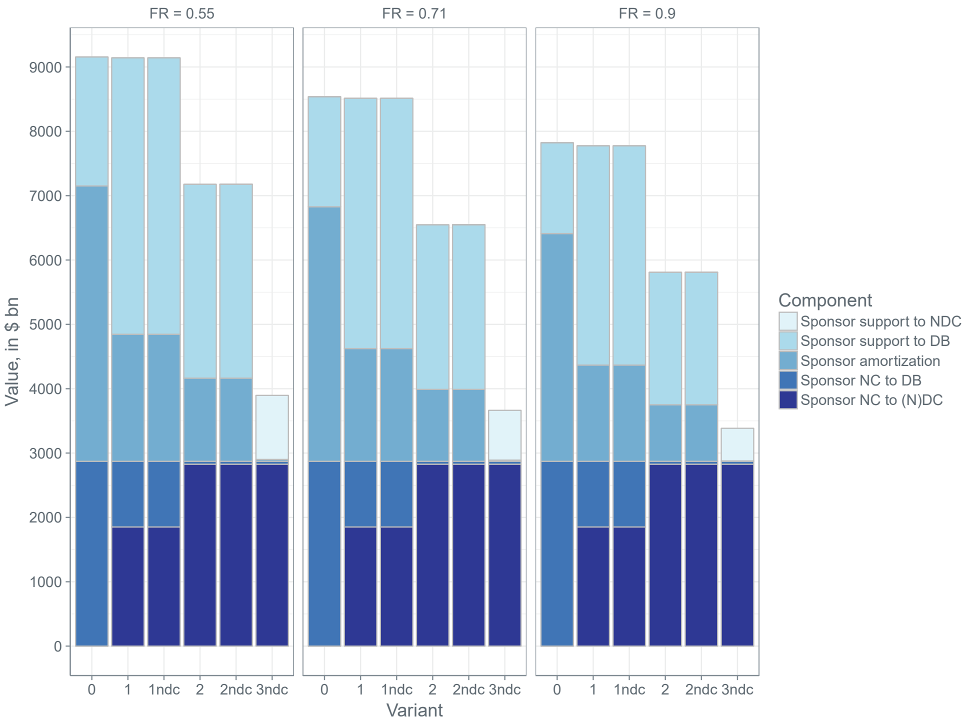
Note: this figure depicts by age cohort the change in the stakeholders' contract value (in billions of dollars) when policy is changed from the baseline variant 0 (continuing the DB plan for all new accrual) to alternative arrangements in which the DB plan is replaced by a DC plan (variant 2) or an NDC plan (variant 2ndc) for all new accrual.

got into trouble. In that light, the alternative systems are at least more transparent form participant's perspective and do not contain hidden risks of unexpected pension cuts. From the perspective of tax payers, these systems are more future-proof and avoid sudden budgetary pressure.

4.4.3 Sensitivity analysis based on initial funding situation

Because states with pension plans that are the most underfunded might have the strongest incentives to reform their pension plan (and in particular to close their DB plans), it is of interest to investigate how our results are affected if we no longer start from the median funding situation, but vary the initial funding ratio of the DB system. In this subsection, we will report the results for reforms based on an initial DB funding situation at the 10th, 50th and 90th percentile of the empirical sample of pension funds. To ensure comparability, we assume that the demography is held constant across the cases; in each case the pension plan represents the entire civil servants' population. Also for comparability, we keep the normal cost contributions identical across the funding situations. Hence, the degree of underfunding only affects the amortization and sponsor support payments.

FIGURE 4.5: Sponsor values (10th, 50th and 90th percentiles of funding ratio)



Note: The figure shows the sponsor's values for different starting funding ratio levels (55% (10th percentile), 71%(median) and 90%(90th percentile)) per component: sponsor's contribution to the (N)DC plan, sponsor's normal cost payment to the DB plan, and sponsor's amortization and support payments to the DB plan.

Figure 4.5 contains three facets based on different initial funding situations of the pension system. The results in the left panel are calculated assuming an initial funding ratio of 55% (10th percentile in our sample of pension plans), the middle one summarizes the results discussed in the previous section, and the right panel assumes an initial funding ratio of 90% (90th percentile).

Whereas the normal cost payments can be viewed as a fixed cost of the system, the size of the variable payments (sponsor amortization and sponsor support) are influenced by different underfunding levels. The value of total amortization payments decreases with the degree of closing the system. This is because it is partially replaced by the sponsor support payments as the DB fund runs out of money faster without new contributions coming in. The total variable payments decrease only slightly when moving from baseline to variants 1 and 1ndc, meaning that new entrants to the system do not contribute much to the underfunding problem. The payments to cover underfunding can be reduced much more when the system is transformed to variant 2 or 2ndc, under which accrual of new DB liabilities is completely terminated at the moment of the reform. Amortization and support payments also decrease with increasing initial funding ratio of the DB plan, as a better initial funding situation lowers the risk of significant future underfunding. In variant 3ndc the sponsor support and amortization payments of the DB system are now replaced by sponsor support to the NDC system, which is much lower in magnitude since the NDC benefits are automatically adjusted when the system faces financial pressure (though not fast enough, therefore still the need for sponsor support). These payments also decrease in size with increasing initial funding situation, since the initial DB assets become the buffer of the NDC system which curbs the need for additional sponsor's support. After all, most of the underfunding risk is transferred to the pool of participants.

The figure also shows the effect of reforms on a macro level for the U.S. For an initial funding ratio equal to the current median of 71% the total sponsor contribution is around 8500 billions under variants 0, 1 and 1ndc, 6500 billions under variants 2 and 2ndc, and 3700 under variant 3ndc. However, if reform were delayed and the macro funding ratio decreases to 55%, the respective sponsor contributions rise to 9200, 7200 and 3900 billion dollars. On the contrary, if the macro funding ratio improves to 90%, the respective sponsor contributions shrink to 7800 and 5800 and 3400 billion dollars.

As an alternative to interpreting this figure as a total system cost to the tax payers under different hypothetical funding situations, one can use it to evaluate the differences in the reform effects across individual pension plans that face varying degrees of underfunding at the moment. In that case only relative differences across panels are of relevance, because the dollar amounts of sponsor cost would be driven by the size of the individual fund.

4.5 Concluding remarks

The current U.S. state pension system is a system with hard guarantees and also substantially underfunded. This is not a sustainable situation and tough political decisions are needed to make the system future-proof. These could be parametric reforms that only change the system gradually but generally have little effect, or more potent system makeovers that convert the current rigid system into a more flexible system meant to withstand future shocks. This paper concerns the later choice, and in particular the options of starting new DC and NDC schemes, while closing the existing DB system partially or completely.

All the reform alternatives considered in this paper lower the value for the participant cohorts. Tax payers as a group benefit from each reform, and more so, if the DB plan is closed to all new accrual and if it is fully transformed into an NDC scheme with all existing assets going over. However, there are some tax payer cohorts that are hurt by a reform, and the specific design of the reform determines by how much. The distribution of the tax payer cohort effects depends on the intertemporal allocation of the amortization and sponsor support payments. Amortization payments only cover a share of the deficit each year. However, if the assets are completely depleted and benefit outflows exceed contribution inflows, the complete deficit has to be covered from sponsor support. Hence, the tax payer burden is smoothed over time when there are assets remaining in the fund, while it becomes relatively high once the assets are depleted. The tax payer benefit comes at the cost of plan participants who have to bear more risks in the alternative systems.

The analysis here is by no means meant as an exhaustive list of reform options. There are countless ways to proceed with reforming the current system and even within a single chosen framework the final effects might vary based on the system parameters selected. The study is rather meant as an illustration of how such decisions affect different generations of stakeholders.

No matter which way of proceeding is chosen, the implicit debt in the current system has to be addressed sooner or later. Some stakeholders will have to pay for it, be it the taxpayers, if benefits continue to be viewed as hard guarantees, or the plan participants, if a switch is made to systems that put the burden of risks on the shoulders of plan participants, or both, in case of a compromise in which both parties assume some risk.

It is up to policymakers to decide which approach is fair. We present a tool that brings insights into intergenerational transfers and transfers between plan participants and tax payers in value terms. This is only one part of the total picture. The insights on value transfers should always be used in combination with other considerations, such as whether the new system is utility improving for participants in terms of benefit transferability, whether it does not create adverse labor market incentives, and if it is future-proof in terms of how it absorbs market and longevity shocks. Nevertheless, it is a useful tool in the toolbox of policymakers that can help to make better informed decisions.

Bibliography

AISEN, A. AND D. HAUNER (2013): "Budget Deficits and Interest Rates: a Fresh Perspective," *Applied Economics*, 45, 2501–10.

ALLIANCE BERNSTEIN (2010): "Municipal Market Update: State and Local Governments Face Difficult Decisions," https://www.alliancebernstein.com/abcom/Perspectives_Web/Current/PrivateClient/MuniMarketUpdate_June2010/MuniMarketUpdate_July2010i.pdf.

ALT, J., D. LASSEN, AND S. ROSE (2006): "The Causes of Fiscal Transparency: Evidence from the American States," *IMF Staff Papers*, 53, Special Issue, 30–57.

ALT, J., D. D. LASSEN, AND J. WEHNER (2014): "It isn't just about Greece: Domestic Politics, Transparency and Fiscal Gimmickry in Europe," *British Journal of Political Science*, 44(4), 707–716.

ALT, J. E. AND D. D. LASSEN (2006): "Fiscal transparency, political parties, and debt in OECD countries," *European Economic Review*, 50, 1403–39.

ANDONOV, A., R. BAUER, AND M. CREMERS (2017): "Pension Fund Asset Allocation and Liability Discount Rates," *Review of Financial Studies*, 30, 2555–2595.

ANDONOV, A., Y. V. HOCHBERG, AND J. D. RAUH (2018): "Political Representation and Governance: Evidence from the Investment Decisions of Public Pension Funds," *The Journal of Finance*, 73, 2041–2086.

ANG, A., G. BEKAERT, AND M. WEI (2008): "The Term Structure of Real Rates and Expected Inflation," *The Journal of Finance*, 63(2), 797–849.

ANG, A. AND M. PIAZZESI (2003): "A No-Arbitrage Vector Autoregression of Term Structure Dynamics with Macroeconomic and Latent Variables," *Journal of Monetary Economics*, 50(4), 745–787.

Ardagna, S., F. Caselli, and T. Lane (2007): "Fiscal Discipline and the Cost of Public Debt Service," *The B.E. Journal of Macroeconomics*, 7 (1), 1–35.

Aubry, J.-P. and C. V. Crawford (2017): "State and Local Pension Reform Since the Financial Crisis," Tech. Rep. 54, Center for Retirement Research at Boston College.

Aubry, J.-P., C. V. Crawford, and A. H. Munnell (2017): "How Have Municipal Bond Markets Reacted to Pension Reform?" Tech. Rep. 57, Center for Retirement Research at Boston College.

Auerbach, A. and R. Lee (2011): "Welfare and generational equity in sustainable unfunded pension systems," *Journal of Public Economics*, 95, 16–27.

Bader, L. and J. Gold (2003): "Reinventing Pension Actuarial Science," *The Pension Forum*, 15.

——— (2007): "The Case against Stock in Public Pension Funds," *Financial Analysts Journal*, 63, 55–62.

Baldacci, E. and M. Kumar (2010): "Fiscal Deficits, Public Debt, and Sovereign Bond Yields," *IMF Working Papers*, 10, available at SSRN: http://ssrn.com/abstract=1669865.

Barclays (2017): "Aggregate/Bond Indices," https://live.barcap.com; retrieved: August 20, 2017.

Beetsma, R. and A. Bucciol (2010): "Inter- and Intra-Generational Consequences of Pension Buffer Policy under Demographic, Financial and Economic Shocks," *CESifo Economic Studies*, 56(3), 366–403.

——— (2011a): "Consequences for Welfare and Pension Buffers under Alternative Methods of Discounting Future Pensions," *Journal of Pension Economics and Finance*, 10(3), 389–415.

——— (2011b): "Differentiating Indexation in Dutch Pension Funds," *De Economist*, 159(3), 323–360.

Beetsma, R., M. Giuliodori, F. de Jong, and D. Widijanto (2013): "Spread the news: the impact of news on the European sovereign bond markets during the crisis," *Journal of International Money and Finance*, 34, 83–101.

Beetsma, R., M. Giuliodori, and I. Sakalauskaite (2017): "Long-term Interest Rates and Public Debt Maturity," *Economica*, 84, 541–558.

BHANOT, K., N. BURNS, D. HUNTER, AND M. WILLIAMS (2014): "News spillovers from the greek debt crisis: impact on the Eurozone financial sector," *Journal of Banking & Finance*, 38, 51–63.

BIGGS, A. G. (2010): "An Options Pricing Method for Calculating the Market Price of Public Sector Pension Liabilities," American Enterprise Institute Working Paper 164.

BLACK, F. (1989): "Should You Use Stocks to Hedge Your Pension Liability?" *Financial Analysts Journal*, 10–12.

BLACK, F. AND M. SCHOLES (1973): "The Pricing of Options and Corporate Liabilities," *Journal of Political Economy*, 81, 637–654.

BLAKE, D. (1998): "Pension Schemes as Options on Pension Fund Assets: Implications for Pension Fund Management," *Insurance: Mathematics and Economics*, 23, 263–286.

BOARD OF GOVERNORS OF THE FEDERAL RESERVE SYSTEM (2015): "3-Month Treasury Bill: Secondary Market Rate," `https://research.stlouisfed.org/fred2/series/TB3MS/`.

BOHN, H. (2011): "Should Public Retirement Plans Be Fully Funded?" *Journal of Pension Economics and Finance*, 10 (02), 195–219.

BOHN, H. AND R. P. INMAN (1996): "Balanced-budget rules and public deficits: evidence from the U.S. states," *Carnegie-Rochester Conference Series on Public Policy*, 13–76.

BOMEY, N. AND A. PRIDDLE (2013): "Detroit Bankruptcy Judge to Issue Ruling Dec. 3," *USA Today*.

BÖRSCH-SUPAN, A. (2004): "From Traditional DB to Notional DC Systems: Reframing PAYG Contributions to "notional savings"," *Annual Meeting of the European Economic Association*.

BRAINARD, K. AND A. BROWN (2018): "Spotlight on Significant Reforms to State Retirement Systems," *National Association of State Retirement Administrators*.

BROADBENT, J., M. PALUMBO, AND E. WOODMAN (2006): "The Shift from Defined Benefit to Defined Contribution Pension Plans - Implications for Asset Allocation and Risk Management," *Working Group on Institutional Investors, Global Savings and Asset Allocation established by the Committee on the Global Financial System*.

Brown, J. and G. Pennacchi (2015): "Discounting Pension Liabilities: Funding Versus Value," *National Bureau of Economic Research Working Paper*, 21276.

Brown, J. and D. Wilcox (2009): "Discounting State and Local Pension Liabilities," *American Economic Review*, 99(2), 538–542.

Brown, J. R., R. Clark, and J. D. Rauh (2011): "The Economics of State and Local Pensions," *Journal of Pension Economics and Finance*, 10(2), 161–172.

Bucciol, A. (2012): "Measuring Self-Control Problems: A Structural Estimation," *Journal of the European Economic Association*, 10, 1084–1115.

Bureau of Labor Statistics (2015): "The Consumer Price Index," `http://download.bls.gov/pub/time.series/cu/cu.data.0.Current`.

Campbell, J. Y., A. W. Lo, and A. C. MacKinlay (1996): *The Econometrics of Financial Markets*, Princeton University Press.

Center for Research in Security Prices (2015): "Stock, Portfolio and Index Returns," `https://wrds-sol1.wharton.upenn.edu/output/9baf5375c0e82afc.html?`

Center for Retirement Research at Boston College (2015): "Public Plans Database," `http://publicplansdata.org/public-plans-database/download-full-data-set/`.

——— (2018): "Public Plans Database," `http://publicplansdata.org/public-plans-database/download-full-data-set/`.

Chantrill, C. (2018): "US Government Spending," `"https://www.usgovernmentrevenue.com/compare_state_revenue_2016bH0a"`; retrieved November 30, 2018.

Chapman, R., T. Gordon, and C. Speed (2001): "Pensions, Funding and Risk," *British Actuarial Journal*, 7, 605–662.

CPB Netherlands Bureau for Economic Policy Analysis (2012): "Generatie-Effecten Pensioenakkoord - Op Verzoek van het Ministerie van Sociale Zaken en Werkgelegenheid," `http://www.cpb.nl/sites/default/files/publicaties/download/cpb-notitie-30mei2012-generatie-effecten-pensioenakkoord.pdf`.

Dai, Q. and K. J. Singleton (2000): "Specification Analysis of Affine Term Structure Models," *The Journal of Finance*, 55(5), 1943–1978.

D'Arcy, S. P., J. H. Dulebohn, and P. Oh (1999): "Optimal Funding of State Employee Pension Systems," *The Journal of Risk and Insurance*, 66(3), 345–380.

Elder, E. M. and G. A. Wagner (2015): "Political Effects on Pension Underfunding," *Econ Polit*, 27, 1–27.

Exley, C. J., S. J. B. Mehta, and A. D. Smith (1997): "The Financial Theory of Defined Benefit Schemes," *British Actuarial Journal*, 4, 835–966.

Federal Reserve Bank of Philadelphia (2015): "Survey of Professional Forecasters," `https://www.philadelphiafed.org/research-and-data/real-time-center/survey-of-professional-forecasters/data-files`.

Federal Reserve Board (2015): "The U.S. Treasury Yield Curve," `http://www.federalreserve.gov/pubs/feds/2006/200628/200628abs.html`.

Grishchenko, O. V. and J. Huang (2012): "Inflation Risk Premium: Evidence from the TIPS market," *Finance and Economics Discussion Series, Divisions of Research & Statistics and Monetary Affairs, Federal Reserve Board, Washington, D.C.*, `http://www.federalreserve.gov/pubs/feds/2012/201206/201206pap.pdf`.

Hastie, K. L. (1972): "Determinants of Municipal Bond Yields," *The Journal of Financial and Quantitative Analysis*, 7, 1729–1748.

Hoevenaars, R. and E. Ponds (2008): "Valuation of Intergenerational Transfers in Funded Collective Pension Schemes," *Insurance: Mathematics and Economics*, 42, 578 – 593.

Holzmann, R. (2017): "The ABCs of Nonfinancial Defined Contribution (NDC) Schemes," *IZA Policy Paper No. 130*.

Jin, L., R. Merton, and Z. Bodie (2006): "Do a firm's equity returns reflect the risk of its pension plan?" *Journal of Financial Economics*, 81, 1–26.

Kelley, D. G. (2014): "The Polical Economy of Unfunded Public Pension Liabilities," *Public Choice*, 158, 21–38.

Kim, D. (2009): "Challenges in Macro-Finance Modeling," *Federal Reserve Bank of St. Louis Review*, 91, 519 – 544.

Le, A., K. J. Singleton, and Q. Dai (2010): "Discrete-Time Affine Term Structure Models with Generalized Market Prices of Risk," *Review of Financial Studies*, 23, 2184–2227.

Lekniūtė, Z., R. Beetsma, and E. Ponds (2018): "A value-based assessment of alternative US state pension plans," *Journal of Pension Economics and Finance*, 17(2), 129–169.

——— (2019): "U.S. municipal yields and unfunded state pension liabilities," *Journal of Empirical Finance*, 53, 15 – 32.

Lucas, D. and S. Zeldes (2009): "How Should Public Pension Plans Invest?" *American Economic Review: Papers and Proceedings*, 99(2), 527–532.

Mitchel, O. S. and R. S. Smith (1994): "Pension Funding in the Public Sector," *Review of Economics and Statistics*, 76(5), 278–290.

Mohl, P. and D. Sondermann (2013): "Has political communication during the crisis impacted sovereign bond spreads in the euro area?" *Applied Economics Letters*, 20, 48–61.

Monahan, A. (2012): "Public Pension Plan Reform: The Legal Framework," *Legal Studies Research Paper Series*, 10-13.

Monfort, A. and J.-P. Renne (2014): "Decomposing euro-area sovereign spreads: credit and liquidity risks," *Review of Finance*, 18, 2103–2151.

Munnell, A. H., J.-P. Aubry, and M. Cafarelli (2014a): "Cola Cuts in State/Local Pensions," Tech. Rep. 38, Center for Retirement Research at Boston College.

——— (2014b): "Defined Contribution Plans in the Public Sector: An Update," Tech. Rep. 27, CRR Issue in Brief.

——— (2014c): "The Funding of State and Local Pensions: 2013-2017," Tech. Rep. 39, Center for Retirement Research at Boston College.

Munnell, A. H., J.-P. Aubry, J. Hurwitz, and M. Medenica (2013): "The Funding of State and Local Pensions: 2012-2016," Tech. Rep. 32, Center for Retirement Research.

Munnell, A. H., J.-P. Aubry, J. Hurwitz, and L. Quinby (2012): "The Impact of Long Vesting Periods on State and Local Workers," Tech. Rep. 26, Center for Retirement Research at Boston College.

Munnell, A. H., K. Haverstick, J.-P. Aubry, and A. Golub-Sass (2008a): "Why Don't Some States and Localities Pay their Required Pension Contributions," Tech. Rep. 7, Center for Retirement Research at Boston College.

Munnell, A. H., K. Haverstick, S. Sass, and J.-P. Aubry (2008b): "The Miracle of Funding by State and Local Pension Plans," Tech. Rep. 5, Center for Retirement Research at Boston College.

Munnell, A. H., W. Hou, A. Webb, and Y. Li (2017): "How Has the Shift to 401k Plans Affected Retirement Income," Tech. rep., Center for Retirement Research at Boston College.

Munnell, A. H. and L. Quinby (2012): "Legal Constraints on Changes in State and Local Pensions," Tech. Rep. 25, Center for Retirement Research at Boston College.

Novy-Marx, R. and J. D. Rauh (2009): "The Liabilities and Risks of State Sponsored Pension Plans," *Journal of Economic Perspectives*, 23, 191–210.

——— (2011): "Pension Promises: How Big Are They and What Are They Worth?" *Journal of Finance*, 66(4), 1207–1245.

——— (2012): "Fiscal Imbalances and Borrowing Costs: Evidence from State Investment Losses," *American Economic Journal: Economic Policy*, 4(2), 182–213.

——— (2014a): "Linking Benefits to Investment Performance in US Public Pension Systems," *Journal of Public Economics*.

——— (2014b): "The Revenue Demands of Public Employee Pension Promises," *American Economic Journal: Economic Policy*, 6(1), 193–229.

OECD (2011): *Pensions at a Glance 2011: Retirement-income Systems in OECD and G20 Countries*, OECD Publishing, Paris.

Palmer, E. (2000): "The Swedish pension reform model: framework and issues," *Social Protection discussion paper. The World Bank.*, SP 0012.

Pennacchi, G. and M. Rastad (2011): "Portfolio Allocations for Public Pension Funds," *Journal of Pension Economics and Finance*, 10(2), 221–245.

Peskin, M. (2001): *Pensions in the Public Sector*, University of Pennsylvania Press, chap. Asset-Liability Management in the Public Sector.

PEW (2016): "State Retiree Health Care Liabilities," Tech. rep., The Pew Charitable Trusts.

PLATANAKIS, E. AND C. SUTCLIFFE (2015): "Pension Scheme Redesign and Wealth Redistribution Between the Members and Sponsor: The USS Rule Change in October 2011," Working paper.

POGHOSYAN, T. (2014): "Long-run and short-run determinants of sovereign bond yields in advanced economies," *Economic Systems*, 38, 100–114.

PONDS, E., C. SEVERINSON, AND J. YERMO (2011): "Funding in Public Sector Pension Plans - International Evidence," Working Paper 17082, National Bureau of Economic Research.

PONDS, E. H. AND B. VAN RIEL (2009): "Sharing Risk: the Netherlands' New Approach to Pensions," *Journal of Pension Economics and Finance*, 8 (1), 91–105.

PONDS, E. H. M. (2003): "Pension Funds and Value-Based Generational Accounting," *Journal of Pension Economics and Finance*, 2, 295–325.

PONDS, E. H. M. AND Z. LEKNIŪTĖ (2011): "Pensioenakkoord en Effecten voor Generaties," *Netspar Discussion Paper*.

RAUH, J. D. (2016): "Hidden Debt, Hidden Deficits: How Pension Promises are Consuming State and Local Budgets." *A Hoover Institution Essay*, April 11.

RECK, J. L. AND E. R. WILSON (2006): "Information Transparency and Pricing in the Municipal Bond Secondary Market," *Journal of Accounting and Public Policy*, 1–31.

SANTIS, R. A. D. (2014): "The euro area sovereign debt crisis: identifying flight-to-liquidity and the spillover mechanisms," *Journal of Empirical Finance*, 26, 150–170.

SCHIEBER, S. J. (2011): "Political Economy of Public Sector Retirement Plans," *Journal of Pension Economics and Finance*, 10(2), 269–290.

SEIDER, M. A. AND B. L. WILLIAMSON (2005): "Pension and OPEB Obligations in U.S. Bankruptcies: Answers to the Most Frequently Asked Questions," Tech. rep., Latham & Watkins.

SHARPE, W. (1976): "Corporate Pension Funding Policy," *Journal of Financial Economics*, 3, 183–193.

SHARPE, W. F. AND J. L. TREYNOR (1977): "The Principles of Corporate Pension Finance," *The Journal of Finance*, 32, 627–638.

Shnitser, N. (2013): "Funding Discipline for U.S. Public Pension Plans: An Empirical Analysis of Institutional Design," *mimeo, Yale University.*

Social Security Administration (2014): "Life Tables for the United States Social Security Area 1900-2100," `http://www.socialsecurity.gov/OACT/NOTES/as120/LifeTables_Tbl_7.html`.

Swedish Pensions Agency (2016): "Orange Report: Annual Report of the Swedish Pension System," Tech. rep., Swedish Pensions Agency.

United States Census Bureau (2014): "National Population Estimates for the 2010s," `https://www.census.gov/popest/data/national/asrh/2012/files/NC-EST2012-ALLDATA-R-File01.csv`.

US. Bureau of Economic Analysis (2015): "Compensation of Employees: Wages and Salary Accruals," `https://research.stlouisfed.org/fred2/series/WASCUR/`.

U.S. Bureau of the Census (2006): "Government Finance and Employment: Classification Manual," .

US Department of the Treasury (2015): "Daily Treasury Real Yield Curve Rates," `https://www.treasury.gov/resource-center/data-chart-center/interest-rates/Pages/TextView.aspx?data=realyieldAll`.

Nederlandse Samenvatting (Summary in Dutch)

In de Verenigde Staten zijn de pensioenen voor werknemers in de publieke sector per staat georganiseerd. De financiering is op basis van kapitaaldekking. Bijna alle fondsen kennen een systeem van pensioentoezegging (defined benefit), met opbouw volgens een eindloonregeling. Veel van deze pensioenfondsen zijn in een positie van grote onderdekking, zelfs bij de bestaande praktijk de geïndexeerde verplichtingen te waarderen tegen een hoge rekenrente die is gebaseerd op een verwacht rendement van 7,5% tot 8%. De onderdekking wordt vaak toegeschreven aan de invloed van politici op het financieel beheer van pensioenfondsen. Met het oog op hun korte-termijn (electorale) belangen staan deze politici vaak een beleid van genereuze pensioentoezeggingen tegen een ontoereikende premie voor.

Hoofdstuk 2 van dit proefschrift, "U.S. municipal yields and unfunded state pension liabilities", gaat na in hoeverre de onderdekking van pensioenfondsen tot gevolg heeft dat de staten zelf hogere leenkosten over de door hen uitgegeven obligaties (zgn. municipalities) moeten betalen. De financieringsliteratuur geeft aan dat beleggers een hogere risicopremie zullen eisen als de schuldpositie groter wordt. Onderdekking is te interpreteren als een impliciete schuld van de staat en zal net als de expliciete schuld moeten worden gefinancierd uit (toekomstige) belastinginkomsten. Het inlossen van de impliciete schuld kan de aflossing en de rentebetaling van het reguliere schuldpapier bemoeilijken, wat kan leiden tot een verhoging van de risicopremie die beleggers zullen eisen. We laten in dit hoofdstuk zien dat staten met pensioenfondsen in onderdekking inderdaad een hogere rentevergoeding moeten betalen, en wel des te meer naarmate de onderdekking groter is. De relatie is evenwel alleen na de kredietcrisis significant, hetgeen suggereert dat beleggers zich pas door de crisis bewust werden van de problematiek van onderdekking bij de pensioenfondsen van de publieke sector, en van het feit dat deze onderdekking als een extra schuld voor de afzonderlijke staten dient te worden beschouwd. Een belangrijke bevinding is ook dat de risicopremie over de impliciete schuld kleiner is dan die over reguliere schuld. Dit suggereert dat beleggers aannemen dat onderdekking voor een deel ook tot een aanpassing van de gedane pensioentoezeggingen zal leiden, en niet enkel voor rekening van de belastingbetaler komt.

Veel staten zijn zich bewust van de grote toekomstige financieringslast die de gedane pensioentoezeggingen met zich meebrengen en zijn inmiddels begonnen met het implementeren van een aantal hervormingsmaatregelen die de mate van onderdekking moeten terugdringen. Hierbij is onderscheid te maken tussen parametrische maatregelen (hoofdstuk 3), en structurele hervormingen (hoofdstuk 4).

In hoofdstuk 3, "A value-based assessment of alternative U.S. state pension plans", richten we ons op maatregelen die aangrijpen op de parameters van de pensioenregeling en op de financieringsopzet, zoals de premiesystematiek en het indexatiebeleid. We ontwikkelen een model waarmee deze parametrische hervormingsmaatregelen op hun financiële effecten zijn te evalueren. Ook kan met het model in beeld worden gebracht in hoeverre de invoering van deze maatregelen tot een herverdeling tussen de bij de pensioenfondsen betrokken stakeholders leidt. Het gaat hierbij met name om de verschillende cohorten van jonge en oude deelnemers, en om de huidige en de toekomstige belastingbetalers. We evalueren verschillende manieren om de premie te verhogen en de indexatie te reduceren. We laten ook de effecten zien van maatregelen die direct aansluiten bij het inperken van de onderdekking zelf, zoals de inkorting van de termijn waarbinnen de onderdekking via extra premie-inleg moet zijn ingelopen. Een belangrijke bevinding is dat met de bijstellingen van de parameters weliswaar een verdergaande verslechtering van de financiële positie kan worden tegengegaan, maar dat een stabiele dekkingsgraad op de langere termijn daarmee niet kan worden gerealiseerd.

Anders dan via aanpassingen aan de parameters van de pensioenregeling of aan de financieringsopzet, kan de onderdekking in de bestaande fondsen ook worden geadresseerd door een structurele hervorming van de pensioenregeling. Dit is het onderwerp van hoofdstuk 4. Een voorbeeld van een structurele aanpassing is de overstap naar een individuele defined contribution (DC) regeling. In de Verenigde Staten is door pensioenfondsen in de marktsector deze overstap al enkele decennia geleden ingezet. Enkele staten hebben inmiddels ook de stap naar DC gezet. Wij introduceren een eigen voorstel, namelijk de overstap van een DB-regeling op basis van kapitaaldekking naar een notional defined contribution regeling (NDC) op basis van omslagfinanciering. De huidige situatie is te typeren als een kapitaalgedekte opbouwregeling met een groot tekort, maar deze situatie kan ook worden gezien als een omslaggedekte opbouwregeling met een groot overschot.

Hoofdstuk 4 evalueert verschillende varianten van individuele DC-regelingen en NDC-regelingen. We variëren hierbij ook de mate waarin het bestaande fonds wordt gesloten, namelijk gesloten voor alleen nieuwe opbouw, gesloten voor alleen nieuwe deelnemers, en tenslotte gesloten voor alle deelnemers, hetgeen dus betekent dat de gehele regeling als NDC regeling wordt voortgezet. Met het in hoofdstuk 3 ontwikkelde model kunnen we nagaan welke herverdelingseffecten tussen de verschillende cohorten van deelnemers en belastingbetalers optreden. Daar de financieringsopzet te interpreteren is als een zero-sum game, zal elke aanpassing aan de pensioenregeling tot omvangrijke herverdelingseffecten leiden. Bij de bestudeerde aanpassingen is er vooral sprake van herverdeling van deelnemers naar belastingbetalers.

Tot slot. Uiteindelijk kan er geen "free lunch" zijn. Politici kunnen lange tijd uit electorale overwegingen een beleid volhouden van het doen van genereuze pensioentoezeggingen in combinatie met ontoereikende premie-inleg, waarmee op het bestaande pensioenvermogen wordt ingeteerd. Dit beleid gaat ten koste van toekomstige belastingbetalers, die uiteindelijk moeten opdraaien voor het aanvullen van een te laag pensioenvermogen. Ook zullen zij de extra financieringskosten van de uitstaande schuld van de staten (municipalities) moeten betalen. Het beleid kan uiteindelijk ook ten koste van de deelnemers zelf gaan, die mogelijkerwijs in de toekomst geconfronteerd worden met onverwachte afboekingen van hun pensioenaanspraken. Dit heeft zich al voorgedaan. Dit proefschrift draagt bij aan het transparant maken van de relevante vraagstukken en helpt zodoende mee met het vinden van een oplossing voor de hier beschreven problematiek.