PIMCO

The PIMCO Glide Path Construction Process

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The savings and investment plan that one follows over the course of one's working and retirement life is among the most critical decisions an individual can make. The balance between consumption and savings determines one's overall quality of life, not just in the "golden years" but throughout one's career as well. The most common academic framework for evaluating lifetime consumption and savings decisions is the life-cycle hypothesis, first developed by Nobel laureate Franco Modigliani in the early 1950s. In Modigliani's framework, risk-averse households seek to smooth consumption across their working and retirement years by saving a portion of wage income and spending from accumulated savings in retirement. Critically, Modigliani's work predicts that individuals prefer a smooth consumption stream to a volatile one. One of the key implications of consumption-smoothing is that investors wish to maintain their quality of lifestyle when they stop working. Hence, the savings and asset allocation plan should be calibrated such that the likelihood of an abrupt change in one's consumption is minimized as one approaches retirement.

1. INTRODUCTION

As stated in Merton (2008), "Sustainable income flow, not the stock of wealth, is the objective that counts for retirement planning." Hence, the goal of a well-designed glide path should not principally be to maximize the expected value of assets available at retirement but rather to balance the growth objective with the volatility of the consumption stream that the investor's accumulated financial assets ultimately generate. The conversion of the financial portfolio into a stream of income is affected by three primary variables: interest rates, inflation and the time horizon over which the retiree plans to consume from their savings. The joint effect of these variables is that the income stream is sensitive to the prevailing level of real interest rates when one retires, with higher rates producing greater income, and vice versa. Given that a relatively stable flow of real postretirement income is important, a well-constructed glide path will allocate, in part, to assets that hedge against fluctuations in real income, with a greater emphasis on hedging assets as one approaches retirement.

In addition, the investor's defined contribution (DC) plan is not their sole source of retirement income. Two other parts of the aggregate portfolio loom large for retirement: Social Security and home equity. Both represent nontrivial fractions of the investor's overall wealth and thus play a critical role in affecting the balance and characteristics of the optimal asset allocation glide path.

The remainder of this paper is structured as follows: In Section 2, we discuss PIMCO's glide path philosophy and how different asset classes may hedge against some of the key risk factors affecting retirement income. In Section 3, we provide a technical explanation of the glide path construction process. In the last section, we compare the PIMCO glide path with the industry average glide path and show how our goal results in a somewhat differentiated asset allocation that seeks a more predictable outcome.

2. GLIDE PATH PHILOSOPHY

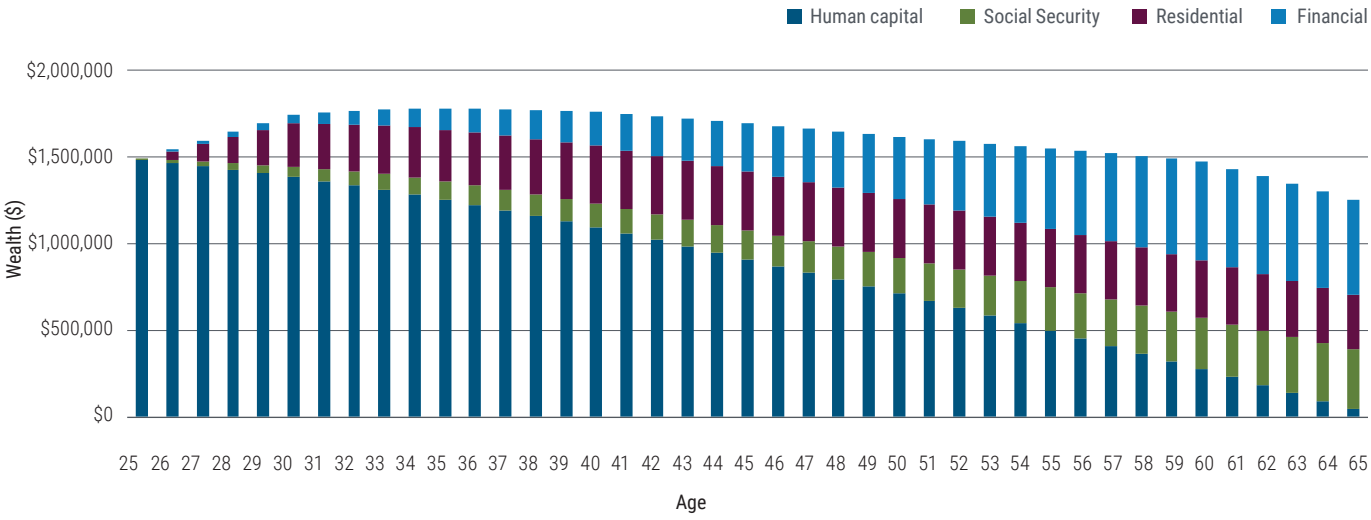
When individuals are starting out in their careers, net financial wealth is typically low. Compensating for this, however, is the present value of future labor income, given the multidecade working careers ahead of them. Over time, through the accumulation of savings, individuals convert human capital wealth into financial wealth, typically by investing in stocks, bonds and housing. At retirement, their income-producing human capital wealth is largely diminished, but their accumulated financial assets are, it is hoped, sufficient to sustain a desired level of consumption going forward. Figure 1 shows the components of the typical worker's projected future real net worth from age 25 to retirement at age 65. At age 25, net worth is made up nearly entirely of the individual's human capital. By the time they retire, their wealth consists roughly of 50% financial assets, 25% housing equity and 25% the present value of their Social Security benefit.

The interplay between the present value of future labor income, financial wealth and a future postretirement consumption stream has some important factors worth considering:

1. **Future labor income is generally increasing with inflation.** As the goal of the household is to smooth real consumption through time, the impact of inflation can be detrimental to sustaining a particular lifestyle. Fortunately, labor income should rise with increases in the general price level, providing a critical inflation-hedging property. However, as shown in Figure 1, the value of human capital declines throughout one's career, increasing a worker's exposure to inflation risk. Therefore, workers should consider compensating for increasing inflation risk as they age by allocating to inflation-hedging assets in the financial portfolio.

2. **The relative size of the present value of labor income versus financial wealth shrinks over time.** When a worker is young and financial wealth is relatively small, financial risk (volatility) taken by the investor has less impact on their overall wealth than it does later in life, when financial wealth is a larger fraction of the total. Therefore, workers can afford to take more volatility risk when they are young, but much less so later in life. Hence, workers should consider transitioning from a financial portfolio made up largely of growth assets when they are young to a more balanced, diversified set of assets as they approach retirement.

Figure 1: Decomposition of net worth by age



Source: Survey of Consumer Finances (SCF), Social Security Administration and PIMCO. Human capital and Social Security data are based on the U.S. Census Bureau and the Social Security Administration as of 2021. We estimate financial wealth from the 2019 SCF, using median values for families holding financial assets. The calculation excludes the "bonds" category, as these assets are held by a very small fraction of households.

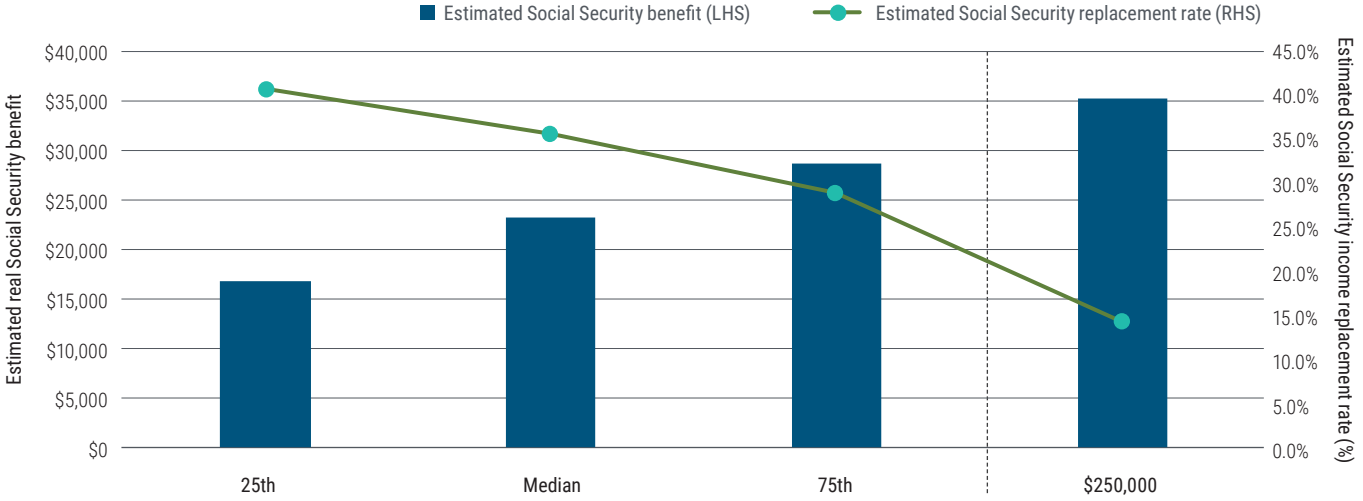
3. **The present value of future labor income has meaningful sensitivity to interest rates.** Because future labor income represents a stream of cash flows over a long prospective working life, it has a significant amount of embedded duration exposure. This is ideal because the duration of human capital directly hedges the significant retirement income risk one faces as one gets older. Unfortunately, like the inflation-hedging property, this benefit diminishes as the value of human capital declines. Thus, the loss of interest rate duration from human capital must be replaced with duration in the financial portfolio, shifting from a growth focus in the early years to an income-hedging focus as one ages.

Although the three properties listed above are relevant for any investor considering a long-term asset allocation plan, the optimal glide path can vary depending on characteristics unique to the individual. Therefore, when constructing a long-term asset allocation, we must think diligently about whom we are building the asset allocation plan for, as there is a substantially different composition of wealth components and availability of income replacement programs as one moves up and down the income strata.

Social Security, which covers more than 90% of the U.S. population, is essentially a hybrid of a savings vehicle and a poverty protection/income transfer mechanism: Dollar benefits increase in average annual income earned during working years but as a percentage of preretirement income fall rather steeply. Figure 2 shows the estimated Social Security benefit and income replacement rate for various income levels. The 25th percentile worker can expect Social Security to provide about $17,000 a year in real income for life. At the 75th percentile, the benefit climbs to around $29,000, rising to $35,000 for someone making $250,000 (benefits are effectively capped at this level for higher-income earners). However, as a percentage of income, the Social Security benefit falls from about 40% of income to around 29% between the 25th and 75th percentiles of income. For a worker earning $250,000, the income replacement rate from Social Security is only 14%.

For those at the lowest end of the income distribution – below the 25th percentile – additional poverty programs provide income or other benefits on top of the material Social Security benefit. Individuals at this level of the wage strata are more likely to rely on social programs to sustain themselves postretirement and are unlikely to have meaningful assets in tax-preferred vehicles such as an IRA or a 401(k) plan. Conversely, for those at the upper end, other considerations play an increasingly large role. First, for these individuals, the income replacement of Social Security declines with income and thus plays a diminishing role in what is already a small income replacement benefit. Households in the top income quartile also tend to hold a substantially larger fraction of their wealth in taxable investment accounts than in tax-preferred

Figure 2: Estimated Social Security benefit and income replacement rate by income category



Source: U.S. Census Bureau, Social Security Administration and PIMCO as of September 2020. Assumes Social Security benefit is taken at age 65. A 13.3% haircut is applied to the benefit estimate based on a full retirement age of 67.

vehicles. For these fortunate households, the DC component of their overall asset allocation plays a much smaller role. Furthermore, because high net worth individuals reside in the highest marginal tax brackets, the tax benefits of tax-preferred structures tend to dictate the asset allocation decision (i.e., allocating tax-inefficient assets to a 401(k) and tax-efficient assets to a taxable account). Thus, the smaller relevance of DC in the tails gives us reason to focus on the middle of the income distribution. For our purposes, the "middle class" is approximately the 25th to 75th percentile of the income distribution, as this group presents a more homogeneous and representative demographic to construct glide paths around. For this group, Social Security benefits under current law replace approximately 30% to 50% of income at retirement, making the benefit significant enough to affect the optimal glide path but not so significant as to dominate the intertemporal asset allocation decision.

Finally, it is important to note the critical role that owner-occupied housing plays in retirement savings. Shelter is the single largest expenditure in most households' consumption bundle and makes up approximately one-third of the CPI (Consumer Price Index) basket. In the U.S., approximately 70% of household debt is in the form of mortgages secured by personal residences, according to the Federal Reserve's 2019 Survey of Consumer Finances. Importantly, the payment of principal on a mortgage is essentially a form of savings.

The financing of one's home also effectively leverages exposure to the shelter hedging component of inflation early on, and this leverage is worn away through time as principal is paid down. Although most individuals do not monetize the wealth saved in their home at retirement, a house owned free and clear represents a prepayment of a significant fraction of future shelter consumption. This, in turn, reduces the retirement saver's need to hedge this component of the inflation basket explicitly. Housing equity also is a valuable contingent asset that can be liquidated as retirees look to downsize, or may have a growing role providing retirement income directly as reverse mortgage markets mature. Importantly, much like future labor income, prefunded housing acts as a long-duration real asset: It hedges the retirement investor against inflation risk, and its value is sensitive to changes in interest rates. As such, owner-occupied housing can act to offset some of the critical properties that are naturally lost as the value of labor income declines through time.

3. THE PIMCO GLIDE PATH CONSTRUCTION PROCESS

The glide path specifies an annual asset allocation from age 25 to 65 and is designed to maximize the trade-off between retirement income and income uncertainty. The first step in this process is to assess how the specific choice of glide path affects the accumulation of real wealth while the individual is working. We simulate long-horizon paths for a wide array of key asset classes, centered around our long-term capital market views. The return to a portfolio at any time *t* is determined by the portfolio's asset allocation and the realized returns along each path at each point in time. For each simulated path of asset returns, we compute the dynamics of an individual's wealth accumulation up until retirement as follows:

$$W_{t+1} = \left(W_t^{DC} r_{t,t+1}^{DC} + W_t^{NDC} r_{t,t+1}^{NDC}\right) + I_{t+1}(S_{t+1} + M_{t+1}) + S_{t+1}^{NDC} \quad (1)$$

where W is wealth; r^{DC} and r^{NDC} are the gross returns to the DC and non-DC portfolios, respectively, I is the individual's income; S and M are the employee savings rate and the employer match rate, respectively; and S^{NDC} is any savings unrelated to DC. All variables are expressed in real terms, and the time subscripts indicate that each variable is allowed to vary over time.

As is evident from Equation 1, the dynamics of wealth accumulation are contingent not only on asset returns but also on assumptions for how much the individual saves each year, employer contributions, the individual's income profile and the composition of DC and non-DC wealth. Each year, the worker saves a fraction of their wage income into DC and non-DC assets (mostly housing wealth) and the employer matches part of their contribution. In the following period, both the DC and non-DC portfolios earn a stochastic return that either increases or decreases existing wealth. Figure 3 shows an example of "average" salaries, employee contribution rates and employer match rates using data from the Employee Benefit Research Institute (EBRI).[1] These levels are a good example of the assumptions that would typically underlie many traditional glide paths.

We assume that at age 65 the worker retires with their total simulated wealth. Based on the distribution of retirement wealth, we compute the distribution of retirement income for a specific choice of glide path. Retirement wealth can be converted into an equivalent retirement income stream along each simulation path *k* using the following formula:

$$I_k^R = \frac{W_k}{\sum_{t=1}^{T}(1+r_{t,k})^{-t}} \quad (2)$$

Figure 3: Representative income and savings assumptions

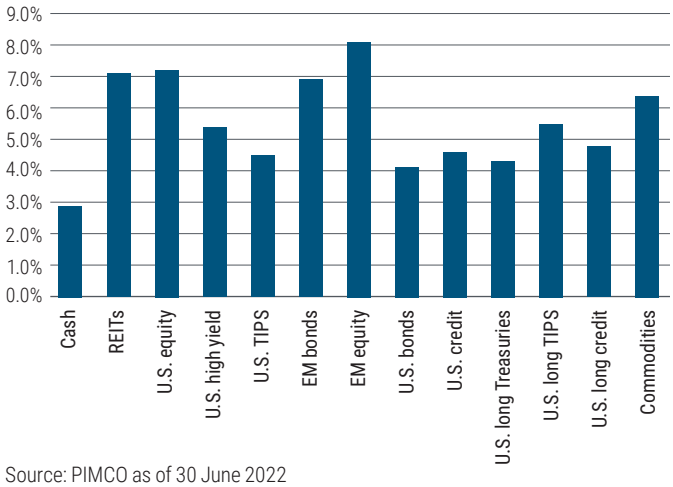
Age	Median salary ($)	Participant savings rate (%)	Average employer contribution rate (%)	Total savings rate (%)
25-30	50,000	5.0%	3.5%	8.5%
30-35	59,000	5.6%	3.8%	9.4%
35-40	65,000	6.0%	4.0%	10.0%
40-45	67,000	6.2%	4.2%	10.4%
45-50	67,000	6.7%	4.2%	10.9%
50-55	67,000	7.3%	4.2%	11.5%
55-60	67,000	8.0%	4.1%	12.1%
60-65	67,000	8.3%	4.0%	12.3%

Source: PIMCO as of 30 June 2022. Salary and savings and contribution rates are from EBRI/ICI Participant-Directed Retirement Plan Data Collection Project for those with full-year salaries of at least $20,000. Salary data is intentionally capped at $67,000, as median salary levels tend to decline with age due to older workers dropping out of the workforce.

where I_k^R is real retirement income along the k^{th} path, W_k is the employee's wealth at retirement age, $r_{t,k}$ is the real interest rate at retirement t, and T is the expected life span of the individual, assumed to be 20 years. Because Equation 2 is computed along all simulation paths, this produces a distribution of real retirement income outcomes for the representative investor. Importantly, calibrating a distribution of retirement income allows for the assessment of not just the mean, or expected level of income, but also income volatility and tail properties.

Equation 2 highlights the important role that interest rates at retirement play in the determination of retirement income. When real rates of interest are high, real retirement income will be higher, all else equal. The sensitivity of retirement income to real interest rates means that if the expected return on all assets in the opportunity set was the same, then the optimal asset allocation for retirement savings would be heavily skewed toward long-duration Treasury Inflation-Protected Securities (TIPS). This is the case because long TIPS help insulate the investor from changes in real rates and inflation, the same drivers of retirement income. However, it is generally the case that asset classes such as equities, high yield fixed income and other return-seeking assets have higher expected returns over time than long-duration TIPS. This introduces a risk/return trade-off between the allocation to growth and hedging assets in the glide path. We formulate our long-term

Figure 4: 5-year capital market assumptions for select asset classes



Source: PIMCO as of 30 June 2022

return views via PIMCO's Capital Market Assumptions (CMAs) process. Our five-year CMAs for select asset classes, as of 30 June 2022, are shown in Figure 4.

Of course, the savings careers of most workers go beyond the five-year horizon of PIMCO's Capital Market Assumptions. Therefore, in addition to utilizing our five-year views, we also employ a series of "supersecular" assumptions that define the long-term path for key risk factors. The purpose of this second set of estimates is to help ensure that 40-year asset return simulations are reasonably consistent with the historical record for interest rates, spreads and equity returns. Hence, our long-term simulation engine is parameterized to our CMAs through years 1 through 5 and the supersecular views for years 6 through 40. Figure 5 shows our five-year and long-term forecasts for select risk factors.

Figure 5: Forecasts for selected risk factors

Risk factor	CMA (5Y)	Long-term
3M T-bill	2.9%	2.5%
10Y nominal yield	3.1%	3.1%
10Y real yield	0.5%	1.0%
Equity risk premium	4.3%	3.3%

Source: PIMCO as of 30 June 2022. **Hypothetical example for illustrative purposes only.** PIMCO supersecular assumptions are a product of PIMCO CMAs and inputs from senior PIMCO investment professionals. Charts are provided for illustrative purposes and are not indicative of the past or future performance of any PIMCO product.

When determining an optimal glide path, the first question we need to ask is, "What is the objective?" Although maximizing Equation 1 may seem intuitive, setting wealth maximization as the goal merely results in an allocation to the highest-returning assets throughout the glide path. After all, the only way to maximize expected wealth is to maximize expected return. **The objective of PIMCO's glide path, rather, is to strike an optimal balance between expected retirement income and its volatility.** To solve for the optimal glide path, we assume that households have preferences over different levels of retirement income that can be captured by a utility function of the constant relative risk aversion (CRRA) form:

$$U(I) = \frac{I^{(1-\rho)}}{1-\rho} \quad (3)$$

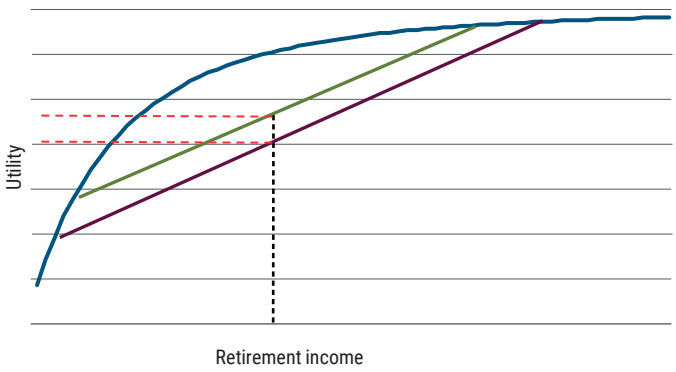
where I is retirement income as defined in Equation 2 and ρ is the coefficient of risk aversion. Constant relative risk aversion preferences are common in the economics and finance literature, and they summarize risk preferences by a single parameter, ρ.[v]

Figure 6 shows a hypothetical example of the CRRA utility function in blue. The function is concave, which implies that our retirement investor is risk-averse, assigning more weight to negative outcomes than to positive ones, all else equal. The key implication is that the retirement investor likes higher retirement income but does not like income volatility. Holding expected retirement income constant, a more volatile retirement outcome is less desirable (i.e., yields lower expected utility) than a more certain one. The solid maroon and green lines illustrate the expected utility associated with two different investment strategies. Both have the same expected income, as measured by the x-axis, but the maroon line allocation results in both better and worse outcomes than the allocation associated with the green line. Comparing the expected utilities on the y-axis, we see that the maroon allocation results in lower expected utility than the green allocation. This difference is due entirely to the greater outcome uncertainty associated with the maroon option. More formally, if we consider alternative glide paths with different retirement income levels, the investor will be indifferent if Equation 4 holds:

$$\mu = \frac{1}{2}\rho\,\sigma^2 \quad (4)$$

Equation 4 shows that the investor is willing to accept some volatility in retirement income, as measured by σ^2, but only provided the expected return, μ, is sufficiently high relative to another available lower-volatility outcome. The more risk-averse the investor (higher ρ), the more the investor requires as compensation to accept a more uncertain retirement income.

Figure 6: Expected utility



Source: PIMCO. **Hypothetical example for illustrative purposes only.** Charts are provided for illustrative purposes and are not indicative of the past or future performance of any PIMCO product.

4. THE PIMCO GLIDE PATH

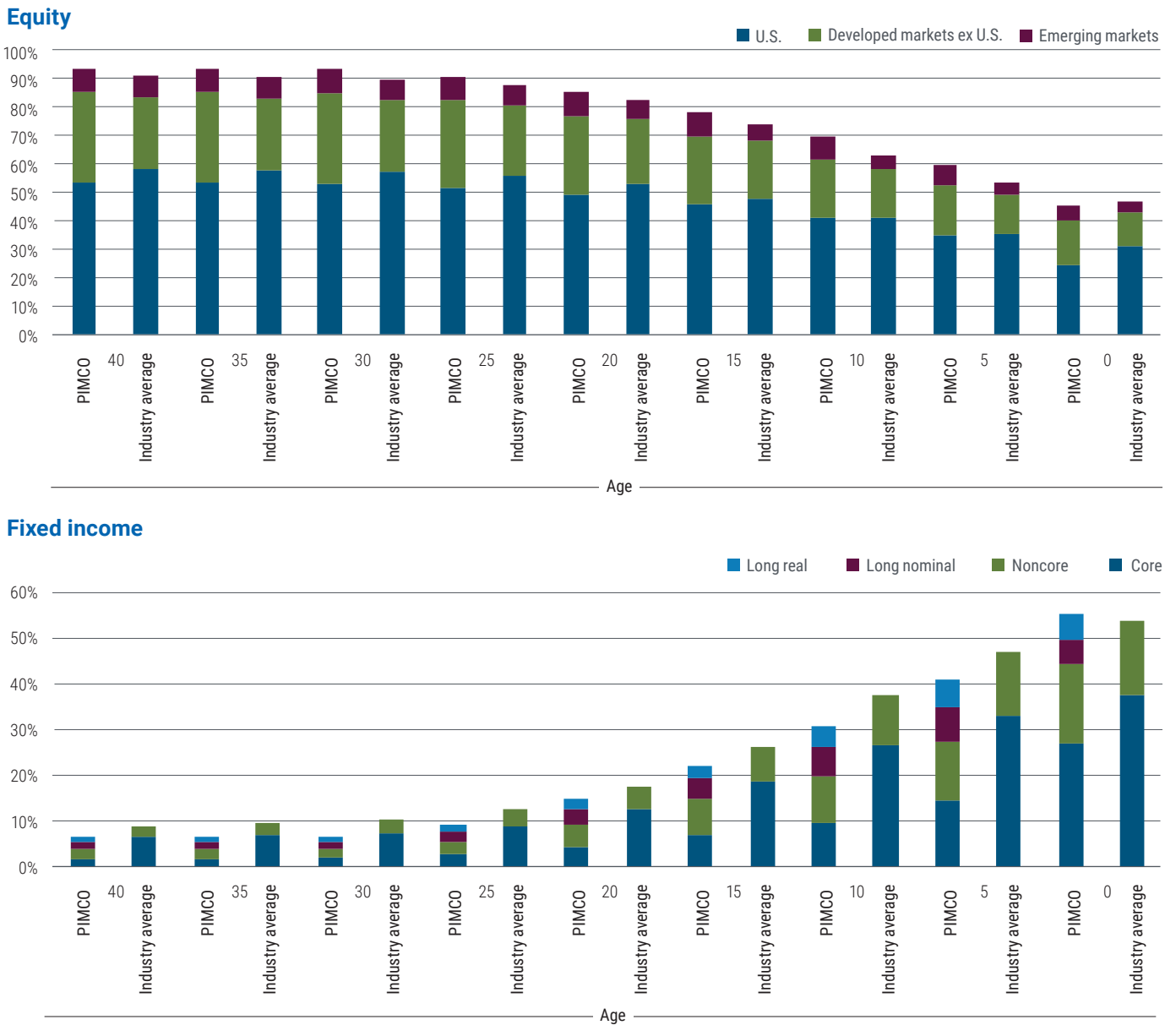
At a high level, most glide paths are similar in structure, with a greater allocation to traditional return-seeking assets, such as equities, in the early years and increasing allocations to traditional fixed income as the investor gets older. Indeed, as described earlier, the "de-risking" inherent in most glide paths reflects the need to replace the time-depleted bond-like human capital with actual bonds in the investment account.

Human capital – the present value of future wages – possesses two key properties that all retirement investors desire: inflation hedging and retirement income hedging. Wages generally increase commensurate with increases in inflation, and the long-duration nature of a future salary stream provides meaningful protection against changes in interest rates. Therefore, as the worker's human capital declines with time, the value of these properties naturally is depleted. Therefore, this must be compensated for through allocations to asset classes in the financial portfolio that possess similar exposures. The PIMCO glide path is specifically geared toward optimizing the trade-off between hedging assets, which tend to have lower expected returns, and traditional and nontraditional forms of return-seeking assets. As a first step in understanding this

balance, Figure 7 compares the current equity and fixed income allocations for PIMCO's outcome-oriented glide path with the industry average.

In general, the PIMCO glide path contains similar – although today slightly higher – overall equity exposure compared to the industry average, across most vintages. However, the composition is generally less U.S.-centric than the industry-average glide path, with more diversified sources of equity exposures, such as emerging markets and non-U.S. developed market equities. Differences are more pronounced within the fixed income allocation, with the PIMCO glide path currently holding a lower allocation to core bonds, reflected in the dark blue bars in Figure 7. The core bond category typically has meaningful exposure to intermediate-duration government bonds, which generally do not provide high levels of real return or the longer duration exposure necessary for a retirement income-oriented objective. This gap is made up with larger allocations to noncore sectors, such as globally diversified credit sectors, as well as higher allocations to long-duration nominal and real bonds. The higher expected returns associated with noncore fixed income are intended to contribute meaningfully to the investor's retirement income objective. The higher allocation to long-duration nominal and

Figure 7: PIMCO glide path asset allocation versus industry average[2]



Source: PIMCO as of 2021

Figure 8: Income replacement outcomes

DC Only		Percentile						
		5%	10%	25%	50%	75%	90%	95%
Income replacement rate	PIMCO	16.8%	20.1%	27.1%	39.6%	61.0%	90.9%	123.5%
	Industry average	16.7%	20.0%	26.6%	38.2%	57.6%	86.1%	115.6%
Real income	PIMCO	$10,548	$12,648	$17,054	$24,898	$38,363	$57,182	$77,666
	Industry average	$10,479	$12,577	$16,714	$24,025	$36,203	$54,141	$72,675
Real wealth	PIMCO	$211,332	$247,304	$321,996	$452,761	$666,433	$982,482	$1,304,535
	Industry average	$210,950	$244,591	$314,529	$436,192	$631,624	$925,113	$1,201,590

DC + Social Security		Percentile						
		5%	10%	25%	50%	75%	90%	95%
Income replacement rate	PIMCO	53.8%	57.1%	64.1%	76.6%	98.0%	127.9%	160.5%
	Industry average	53.7%	57.0%	63.6%	75.2%	94.6%	123.1%	152.6%
Real income	PIMCO	$33,809	$35,909	$40,315	$48,159	$61,624	$80,443	$100,926
	Industry average	$33,740	$35,838	$39,975	$47,286	$59,464	$77,401	$95,935
Real wealth	PIMCO	$211,332	$247,304	$321,996	$452,761	$666,433	$982,482	$1,304,535
	Industry average	$210,950	$244,591	$314,529	$436,192	$631,624	$925,113	$1,201,590

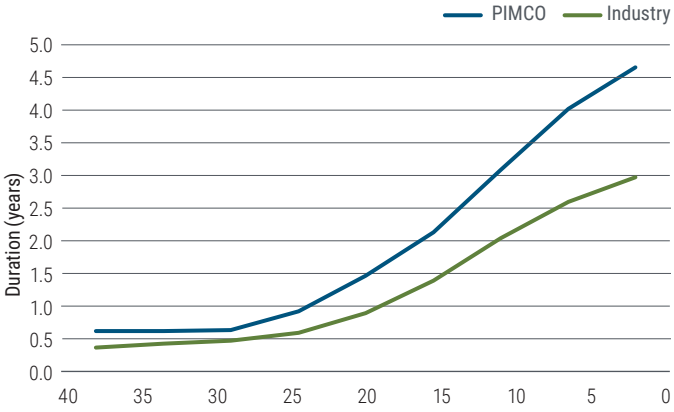
Source: PIMCO, EBRI, Morningstar and the Social Security Administration as of 30 June 2022. **Hypothetical example for illustrative purposes only.** Figure 8 uses assumptions outlined in Figure 3 (see technical appendix for additional information). Results are calculated assuming participants retire at 65. Different assumptions will produce different results. Management fees have not been applied, and if they were applied, results would be lower. Charts are provided for illustrative purposes and are not indicative of the past or future performance of any PIMCO product.

real bonds, particularly as the investor approaches retirement, provides the critical inflationary and retirement income hedging properties that all workers need. We anticipate these differences versus the industry average within the fixed income allocation being structural in nature going forward.

Figure 8 shows the ultimate expected distribution of outcomes in terms of income replacement rate, real retirement income and final real wealth for the PIMCO glide path versus the industry average, based on the salary and savings assumptions detailed in Figure 3. It is important to keep in mind that the savings decision is generally the single most important factor in determining the distribution of retirement income, and results will be highly sensitive to these assumptions. For the PIMCO glide path, before the contribution of Social Security the median participant is expected to generate an income replacement rate of 39.6% of final salary, which translates to a real income of $24,898 a year.[3] Social Security is expected to contribute an additional 37%, bringing the overall median replacement rate to 76.6%, or about $48,000 per year. In addition to the 1.4 percentage point higher median expected replacement rate for the PIMCO glide path versus the industry average, there are also notable differences in the tails of the distribution. Though the PIMCO glide path outperforms the industry average glide path, in the right tail of the distribution, it is not expected to produce lower wealth and income levels in the left tail of the distribution. One of the reasons for this is the greater contribution of long-duration bonds close to retirement,[3] which help to preserve retirement income levels in low rate environments. **Importantly, the results in Figure 8 are presented on a purely passive basis and do not include any assumptions about "alpha," or returns in excess of a passive benchmark. Positive alpha relative to the industry average glide path will improve income replacement and wealth levels relative to the values shown in Figure 8.**

As shown in Equation 2, income is directly affected by the level of interest rates when one retires. And while our savings rate and investment decisions are largely within our own control, the level of interest rates when we retire is generally not. Thus, interest rate risk is something that a well-constructed glide path should help hedge against. To further illustrate this point, Figure 9 shows the duration over time for both the PIMCO and the industry average glide paths. The PIMCO glide path has systematically higher duration than the industry average, but there is a notable uptick around age 45. This is a critical period 20 years prior to retirement in which retirement success may be either gained or lost. An increasing allocation to duration is essential during this period of the savings cycle, as it helps to mitigate left tail outcomes at retirement age caused by the detrimental impact of low interest rates at retirement.

Figure 9: Duration by age



Source: PIMCO and Morningstar as of 30 June 2022

CONCLUSION

Proper, thoughtful design of the asset allocation glide path is a critical piece of the retirement savings puzzle. While the standard approach, which allocates to risk assets in the early years and gradually de-risks as the worker ages, is undoubtedly correct, the devil, as always, is in the details. As workers age and the value of their human capital is depleted, they lose exposure to two critical factors: inflation hedging and retirement income hedging. The financial portfolio must compensate for the loss of these characteristics. The PIMCO glide path construction process seeks to optimize the balance between retirement income and income uncertainty by allocating in a balanced fashion to both return-seeking and hedging assets. We believe our rigorous approach to glide path construction should result in the best possible outcome for retirement investors. The result is an asset allocation that, given a prudent savings plan, seeks to replace a meaningful portion of the typical worker's final salary in retirement before Social Security, and aims to do so with less variation than the industry average glide path.

TECHNICAL APPENDIX

We categorize the simulation of risk factors into three categories: rates, spreads and risk assets. Real interest rates are modeled using an Ornstein-Uhlenbeck (OU) process, while nominal interest rates and spreads are modeled using a variation of the Cox-Ingersoll-Ross (CIR) model. The choice of an OU process for real rates allows for the realization of negative rate levels, whereas a CIR structure ensures positive levels for nominal interest rates and spreads. The dynamics for yields and spreads are governed by the following differential equation:

$$dx = \theta(\mu - x)dt + \sigma x^i dz \tag{1a}$$

where dz is a multivariate Wiener process with covariance matrix Σ, μ is the long-term (10-year) equilibrium factor level, σ is the shock volatility, and θ is a mean-reversion parameter. For real rates, i=0, and for nominal rates and spreads, i=0.5. All simulation paths are conditioned on the current level, x_0. Therefore, the discretized path at time t for any risk factor is given by

$$x_t = x_0 + \theta(\mu - x_0)\Delta t + \sigma x_0^i \sqrt{\Delta t}\epsilon_t \tag{2a}$$

Equation 2a is estimated for three-month, two-year, 10-year and 30-year tenors for nominal rates and two-year, 10-year and 30-year tenors for real rates and spreads. Interest rate and credit curves are then fitted using a four-factor Nelson-Siegel model. Simulated inflation is endogenous to the realized path for nominal and real interest rates, and is modeled based on breakeven inflation, or the difference between nominal and real rates. Formally, realized inflation, i_t, is determined by the following dynamics:

$$i_t = BE_t + \sigma_i \sqrt{\Delta t} v_t \tag{3a}$$
$$BE_t = y_{1,t}^n - y_{1,t}^r + \pi \tag{4a}$$

where σ_i is inflation volatility; $y_{1,t}^n$ and $y_{1,t}^r$ are the one-year nominal and real rates at time t, respectively; π is a shift parameter containing both the inflation risk premium and a liquidity premium; and v_t is a standard normal shock. Finally, equities are modeled based on the following equation:

$$r_t = r_t^f + ERP + e^{(-0.5\sigma_r^2 \Delta t + \sigma_r \sqrt{\Delta t}\varepsilon_t)} - 1 \tag{5a}$$

where r_t^f is the risk-free rate (three-month Treasury yield) at time t, ERP is the equity risk premium, σ_r is the equity volatility, and ε_t is a standard normal shock. Hence, the system is fully described by the risk factor returns $[x,i,r]$, where x represents the full set of nominal rates, real rates and credit spreads. We explicitly account for nonzero correlations across ϵ_t, v_t and ε_t.

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1 We have modified the EBRI data so that there is no change in the median salary after age 55. The raw EBRI data show median wages declining toward retirement. However, this is primarily a result of some older workers changing to part-time employment. Our intention is to model the profile of an individual working full-time until retirement. Participant savings and employer contribution assumptions are determined by mapping the average savings and contribution rates for each salary cohort to the age-based salary assumptions.

2 Calculations exclude both commodities and cash.

3 For a detailed discussion of this topic, see N. Pedersen and S. Sapra. 2017. "The Role of Long-Maturity TIPS in Retirement Portfolios," *Journal of Retirement.*

BIOGRAPHIES

Erin Browne is a managing director and portfolio manager in the Newport Beach office, focusing on asset allocation strategies, including PIMCO's multi-asset funds and RealPath Blend target date offerings. She manages multi-asset strategies, leads the Glide Path leadership team and has served as a rotating member of the Investment Committee. Prior to joining PIMCO in 2018, Ms. Browne was a managing director and head of asset allocation at UBS Asset Management, helping to drive the firm's macro research, capital market assumptions, tactical asset allocation and strategic asset allocation views across asset classes. Previously, she was head of macro investments at UBS O'Connor, a multi-strategy hedge fund manager, and a global macro portfolio manager at Point72 Asset Management. She has also held roles at Citigroup, Moore Capital Management, Neuberger Berman and Lehman Brothers. She regularly appears on CNBC, Bloomberg Television and in other financial news media. She serves as the board treasurer of the Ecology Center and is on the advisory board of Girls Who Invest. She has 21 years of investment experience and holds a bachelor's degree in economics from Georgetown University.

Niels Pedersen is a senior vice president in the client analytics group in the Newport Beach office. He joined PIMCO in 2008 and specializes in asset allocation, quantitative risk management and design of customized tail risk hedging strategies. He holds a Ph.D. and a master's degree in economics from Northwestern University and received an undergraduate degree in economics from the University of Aarhus in Denmark. Mr. Pedersen has published papers in the *Journal of International Money and Finance* and the *Journal of Derivatives & Hedge Funds*.

Steve Sapra is an executive vice president in the Newport Beach office and head of client analytics for North America. Prior to joining PIMCO in 2012, he was a managing director at TOBAM, a quantitative asset manager headquartered in Paris. From 1999-2010, Mr. Sapra served as a portfolio manager at Analytic Investors, where he oversaw the research and implementation of approximately $8 billion in U.S. equity assets. Mr. Sapra has written and spoken extensively on issues pertaining to investing and risk management and has published papers in several journals, including the *Financial Analysts Journal*, *Journal of Portfolio Management* and *Journal of Sports Economics*. He was an adjunct faculty member at the University of Southern California Marshall School of Business. He has 19 years of investment experience and holds a Ph.D. in economics from Claremont Graduate University and a master's degree in economics from the University of Southern California.

This paper contains **hypothetical analysis**. Hypothetical and simulated examples have many inherent limitations and are generally prepared with the benefit of hindsight. There are frequently sharp differences between simulated results and the actual results. There are numerous factors related to the markets in general or the implementation of any specific investment strategy, which cannot be fully accounted for in the preparation of simulated results and all of which can adversely affect actual results. No guarantee is being made that the stated results will be achieved.

Return assumptions are for illustrative purposes only and are not a prediction or a projection of return. Actual returns may be higher or lower than those shown and may vary substantially over shorter time periods.

Glide Path is the asset allocation within a Target Date Strategy (also known as a Lifecycle or Target Maturity strategy) that adjusts over time as the participant's age increases and their time horizon to retirement shortens. The basis of the Glide Path is to reduce the portfolio risk as the participant's time horizon decreases. Typically, younger participants with a longer time horizon to retirement have sufficient time to recover from market losses, their investment risk level is higher, and they are able to make larger contributions (depending on various factors such as salary, savings, account balance, etc.). Generally, older participants and eligible retirees have shorter time horizons to retirement and their investment risk level declines as preserving income wealth becomes more important.

Charts are provided for illustrative purposes and are not indicative of the past or future performance of any PIMCO product. It is not possible to invest directly in an **unmanaged index**.

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CMR2022-1222-2649452