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DISCOUNTING PENSION LIABILITIES:  
FUNDING VERSUS VALUE

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Working Paper 21276  
<http://www.nber.org/papers/w21276>

NATIONAL BUREAU OF ECONOMIC RESEARCH  
1050 Massachusetts Avenue  
Cambridge, MA 02138  
June 2015

We thank Joshua Rauh and participants in the 2015 NBER conference on Retirement and Health Benefits in the Public Sector for helpful feedback and suggestions. Disclosure: Brown is a trustee for TIAA, a financial services company that provides services to numerous public sector retirement plans. The views expressed herein are those of the authors and do not necessarily reflect the views of the National Bureau of Economic Research.

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NBER Working Paper No. 21276  
June 2015  
JEL No. G20,H55,J26

**ABSTRACT**

We argue that the appropriate discount rate for pension liabilities depends on the objective. In particular, if the objective is to measure pension under- or over- funding, a default-free discount rate should always be used, even if the liabilities are themselves not default-free. If, instead, the objective is to determine the market value of pension benefits, then it is appropriate that discount rates incorporate default risk. We also discuss the choice of a default-free discount rate. Finally, we show how cost-of-living adjustments (COLAs) that are common in public pensions can be accounted for and valued in this framework.

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## Discounting Pension Liabilities: Funding versus Value

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### 1. Introduction

There is a long-standing debate among financial economists, pension actuaries and other interested parties about the appropriate rate to use for discounting future pension liabilities. The Government Accounting Standards Board (GASB) has long used rules that relate the discount rate to the expected return on pension plan assets, a position that has been defended by numerous actuaries and plan sponsors.<sup>3</sup> In contrast, most financial economists argue that liabilities should be discounted using a rate that reflects the risk of the liabilities (Novy-Marx and Rauh, 2011; Brown and Wilcox 2009; Lucas and Zeldes 2009; Andonov, Bauer, and Cremers, 2014). In the special case where the public pension benefits are considered free of default risk, such as in the presence of strong constitutional protections, financial economists have argued that the appropriate rate to use is a default-free one (e.g., Brown and Wilcox 2009).

In this paper, we make a simple but important conceptual point. We argue that there is an important difference between the appropriate measure of a plan's funding status and the appropriate measure of its market value. Specifically, we argue that the correct discount rate for determining a plan's funding status is the default-free rate: in a departure from prior studies in financial economics, we argue that this is true *regardless of whether the liabilities are default-free or not*. In contrast, a default-risky discount rate is the appropriate rate to use for measuring the market value of the liabilities.

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<sup>3</sup> In 2012, GASB issued new standards for discounting public pension liabilities. Whereas the previous standards discounted liabilities with the expected return on plan assets, the new standard uses a "blended rate." Roughly speaking, the new standard permits plans to use the expected return assumption for discounting so long as they are adequately funded using that discount rate. For underfunded plans, the standard calls for discounting the unfunded portion using a default free rate. As with the prior standard, the new GASB standard has no grounding in financial theory. As such, it is not clear what question, if any, the resulting measure of funding actually answers.

Measuring underfunding and placing a market value on liabilities are clearly two distinct concepts, and are useful for answering different questions. For example, the use of a default-free discount rate is informative to participants who want to know how much money the plan would need to be assured that the plan will be able to pay promised benefits. This would also be a relevant measure if the plan wished to offload its liabilities to an insurance company that intends to make good on the future benefit payments. For example, a number of defined benefit (DB) plans, including General Motors, have recently transferred their currently-accrued pension liabilities to an insurance company (Prudential, in the GM case) that will then provide the retirement annuities to the sponsor's employees. The insurance company taking over the plan would rationally require the sponsor to pay the difference between the accrued plan liabilities discounted at the default-free rate and the plan's assets (plus any administrative costs). If the insurance company received this payment along with the plan's current assets, it would permit the insurance company to invest in exactly those default-free securities that guarantees its ability to meet future obligations to the sponsor's employees. Thus, for the purposes of determining how much it would cost the sponsor to sell off its pension liabilities, discounting the liabilities at the default-free rate is needed to determine the payment to the acquirer of the liabilities.

However, there are also cases for which the market value of the liability is important. Current or potential plan participants might want to know the market value of pension liabilities (rather than the promised value) when they are making decisions about the value of pension benefits being offered by two different employers. Current employees may also want to know the market value of pension promises when they are deciding when to retire: if their employer is likely to default on pension promises, they may want to work longer to increase their savings from current salary. The market value of a DB plan's promises would also be informative to

individuals faced with a choice between a DB and a DC plan, a choice that a number of states provide to their public employees.

Prior research analyzing the financial condition of public pension funds often fails to distinguish between accounting for pension liabilities to compute a pension fund's level of (under-) funding and determining the market value of a pension fund's liabilities. We demonstrate that these are distinct exercises, though previous work frequently treats them as being the same. Specifically, it has been common in academic studies to justify the use of a pension discount rate based on the likelihood that a state or local government will default on its pension obligations: a higher probability of default would warrant a higher discount rate.

We apply the standard Merton (1974) structural credit risk model to the context of a defined-benefit pension fund. We show that discounting the liability with a default-free rate has the attractive property that the size of the total liability (funded plus unfunded) is not affected by the plan's funding status. We further show that it has the desirable property that the measure of fundedness declines to zero as plan assets fall to zero. For comparison, we show that the market value of the liability can have odd properties as a system of funding measurement: specifically, the size of the total (funded plus unfunded) liability can vary with the degree of funding, and that funding levels asymptotically approach 100 percent as assets approach zero.

Our argument, therefore, is that the appropriate measure of funding uses default-risk-free rates. This naturally leads to the practical question of how to measure default-free discount rates. There are at least three reasons that the most commonly-used proxies – the yields on debt securities issued by the federal government – are occasionally criticized for being biased measures of the economy's default-free rates. First, government bonds are not truly default-free. Although the risk of a U.S. government default is not high, it is also not zero, as is evidenced by

the very existence of a market for credit default swaps on government bonds. Second, there are state income tax advantages to U.S. government bonds, suggesting that some investors in high marginal tax rate states might be willing to accept a lower yield compared to other securities with the same default risk. Third, government bond yields might be lowered by their high liquidity relative to other fixed income assets. Our paper discusses these factors and their quantitative importance as a way of bounding the measure of a default-free rate. In the end, we find that the effects are roughly offsetting and that Treasury yields are a reasonable approximation to a default-free rate.

Having established that the appropriate way to discount pension liabilities for purposes of measuring funding status is to use (a proxy for) the default-free rate, we then turn to the question of how to incorporate cost-of-living adjustments (COLAs) that are common in public sector plans. Were COLAs pure CPI-indexation, and were there a deep market for CPI-indexed default-free bonds available in the economy, one could simply use the term structure of default-free real yields on these indexed bonds, rather than the term structure of default-free nominal yields. However, as we discuss below, most public pensions in the U.S. do not use straight CPI indexation for their COLAs. Rather, COLAs are contractually subject to upper and lower bounds (caps and floors) on inflation. Thus, we discuss how one can use market prices of inflation derivatives to compute the default-free values of these promised, state contingent COLAs.

This paper proceeds as follows: In section 2, we provide a brief discussion of issues that arise when choosing an appropriate discount rate for public pensions and the debate that surrounds this issue. In section 3, we apply the Merton (1974) model to a discussion of Defined Benefit (DB) pension liabilities and use it to illustrate the distinction between measuring funded

status and valuing liabilities. In section 4, we discuss how one should think about the choice of a default-free rate to use for discounting. We acknowledge three common criticisms of the use of the yield curve for U.S. Treasuries, present relevant evidence, and ultimately conclude that Treasury yields are a “close enough” measure of default-free rates that they represent a reasonable proxy. In section 5, we turn to the issue of how to account for the presence of COLAs that are common in public pensions. We show that COLAs often have the same promised payments as particular combinations of inflation derivatives, so that the price of these derivatives represents the market cost of replicating the COLA payments. We provide examples of how this approach can be used to value several COLAs that are common in the public sector. Section 6 concludes.

## **2. Background on Public Pension Funding Measures**

Unlike private pensions in the U.S., which are required to meet funding standards imposed by the federal government, state and local plans are not subject to externally imposed funding rules. Despite the lack of compulsion, most states have adopted policies for funding their public employee pensions. The funding policies are typically based on standards issued by the Government Accounting Standards Board (GASB), an independent organization responsible for establishing accounting and financial reporting standards for state and local governments. GASB has no enforcement authority and its pronouncements only have any legally binding nature if the state or local government chooses to voluntarily adopt the standards as law or regulation.

Because states have no external legal requirement to fund pensions, the level of funding is a policy decision. Although “full funding” is one natural benchmark, it is worth noting that economic theory does not dictate that full-funding is optimal. If a populace wishes to engage in

some form of intergenerational redistribution, then transferring resources across cohorts can be achieved through under or over funding pensions, just as it can be done through adjusting the level of other debt obligations or, even more generally, through whether resources are spent on consumption versus investment. Indeed, the largest public pension in the U.S. – the Social Security system – has operated in a manner closer to a true pay-as-you-go system than as a funded system. Although states are less able to sustain pure unfunded systems than is the U.S., owing to the fact that it is much easier to move capital and labor out of a fiscally distressed state than out of the country, they nonetheless have some policy flexibility in choosing how much to fund.

A reason it is important to acknowledge that a funding ratio is a policy choice rather than a requirement is that it allows one to separate the measurement of the level of funding from the choice of the level of funding. One can accept that the appropriate way to measure funding is to use a default-free rate without it necessarily following that the optimal funding level for a state is to always be 100 percent funded according to this measure. This paper is focused on the issue of how to measure the level of funding, without taking a view on what the optimal level of funding should be.

In contrast to GASB standards that rely upon expected asset returns, numerous financial economists have argued that the appropriate rate is one adjusted for the risk of the liabilities being discounted. Several authors have then made the argument that public pensions are “close to” default-free. For example, Brown and Wilcox (2009) use several historical case studies to argue that public pension benefits have little default risk.

The discount rate assumptions matter for the measurement of funding status. For example, Munnell, Aubrey and Cafarelli (2014) estimated that the actuarial value of assets for



the 150 state and local plans in their database was \$2.9 trillion at the end of 2013.<sup>4</sup> Using the prior GASB standards that allow for discounting based on the expected return of plan assets, they calculated the present value of liabilities at \$4.1 trillion. This 72 percent funded ratio, however, clearly overstates the financial health of these plans because of the use of a high discount rate. Government bond yields were quite low in 2013: on December 21, 2013, the yield on a 30-year Treasury was only 3.96 percent, and the yield on shorter-term bonds was even lower. Assuming a flat four percent term structure, Munnell, Aubry and Cafarelli calculate an aggregate liability of \$6.8 trillion, for an average funding ratio of approximately 43 percent.

In a departure from most existing papers in financial economics (including one co-authored by one of the current authors), it is our contention that *the appropriate discount rate to use for measuring funding shortfalls is the default-free rate, even if the liabilities are not default-free*. We discuss this more in the next section with the help of a simple model.

Before turning to this discussion, we note that we are focusing on discounting the Accumulated Benefit Obligation (ABO) rather than the Projected Benefit Obligation (PBO). The general distinction is that the ABO represents the liability that the plan has accrued to date and is measured at current earnings levels. The PBO, in contrast, accounts for the fact that many of today's participants have earned a benefit that will not be payable until some future date and will, at that time, be based on a higher earnings level. We focus on the ABO for the reasons outlined in Brown and Wilcox (2009) and Bulow (1982), including that the ABO measure has the effect of treating salary and pension accruals similarly. In other words, employers are not required to report a higher salary today just because employees are likely to receive a higher salary in the future. Similarly, we believe it is appropriate to account for the effect of future

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<sup>4</sup> [http://crr.bc.edu/wp-content/uploads/2014/06/slp\\_39.pdf](http://crr.bc.edu/wp-content/uploads/2014/06/slp_39.pdf)

salary increases on pension liabilities only after those salary increases have become effective. Because we are focused only on the ABO, we do not need to worry about adjusting discount rates to reflect the risk of liabilities that might arise from uncertain earnings growth. Lucas and Zeldes (2006, 2009) discuss the implications of PBO hedging for both discount rate selection and portfolio allocation.

### 3. A Simple Model for Measuring Pension Funding

To illustrate the distinction between measuring liabilities and placing a market valuation on them, we apply the standard Merton (1974) structural credit risk model to the context of a defined-benefit pension fund. To make our point transparent, we first consider a highly simplified case in which a pension plan promises a single lump-sum benefit payment at one future date. The model makes the following four simplifying assumptions:

- 1) The pension fund invests in risky assets that have a current date  $t$  market value of  $A_t$  and a rate of return volatility (annual standard deviation) of  $\sigma$ .
- 2) The pension fund promises a single retirement benefit equal to  $X$  payable at date  $t + \tau$ .
- 3) The continuously-compounded, default-free interest rate (yield) is constant, equal to  $y$ .
- 4) The sponsor of the pension fund is expected to contribute to the fund's assets in amounts  $cA_t$  per unit time until date  $t + \tau$ .<sup>5</sup> If at date  $t + \tau$  the pension fund has sufficient asset value, pension participants receive their promised payment of  $X$ . Instead, if  $A_{t+\tau}$  is worth less than  $X$ , the pension fund defaults and the participants receive only  $A_{t+\tau}$ .

Let us denote the date  $t$  market value of the pension fund's liabilities as  $L_t$ .  $L_t$  is the current fair market value that investors would pay for the possibility of receiving the default-

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<sup>5</sup> There may be more realistic ways of specifying future contributions. Our assumption that contributions are a fixed proportion of current assets might describe the phenomenon that when pension assets experience losses during a market downturn, the sponsor is likely to be financially weak and reduce contributions.

risky cash flow of  $\min[X, A_{t+\tau}]$  at the future date  $t+\tau$ . Similar to Merton (1974), the market value of this default-risky pension liability equals

$$L_t = Xe^{-y\tau} N(d_2) + A_t e^{c\tau} N(-d_1) \quad (1)$$

where  $d_1 = \left( \ln \left[ A_t / (Xe^{-y\tau}) \right] + \left( c + \frac{1}{2} \sigma^2 \right) \tau \right) / (\sigma \sqrt{\tau})$  and  $d_2 = d_1 - \sigma \sqrt{\tau}$ .  $N(\cdot)$  is the standard normal cumulative distribution function. Note from equation (1) that  $L_t$  is a function of five quantities: 1) the current market value of assets,  $A_t$ ; 2) the rate at which new assets are expected to be contributed to the fund,  $c$ ; 3) the volatility of assets,  $\sigma$ ; 4) the time until the pension's benefit is due to be paid,  $\tau$ , and 5) the promised pension benefit discounted at the default-free interest rate,  $Xe^{-y\tau}$ .

Equation (1) provides several immediate insights. One is that the market value of liabilities,  $L_t$ , can never be worth more than the promised payment discounted at the default-free rate,  $Xe^{-y\tau}$ . Further, as the value of the pension fund's current assets grows,  $L_t$  converges to  $Xe^{-y\tau}$ :

$$\lim_{A_t \rightarrow \infty} L_t = Xe^{-y\tau} \quad (2)$$

The quantity  $Xe^{-y\tau}$  plays a natural role in the concept of a fully-funded pension plan for at least two reasons. First, if the current value of pension assets equals  $A_t = Xe^{-y\tau}$ , then there exists an investment strategy that can guarantee to participants their full payment of  $X$ , without any need for the sponsor to make future asset contributions to the fund ( $c=0$ ). This strategy consists of investing all of the pension assets in the default-free security at rate  $y$ . Indeed, if this plan were to transfer its currently-accrued liabilities to an insurance company, so that it would not be making any new contributions after the transfer, it would need to top up its assets to equal  $A_t = Xe^{-y\tau}$  in order for the insurance company to implement this riskless investment strategy.

Second, we argue that the *ratio of the default-risky market value of liabilities to its default free value is a good measure of the relative risk faced by a pension participant*. This quantity  $L_t / Xe^{-y\tau} = N(d_2) + \left[ A_t / (Xe^{-y\tau}) \right] e^{c\tau} N(-d_1)$  is a function of only four factors:  $c$ ,  $\sigma$ ,  $\tau$ , and  $A_t / (Xe^{-y\tau})$ . Thus, the pension funding ratio for which liabilities are discounted at the default-free rate,  $A_t / (Xe^{-y\tau})$ , emerges as the natural factor for measuring pension risk.

Moreover, it is clear that this definition of a funding ratio delivers the sensible result that as the value of pension assets declines, the funding ratio goes to zero:

$$\lim_{A_t \rightarrow 0} A_t / (Xe^{-y\tau}) = 0 \quad (3)$$

If, instead, pension liabilities were discounted at a risk-adjusted rate, say  $Y$ , that reflected their true default risk, then  $Xe^{-Y\tau} = L_t$ . However, using this liability measure to account for the pension plan's funding ratio,  $A_t / L_t$ , is problematic. It is also straightforward to show that such a value of liabilities leads to the illogical result that the pension plan becomes fully funded as the value of assets shrink:

$$\lim_{A_t \rightarrow 0} A_t / L_t = 1 \quad (4)$$

A simple numerical example illustrates the importance of this distinction. Consider a plan that has a single nominal liability of  $X = \$1,000$  that is payable in ten years. If the current continuously-compounded yield on a 10-year default-free bond is  $y = 3.0$  percent, then investing  $Xe^{-y\tau} = \$1,000 e^{-0.03 \times 10} = \$740.82$  in this bond today, without any need for the sponsor to make future contributions ( $c = 0$ ), would guarantee that the plan could make good on its liability.

Now suppose the plan was underfunded, having assets of only  $A_t = \$500$  on hand today. Using the default-free rate, the plan would be  $Xe^{-y\tau} - A_t = \$240.82$  underfunded, or a funding

ratio of  $A_t / (X e^{-y\tau}) = 67.5$  percent. Contrary to how GASB discounts, this level of underfunding is the same regardless of how the \$500 is invested. We argue that this 67.5 percent is the appropriate measure of a plan's funding status because it tells participants and other stakeholders how much money the plan would need today to pay full promised benefits in the future. This measure would also be helpful to determine the future contribution rate,  $c$ , that would be expected to close this funding gap over some future horizon.<sup>6</sup>

Next, consider the consequence of incorporating default risk when discounting pension liabilities. Suppose that the rate of return on the plan's assets has an annual standard deviation of  $\sigma = 20$  percent. If the sponsor is expected to make additional contributions to the fund at the rate of  $c = 2$  percent per year, the current market value of liabilities calculated from equation (1) is  $L_t = \$476.64$ . This market value is equivalent to discounting the plan's promised liabilities by  $Y = 7.41$  percent. That is,  $L_t = \$476.64 = X e^{-Y\tau} = 1000 \times e^{-0.0741 \times 10}$ . If one then discounted the plan's benefit promises by a rate that reflects the true likelihood of default and used the result to measure funding, then the plan would be overfunded by  $\$500 - \$476.64 = 23.36$  and its funding ratio would be  $A_t / (X e^{-Y\tau}) = 104.9\%$ .

While discounting benefit promises by a risk-adjusted rate leads to a distorted measure of funding, information on the  $L_t = \$477$  current market value of liabilities would be quite valuable, for example, to an employee deciding between the DB plan and, say, a \$600 immediate contribution to a DC plan. If the DB plan was fully funded and default-free, the individual might

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<sup>6</sup> The contribution rate at which the risk-neutral expected asset value equals liabilities by the time that benefits are promised to be paid is given by the value of  $c$  such that  $(A_t / (X e^{-y\tau})) \times e^{c\tau} = 1$ , or  $c = \ln(X e^{-y\tau} / A_t) / \tau$ . For our example, this is  $c = 3.93$  percent.

rationally choose the \$741 DB over a \$600 DC.<sup>7</sup> But if the DB plan is underfunded, the rational choice might be the \$600 DC rather than the \$477 market value of the DB.

Thus, the market value of the DB liability contains useful information. But it is not a particularly robust measure of funding levels, i.e., how much money the plan sponsor would need to set aside today to pay promised benefits. For example, if one is interested in measuring funding status, it makes little sense to effectively “reward” the plan sponsor for underfunding their plan. As indicated in the model above, if a plan sponsor does not fund at all, and if this drives the probability of the plan sponsor making good on its promises toward zero, then the market value of the liability can disappear completely. That is useful information to someone trying to value their future benefit, but it serves little purpose as a measure of the funding shortfall.

In practice, Novy-Marx and Rauh (2011) consider two candidate rates as being potentially appropriate for discounting state pension liabilities. One is a tax-adjusted general obligation municipal bond rate. They argue that such a rate is appropriate if a state is just as likely to default on its pension obligations as it is to default on its general obligation bonds. Their second candidate discount rate is based on the logic of Brown and Wilcox (2009) who document that a majority of states’ pension obligations are protected by state constitutional guarantees. It is argued that these states have a lower probability of defaulting on their pension obligations than of defaulting on their municipal bonds. Therefore, they argue that the appropriate discount rate for pension liabilities should be less than a municipal bond rate and closer to a nearly default-free zero-coupon U.S. Treasury rate.<sup>8</sup> The main point of our paper is

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<sup>7</sup> For purposes of this illustration, we are ignoring other differences between DB and DC which might influence this choice, such as access to annuitized income in retirement.

<sup>8</sup> Similar reasoning on accounting for pension liabilities is found in Andonov, Bauer, and Cremers (2014): “public pension funds should use lower discount rates than private pension funds, because public plan benefits are virtually

that this discussion is relevant to computing the market value of public pension liabilities, but that only the default-free rate is relevant for measuring the degree of underfunding. We argue that there is no need to justify the choice of the liability discount rate based on the municipality's likelihood of default because finance theory supports the discounting of promised pension obligations by a default-free rate, whether the pension fund sponsor is the U.S. government, the State of Illinois, or the City of Detroit.<sup>9</sup>

As we discuss in the following sections, the insights obtained from the simple model in equation (1) carry over to more realistic models where benefits are promised at many future dates. For the purpose of measuring a plan's funding status, each future promised benefit payment should be discounted using the yield on the default-free bond that matures at the benefit's payment date. Furthermore, when promised benefits are state contingent, as they are in the case of COLAs subject to limits on future inflation, these promises should be valued as if they were default-free. If there exists default-free securities that can replicate the plan's state-contingent benefit promises, then the cost of these securities should be used to value liabilities when calculating funding status. In other words, while valuation for the purpose of measuring funding status should account for the state-contingent risk of the plan's contracted benefits, it should not account for benefits' default risk which would constitute a violation or renegotiation of the benefit contract.

#### **4. How to Measure Default-Free Rates**

To account for a pension plan's funding level, we argued in the previous section that liabilities should be valued as if future promised payments were default free, unless explicit

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free of risk as accrued benefits are usually backed by constitutional guarantees; in contrast, members of private plans still risk losing part of their pensions if the firm enters bankruptcy.”

<sup>9</sup> One exception is the case where pension benefit promises contain explicit provisions for write-downs if pension asset values are insufficient.

contractual provisions allow for changes in these payments. Our rationale is that full funding should imply that the plan has sufficient asset value to implement an investment strategy that guarantees payment of the plan's promised retirement benefits. If the plan's promised benefits can be replicated by a particular portfolio of securities, then the minimum cost of this portfolio equals the plan's fully-funded asset value. In turn, the difference between this portfolio's cost and the plan's current asset value equals the plan's underfunding. Equivalently, should the sponsor terminate the plan and transfer its accrued liabilities to an insurance company, the company's cost of implementing an investment strategy that guarantees payment of the benefits is the value of the replicating portfolio.

As we discuss below, there exist several nominal and inflation-related securities that can replicate many promised plan benefits.<sup>10</sup> In this section, we consider purely nominal liabilities and then cover inflation-related cost-of-living adjustments (COLAs) in the following section.

The simple model in the previous section assumed a single future promised payment,  $X$ , and a single default-free interest rate,  $y$ . The qualitative insights of that model extend to payments promised at multiple future dates. Suppose the current date is 0 and a plan promises payments each year for  $T$  future years,  $t = 1, \dots, T$ , with corresponding amounts  $X_t$ ,  $t = 1, \dots, T$ . Then the current date 0 default-free value of the plan's liabilities is

$$\sum_{t=1}^T X_t e^{-y_{0,t}t} \quad (5)$$

where  $y_{0,t}$  denotes the date 0 continuously-compounded yield to maturity on a default-free zero-coupon bond that matures at date  $t$ . Consequently, if the plan had asset value sufficient to

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<sup>10</sup> If there do not exist securities that perfectly replicate some types of plan benefits, the asset value required for full funding can be modified to equal the cost of purchasing the security portfolio that best hedges promised future benefit payments. Presumably, such a marketable security portfolio that most closely matches the plan's promised payments will hedge the lion's share of the liabilities' systematic risks so that unhedged risks should be mostly diversifiable. A large insurance company may be willing to guarantee the plan's liabilities for the cost of this hedge portfolio because the plan's unhedged risks can be diversified away if the insurance company has other business lines with uncorrelated risks.



purchase  $T$  default-free bonds with maturity values  $X_t$ ,  $t = 1, \dots, T$ , it could guarantee payment of the benefits. Thus, expression (5) represents the plan's fully-funded asset value. Equivalently, a portfolio of default-free bonds whose value and duration equals that of (5) is sufficient to pay future benefits and immunizes the plan from interest rate risk.

Lewis and Pennacchi (1999) extend the model of the previous section to find the market value a DB plan's liabilities or, equivalently, the fair cost insuring its liabilities from default. Their model permits benefit payments and contributions from a plan sponsor at multiple future dates and assumes default occurs if the plan's sponsor (e.g., a corporation or a municipality) declares bankruptcy at the same time that the pension plan is underfunded. Consistent with (5), the model assumes that there exists a duration-matching bond portfolio that replicates the plan's promised benefits. The term structure of default-free yields changes randomly according to the Vasicek (1977) no-arbitrage model. The insight of the previous section carries over to this extended model in that the critical measure of the plan's funding status is the ratio of the market value of the plan's assets to the value of the duration-matched, default-free bond portfolio that replicates the plan's promised future benefits.<sup>11</sup>

The issue that we now address is how to determine the appropriate set of default-free yields. A natural starting point is yields on Treasury securities. The term structure of zero-coupon Treasury yields can be obtained from Treasury STRIPS or the zero-coupon yields implicit in the prices of Treasury coupon-paying notes and bonds.<sup>12</sup> However, several objections might be made for using unadjusted Treasury yields to discount pension promises. We briefly

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<sup>11</sup> Similarly, a state variable that determines the sponsor's likelihood of bankruptcy is the ratio of the sponsor's total non-pension plan assets to the default-free value of the sponsor's non-pension plan liabilities. A similar model but without random interest rates is developed in Pennacchi and Lewis (1994).

<sup>12</sup> STRIPS (Separate Trading of Registered Interest and Principal Securities) are individual coupons or principal payments of Treasury notes and bonds that trade separately and represent a true zero-coupon Treasury security. Zero-coupon yields implicit in Treasury note and bond prices can be calculated using a bootstrapping method.

discuss these concerns, and use the existing literature to place bounds on adjustments that might be made when using a Treasury yield curve to proxy default-free rates.

#### *4.1 U.S. Government Debt is not Default-Risk-Free*

One criticism of using Treasury securities as proxies for default-free assets is that they, like any sovereign debt, are not truly free from default risk. Evidence that at least some investors believe U.S. Treasuries are default risky comes from the credit default swap (CDS) market.<sup>13</sup> CDS are insurance contracts against default. If an investor purchases a default-risky bond and also buys CDS protection against the bond's default, this combined investment approximates a default-free bond whose annual yield equals the default-risky bond's promised yield minus the annualized CDS spread.

Figure 1 shows U.S. Treasury CDS spreads reported by Bloomberg over the period from December 2007 to December 2014. See the Appendix for details, including Bloomberg codes, on the data used in this paper. The average CDS spreads over this sample period were 22.9, 34.6, and 46.0 basis points for contract maturities of one, five, and ten years, respectively. CDS spreads increased sharply following the Lehman Brothers bankruptcy, peaking in February of 2009. There was also an especially large spike for spreads of the one-year contract in July 2011 just before the resolution of a debt ceiling crisis on July 31, 2011.<sup>14</sup> CDS spreads rose to a smaller extent prior to the culmination of a second debt ceiling crisis that was resolved on October 17, 2013.<sup>15</sup> In summary, based on evidence from CDS spreads, yields on Treasuries might contain roughly a 20 to 50 basis point default risk premium, depending on maturity.

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<sup>13</sup> It is interesting that CDS on U.S. Treasuries are quoted in euros, rather than U.S. dollars, suggesting that foreign investors might be most concerned about default risk. Since CDS spreads are expressed as annual premiums per amount of notional principal, they are largely unaffected by the currency denomination.

<sup>14</sup> The U.S. Treasury was scheduled to exhaust its borrowing authority on August 2, 2011. On August 5, 2011, Standard & Poor's downgraded the U.S. government's long-term credit rating from AAA to AA+.

<sup>15</sup> A partial government shutdown began on October 1, 2013.

#### *4.2 U.S. Government Debt Provides State-Tax Advantages*

States that tax investment income typically exempt interest from federal government bonds from the tax base. According to standard tax clientele theory, high-marginal-tax-rate investors would be willing to accept a lower pre-tax yield on U.S. government debt than they are willing to accept on an otherwise identical, but taxable, asset. This would drive the yield on government bonds down and therefore require that one adjust the yields by  $1/(1-\tau)$ , where  $\tau$  is the relevant state tax rate on interest income.

However, the tax clientele theory does not appear to be empirically relevant. Using data from the Federal Reserve Bank of St. Louis as of April 1, 2014, out of the \$12,877 million of U.S. federal debt outstanding (a figure that excludes government holdings of its own debt, such as in the Social Security trust funds), just over \$6 billion (47 percent of total) was held by foreign investors, including foreign governments for which tax considerations do not apply. Another 2.7 billion (21 percent) was held by Federal Reserve Banks, who also do not face a tax wedge between government and corporate bonds. This leaves less than one-third of all U.S. government debt held by private U.S. investors. These private investors, in turn, are dominated by pension funds, life insurance companies, and other institutional investors. As noted by Cochrane (2015), “the market for Treasury debt is heavily segmented, with few taxable investors holding any debt.” Non-taxable investors do not experience any tax advantage to holding Treasuries relative to other assets, and thus there is little reason to think that U.S. Treasury yields are significantly affected by the state tax exemption. Thus, to a first approximation, we believe it is appropriate to make no adjustment to Treasury yields to account for their preferential state tax status.

#### *4.3 Liquidity Premia for U.S. Government Debt*

Another objection to using unadjusted Treasury yields as default-free rates relates to Treasury securities' high liquidity which that makes them especially attractive for investors that may have needs to trade. Treasuries can be quickly converted to cash or easily used as collateral for borrowing via repurchase agreements, features which raise their prices and lower their yields relative to a less-liquid default-free security. However, if a pension fund tends to buy and hold bonds until they mature, it may be able to form a replicating portfolio with default-free securities that are less liquid than U.S. Treasuries. Doing so would allow it to purchase default free securities at lower prices and higher yields.

Longstaff (2004) provides evidence of such a possibility. He examines yields on bonds issued by a U.S. government agency, Refcorp.<sup>16</sup> Unlike other government agencies such as Fannie Mae or Freddie Mac, Refcorp bonds are fully collateralized by U.S. Treasury securities and, hence, have the same credit risk as Treasuries. Over his April 1991 to March 2001 sample period, the average difference in Refcorp bond yields relative to equivalent maturity Treasury yields was 13.1 basis points at the 10-year maturity and 16.3 basis points at the 30-year maturity. However, these yield spreads tended to be higher during periods of financial market stress or “flights to liquidity.” Other research finds that, even among different Treasury securities, liquidity premia affect yields. Recently auctioned “on-the-run” Treasury notes and bonds tend to have yields that are 5 to 10 basis points lower than similar maturity but seasoned “off-the-run” Treasury notes and bonds.<sup>17</sup> Thus, if a pension plan does not benefit from the greater liquidity of on-the-run Treasuries, it would be justified to discount nominal payments using yields of off-the-run securities or equivalent credit risk agency securities, such as Refcorp bonds.

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<sup>16</sup> Refcorp is the funding vehicle for the Resolution Trust Company that was established by the 1989 Financial Institutions Reform, Recovery, and Enforcement Act (FIRREA).

<sup>17</sup> Evidence of an off-the-run versus on-the-run yield spread includes Krishnamurthy (2002) and Graveline and McBrady (2011).

#### *4.4 Net Effect: Treasuries are a Reasonable Proxy*

Starting with Treasury yields, the above evidence suggests that it may be appropriate to subtract 20-50 basis points to remove the effect of a small default-risk premium and then add 10-16 basis points to remove the average effect of the liquidity premium. While Figure 1 seems to indicate that Treasuries' credit risk spread rises during periods of financial distress, research also finds that their relative liquidity is highest during such periods, so time variation in these two effects might partially offset each other. We further argued that the marginal investor in Treasury securities is unlikely to be taxable, given the large share of government bonds held by foreign governments and tax-exempt institutional investors. The net effect of these adjustments is close to a wash: if anything, the previous evidence might suggest that a true default-free rate in the U.S. economy is up to 35 basis points below the yields on government bonds.

Additional evidence on whether Treasury yields are a reasonable proxy for default free rates might be to compare the effective yields on synthetic default-free bonds created from CDS-insured, high credit quality corporate bonds. We carried out a very rough, exploratory analysis by obtaining yields on all existing AAA-rated, non-callable corporate bonds.<sup>18</sup> Currently, the only two corporations with outstanding AAA-rated, noncallable bonds are Johnson & Johnson and Microsoft. To see how yields on their corporate bonds compare to similar Treasuries, we matched each corporate bond that currently has at least four years until maturity to a Treasury note or bond with the most similar maturity date and coupon rate. Data on yields for each corporate bond and matching Treasury bond were obtained from Bloomberg. Summary statistics from this exercise are reported in Table 1.

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<sup>18</sup> We limited the analysis to only AAA bonds because there might be more noise and idiosyncrasies in using lower-grade bonds. We also examine only non-callable bonds because callable bonds have random maturities and their yields are elevated by a call premium. All outstanding U.S. Treasury securities are non-callable.

The sample period over which yield data was available for each corporate and matching Treasury bond is given in the first column of Table 1. Columns 2, 3, and 4 give each corporate bond's maturity date, coupon rate, and average yield over the sample period, respectively. The same data items for each bond's matching Treasury are given in columns 5, 6, and 7. In the last column 8 is the difference in the average yields of the corporate bond and its matching Treasury, which we refer to as the "average spread."

Table 1 lists the bonds by corporation and maturity date. As is indicated in column 8, the corporate – Treasury spread tends to rise with the bonds' time until maturity.<sup>19</sup> Averaged over all corporate bonds, the average spread is about 60 basis points for each corporate issuer. However, if we limit the comparison to only bonds with a current time until maturity of 10 years or less, then the average spread is 29.8 basis points for the (six) Johnson & Johnson bonds and 48.7 basis points for the (four) Microsoft bonds. The reason that we focus on bonds of 10 years or less is that data on CDS spreads for these corporate bonds were available only for CDS contract maturities of 5 and 10 years.<sup>20</sup>

The last four rows in Table 1 compare these corporations' spreads for 5-year and 10-year CDS contracts to those of the U.S. Treasury. Johnson & Johnson and Treasury CDS spreads are over the sample period beginning in December of 2007. However, since Microsoft issued its first corporate bond in 2009, its CDS is compared to that of Treasuries for a shorter sample period. As can be seen from the table, the differences are small, between 0 and 10 basis points.

By subtracting this difference in relatively higher corporate CDS spreads from their relatively higher yields, we can roughly estimate that the net yield from creating a synthetic

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<sup>19</sup> Spreads that rise with the time until maturity would be expected if the long-run default risk of the federal government is less than that of these currently AAA-rated corporations.

<sup>20</sup> While we only have data on CDS spread for maturities up to 10 years, like the corporate bond – Treasury yield spread we might expect that the difference between corporate and Treasury CDS spreads would also grow with maturities beyond 10 years.

default-free 10-year Johnson & Johnson bond is about  $30 - 5 = 25$  basis points greater than that for a default-free synthetic Treasury. Similarly, the net yield from creating a synthetic, default-free 10-year Microsoft bond is about  $49 - 10 = 39$  basis points greater than that for a default-free Treasury. Therefore, while our previous evidence suggested that using CDS to make Treasuries default-free would subtract up to 35 basis points from raw Treasury yields, this evidence from less-liquid corporate bonds suggests that the raw Treasury yield is approximately the correct return from creating a synthetic default-free bond from AAA corporates.<sup>21</sup> Thus, a solid argument could be made that it is appropriate to use U.S. Treasuries as the base case for measuring the degree of pension underfunding.

## 5. Accounting for Cost-of-Living Adjustments

The discussion above indicates that using the U.S. Treasury yield curve to discount nominal pension liabilities, and comparing this to the market value of plan assets, is an appropriate way to measure the degree of underfunding of a plan. However, the exercise assumes that pension liabilities are fixed nominal liabilities. In fact, many public pension plans have cost-of-living adjustments (COLAs), an issue that can complicate the discounting process.

Figure 2 shows the number and percentage of the 127 plans in NASRA's *Public Fund Survey* with various types of COLAs. 36 plans use a post-retirement benefit adjustment that is not a true COLA at all, but rather is a pre-determined rate of automatic increase in nominal benefits. Illinois is one such example: current retirees receive an annual 3 percent "automatic

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<sup>21</sup> Another way of seeing this is that, for bonds of 10 years or less, the average yield on Johnson & Johnson and Microsoft bonds over their matched Treasuries are 30 and 49 basis points, respectively. Since Table 1 shows the 10-year CDS spreads for Johnson & Johnson and Microsoft are 51 and 60 basis points, respectively, these CDS insured bonds would have a net yield of  $30 - 51 = -21$  basis points and  $49 - 60 = -11$  basis points below raw Treasury yields. So a raw Treasury yield might be only slightly higher than the net yield on a synthetic default-free corporate bond.

annual increase” regardless of the rate of inflation. In such cases, one can apply the nominal Treasury yield curve directly to the growing nominal stream of benefits.

45 plans use a COLA that is based on the CPI. If these plans were fully indexed, i.e., if benefits were simply real rather than nominal, then one could use a real yield curve, rather than a nominal yield curve, to discount benefits. However, very few of the plans are purely inflation-indexed. 38 of the 45 plans have some sort of ceiling on the inflation adjustment, ranging from a low of 1.5% in the Kentucky ERS to a high of 6% in the Connecticut SERS plan. The most common ceiling is 3%, with 15 plans capped at this level. Five plans report floors, although we suspect that more plans than this have an implicit floor of zero. It would be misleading to use a real term structure to discount a stream of benefits that is subject to floors and ceilings on the inflation adjustment.

Unlike prior research that values COLAs by making ad hoc assumptions regarding future inflation, we show particular types of limited pension COLAs can be replicated and valued using the market prices of recently available inflation derivatives, such as inflation swaps, inflation caps, and inflation floors. Few, if any, assumptions regarding the process for inflation need to be made when taking this approach. In addition, because market data is available at high frequency, immediate updates on the cost of COLAs can be recognized.

This approach is useful for at least two purposes. First, it allows us to convert the COLA provisions into a fixed nominal price that can then be discounted back using the nominal default-free term structure. Second, it provides a tool for evaluating the cost savings associated with reforms that reduce COLAs. This latter point is highly relevant to the current policy environment: Munnell, Aubry, and Cafarelli (2014) report that between 2010 and 2013, 30 plans across 17 states either reduced, suspended or eliminated COLAs for existing employees. Of



these, 13 also reduced COLAs for current retirees. Although these changes were legally challenged in at least 12 of the states, the cuts were upheld in most of the states.

### 5.a Fixed Rate COLAs

Valuing automatic fixed-rate COLAs, such as a compounded or simple 3% annual increase is straightforward and can be done using the term structure of default-free nominal bond yields. To illustrate this calculation, we assume for simplicity that each future year's annuity payment is made in a lump sum at the end of each year, rather than paid monthly throughout the year. If the COLA is compounded at the rate  $r$ , then for each \$1 of base year's annuity, the cashflow paid  $t$  years in the future is  $(1+r)^t - 1$ . If  $y_{0,t}$  is the initial, date 0 annually-compounded yield to maturity on a default-free zero-coupon bond maturing at date  $t$ , then the present value of this future year's promised COLA payment is simply  $[(1+r)^t - 1]/(1+y_{0,t})^t$ . Over a  $T$ -year retirement horizon, the present value of all future years' COLA payments are

$$\sum_{t=1}^T \frac{(1+r)^t - 1}{(1+y_{0,t})^t} \quad (6)$$

Expression (6) is the value of the COLA per \$1 of base annuity value. Expressing it as a proportion of the present value of the total nominal annuity received over  $T$  years, i.e., the present value of a \$1 per year benefit without a COLA, leads to:

$$\left[ \sum_{t=1}^T \frac{(1+r)^t - 1}{(1+y_{0,t})^t} \right] / \left[ \sum_{t=1}^T \frac{1}{(1+y_{0,t})^t} \right] \quad (7)$$

Expression (7) is then the default-free value of a fixed rate, compounded COLA over a  $T$ -year period as a proportion of the value of the nominal annuity over that same period. The corresponding expression for a non-compounded (simple) COLA at the fixed rate  $r$  is

$$\left[ \sum_{t=1}^T \frac{r \times t}{(1 + y_{0,t})^t} \right] / \left[ \sum_{t=1}^T \frac{1}{(1 + y_{0,t})^t} \right] \quad (8)$$

We calculate (7) and (8) using Treasury security data compiled by Gürkaynak, Sack, and Wright (2007). They provide daily estimates of zero-coupon Treasury yields from daily prices of Treasury coupon notes and bonds. Because their estimates use data on “off-the-run” Treasury securities, liquidity premia that are highest for “on-the-run” Treasury securities are mitigated.<sup>22</sup> Hence, these yields reflect what a pension fund would earn on more illiquid, seasoned Treasury securities.

The single most common fixed rate that pension funds choose for automatic COLAs is 3 percent, both when this rate is compounded and when it is not. Therefore, we compare the value of 3 percent compounded and simple (non-compounded) COLAs for retirement horizons of 10, 20, and 30 years. In each case the COLA values are expressed as a percentage of the value of the same-horizon retirement annuity that does not contain the COLA. We make these calculations for each day starting from the beginning of October 2004 until February 2015. These days’ values are averaged over each month and graphed in Figure 3.

As would be expected, Figure 3 indicates that the difference between compounded and simple COLAs grows as the retirement horizon lengthens. The average compounded versus simple COLAs per nominal benefit at the 10, 20, and 30 year horizons are 17.0% versus 15.6%, 32.5 versus 27.1%, and 48.2 versus 36.8%, respectively. Relative COLA values are also higher during periods when the yield curve was generally lowest, such as during the depth of the financial crisis in late 2008 and early 2009, as well as the most recent period of Federal Reserve “quantitative easing.”

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<sup>22</sup> Their daily estimates of the zero-coupon bond yield curve derive from prices of Treasury coupon securities that exclude the two most recently issued securities with maturities of two, three, four, five, seven, 10, 20, and 30 years.

### 5.b Fully Inflation-Indexed COLAs

Inflation-indexed COLAs provide future cashflows that are random in terms of nominal payments but fixed in terms of real purchasing power. Previous research such as Novy-Marx and Rauh (2011) estimates COLAs tied to the Consumer Price Index (CPI) by making an assumption regarding future inflation and discounting the resulting expected nominal cashflows by nominal yields. Alternatively, one might discount a CPI-indexed annuity payment using the term structure of real yields, rather than nominal yields. Daily zero-coupon real yield curves estimated from U.S. Treasury Inflation Protected Security (TIPS) coupon prices are available for maturities from 2 to 20 years and could be used.<sup>23</sup> However, TIPS are less liquid than nominal U.S. Treasuries, and there is evidence that their yields became unrealistically high (and prices unreasonably low) during stress periods such as the 2008-2009 financial crisis.<sup>24</sup>

An alternative to using TIPS to value CPI-indexed COLAs is to use an inflation derivative security known as a zero-coupon inflation swap. Zero-coupon inflation swaps are the most common and liquid type of inflation derivative. Also, traders in inflation swap contracts are subject to regulatory collateral requirements that are intended to minimize counterparty default risk.<sup>25</sup> A zero-coupon inflation swap is really a forward contract in which there is a single future exchange between two parties where one party pays a fixed payment and the other pays an inflation-linked payment. For a swap negotiated at date 0 and maturing at the end of year  $t$ , the net payment from the point of view of the fixed-rate payer is  $(1+k_{0,t})^t - CPI_t/CPI_0$ , where  $k_{0,t}$  is the inflation swap rate negotiated at date 0 on this  $t$ -year inflation swap and  $CPI_t$  is the  $CPI$  at

<sup>23</sup> This data is available at <http://www.federalreserve.gov/econresdata/researchdata/feds200805.xls>.

<sup>24</sup> For evidence that TIPS were underpriced relative to nominal Treasuries and inflation swaps, see Haubrich, Pennacchi, and Ritchken (2012) and Fleckenstein, Longstaff, and Lustig (2014).

<sup>25</sup> Under current international regulations, most standard swaps, such as interest rate swaps, are required to be processed through central clearinghouses that set margin requirements. However, inflation swaps, as well as cross-currency swaps and swaptions, are exempt from central clearing requirements. These uncleared, over-the-counter derivatives are subject to different collateral requirements that are designed, in principle, to be greater than those for centrally-cleared swaps. See Basel Committee on Banking Supervision (2015).

date  $t$ .<sup>26</sup>  $k_{0,t}$  is the inflation swap rate agreed to by the parties at date 0 such that the present value of the future exchange is zero.

Let  $r_{0,t}$  be the annualized real yield on a zero-coupon inflation indexed bond (e.g., TIPS) that promises one unit of current date 0 purchasing power at the future date  $t$ , which in nominal terms equals  $CPI_t/CPI_0$ . Then the present value of the swap's inflation payment is  $1/(1+r_{0,t})^t$  while the present value of the swap's fixed-rate payment equals  $(1+k_{0,t})^t/(1+y_{0,t})^t$ . Equating the value of these two payments, since the exchange has zero value, implies  $k_{0,t} = (1+y_{0,t})/(1+r_{0,t}) - 1 \approx y_{0,t} - r_{0,t}$ , which makes the inflation swap rate equal to what is known as the “breakeven inflation” rate.<sup>27</sup> Hence, knowledge of the term structure of inflation swap rates, along with the term structure of nominal yields, implies a term structure of real interest rates.<sup>28</sup> Inflation swaps also have advantages because they are quoted daily in maturities from 1 to 30 years, and sometime as long as 50 years.

Figure 4 gives time series data from Bloomberg on 5-, 10-, 20-, and 30-year swap rates over the 2004 to 2015 period. Notice that the 5-year rate dipped to just below zero, indicating deflation, following the Lehman Brothers bankruptcy. However, it should be noted that during this same period, breakeven inflation implied by the five-year nominal and TIPS yields was even lower, illustrating TIPS's high yields and lower liquidity relative to inflation swaps.

Like TIPS breakeven inflation rates, zero-coupon swap rates equal “risk-neutral” or “certainty equivalent” expectations of inflation. In other words, zero-coupon swap rates equal

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<sup>26</sup> In practice, an inflation swap maturing at date  $t$  is based on the CPI index recorded approximately 3 months earlier and its initial CPI index,  $CPI_0$ , is based on the CPI index recorded approximately 3 months prior to the initiation of the contract. Thus, a  $t$ -year swap involves an exchange of a full  $t$  years of inflation but lagged 3 months. This is exactly the same convention used to calculate TIPS payments.

<sup>27</sup> Note that the approximation  $k_{0,t} \approx y_{0,t} - r_{0,t}$  becomes an exact equality if all rates are measured as continuously-compounded rates, rather than annually-compounded rates.

<sup>28</sup> Indeed, purchasing a zero-coupon nominal Treasury with face value  $(1+k_{0,t})^t$  and current price  $(1+k_{0,t})^t/(1+y_{0,t})^t$ , and then entering into an inflation swap with notional principle of \$1 produces a real cash flow worth a current \$1 at date  $t$ . In other words, purchase of a nominal Treasury and a fixed-rate swap position replicates a real (TIPS) payment.

actual (physical) expectations of inflation plus an inflation risk premium. Studies that attempt to estimate this inflation risk premium typically find that it is positive.<sup>29</sup> Additional evidence is given in Figure 5 which graphs the 10-year zero coupon inflation swap rate versus the 10-year mean forecast of inflation from the Federal Reserve Bank of Philadelphia's Survey of Professional Forecasters.<sup>30</sup>

The figure shows that, over the 2004 to 2014 sample period, the average 10-year zero coupon inflation swap rate of 2.65% exceeds the survey's average 10-year expected inflation rate of 2.44%, reflecting an average inflation risk premium of 21 basis points for a 10-year horizon. Note, as we discuss next, that use of inflation swap rates that include this inflation risk premium is appropriate for valuing inflation-linked COLAs.

Inflation swaps imply that the value of the random accumulated inflation from the current date 0 to future date  $t$ ,  $CPI_t/CPI_0 - 1$ , equals a fixed payment of  $(1+k_{0,t})^t - 1$  at date  $t$ . Thus, the present value of this accumulated inflation payment equals  $[(1+k_{0,t})^t - 1]/(1+y_{0,t})^t$ . Aggregated over a  $T$ -year retirement horizon, a fully CPI-indexed COLA per \$1 of initial base year annuity payment equals

$$\sum_{t=1}^T \frac{(1+k_{0,t})^t - 1}{(1+y_{0,t})^t} \quad (9)$$

and the value of this COLA as a proportion of the total nominal annuity without the COLA is

$$\left[ \sum_{t=1}^T \frac{(1+k_{0,t})^t - 1}{(1+y_{0,t})^t} \right] / \left[ \sum_{t=1}^T \frac{1}{(1+y_{0,t})^t} \right] \quad (10)$$

<sup>29</sup> See Haubrich, Pennacchi, and Ritchken (2012) for references to these studies.

<sup>30</sup> The approximately 40 participants in this survey make this 10-year forecast of inflation once per quarter. Ang, Bekaert, and Wei (2007) find that this survey is the most accurate measure of expected inflation.

Note that these expressions are similar to those of the fixed-rate COLAs but where the term structure of inflation swap rates,  $k_{0,t}$   $t=1, \dots, T$ , replaces the single fixed rate,  $r$ .

To compute the COLA values in (9) and (10), we obtained data from Bloomberg on daily zero-coupon swap rates at maturities from 1 to 10 years and 12, 15, 20, 25, and 30 years. A swap rate yield curve for every annual horizon greater than 10 years was fitted by a cubic spline that passed through the observed 12, 15, 20, 25, and 30 year rates. Along with the daily nominal yield curve obtained from the aforementioned Gürkaynak, Sack, and Wright (2007) database, expressions (9) and (10) were calculated for each day from November 2004 through January 2015. The monthly averages of these daily COLA values are plotted in Figures 6 and 7.

Figure 6 shows that over the entire sample period, the COLA values for 10, 20, and 30 year horizons averaged 1.1, 3.9, and 7.5 times the initial year's annual benefit, respectively. The values declined dramatically at the depth of the financial crisis as deflation fears heightened. Values appear to have peaked early in 2013 when beliefs that quantitative easing could produce greater inflation may have been highest.

Figure 7 plots the same COLA values but as a percentage of the value of the nominal annuity over the same horizons. Over the sample period, COLA values for 10, 20, and 30 year horizons averaged 13.3%, 27.7%, and 42.5%, respectively, of the nominal annuity values. The declines in these relative values in late 2008 were even more dramatic since deflation fears coincided with a dramatic decline in the nominal term structure which raised the value of the nominal annuity.

### *5.c Inflation-indexed COLAs subject to Zero-Coupon Floors and Caps*

As mentioned at the start of this section, few, if any, actual COLAs are linked purely to the CPI without any constraints. Rather, COLAs typically are constrained by a minimum

inflation rate floor, say  $r_f$ , and often limited to a maximum inflation rate cap, say  $r_c$ . For example,  $r_f$  is almost always 0 and  $r_c$  is often 2% or 3%. If these minimum and maximum rates are compounded relative to the annuity's base year (date 0), then the COLA paid at the end of future year  $t$  can be written as

$$\frac{CPI_t}{CPI_0} - 1 + \max\left[\left(1+r_f\right)^t - \frac{CPI_t}{CPI_0}, 0\right] - \max\left[\frac{CPI_t}{CPI_0} - \left(1+r_c\right)^t, 0\right] \quad (10)$$

In expression (10),  $CPI_t/CPI_0 - 1$  is the unconstrained inflation payment made in year  $t$ . The next term  $\max[(1+r_f)^t - CPI_t/CPI_0, 0]$  is the payoff of a put option on inflation, also referred to as a zero-coupon inflation floor. If  $r_f = 0$ , the floor pays the owner the amount of deflation since the start of the retirement annuity at the initial date 0.<sup>31</sup> This floor combined with the unconstrained inflation payment  $CPI_t/CPI_0 - 1$  implies that the future COLA adjustment is always nonnegative so that the future annual benefit payment is never less than the base year annual payment. The last term,  $\max[CPI_t/CPI_0 - (1+r_c)^t, 0]$  is the payoff of a call option on inflation, also referred to as a zero coupon inflation cap.

Over a  $T$ -year retirement horizon, the present value per \$1 of base year annuity of the payoff in expression (10) is

$$\sum_{t=1}^T \frac{(1+k_{0,t})^t - 1}{(1+y_{0,t})^t} + \sum_{t=1}^T \left[ zcf_0(r_f, t) - zcc_0(r_c, t) \right] \quad (11)$$

where  $zcf_0(r_f, t)$  is the date 0 value of a zero coupon floor with floor rate  $r_f$  and time to maturity  $t$  and  $zcc_0(r_c, t)$  is the date 0 value of a zero coupon cap with cap rate  $r_f$ . The combination of purchasing a floor and writing a cap is referred to as a "collar." Prices of zero coupon floors and

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<sup>31</sup> The principal payment on a TIPS bond has exactly this type of a zero inflation floor such that the investor will never receive less than the bond's nominal (accrued) principal value when it was first issued. However, TIPS coupon payments are unconstrained as in our previous example.

caps are quoted daily for a variety of floor and cap rates. We obtained from Bloomberg daily prices for floors with a floor rate of 0% and for caps with cap rates of 2% and 3%. Prices for 0% floors and 2% caps were available since October 2009, and prices for 3% caps were available starting in April of 2011. Similar to zero coupon inflation swaps, these floor and cap prices are quoted for maturities of 1 to 10 years and 12, 15, 20, 25, and 30 years. Prices for every annual horizon between 10 and 30 years were obtained by fitting a cubic spline.

Figure 8 plots CPI COLAs with 0% floors as well as CPI COLAs with 0%, 3% collars and 0%, 2% collars. These COLAs are computed for horizons of 10 and 30 years as a percent of the present value of the total nominal annuity for the corresponding horizon. Comparing the values of CPI COLAs with a 0% floor to the pure CPI COLAs in Figure 7, one sees that the 0% zero-coupon floor adds relatively little value. On average over the sample period, the value of the floors adds 3.9%, 2.4%, and 1.9% at the 10, 20, and 30 year horizons, respectively, to the value of the pure CPI COLAs. Thus, these low floor values indicate that likelihood of deflation over horizons of many years is small. In contrast, the 3% cap at the 10, 20, and 30 year horizons subtracts 12.9%, 17.9%, and 20.5%, respectively from the pure CPI COLAs. For the 2% cap at the 10, 20, and 30 year horizons the deductions are 32.6%, 39.2%, and 43.9%, respectively. As expected, the lower the cap, the less valuable is the COLA.

#### *5.d “Simple” Inflation-Indexed COLAs subject to Year on Year Floors and Caps*

A few states offer non-compounded, CPI-linked COLAs subject to a 0% floor and a cap. For illustrative purposes, we focus on this type of COLA provided by the State of Illinois.<sup>32</sup> The Illinois COLA applies to state employees hired after December 31, 2010. It is a non-compounded

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<sup>32</sup> Other examples are the political subdivisions of the State of Tennessee which have the option of providing a non-compounded COLA equal to the lesser of the CPI and 3%. The State of Utah also provides a non-compounded CPI-linked COLA. For those hired before July 1, 2011, it is the lesser of CPI inflation and 4%. Newer hires receive the lesser of the CPI and 2.5%.



COLA where annual benefit increases are the lesser of  $\frac{1}{2}$  of CPI inflation and 3%, or zero when annual inflation is negative. Therefore, if annual CPI inflation exceeds 6%, the total annual benefit increase is limited to 3%. Because increases are non-compounded, each future year's increase is based on the initial year's annuity value, not the year previous to the increase. Since this non-compounded COLA is tied to  $\frac{1}{2}$  of annual CPI inflation subject to a 3% cap and 0% floor, the COLA is equivalent to a non-compounded COLA equal to the full CPI subject to a 6% cap and 0% floor but where the COLA applies to only one-half of the annuitant's initial-year pension payment.

As in our prior calculations, let us assume that each future year's annuity payment is made in a lump sum at the end of each year and includes the year's COLA with no indexation lag. In this case, the total non-compounded COLA cashflow received at the end of year  $T$  per \$1 of base year annual benefit equals:

$$\begin{aligned} & \sum_{t=1}^T \min \left[ \frac{1}{2} \max \left[ r_f, \left( \frac{CPI_t}{CPI_{t-1}} - 1 \right) \right], \frac{1}{2} r_c \right] \\ &= \frac{1}{2} \sum_{t=1}^T \min \left[ \max \left[ r_f, \left( \frac{CPI_t}{CPI_{t-1}} - 1 \right) \right], r_c \right] \end{aligned} \quad (12)$$

where in the case of the Illinois COLA,  $r_f=0$  and  $r_c = 6\%$ .

Each year's annual future random inflation,  $CPI_t/CPI_{t-1}$ , can be valued using forward inflation rates implied by the term structure of zero-coupon inflation swaps.<sup>33</sup> Recall that for a swap maturing at the end of year  $t$ , the net payment from the point of view of the fixed-rate payer is  $(1+k_{0,t})^t - CPI_t/CPI_0$ , where  $k_{0,t}$  is the inflation swap rate negotiated at date 0 on a  $t$ -year inflation swap. Similarly, for a swap maturing at the end of year  $t - 1$ , the net payment from the

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<sup>33</sup> This is done in a manner similar to how random future interest rates can be valued using forward interest rates implied by the term structure of zero-coupon bond interest rates.

point of view of the fixed-rate payer is  $(1+k_{0,t-1})^{t-1} - CPI_{t-1}/CPI_0$ , where  $k_{0,t-1}$  is the inflation swap rate negotiated at date 0 on a  $(t-1)$ -year inflation swap.

The inflation payment received on a  $t$ -year inflation swap,  $CPI_t/CPI_0$ , can be replicated by entering into a  $t-1$  year inflation swap at date 0, and then at date  $t-1$  using the inflation proceeds to enter into a one-year inflation swap with the notional principal of  $CPI_{t-1}/CPI_0$ . The accumulated inflation proceeds at date  $t$  is then  $(CPI_{t-1}/CPI_0) \times (CPI_t/CPI_{t-1}) = CPI_t/CPI_0$ , the same as the  $t$ -year inflation swap. Thus, the implied forward inflation swap rate that equates the value of the replicating contract is  $(1+k_{0,t-1})^{t-1} \times (1+k_{t-1,t}) = (1+k_{0,t})^t$ , or

$$k_{t-1,t} = \frac{(1+k_{0,t})^t}{(1+k_{0,t-1})^{t-1}} - 1 \quad (13)$$

Consequently, the random inflation payment of  $CPI_t/CPI_{t-1}$  received at date  $t$  has the same date 0 value as receiving a fixed payment of a  $(1+k_{t-1,t})$  at time  $t$ . Equivalently, the payment of  $CPI_t/CPI_{t-1} - 1$  received at date  $t$  has the same date 0 value as receiving  $k_{t-1,t}$  at time  $t$ .

Therefore, since the COLA payment received at date  $t$  includes all previous non-compounded annual inflation increases, the present value of the total non-compounded CPI-linked COLA with no floor or cap paid at the end of year  $t$  is

$$\frac{\sum_{i=1}^t k_{i-1,i}}{(1+y_{0,t})^t} \quad (14)$$

where  $y_{0,t}$  is the date 0 annually-compounded yield to maturity on a default-free zero-coupon bond maturing at date  $t$ . Thus, from the term structure of zero-coupon inflation swaps and zero-coupon Treasury securities, we can value future non-compounded annual inflation payments.

Importantly, floors and caps on non-compounding annual CPI inflation payments are traded. They are referred to as “year on year” inflation options. For example, the purchase of a

year on year CPI inflation cap with a maturity of  $t$  years and a cap rate of  $r_c$  would pay  $\max[(CPI_i/CPI_{i-1} - 1) - r_c, 0]$  at the end of each year  $i = 1, \dots, t$ .<sup>34</sup> Similarly, the purchase of a year on year CPI inflation floor with a maturity of  $t$  years and a strike price of  $X$  would pay  $\max[r_f - (CPI_i/CPI_{i-1} - 1), 0]$  at the end of each year  $i = 1, \dots, t$ . Thus, for each \$1 of initial base annuity, the Illinois COLA paid at the end of year  $t$  has a value equal to one-half of

$$\frac{\sum_{i=1}^t k_{i-1,i}}{(1 + y_{0,t})^t} + yyf_0(r_f = 0\%, t) - yyc_0(r_c = 6\%, t) \quad (15)$$

where  $yyf_0(r_f=0\%, t)$  is the date 0 value of a 0%  $t$ -year, year on year inflation floor and where  $yyc_0(r_c=6\%, t)$  is the date 0 value of a 6%  $t$ -year, year on year inflation cap. The expression (15) gives the present value of the floored and capped inflation payment made at the end of a single future year,  $t$ . Therefore, the present value of COLA payments for years  $t = 1, \dots, T$  has a value equal to one-half of

$$\begin{aligned} & \sum_{t=1}^T \left( \frac{\sum_{i=1}^t k_{i-1,i}}{(1 + y_{0,t})^t} + yyf_0(r_f = 0\%, t) - yyc_0(r_c = 6\%, t) \right) \\ &= \sum_{t=1}^T \left( \frac{\sum_{i=1}^t k_{i-1,i}}{(1 + y_{0,t})^t} \right) + \sum_{t=1}^T (yyfc_0(r_f = 0\%, r_c = 6\%, t)) \end{aligned} \quad (16)$$

where  $yyfc_0(r_f=0\%, r_c=6\%, t)$  is a year on year inflation collar with a 0% floor and 6% cap.

Daily prices of year on year 0% floors and 6% caps were obtained from Bloomberg over the period from October 2009 through January 2015. As with the zero coupon floors and caps, these year on year floor and cap prices are quoted for maturities of 1 to 10 years and 12, 15, 20,

<sup>34</sup> Note that the previously discussed zero-coupon floors and caps were contracts on a single option payoff at the maturity of the contract. Year on year floors and caps are contracts on multiple option payoffs at the ends of each year throughout the life of the contract.

25, and 30 years. As before, we fit a cubic spline to obtain prices for every annual horizon between 10 and 30 years.

Figure 9 plots the results of calculating one-half of the value of the expression (16), first including a pure simple (non-compounded) yearly change in the CPI, then adding the zero rate floor, and finally adding the 6% cap rate. COLA costs were computed for 10 and 30 year retirement horizons.

Compared to the previous section's calculations that used zero-coupon floors and caps, year on year floors and caps have values that are larger compared to their corresponding unconstrained simple interest COLAs. On average over the sample period, the value of the floors adds 17.0%, 21.2%, and 26.4% at the 10, 20, and 30 year horizons, respectively, to the value of the simple CPI COLAs. The, 6% cap (3% on  $\frac{1}{2}$  of the CPI) decreases the simple CPI COLA by 10.0%, 15.9%, and 21.5% at the 10, 20, and 30 year horizons, respectively. The intuition for the relatively large effects of these floors and caps is that they are based on each year's change in the CPI, rather than the CPI accumulated since the beginning of retirement. If inflation is believed to follow a process that mean-reverts to a target between the floor and cap constraints, the value on long-dated options may be less than that of short-dated ones.

Figure 10 compares the Illinois  $\frac{1}{2}$  CPI simple COLA with the 0%,6% collar graphed in Figure 9 with an automatic 3% compounded fixed rate COLA. This latter COLA covered all Illinois state employees prior to the implementation of the new Illinois COLA. Over the sample period, the average COLA value as a percent of the total nominal retirement benefit declines from 17.2% to 5.8% for a 10-year retirement horizon. At the 20 and 30 year retirement horizons, the declines in the COLA values were 33.0% to 9.4% and 49.1% to 11.2%. Clearly the new COLA represents a substantial reduction in value.

### 5.e Limited Price Index COLAs

One of the more common types of COLA is an inflation-indexed, compounded COLA with year on year floors and caps. This COLA is similar to the previous section's non-compounded "simple" COLA with year on year floors and caps. However, standard year on year floors and caps are not equivalent to this compounded COLA's limits because standard year on year floors and caps are based on the same, non-compounded notional principal throughout the lives of the options.

In contrast, compounded COLAs with annual limits on inflation payments can be linked to a Limited Price Index (LPI) that derives from the CPI. Specifically, let  $LPI_t$  be the LPI at the end of year  $t$ , and set  $LPI_0 = CPI_0$  at the initial date 0. Let this LPI be subject to a year on year floor rate of  $r_f$  and a year on year cap rate of  $r_c$ . Then the annual change in the LPI is

$$LPI_t = LPI_{t-1} \times \max \left[ \min \left[ \frac{CPI_t}{CPI_{t-1}}, 1 + r_f \right], (1 + r_c) \right] \quad (17)$$

so that its process from date 0 to the end of year  $T$  satisfies:

$$LPI_T = \prod_{t=1}^T \max \left[ \min \left[ \frac{CPI_t}{CPI_{t-1}}, 1 + r_f \right], (1 + r_c) \right] \quad (18)$$

Thus, LPIs have annual growth rates that are equal to the corresponding annual CPI growth rate, but with the annual growth floored at rate  $r_f$  and capped at rate  $r_c$ .

In the United Kingdom, regulation requires that all private sector pension plans provide limited price indexation linked to the Retail Price Index (RPI), which is similar to the U.S. CPI. Perhaps due to this COLA uniformity and a desire by U.K. pension managers to hedge this type of inflation risk, zero coupon inflation swaps trade on LPIs with specific floors and caps. As with a zero coupon swap tied to the RPI or CPI, a zero coupon swap tied to an LPI represents a single

future exchange between two parties. For an LPI swap negotiated at date 0 and maturing at the end of year  $t$ , the net payment from the point of view of the fixed-rate payer is  $(1+k_{0,t})^t - LPI_t/LPI_0$ , where  $k_{0,t}$  is the LPI swap rate negotiated at date 0 on this  $t$ -year swap. Two of the most popular swaps are based on LPIs with the sets of limits ( $r_f=0\%$ ,  $r_c=5\%$ ) and ( $r_f=0\%$ ,  $r_c=3\%$ ).

Given the existence of zero coupon swaps on an LPI, the value of such an LPI-based COLA is easily valued using the same method for a zero coupon swap based on the CPI (or RPI). That is by using the expressions in (9) or (10). From Bloomberg, we collected daily data on three different U.K. zero-coupon swaps: the first based on the RPI, the second on the LPI with ( $r_f=0\%$ ,  $r_c=5\%$ ), and the third on the LPI with ( $r_f=0\%$ ,  $r_c=3\%$ ). Daily zero-coupon bond yield curves based on U.K. gilts also were obtained from the Bank of England.<sup>35</sup>

Figure 11 graphs COLA values for indexation based on the RPI (with no floor or cap), the LPI with  $r_f=0\%$ ,  $r_c=5\%$  (denoted LPI05) and LPI with  $r_f=0\%$ ,  $r_c=3\%$  (denoted LPI03). This is done for the period of July 2012 through December 2014 for retirement horizons of 10, 20, and 30 years and expressed as a percent of total nominal annuity value.

For all horizons, the LPI05 COLA values are very similar to those based on the RPI. On average over the sample period, the LPI05 COLAs are worth 99.0%, 99.6%, and 100.8% of RPI COLAs for horizons of 10, 20, and 30 years, respectively. Consequently, the value of the 0% floor is approximately equal to the value of the 5% cap. In contrast, the LPI03 COLAs are worth 77.7%, 72.2%, and 68.4% of RPI COLAs for horizons of 10, 20, and 30 years, respectively. Thus, the tighter 3% cap significantly reduces the COLA value.

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<sup>35</sup> Yield curve data is available for maturities out to 25 years. To value COLAs based on swaps with maturities out to 30 years, we assumed that gilt yields for maturities from 26 to 30 years were the same as the 25-year yield.

At this time, LPI swaps based on the U.S. CPI are not traded. In the absence of these swaps, valuing LPI-based COLAs require additional assumptions regarding the random process followed by the CPI index.<sup>36</sup> Such valuation, while straightforward, is beyond the scope of our paper. However, given that the CPI inflation has been similar to RPI inflation in the last few years, we expect LPIs based on the U.S. CPI might not be too different from those in Figure 10.

#### *5.f COLAs Conditional on Funding Status or Legislative Discretion*

Several public pension plans offer COLAs that are explicitly contingent on the plan's funding status. Since funding status depends, at least partially, on the pension fund's asset returns, one approach to account for these types of promised COLA payments is to value them as options on the pension fund's assets. Promised future COLA benefits would be higher (*lower*) when future asset values are greater (*less*) than the COLA-contingent exercise value. Bikker and Vlaar (2006) take such an approach when valuing COLAs of Dutch pension funds which guarantee nominal pension benefits but have COLAs contingent on a plan's funding ratio. Novy-Marx and Rauh (2014) also use option-pricing theory to value various types of retirement benefit adjustments linked to investment performance.

In practice, it may be difficult to accurately value options written on a pension fund's asset portfolio. An alternative might be to calculate two liability measures of a plan's funding status: one which values only promised nominal payments assuming no COLA will be paid; another which values both nominal and COLA payments assuming the COLA is paid with certainty. These two measures would represent lower and upper bounds on the default-free value of pension benefits.

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<sup>36</sup> See, for example, Ticot and Charvet (2013) and its references.

This two-measure approach for valuing promised pension liabilities also would be reasonable when a plan's COLA is at the discretion of legislators or the plan's directors.<sup>37</sup> Moreover, providing two liability measures, one with and one without a COLA, makes the marginal COLA cost transparent and should lead to improved policy.

## 6. Conclusion

How pension plans should account for the value of their liabilities is a prominent policy issue, as evidenced by a recent U.S. Senate-requested Government Accountability Office (2014) study of this topic. The GAO found that "experts sharply disagree on which approach should be taken to calculate these plans' estimated obligations for benefits promised to workers and retirees." Given this lack of consensus, it is not surprising that the GAO study decided against making any recommendations as a result of its findings.

We hope that our paper clarifies the essential issues of pension discounting and, as a consequence, creates consensus on how discounting should be done. Our main point is that the appropriate rate for discounting depends on the purpose of the discounting exercise. In particular, if the objective is to account for pension under- or over- funding, a default-free discount rate should *always* be used.<sup>38</sup> Instead, if the objective is to determine the market value of an employee's pension benefits, then it is appropriate that discount rates incorporate the plan's default risk.

Another contribution of our work is to show how to account for different types of COLAs in pension plan benefits. In many instances, inflation-linked benefits can be valued by recognizing that they are replicated by inflation derivatives, such as inflation swaps, floors, and

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<sup>37</sup> Attempting to calculate a single measure for the plan's promised liability value would require modeling policymakers' decisions, which appears to be a highly speculative exercise.

<sup>38</sup> Moreover, we have argued that use of a default-free discount when measuring a plan's funding status is likely to be most important when the plan is on the brink of default.



caps. By using the market prices of these derivative securities, the cost of specific COLAs can be objectively determined. The ability to accurately value COLAs is particularly important for gauging the impact of recent and proposed public pension plan reforms.

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Table 1

## AAA Corporate Bond – Treasury Spreads

<u>Sample Period</u>	<b>Johnson &amp; Johnson</b>			<b>Matched Treasury</b>			<u>Av Spread</u>
	<u>Maturity</u>	<u>Coupon</u>	<u>Av Yield</u>	<u>Maturity</u>	<u>Coupon</u>	<u>Av Yield</u>	
12/14-3/15	12/05/19	1.875	1.54	12/31/19	1.625	1.47	7.8
8/13-3/15	9/01/20	2.950	2.17	8/31/20	2.125	1.93	23.2
5/11-3/15	5/15/21	3.550	2.33	5/15/21	3.125	1.93	39.3
12/14-3/15	12/05/21	2.450	1.96	12/31/21	2.125	1.77	19.7
4/04-3/15	11/15/23	6.730	4.18	8/15/23	6.250	3.66	51.7
12/13-3/15	12/05/23	3.374	2.78	11/15/23	2.750	2.41	37.1
2/04-3/15	9/01/29	6.950	4.68	8/15/29	6.125	3.94	74.4
8/07-3/15	8/15/37	5.950	4.64	5/15/37	5.000	3.48	115.0
6/08-3/15	7/17/38	5.850	4.66	5/15/38	4.500	3.34	131.6
8/10-3/15	9/01/40	4.500	4.10	8/15/40	3.875	3.36	74.2
5/11-3/15	5/15/41	4.850	3.98	5/15/41	4.375	3.18	<u>79.9</u>
Average							59.4

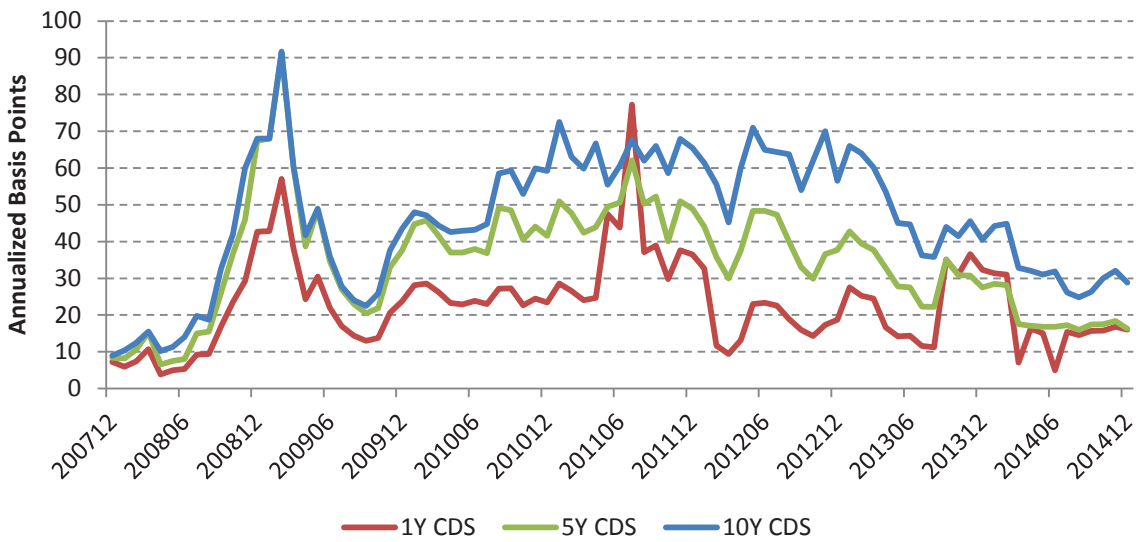
<u>Sample Period</u>	<b>Microsoft</b>			<b>Matched Treasury</b>			<u>Av Spread</u>
	<u>Maturity</u>	<u>Coupon</u>	<u>Av Yield</u>	<u>Maturity</u>	<u>Coupon</u>	<u>Av Yield</u>	
5/09-3/15	6/01/19	4.200	2.53	5/15/19	3.125	2.06	47.1
11/10-3/15	10/01/20	3.000	2.44	11/15/20	2.625	2.01	43.2
2/11-3/15	2/08/21	4.000	2.51	2/15/21	3.625	1.97	54.5
11/12-3/15	11/15/22	2.125	2.73	11/15/22	1.625	2.23	50.0
5/09-3/15	6/01/39	5.200	4.48	05/15/39	4.250	4.30	18.6
11/20-3/15	10/01/40	4.500	4.23	11/15/40	4.250	3.33	91.1
2/11-3/15	2/08/41	5.300	4.24	2/15/41	4.750	3.24	99.3
11/12-3/15	11/15/42	3.500	4.10	11/15/42	2.750	3.29	<u>81.1</u>
Average							60.6

## Average CDS Spreads

<u>Corporation</u>	<u>CDS Maturity</u>	<u>Sample Period</u>	<u>Corporation</u>	<u>Treasury</u>	<u>Difference</u>
Johnson & Johnson	5 Years	12/07-12/14	32.8	34.6	-1.8
Johnson & Johnson	10 Years	12/07-12/14	51.4	46.0	5.4
Microsoft	5 Years	1/13-12/14	33.7	25.2	8.6
Microsoft	10 Years	9/09-12/14	60.1	49.8	10.2

Source: Bloomberg

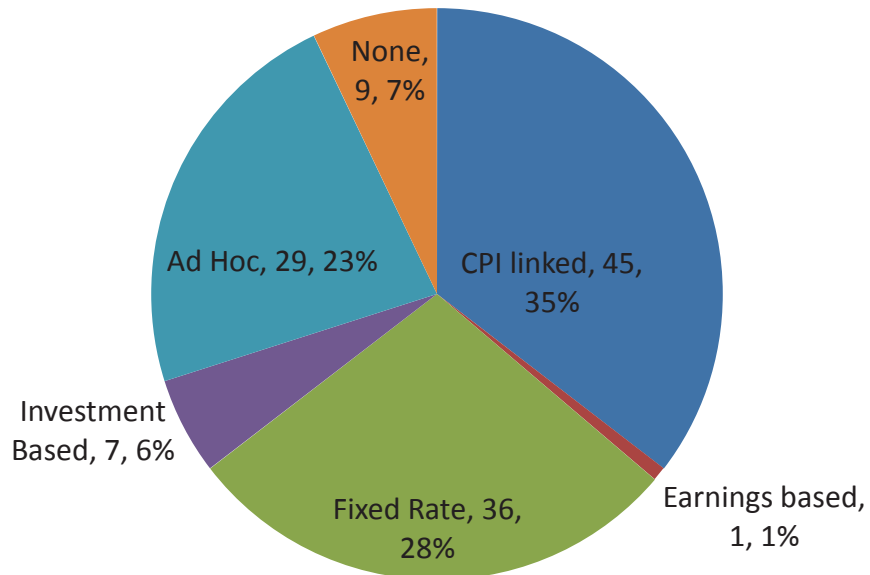
**Figure 1 CDS Spreads for U.S. Treasury Securities**



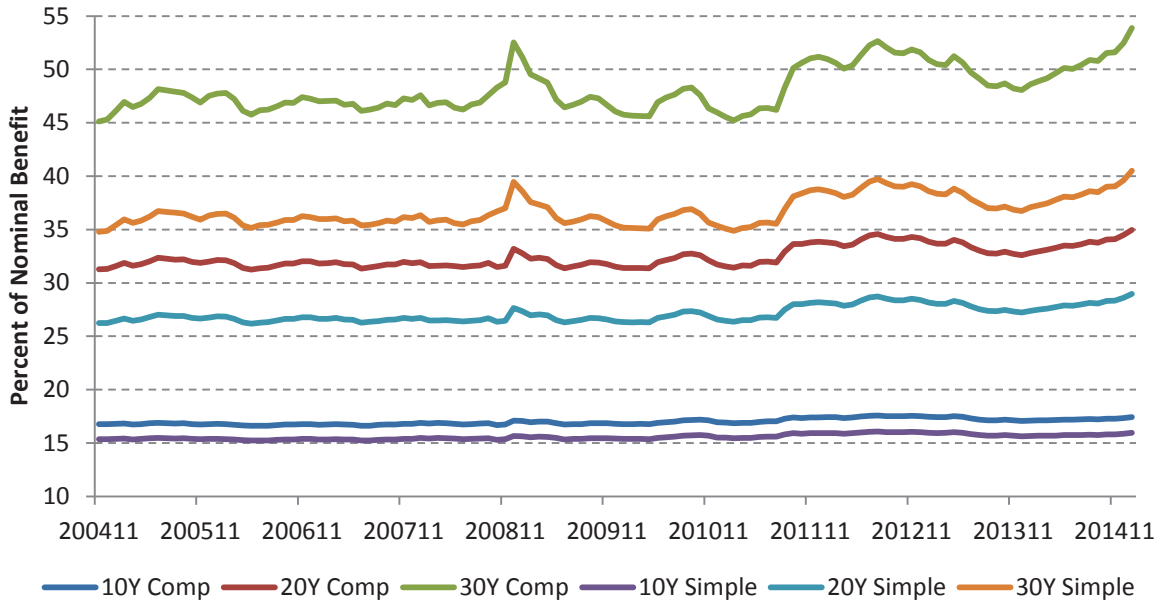
Source: Bloomberg

**Figure 2 Types of COLAs in Public Plans**

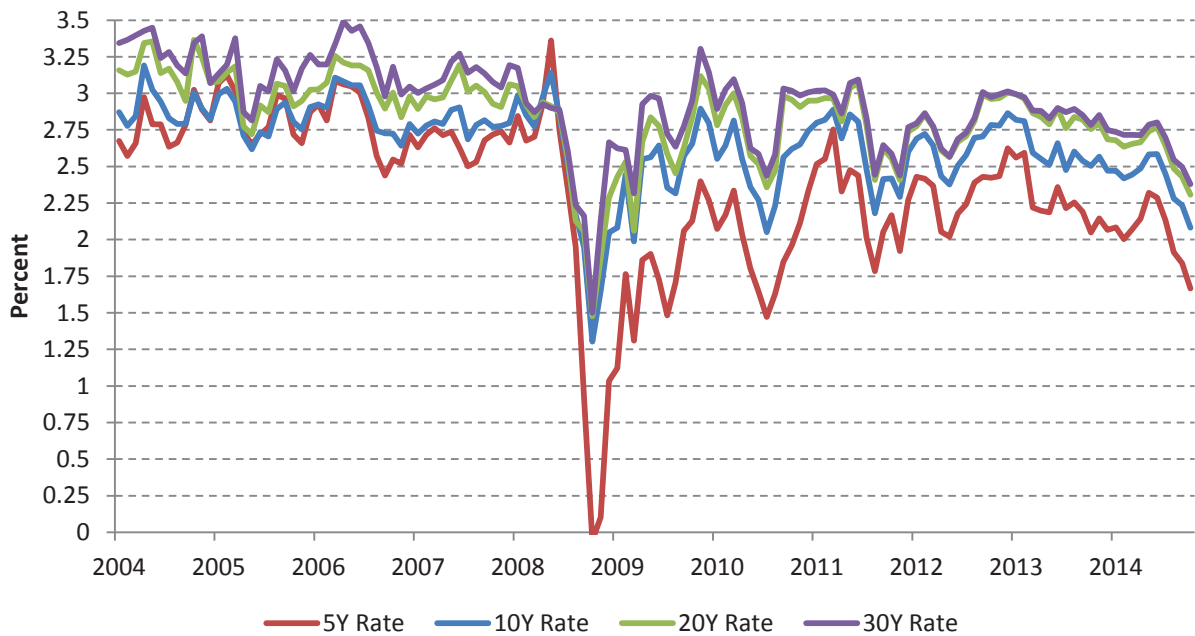
**Type, Number, Percent  
out of 127 Plans in NASRA Public Fund Survey**



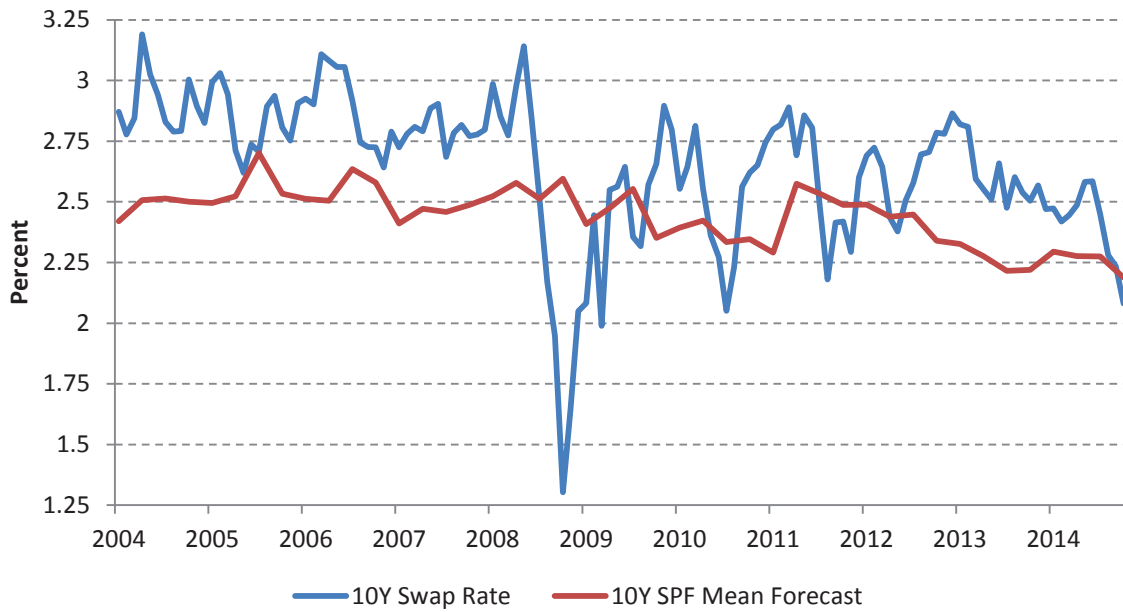
**Figure 3 Compounded and Simple Fixed-Rate COLAs**



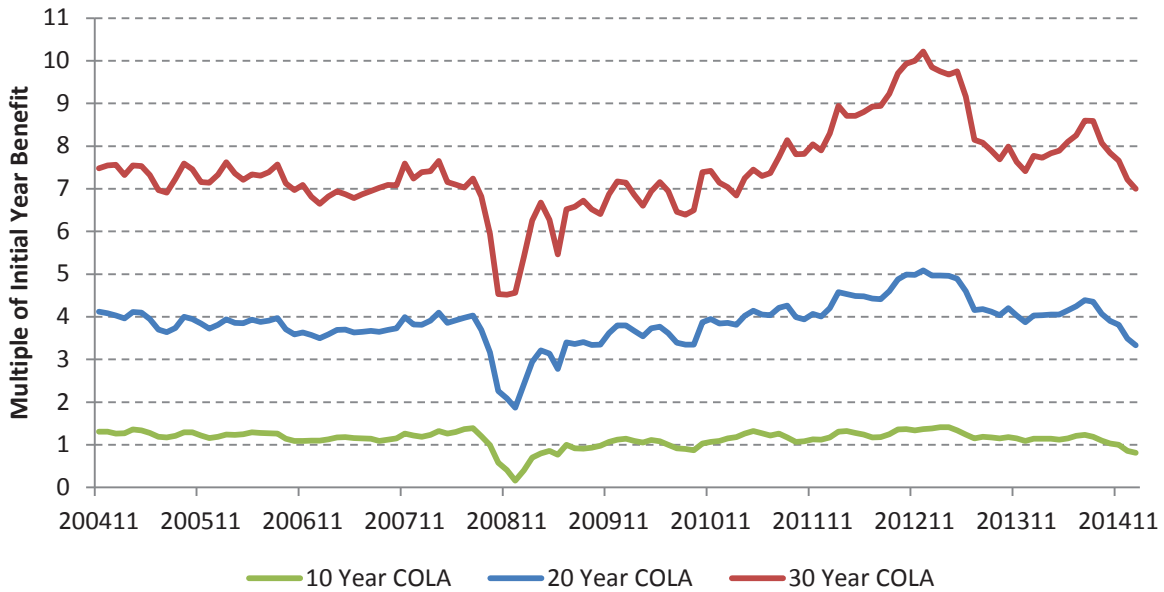
**Figure 4 Zero-Coupon Inflation Swap Rates**



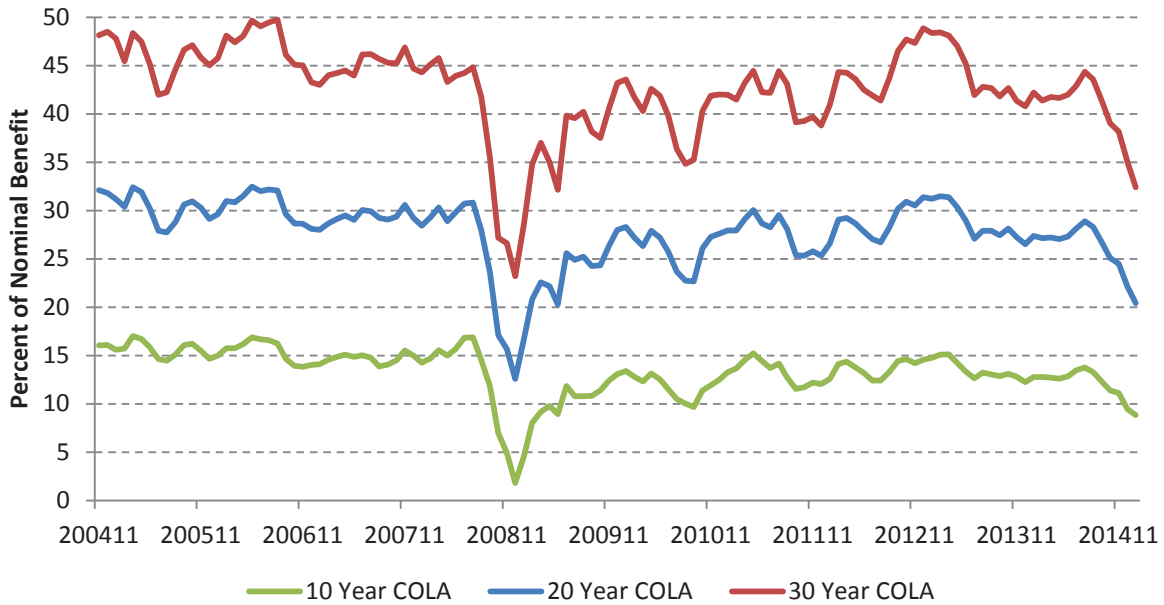
**Figure 5 10-Year Zero Coupon Inflation Swap Rates versus 10-year Survey of Professional Forecasters Mean 10-Year Inflation Forecast**



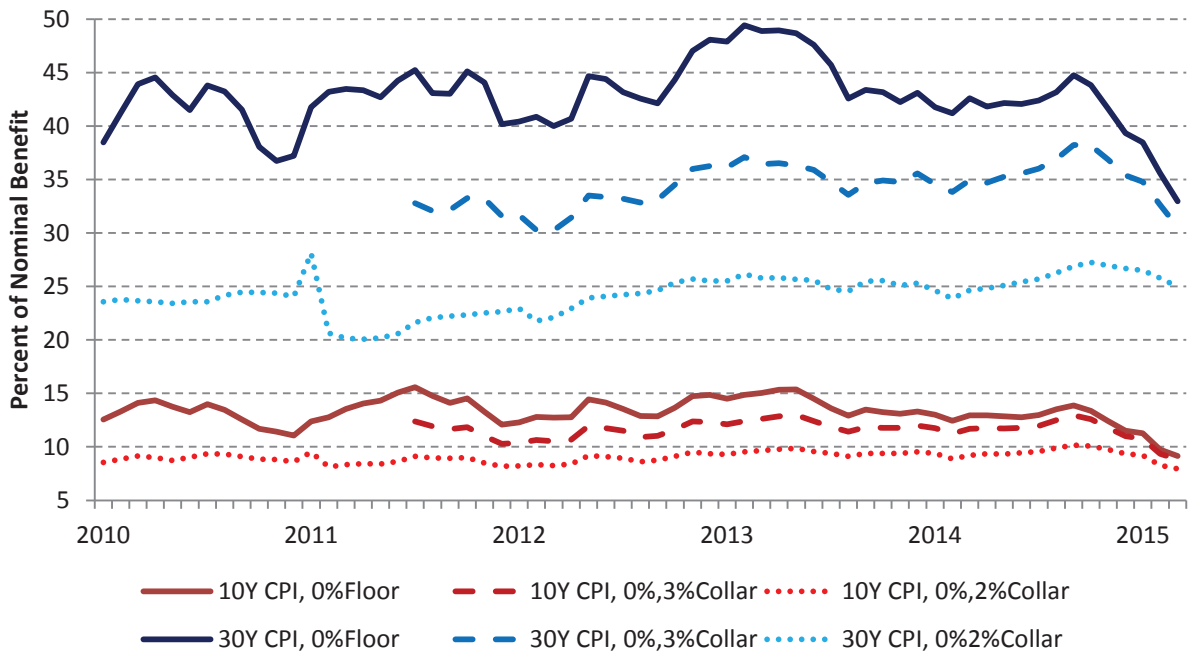
**Figure 6 CPI-Indexed COLA Values as a Multiple of Initial Year Benefit**



**Figure 7 CPI-Indexed COLA Values as a Percent of Total Nominal Benefit**

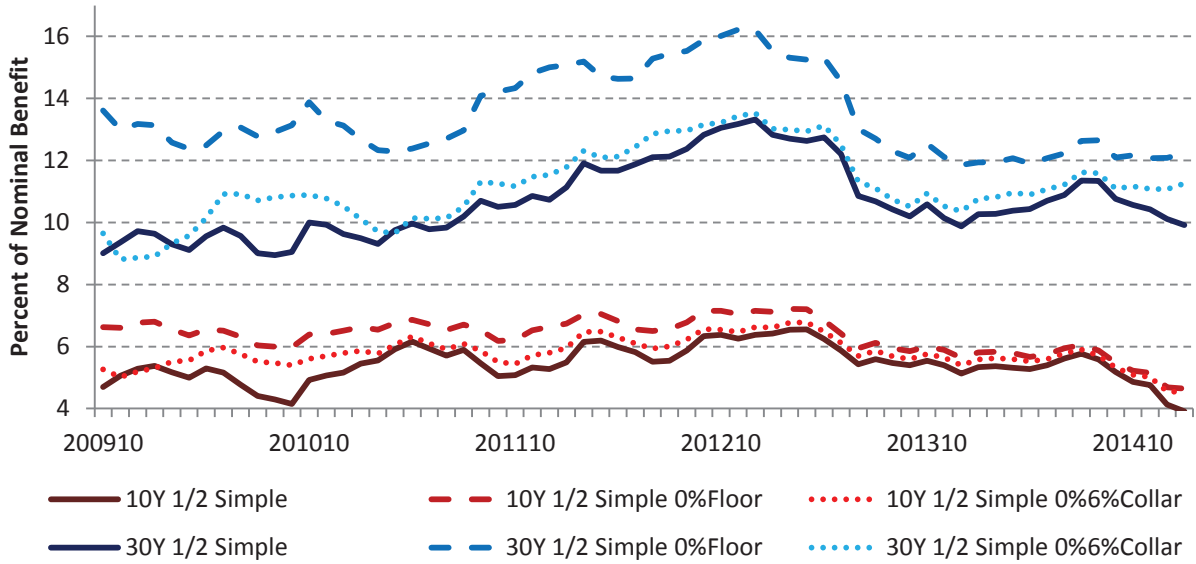


**Figure 8 Values of CPI COLAs with Zero-Coupon Floors and Caps as a Percent of Total Nominal Benefit**

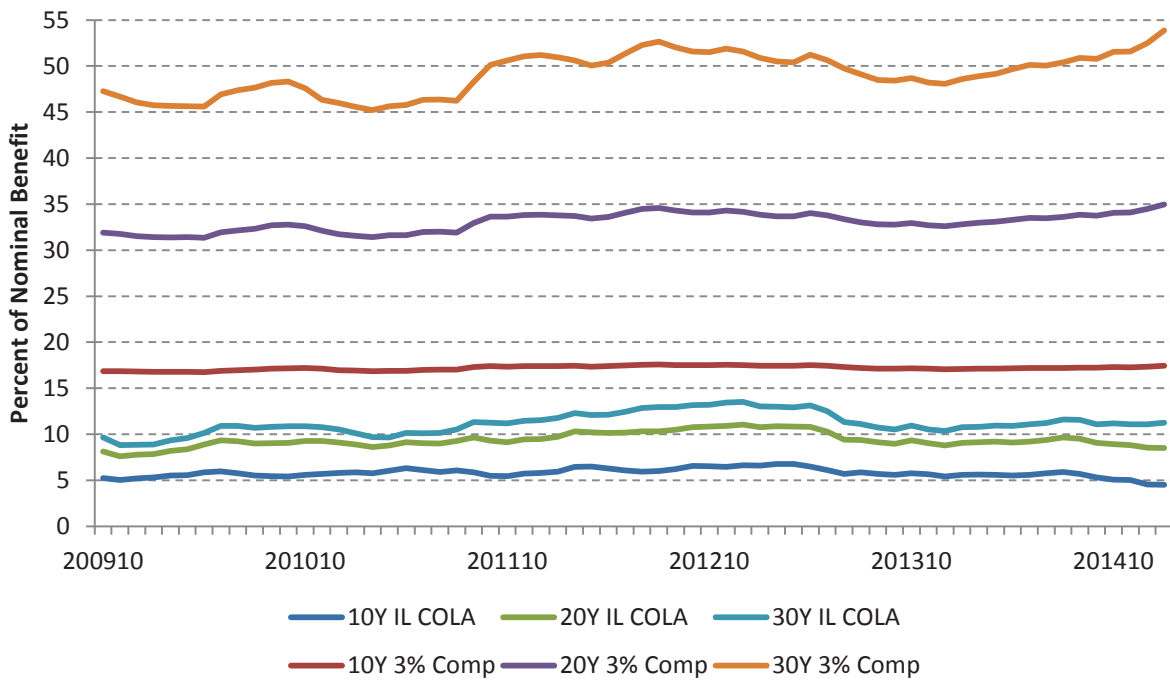




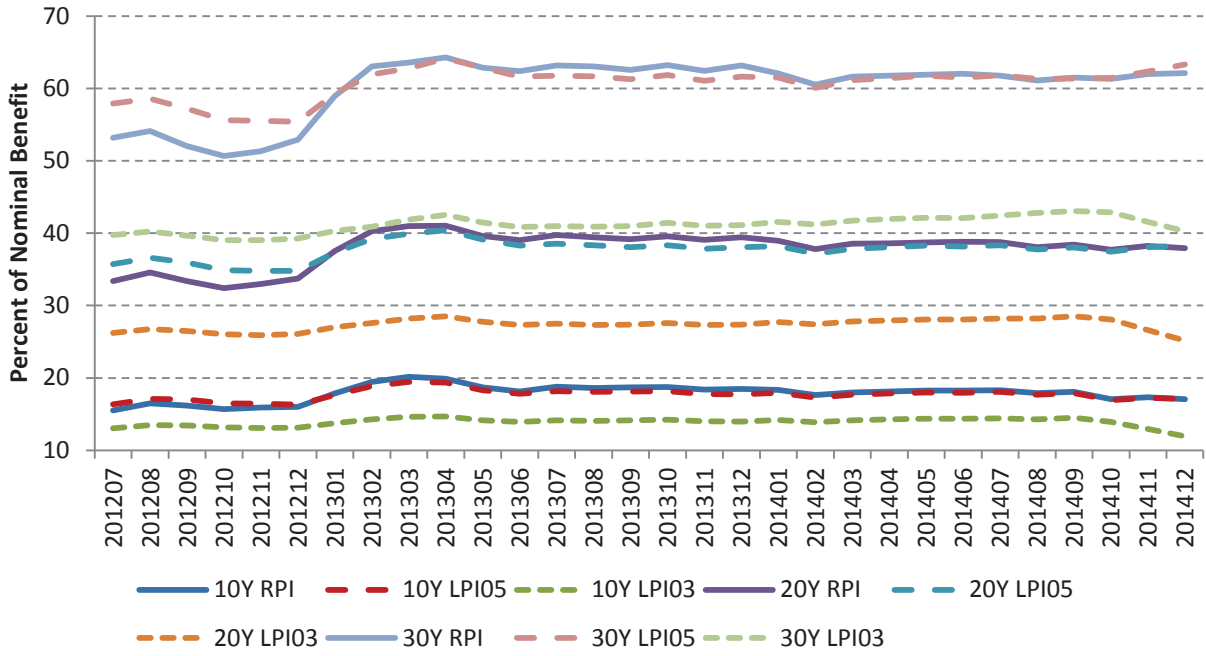
**Figure 9 Values of the Illinois COLA as a Percent of Total Nominal Benefit**



**Figure 10 Illinois COLA versus 3% Compounded Fixed Rate Values as a Percent of Total Nominal Benefit**



**Figure 11 RPI- and LPI- Based COLA Values as a Percent of Total Nominal Benefit**



<u>Description</u>	<u>Source</u>
CDS spreads on U.S. Treasuries	Bloomberg code US CDS EUR SR $yY$ , where $y = 1, 2, \dots$ , or 10
Yields on Treasury coupon notes and bonds	Bloomberg code T $C.R$ $mm/dd/yy$ where $C.R$ is the bond's coupon rate (e.g. 2.125) and $mm/dd/yy$ is the bond's maturity date.
Johnson & Johnson bond yields	Bloomberg code JNJ $C.R$ $mm/dd/yy$ where $C.R$ is the bond's coupon rate (e.g. 5.95) and $mm/dd/yy$ is the bond's maturity date.
Johnson & Johnson CDS spreads	Bloomberg code JNJ CDS USD SR $yY$ , where $y = 5$ or 10
Microsoft bond yields	Bloomberg code MSFT $C.R$ $mm/dd/yy$ where $C.R$ is the bond's coupon rate (e.g. 2.125) and $mm/dd/yy$ is the bond's maturity date.
Microsoft CDS spreads	Bloomberg code MSFT CDS USD SR $yY$ , where $y = 5$ or 10
Yields on zero coupon Treasury securities	Gürkaynak, Sack, and Wright (2007) and available at <a href="http://www.federalreserve.gov/econresdata/researchdata/feds200628.xls">http://www.federalreserve.gov/econresdata/researchdata/feds200628.xls</a> .
Zero-coupon inflation swap rates	Bloomberg code USSWIT $m$ where $m$ is the maturity in years (e.g., $m = 20$ ).
Survey of Professional Forecasters' 10-year inflation forecast	<a href="https://www.philadelphiafed.org/research-and-data/real-time-center/survey-of-professional-forecasters/">https://www.philadelphiafed.org/research-and-data/real-time-center/survey-of-professional-forecasters/</a>
Zero-coupon inflation floors and caps	Bloomberg code for floors is USIZF $fm$ and for caps is USIZC $cm$ where $f$ is the floor rate (e.g., $f = A$ is zero % floor), $c$ is the cap rate (e.g., $c = 3$ is 3% cap) and $m$ is the maturity in years (e.g., $m = 10$ ).
Year on year inflation floors and caps	Bloomberg code for floors is USISF $fm$ and for caps is USISC $cm$ where $f$ is the floor rate (e.g., $f = A$ is zero % floor), $c$ is the cap rate (e.g., $c = 3$ is 3% cap) and $m$ is the maturity in years (e.g., $m = 10$ ).
U.K. zero-coupon RPI inflation swap rates	Bloomberg code BPSWIT $m$ where $m$ is the maturity in years (e.g., $m = 20$ ).
U.K. zero-coupon LPI inflation swap rates	Bloomberg code for the 0% floor 3% cap LPI is BPIL03 $m$ and for the 0% floor 5% cap LPI is BPIL05 $m$ where $m$ is the maturity in years (e.g., $m = 30$ ).
Yields on zero coupon U.K. Treasury securities	Bank of England, available at <a href="http://www.bankofengland.co.uk/statistics/pages/yieldcurve/default.aspx">http://www.bankofengland.co.uk/statistics/pages/yieldcurve/default.aspx</a> .

## Appendix Data Sources