
Insurance Overlays and Retirement Spending: The Case of Protected Lifetime Income

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Insurance overlays allow investors to protect a portfolio against longevity risk without transferring their assets to an insurance company. We study protected lifetime income benefits (PLIB), a type of insurance overlay that allows investors to receive lifetime payments whose annual value fluctuates closely with investment performance. We compare the performance of retirement spending strategies that involve PLIB to strategies that do not involve insurance. Our main finding is that PLIB are effective at raising lifetime income relative to other spending strategies over a range of asset allocations and scenarios. In particular, their higher potential for income growth is helpful for keeping up with inflation. We also highlight the role of income banking, a strategy that may help reduce fluctuations in annual spending.

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1. Introduction

Insurance overlays, also marketed as contingent deferred annuities (CDA), allow investors to protect a portfolio against longevity risk without transferring their assets to an insurance company. The assets remain in the investment account of the client at a custodian (e.g., a brokerage account). Investors pay an annual premium taken from the covered assets and, in exchange, receive a lifetime stream of payments that continues once the account is depleted. Investors can stop paying the premium and forgo protection at any time. Any assets remaining in the account when the investor passes away can be bequeathed.

Traditionally, the income benefits and premiums of CDAs were similar to those of guaranteed lifetime withdrawal benefits (GLWB) riders available in variable annuities contracts. GLWB guarantees are expensive for investors and risky for insurers since they typically protect against both longevity and investment risk, limiting their appeal (see Blanchett 2023 for a recent discussion). Traditional CDAs that mirror the guarantees of GLWBs are potentially subject to the same drawbacks.

More recently, protected lifetime income benefits (PLIB) that allow investors to receive a stream of lifetime income whose value evolves based on the performance of an underlying portfolio have become commercially available. The key innovation of PLIB comes from their benefit formula, which tightly links portfolio returns and the income received by the investor. The investor is entitled to receive a percentage of a benefit base as income every period. The percentage is fixed over the life of the contract and initially set based on age.¹ The benefit base first equals the initial account value. It then evolves according to net (of fees and insurance premiums) returns on the underlying portfolio. Crucially, withdrawals do not reduce the benefit base. When the underlying portfolio is depleted, the last value of the benefit base determines the value of the remaining lifetime income stream.

While longevity risk sharing may be beneficial, investors are averse to annuitizing their assets (e.g., Benartzi et al. 2011; French et al. 2023). PLIB are interesting because they may remove two key hurdles. First, like traditional CDAs, PLIB do not require investors to transfer their assets to an insurance company. Second, investors who apply PLIB to an existing account retain substantial exposure to investment risk. This feature may result in lower insurance premiums and higher upside participation, two characteristics that contrast with the high costs and foregone investment growth that traditional annuities and GLWB/CDA guarantees may entail. PLIB may thus provide an attractive option for investors who wish to benefit from longevity risk protection while retaining control over their investments.

The goal of this paper is to compare the performance of retirement spending strategies that involve PLIB to strategies that do not involve insurance. Our main finding is that PLIB are effective at raising lifetime income relative to other systematic withdrawal strategies. In particular, their

1. For a given age, pricing on a new contract may vary over time due to changing economic conditions.

higher potential for income growth is helpful for keeping up with inflation. Our findings complement those of Blanchett (2023), who studies the use of PLIB as part of a broader retirement income strategy using a utility framework and discusses factors that may account for the relative attractiveness of PLIB relative to other insurance guarantees, including GLWBs. We focus on account values and spending trajectories under different asset allocations with and without a PLIB overlay, study the use of PLIB benefits to target a stable income stream through income banking, and examine the impact of lower-than-expected returns early in retirement.

The paper is organized as follows. Section 2 presents an introduction to PLIB. The mechanics are presented through a worked-out example. PLIB are then situated within the wider landscape of retirement income strategies. Section 3 presents the main simulation results, including results under different asset allocations and adverse portfolio returns. Section 4 concludes.

2. An Introduction to PLIB

We introduce PLIB by contrasting their features to GLWB.

a. GLWB Mechanics

Consider an account with \$1 million. Once income is activated, GLWB payments work as follows.

- The benefit base (sometimes called the income base) is initially set equal to the account value (here, \$1 million). Then, typically, the benefit base is the running maximum of the account value.
- A permissible withdrawal rate is prescribed (e.g., 5%). The annual payment is the product of the benefit base and the withdrawal rate (here, \$50,000 initially).
- The premium can be a percentage of the benefit base or the account value. Blanchett (2023) models a GLWB with full survivor benefits for a couple aged 65 as having a 4.5% withdrawal rate and a 1.5% fee as a percentage of the account value.

The combined drag of the premiums and withdrawals makes it hard for the portfolio to set a new high-water mark and increase the benefit base, except in the case of strong returns early in retirement. Once the account value is low enough, establishing a new high becomes virtually impossible, and withdrawals are normally flat (in nominal terms) until the account is depleted, at which point the GLWB kicks in. Before depletion, investors can typically withdraw any fraction of their account balance at any time. If withdrawals are larger than the regular amount, the guaranteed payments are permanently reduced, often by the ratio of excess withdrawals to current assets.

b. PLIB Mechanics

The distinguishing feature of the PLIB is that the benefit base is indexed to portfolio (net) returns. Net returns are net of the insurance premium (assumed to be 1% in this paper), advisory fees, underlying fund fees, etc. If the initial balance is \$1 million again, the withdrawal rate is 5% and the portfolio net return is 10%, then:

- The account value at the beginning of the second period will be $(\$1,000,000 - \$50,000) \times (1 + 0.1) = \$1,045,000$.
- The benefit base at the beginning of the second period will simply be $\$1,000,000 \times (1 + 0.1) = \$1,100,000$. The prescribed withdrawal at the beginning of the second period (i.e., the highest withdrawal that can be taken without decreasing the benefit base) is $\$1,100,000 \times 0.05 = \$55,000$. The benefit base will therefore tend to increase over time until the account is depleted. At that point, the benefit base becomes constant, and the annuity starts paying fixed payments (again, in nominal terms).

This type of indexing has the interesting property that, for any given stream of returns, the account is depleted after a fixed number of periods, given by the inverse of the withdrawal rate. For instance, with a 4% withdrawal rate, the account is depleted after 25 years exactly. Again, this statement does not merely hold in expectation—it holds in any state of the world. A proof is provided in the Appendix.

Exhibit 1 compares the evolution of an account with PLIB and GLWB overlays. Under both guarantees, annual income is assumed to be 5% of the benefit base. The benefit base of the PLIB depends on net returns only, and the available annual income varies accordingly. The GLWB benefit base, by contrast, is the running maximum of the account values, which are reduced by withdrawals. The exhibit is a stylized version of what happens under more complete simulations: more variable but growing income under PLIB, more stable income with lower growth potential under GLWB.

EXHIBIT 1: Trajectory of the Account Value, Benefit Base, and Annual Income with PLIB and GLWB Guarantees

t =	Net Return	PLIB			GLWB		
		Account Value	Benefit Base	Annual Income	Account Value	Benefit Base	Annual Income
0	-	\$1,000,000	\$1,000,000	\$50,000	\$1,000,000	\$1,000,000	\$50,000
1	10%	\$1,045,000	\$1,100,000	\$55,000	\$1,045,000	\$1,045,000	\$52,250
2	-10%	\$891,000	\$990,000	\$49,500	\$893,475	\$1,045,000	\$52,250
3	10%	\$925,650	\$1,089,000	\$54,450	\$925,348	\$1,045,000	\$52,250

All values are hypothetical. Net returns reflect insurance premiums.

Investors who withdraw the prescribed amount every period may experience large fluctuations in the income they receive. One potential tool to stabilize the income stream consists of income banking, a feature offered by some PLIB solutions. Income banking creates a side account that

evolves according to the same returns as the benefit base and is based on deposits (the gap between actual and prescribed spending when actual spending is lower) and withdrawals (excess spending over the prescribed amount). Banked income would typically be paid as a lump sum when the main account is depleted and guaranteed payments begin.² This feature, however, can also be used by investors who prefer more stability to faster income growth, or those who want the possibility of accessing savings in the future without reducing their guaranteed income.

One extreme case, shown in **Exhibit 2**, is that of an investor who attempts to keep their withdrawals completely fixed and uses banked income to smooth over periods during which the target income (\$50,000) is above what the PLIB can support. At the end of the first period ($t = 1$), the prescribed income is \$55,000. The extra \$5,000 is banked and evolves according to net returns. At the end of the second period ($t = 2$), the banked income is worth 10% less because of the negative 10% return, that is, \$4,500. So, \$500 is used to make up the shortfall between prescribed (\$49,500) and target (\$50,000) spending, leaving the investor with \$4,000 in banked income.

EXHIBIT 2: Income Banking with PLIB

$t =$	Net Return	PLIB				
		Account Value	Benefit Base	Prescribed Annual Income	Withdrawn Annual Income	Banked Income
0	-	\$1,000,000	\$1,000,000	\$50,000	\$50,000	\$0
1	10%	\$1,045,000	\$1,100,000	\$55,000	\$50,000	\$5,000
2	-10%	\$895,500	\$990,000	\$49,500	\$50,000	\$4,000
3	10%	\$930,050	\$1,089,000	\$54,450	\$50,000	\$8,850

All values are hypothetical. Net returns reflect insurance premiums.

c. Comparison to Other Retirement Strategies

Investors planning for retirement face two key risks: investment risk and longevity risk. The simplest way to hedge longevity risk is mortality pooling. Mortality pooling is achieved when a group agrees that the contributions of those who die early will benefit those who survive (e.g., defined benefit pension plan, annuity), or, conversely, that the contributions of those who die late will benefit the estate of those who die early (e.g., life insurance). Longevity risk is conceptually separate from investment risk.³ However, the desired combination of investment risk, longevity risk, and flexibility (i.e., whether assets are irrevocably committed or not) may not be available. **Exhibit 3** presents a two-by-two box with examples of financial instruments used in retirement planning and how they vary along both dimensions.⁴ Arguably, GLWBs would be somewhere between the top-left and top-right quadrants.

2. Even in PLIB solutions that do not explicitly offer income banking, investors could achieve a similar result by withdrawing the entire income they are eligible for and investing the excess funds in a side account.

3. See Yaari (1965) for a theoretical treatment and Fullmer (2019) for an introduction to tontines, which potentially allow investors to decouple investment and longevity risk. Blanchett (2023) also notes the connection between PLIB and pure mortality pooling.

4. Pfau and Murguia (2021) present a two-by-two classification, the RISA matrix, with psychological preferences for safety/risk and commitment/optionality as the two main dimensions. Mortality pooling may be associated with greater commitment through the explicit contract terms of annuities and other longevity guarantees. However, the degree of flexibility available to investors varies considerably across solutions (irrevocable commitment for traditional annuities, greater flexibility for GLWB/PLIB).

EXHIBIT 3: Longevity Risk vs. Investment Risk for Different Investments

		Investment Risk	
		Less Risk	More Risk
Longevity Risk	Mortality Pooling	<ul style="list-style-type: none"> ▪ Single premium immediate annuity ▪ Defined benefit pension plan 	<ul style="list-style-type: none"> ▪ Variable annuity with variable annuitization ▪ Protected lifetime income benefits (PLIB)
	No Mortality Pooling	<ul style="list-style-type: none"> ▪ Treasury bills ▪ Investment-grade bonds 	<ul style="list-style-type: none"> ▪ Stocks ▪ Real estate investment trusts (REITs) ▪ High-yield bonds

For Illustrative Purposes Only.

PLIB offer protection against longevity risk, allow investors to control the tradeoff between income growth and downside potential by tightly linking income to the performance of a portfolio that they choose, and allow investors to access their assets at any time. Therefore, PLIB may expand the investment opportunity set of investors relative to other existing solutions. In particular, PLIB are most similar to variable annuitization, a strategy that also involves lifetime payments whose value is tightly linked to a portfolio.⁵ However, variable annuitization involves irrevocably committing assets. PLIB paired with either low-risk or high-risk investments, or even hedging instruments (e.g., inflation-indexed bonds), could be used to achieve a wide range of lifetime payoff streams.⁶ The possibility of income banking further increases the range of payoff streams that could be generated.

5. In particular, variable annuitization with an assumed interest rate (AIR) of zero percent would generate payments that fluctuate one-for-one with portfolio returns (e.g., Chapter 5 in Dellinger, 2023).

6. For more information about the average real returns on different asset classes and their behavior during inflationary periods, see Dai and Medhat (2021).

3. Simulation Evidence

To analyze PLIB behavior in various market environments, we bootstrap annual returns and inflation between 1985 and 2024 to construct 10,000 simulations of 50-year return histories. The returns are based on asset allocation indices, the Dimensional Core Index Allocations, for different splits between equities and fixed income (0/100, 20/80, ..., 100/0). A fee of 1%, meant to capture advisory fees and fees on underlying investments, applies to all strategies.⁷ The insurance premium for strategies involving a PLIB is assumed to be 1% of the portfolio value.

We examine four withdrawal strategies, all with an initial withdrawal rate of 4.25% and an initial balance of \$1 million.

- **Flexible rule:** The investor spends 4.25% of the account balance in every period.
- **Insured flexible rule:** The investor spends the prescribed PLIB amount in every period. Since the benefit base is not affected by withdrawals, the withdrawal percentage of assets under this strategy ("effective withdrawal rate") will tend to grow much larger than 4.25%.
- **Fixed rule:** The initial payment is \$42,500. The payment in subsequent years is the initial payment indexed to inflation. When the payment is larger than remaining assets, the account is depleted, and failure occurs.
- **Insured fixed rule:** The initial payment is \$42,500. The target payment in subsequent years is the initial amount indexed to inflation. The investor withdraws the minimum of (i) the target payment and (ii) the amount prescribed by the PLIB, plus any remaining banked income. While the strategy allows for adjustments in the face of poor returns, which the fixed rule does not, the objective is the same—sustain a fixed stream of consumption over retirement.

We present results for income and account balance. All quantities are presented in real terms.

a. Baseline Results

Baseline results assume a 60/40 allocation. We first look at medians (50th percentile) across simulations for spending and account values over a 50-year investment horizon.

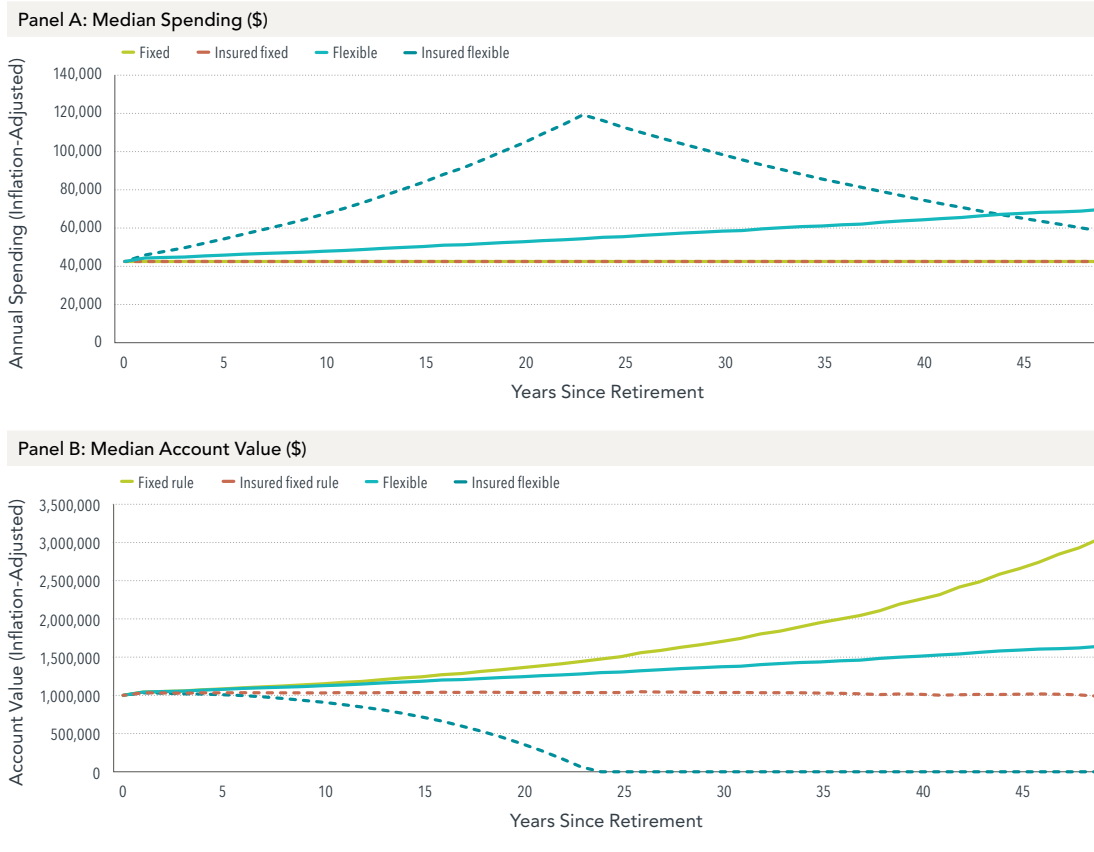
The median payment under the fixed rule is \$42,500 over the entire 50-year horizon because the failure rate does not rise over 50%. The median account balance grows throughout retirement. The median payment under the flexible rule grows steadily, as does the account value, albeit slower than under the 4.25% rule.

The insured fixed rule cannot experience complete failures but can still experience below-target income if the PLIB-prescribed spending is below target and there isn't sufficient banked income to make up for the difference. Nevertheless, the trajectory of median income is flat and equal to that of the fixed rule: Median spending after 50 years is still \$42,500 in real terms. However,

7. Assumptions about fees are implicitly based on a setup in which a hypothetical client who already works with a financial advisor compares the tradeoff between spending strategies with and without insurance.

the median account value stagnates: The median account value after 30 years, the length of a typical retirement, would be \$1 million, compared to \$1.7 million for the uninsured fixed rule. The gap reflects the cost of insurance.

EXHIBIT 4: Median (50th Percentile) Real Spending and Real Account Balances over Time, 60/40 Allocation



All amounts shown are in constant dollars. Results are based on 10,000 simulated 50-year return histories constructed via bootstrap. Annual real returns are based on Dimensional Core Index Allocations and US inflation as measured through the consumer price index (CPI). The historical sample from which bootstrapped values are taken ranges from 1985 to 2024 inclusively. All returns are reduced by 1% to reflect hypothetical advisory fees. Returns are reduced by a further 1% for the insured strategies to reflect the cost of insurance guarantees. See Section 3 for a complete description of spending strategies. See Appendix A for a description of Dimensional Core Index Allocations.

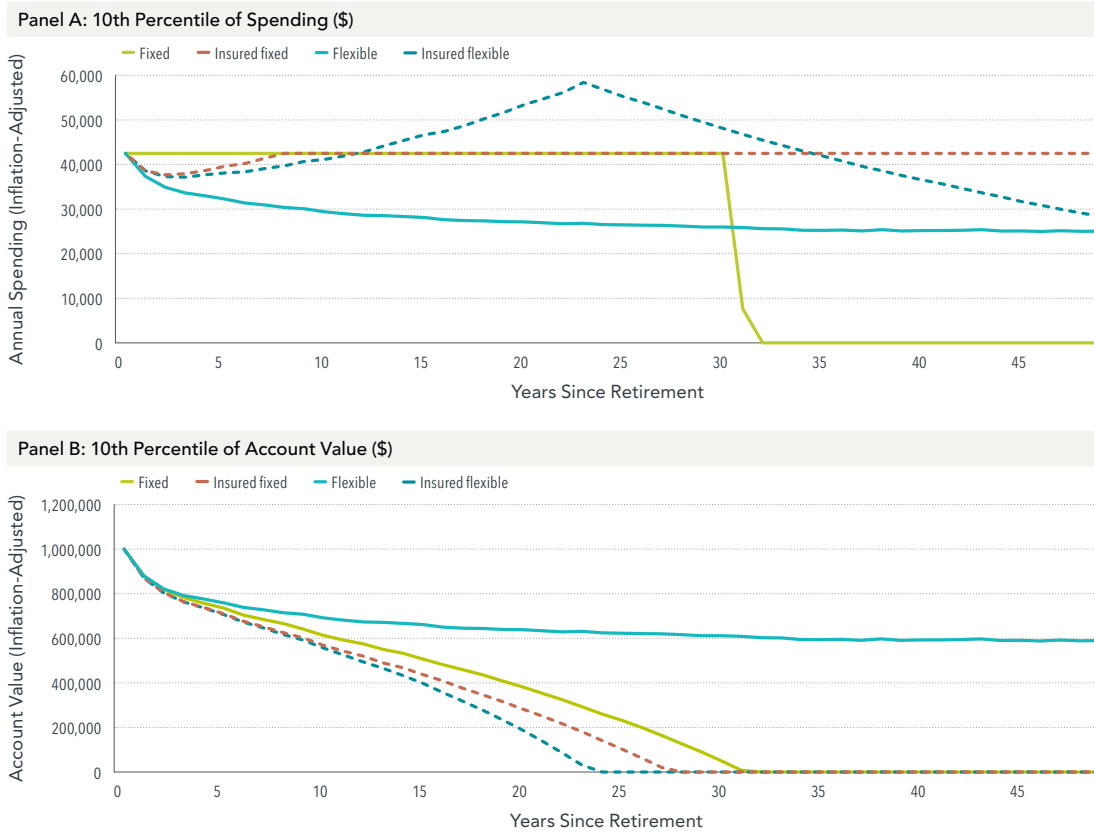
The insured flexible rule generates the highest median income by far, with a tent-shaped profile. With a 4.25% withdrawal rate, account depletion occurs after 23.5 years. After that point, the account is empty, and the income paid by the annuity is flat in nominal terms, leading to a gradual erosion of purchasing power. It nevertheless offers much higher income than the fixed strategies, even late in retirement. Median income peaks around \$120,000, close to three times the starting income, right before the benefit base starts growing.

We also consider the 10th percentile of outcomes at each point in time. The 10th percentile of spending under the fixed rule falls at 0 after approximately 30 years, which corresponds to when the failure rate rises above 10%. Spending under the flexible rule decreases steadily, as does the account value, though both quantities eventually stabilize.

The insured fixed rule is equal to \$42,500 throughout, save for a brief blip in spending at the beginning. The result implies that in later years, the prescribed PLIB withdrawal is constraining less than 10% of the time. Note that the account value eventually depletes, which is not the case under the median scenario. In our simulations, the banked income feature is available after account depletion as well. Therefore, two mechanisms potentially explain why the income stays constant in real terms even when the account is depleted.

- In the absence of any banked income, the prescribed PLIB spending may be so much higher than the target spending that it takes decades for the constraint to be binding (when inflation eventually pushes the target payment above the PLIB-prescribed amount). During that period, the target spending (\$42,500 in real terms) remains untouched.
 - During that period, the investor keeps banking income, which grows according to net returns. Once the constraint finally becomes binding, banked income can be depleted to bridge the difference.
 - In practice, banked income is paid out as a lump sum when the account is depleted. Similar results as in the simulations could be achieved by taking the lump sum, putting it in a separate account, spending according to the PLIB-prescribed amount, then depositing excess funds in the separate account.
- Spending under the insured flexible rule is much lower at the 10th percentile than the median case, peaking at less than \$60,000 at account depletion rather than more than \$120,000 at the median, and falls below that of the insured fixed rule later in retirement. Account depletion happens at the exact same time but follows a sharper downward trajectory.

EXHIBIT 5: 10th Percentile of Real Spending and Real Account Balances over Time, 60/40 Allocation



All amounts shown are in constant dollars. Results are based on 10,000 simulated 50-year return histories constructed via bootstrap. Annual real returns are based on Dimensional Core Index Allocations and US inflation as measured through the consumer price index (CPI). The historical sample from which bootstrapped values are taken ranges from 1985 to 2024 inclusively. All returns are reduced by 1% to reflect hypothetical advisory fees. Returns are reduced by a further 1% for the insured strategies to reflect the cost of insurance guarantees. See Section 3 for a complete description of spending strategies. See Appendix A for a description of Dimensional Core Index Allocations.

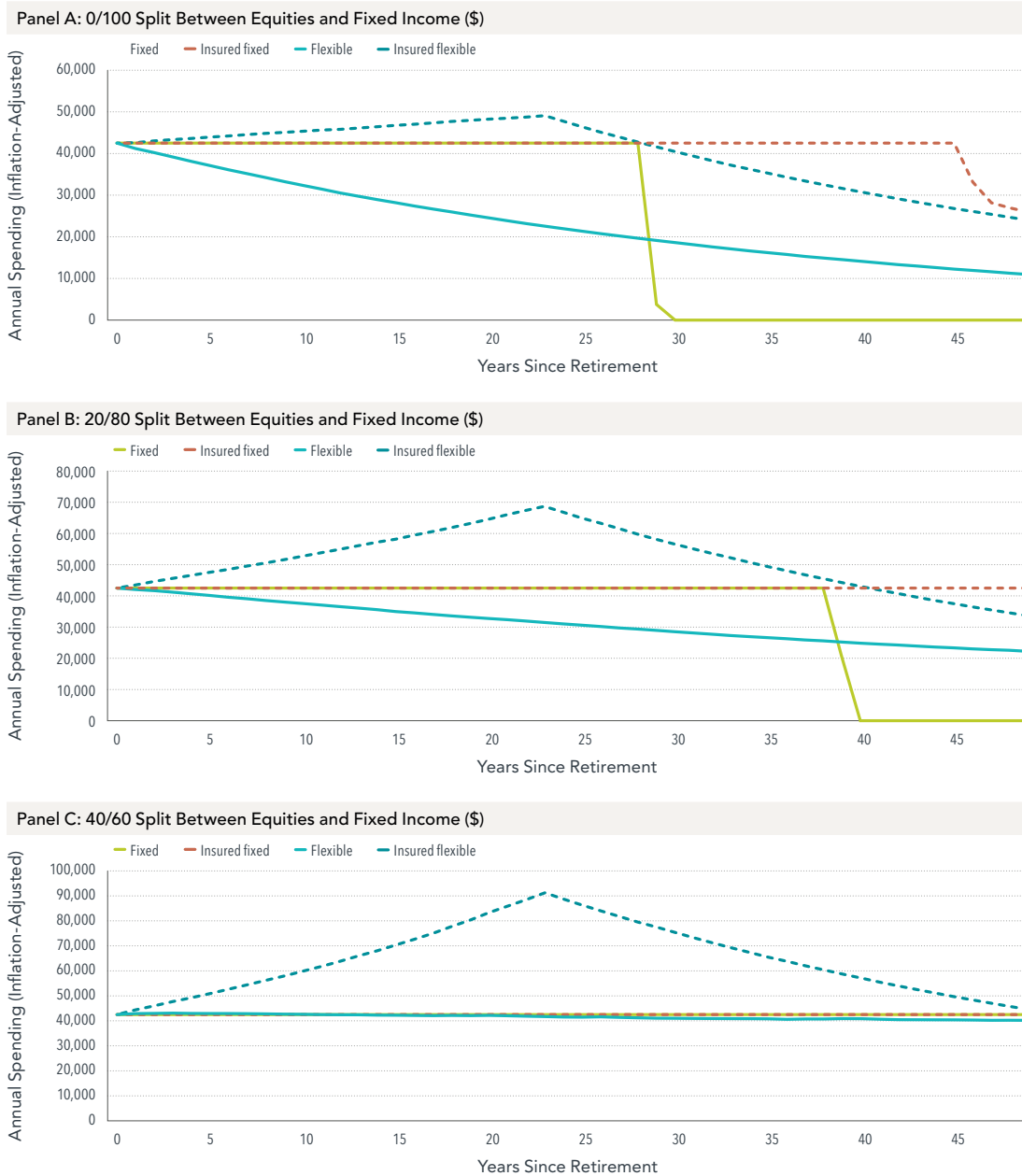
b. Comparison Among Asset Allocations

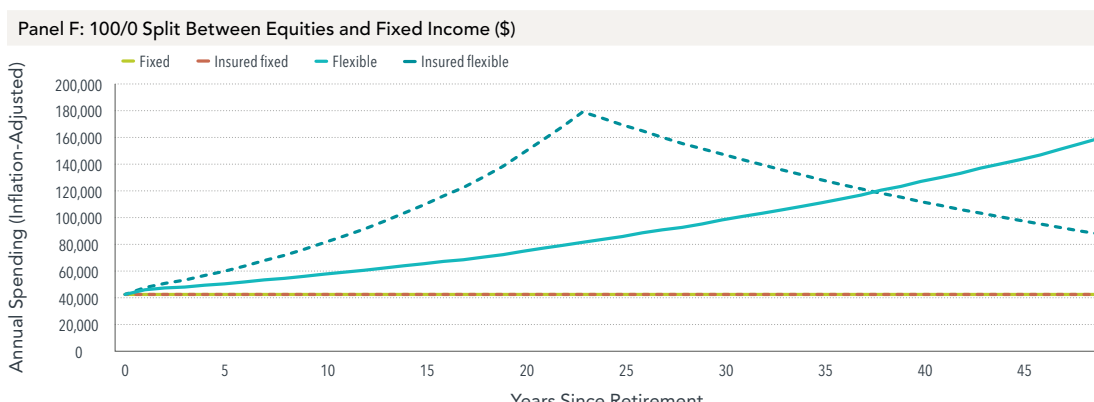
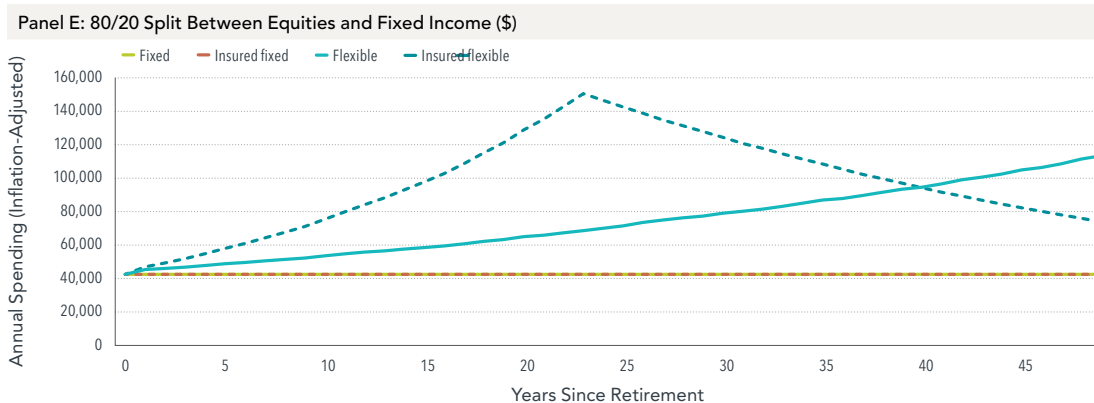
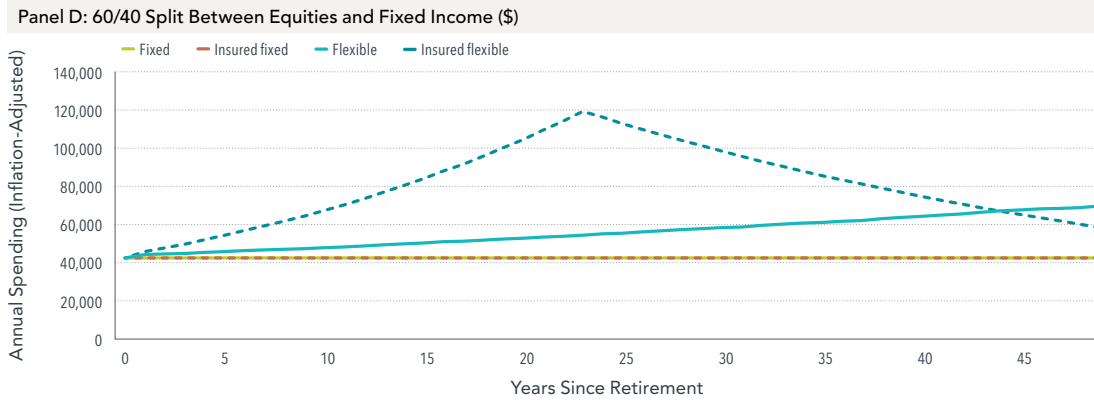
For brevity, we focus on median spending only. We consider asset splits between equities and fixed income ranging from 0/100 to 100/0 by increments of 20%.

- Failure under the fixed rule happens before 30 years more than 50% of the time with an all-bond allocation, and within 40 years with a 20/80, since returns are not high enough to sustain spending. The rule experiences few failures under more aggressive allocations because of the high average stock returns over the sample (12.6%).
- The median payment under the flexible rule declines steadily under the 0/100 and 20/80 allocations. A 4.25% withdrawal rate every period, in addition to a 1% advisory fee, amounts to a 5.25% hurdle for returns to overcome. In contrast, the payment is stable under a 40/60 allocation and grows with higher allocations to equities.

- Interestingly, the insured fixed rule behaves as before and sustains spending even under a 20/80 allocation. The PLIB-prescribed spending constraint only becomes binding late in retirement under a 0/100 allocation.
- The insured flexible rule exhibits the expected behavior: a slower rise of spending to a lower peak with 0/100, and a faster rise to a higher peak with 100/0, with other cases in between.

EXHIBIT 6: Median Real Spending over Time for All Asset Allocations





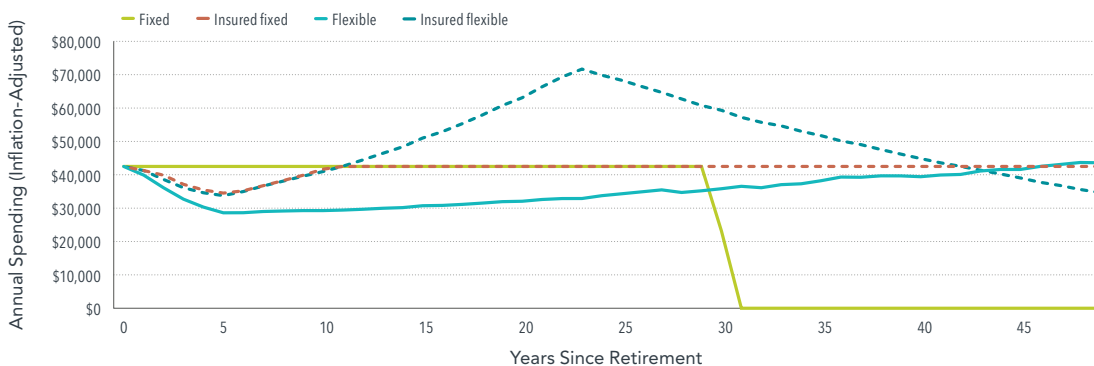
All amounts shown are in constant dollars. Results are based on 10,000 simulated 50-year return histories constructed via bootstrap. Annual real returns are based on Dimensional Core Index Allocations and US inflation as measured through the consumer price index (CPI). The historical sample from which bootstrapped values are taken ranges from 1985 to 2024 inclusively. All returns are reduced by 1% to reflect hypothetical advisory fees. Returns are reduced by a further 1% for the insured strategies to reflect the cost of insurance guarantees. See Section 3 for a complete description of spending strategies. See Appendix A for a description of Dimensional Core Index Allocations.

c. Portfolio Shock

Our analysis is based on 10,000 simulated paths. We now focus on the subset of 1,000 paths that has the lowest portfolio returns in the first five years of retirement. This is deemed to be the “portfolio shock” subsample. The average annual return on the all-stock allocation in the sample (and, therefore, during the first five years of retirement) is 12.6%. In the subsample, the average annual return over the first five years is –2.9% for an all-stock portfolio. Under the portfolio shock:

- The median payment under the fixed rule goes to zero more quickly, owing to earlier and more numerous failures.
- The median payment under the flexible rule drops, then recovers.
- The insured fixed rule experiences a dip early in retirement as the PLIB-prescribed spending is binding, but eventually recovers to the usual path.
 - Taken together, the findings suggest that the insured 4.25% strategy, or using banked income more generally, works fairly well to stabilize income across asset allocations and environments.
- The insured flexible rule drops, then recovers, exhibiting the usual pattern (albeit with a much lower peak).

EXHIBIT 7: Median Real Spending, 60/40 Allocation, Based on the 10% of Simulations with the Lowest Portfolio Returns in the First Five Years of Retirement



All amounts shown are in constant dollars. Results are based on the 1,000 out of 10,000 simulated 50-year return histories constructed via bootstrap with the lowest average return in the first five years. Annual real returns are based on Dimensional Core Index Allocations and US inflation as measured through the consumer price index (CPI). The historical sample from which bootstrapped values are taken ranges from 1985 to 2024 inclusively. All returns are reduced by 1% to reflect hypothetical advisory fees. Returns are reduced by a further 1% for the insured strategies to reflect the cost of insurance guarantees. See Section 3 for a complete description of spending strategies. See Appendix A for a description of Dimensional Core Index Allocations.

4. Conclusion

Our study suggests that protected lifetime income benefits (PLIB) may be a valuable tool to help investors increase their retirement spending. The structure of the guarantee, which decouples longevity risk hedging through mortality pooling from investment risk management, may make PLIB less onerous and more flexible than traditional insurance guarantees. In particular, the tight link between investment performance and income may help investors (and their advisors) better target the desired tradeoff between income volatility and income growth by choosing appropriate investments. Finally, our simulations outline how income banking may allow PLIB guarantees to create more customized spending strategies, including strategies that reduce annual spending fluctuations.

5. References

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6. Appendix

a. Dimensional Core Index Allocations

EXHIBIT A1: Dimensional Core Index Allocations

Dimensional Core Index Allocations

WEIGHTS (%)

The Dimensional Index Allocations represent Dimensional's research-driven, systematic approach to asset allocation. The Core Index Allocations are constructed using mostly Dimensional indices and are designed to have a stronger emphasis on securities with higher expected returns than the Core Market Index Allocations. The allocations may inform expectations about the performance of different asset allocations over time and about return deviations versus the market.

	0%	20%	40%	60%	80%	100%
EQUITY	0%	20%	40%	60%	80%	100%
Dimensional US Core Equity 1 Index	0.0	7.1	14.2	21.3	28.4	35.5
Dimensional US Core Equity 2 Index	0.0	7.1	14.2	21.3	28.4	35.5
Dimensional International Core Equity 2 Index	0.0	3.8	7.6	11.4	15.2	19.0
Dimensional Emerging Markets Core Equity 2 Index	0.0	1.6	3.2	4.8	6.4	8.0
S&P Global REIT Index	0.0	0.4	0.8	1.2	1.6	2.0
FIXED INCOME	100%	80%	60%	40%	20%	0%
Bloomberg US TIPS Index	20.0	0.0	0.0	0.0	0.0	0.0
Dimensional Short-Term Extended Quality Index	80.0	50.0	30.0	15.0	0.0	0.0
Dimensional US Core Fixed Income Index	0.0	15.0	15.0	10.0	5.0	0.0
Dimensional Global ex US Core Fixed Income Index (Hedged to USD)	0.0	15.0	15.0	10.0	5.0	0.0
Dimensional Global Credit Bond Index (Hedged to USD)	0.0	0.0	0.0	5.0	10.0	0.0

Weights as of December 31, 2024. Rebalanced monthly. Totals may not equal 100% due to rounding. For illustrative purposes only. The Index Allocations are unmanaged and are not subject to fees and expenses typically associated with managed accounts or investment funds. Indices are not available for direct investment. **Past performance is no guarantee of future results.**

The Dimensional indices used in the construction of the Index Allocations represent academic concepts that may be used in portfolio construction. The Index Allocations and the indices are not available for direct investment or for use as a benchmark. Their performance does not reflect the expenses associated with the management of an actual portfolio. The Index Allocations and index returns are not representative of actual portfolios and do not reflect costs and fees associated with an actual investment. See "Sources and Descriptions of Data" for additional information, including descriptions of the Dimensional index data.

b. Proof That the Time to Account Depletion Is Proportional to the Inverse of the Withdrawal Rate

The withdrawal rate is d , r is the net return, A is the account balance and B is the benefit base. Let T be the time at which depletion occurs. We want to prove that $T = 1/d$.

First, we will show that for any period t :

$$A_t = B_0 (1 + r_1) \times \dots \times (1 + r_t)(1 - d \times t)$$

If the relation holds, the last term implies that assets are positive when $t < 1/d$ and zero when $t = T = 1/d$.

We prove the result by induction. Note that for period one, A_1 can be written as:

$$A_1 = (A_0 - B_0 \times d) (1 + r_1) = B_0(1 + r_1)(1 - d)$$

Therefore, the relation holds for $t = 1$. Now, if we assume that the relation holds for t arbitrary, it holds for $t + 1$ as well. $B_t = B_0 (1 + r_1) \times \dots \times (1 + r_t)$

$$A_t = B_0 (1 + r_1) \times \dots \times (1 + r_t)(1 - d \times t)$$

Using the formulation for benefit base and the assumption that the relation holds for t , we have that:

$$\begin{aligned} A_{t+1} &= (A_t - B_t \times d) (1 + r_{t+1}) = B_0(1 + r_1) \times \dots \times (1 + r_t)(1 + r_{t+1}) [(1 - d \times t) - d] \\ &= B_0(1 + r_1) \times \dots \times (1 + r_t)(1 + r_{t+1}) (1 - d \times [t + 1]) \end{aligned}$$

This completes the proof.

Sources and Descriptions of Data

Dimensional US Core Equity 1 Index

January 1975–present

Compiled by Dimensional from CRSP and Compustat data. Targets all the securities in the eligible market with an emphasis on companies with smaller capitalization, lower relative price, and higher profitability, excluding those with the lowest profitability and highest relative price within the small cap universe. The index also excludes those companies with the highest asset growth within the small cap universe. Profitability is defined as operating income before depreciation and amortization minus interest expense divided by book equity. Asset growth is defined as change in total assets from the prior fiscal year to current fiscal year. The eligible market is composed of securities of US companies traded on the NYSE, NYSE MKT (formerly AMEX), and Nasdaq Global Market. Exclusions: non-US companies, REITs, UITs, and investment companies. The index has been retrospectively calculated by Dimensional and did not exist prior to March 2007. Accordingly, the results shown during the periods prior to March 2007 do not represent actual returns of the index. Other periods selected may have different results, including losses. The calculation methodology for the index was amended in January 2014 to include profitability as a factor in selecting securities for inclusion in the index. The calculation methodology for the index was amended in December 2019 to include asset growth as a factor in selecting securities for inclusion in the index.

Prior to January 1975

Compiled by Dimensional from CRSP and Compustat data. Targets all the securities in the eligible market with an emphasis on companies with smaller capitalization and lower relative price. The eligible market is composed of securities of US companies traded on the NYSE, NYSE MKT (formerly AMEX), and Nasdaq Global Market. Exclusions: non-US companies, REITs, UITs, and investment companies.

Dimensional US Core Equity 2 Index

January 1975–present

Compiled by Dimensional from CRSP and Compustat data. Targets all the securities in the eligible market with an emphasis on companies with smaller capitalization, lower relative price, and higher profitability, excluding those with the lowest profitability and highest relative price within the small cap universe. The index also excludes those companies with the highest asset growth within the small cap universe. Profitability is defined as operating income before depreciation and amortization minus interest expense divided by book equity. Asset growth is defined as change in total assets from the prior fiscal year to current fiscal year. The eligible market is composed of securities of US companies traded on the NYSE, NYSE MKT (formerly AMEX), and Nasdaq Global Market. Exclusions: non-US companies, REITs, UITs, and investment companies. The index has been retrospectively calculated by Dimensional and did not exist

prior to March 2007. Accordingly, the results shown during the periods prior to March 2007 do not represent actual returns of the index. Other periods selected may have different results, including losses. The calculation methodology for the index was amended in January 2014 to include profitability as a factor in selecting securities for inclusion in the index. The calculation methodology for the index was amended in December 2019 to include asset growth as a factor in selecting securities for inclusion in the index.

Prior to January 1975

Compiled by Dimensional from CRSP and Compustat data. Targets all the securities in the eligible market with an emphasis on companies with smaller capitalization and lower relative price. The eligible market is composed of securities of US companies traded on the NYSE, NYSE MKT (formerly AMEX), and Nasdaq Global Market. Exclusions: non-US companies, REITs, UITs, and investment companies.

Dimensional International Core Equity 2 Index

Compiled by Dimensional from Bloomberg securities data. Targets all the securities in the eligible markets with an emphasis on companies with smaller capitalization, lower relative price, and higher profitability, excluding those with the lowest profitability and highest relative price within their country's small cap universe. The index also excludes those companies with the highest asset growth within their country's small cap universe. Profitability is defined as operating income before depreciation and amortization minus interest expense divided by book equity. Asset growth is defined as change in total assets from the prior fiscal year to current fiscal year. The index monthly returns are computed as the simple average of the monthly returns of four subindices, each one reconstituted once a year at the end of each quarter of the year. Maximum index weight of any one company is capped at 5%. Countries currently included are Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Hong Kong, Ireland, Israel, Italy, Japan, the Netherlands, New Zealand, Norway, Portugal, Singapore, Spain, Sweden, Switzerland, and the UK. Exclusions: REITs and investment companies. The index has been retrospectively calculated by Dimensional and did not exist prior to April 2008. Accordingly, the results shown during the periods prior to April 2008 do not represent actual returns of the index. The calculation methodology for the index was amended in January 2014 to include profitability as a factor in selecting securities for inclusion in the index. The calculation methodology for the index was amended in November 2019 to include asset growth as a factor in selecting securities for inclusion in the index

Dimensional Emerging Markets Core Equity 2 Index

Compiled by Dimensional from Bloomberg securities data. Targets large cap securities in the eligible markets with an emphasis on companies with smaller capitalization, lower relative price, and higher profitability. Profitability is defined as operating income before depreciation and amortization minus interest expense divided by book equity. The index monthly returns are

computed as the simple average of the monthly returns of four subindices, each one reconstituted once a year at the end of each quarter of the year. Maximum index weight of any one company is capped at 5%. Countries currently included are Brazil, Chile, China, Colombia, the Czech Republic, Greece, Hungary, India, Indonesia, Kuwait, Malaysia, Mexico, Peru, the Philippines, Poland, Qatar, Saudi Arabia, South Africa, South Korea, Taiwan, Thailand, Turkey, and the UAE. Exclusions: REITs and investment companies. The index has been retrospectively calculated by Dimensional and did not exist prior to April 2008. Accordingly, the results shown during the periods prior to April 2008 do not represent actual returns of the index. The calculation methodology for the index was amended in January 2014 to include profitability as a factor in selecting securities for inclusion in the index. The calculation methodology for the index was amended in November 2019 to include asset growth as a factor in selecting securities for inclusion in the index.

S&P Global REIT Index

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Bloomberg US TIPS Index

Bloomberg data provided by Bloomberg.

Dimensional Short-Term Extended Quality Index

Compiled by Dimensional using data provided by Bloomberg. Includes securities in Bloomberg US 3–5 Year Government, Credit Aaa, Aa, A, Baa indices, and Bloomberg US 1–3 Year Government, Credit Aaa, Aa, A, Baa indices. Securities can be over- or underweighted based on government/credit spreads. When the difference in yields between credit and government bonds is narrow, government bonds may be overweighted. When the difference in yields between credit and government bonds is wide, government bonds may be underweighted. Securities can be over- or underweighted with respect to their market cap weight based on credit spreads. When the difference in yields between AAA+AA and A+BBB is narrow, AAA+AA bonds may be held above market cap weight. When the difference in yields between AAA+AA and A+BBB is wide, AAA+AA bonds may be held below market cap weight. When the difference in yields between AAA+AA and BBB is narrow, BBB bonds may be held below market cap weight. When the difference in yields between AAA+AA and BBB is wide, BBB bonds may be held above market cap weight. The duration of the index is based on the term spread between the 3–5 year government/credit bonds and 1–3 year government/credit bonds. When the term spread is wide, the duration of the index can be longer than the duration of the Bloomberg US Credit 1–5 Year Index. When the term spread is narrow, the duration of the index can be shorter than the duration of the Bloomberg US Credit 1–5 Year Index. The duration of the government component is based on the term spread between 3–5 year government bonds and 1–3 year government bonds. When the term spread is wide, the duration of the index can be longer

than the duration of the Bloomberg US Government 1–5 Year Index. When the term spread is narrow, the duration of the index can be shorter than the duration of the Bloomberg US Government 1–5 Year Index. Rebalanced monthly. The index has been retrospectively calculated by Dimensional and did not exist prior to January 2020. Accordingly, results shown during the periods prior to January 2020 do not represent actual returns of the index. Other periods selected may have different results, including losses.

Dimensional US Core Fixed Income Index

Compiled by Dimensional using data provided by Bloomberg. Includes securities in the Bloomberg US 5–10Y Government, Credit Aaa, Aa, A, Baa indices; Bloomberg US 1–5Y Government, Credit Aaa, Aa, A, Baa indices; and Bloomberg Remix Portfolio (TBA Proxy) Index. Securities can be over- or underweighted based on government/ credit spreads. When the difference in yields between credit and government bonds is narrow, government bonds may be held above 50%. When the difference in yields between credit and government bonds is wide, government bonds may be held below 50%. Securities can be over- or underweighted with respect to their market cap weight based on credit spreads. When the difference in yields between AAA+AA and A+BBB is narrow, AAA+AA bonds may be held above market cap weight. When the difference in yields between AAA+AA and A+BBB is wide, AAA+AA bonds may be held below market cap weight. When the difference in yields between AAA+AA and BBB is wide, BBB bonds may be held above market cap weight. The duration of the index is based on the duration of its government/credit component and the duration of the Bloomberg Remix Portfolio (TBA Proxy) Index. The duration of the government/credit component of the index is based on the term spread between 5–10 year government/credit bonds and 1–5 year government/credit bonds. When the term spread is wide, the duration of the government/credit component can be slightly shorter than the duration of the Bloomberg US Aggregate Bond Index.

When the term spread is narrow, the duration of the government/credit component can be moderately shorter than the duration of the Bloomberg US Aggregate Bond Index. The duration of the government component is based on the term spread between 5–10 year government bonds and 1–5 year government bonds. When the term spread is wide, the duration of the government component can be slightly shorter than the duration of the Bloomberg US Government Index. When the term spread is narrow, the duration of the index can be moderately shorter than the duration of the Bloomberg US Government Index. The index's backtested performance is based on the performance of the government/credit component, the Bloomberg Remix Portfolio (TBA Proxy) Index, and the ICE 1M USD LIBOR Index. Rebalanced monthly. The index has been retrospectively calculated by Dimensional and did not exist prior to December 2021. Accordingly, results shown during the periods prior to December 2021 do not represent actual returns of the index. Other periods selected may have different results, including losses. Data includes composite data from multiple sources or custom blends.

Dimensional Global ex US Core Fixed Income Index (Hedged to USD)

Compiled by Dimensional using data provided by Bloomberg. Based on securities in the universe of the Bloomberg Global Aggregate Bond Index; includes global government bonds and global investment grade corporate bonds. Eligible currencies: AUD, CAD, CHF, EUR, GBP, and JPY. Within the universe, the index identifies the yield curves that offer higher expected returns and the duration ranges on those yield curves offering higher expected returns, and assesses the increased expected returns associated with allocation to bonds with different credit qualities. It then overweights (with respect to their market cap weight) bonds of yield curves, duration ranges, and credit qualities that offer higher expected returns. It also employs credit quality, currency, and duration requirements relative to the eligible market. Rebalanced monthly. The index has been retrospectively calculated by Dimensional and did not exist prior to October 2023. Accordingly, results shown during the periods prior to October 2023 do not represent actual returns of the index. Other periods selected may have different results, including losses.

Dimensional Global Credit Bond Index (Hedged to USD)

Compiled by Dimensional using data provided by Bloomberg. Based on securities in the universe of the Bloomberg Global Aggregate Bond Index and includes global investment grade corporate bonds, global supranationals bonds, global sovereign bonds, global foreign agency bonds, global foreign local authorities bonds, and US local authorities bonds. Eligible currencies: AUD, CAD, CHF, EUR, GBP, JPY, and USD. Within the universe, the index identifies the yield curves that offer higher expected returns, and the duration ranges on those yield curves offering higher expected returns, and assesses the increased expected returns associated with allocation to bonds with different credit qualities. It then overweights (with respect to their market cap weight) bonds of yield curves, duration ranges, and credit qualities that offer higher expected returns. It also employs credit quality, currency, and duration requirements relative to the eligible market. Rebalanced monthly. The index has been retrospectively calculated by Dimensional and did not exist prior to October 2023. Accordingly, results shown during the periods prior to October 2023 do not represent actual returns of the index. Other periods selected may have different results, including losses.

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