Vanguard's Life-Cycle Investing Model (VLCM): A general portfolio framework for goals-based investing

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Roger Aliaga-Díaz, PhD; Harshdeep Ahluwalia, M.Sc; Victor Zhu, CFA, CAIA; Scott Donaldson, CFA, CFP; Ankul Daga, CFA; and David Pakula, CFA

- Investors have multiple goals throughout their lifetime, each requiring them to make complex, interconnected decisions about saving, spending, and asset allocation. We present a framework for making asset allocation decisions based on an investor's goals, preferences, and personal circumstances and factoring in the uncertainty of asset returns.

- The Vanguard Life-Cycle Investing Model (VLCM) is a proprietary model for glide-path construction that can assist in the creation of custom investment portfolios for retirement as well as nonretirement goals, such as saving for college.

- The VLCM embodies key principles of life-cycle investing theory, including a utility-based framework encompassing risk aversion and time preference. It also incorporates important behavioral finance considerations such as loss aversion and income shortfall aversion. The use of the VLCM enables cost-benefit analysis of glide-path customization, evaluation of risk-return trade-offs of various asset and sub-asset allocation choices, and multiple portfolio analytics of the probability of success and odds of income sufficiency.

- Based on VLCM's analytical framework, we find that risk-aversion levels are the dominant factor behind the broad stock-bond split in the glide path, affecting both glide-path slope and ending allocation.

Goals-based investing and the need for a model

For the most part, individual investors have two types of investment goals: long-horizon retirement and legacy goals and intermediate-horizon nonretirement goals, such as investing for a child's college tuition or purchasing a home.

In a goals-based investment plan, periodic savings or contributions are invested in assets that provide growth, stability, or a blend of both. Moreover, theory suggests that the mix between risk assets such as broad, diversified equities and more stable assets such as high-quality fixed income investments should also evolve as one gets closer to the spending phase. This change in the portfolio's risk asset composition is called a glide path.

Downward-sloping glide paths are common in the industry and are suggested by many researchers as well (see Bodie, Merton, and Samuelson, 1992, and Gomes, Kotlikoff, and Viceira, 2008). However, debate about the shape of the glide path remains unsettled. Shiller (2005), Basu et al. (2013), Arnott (2012), and Arnott, Sherrerd, and Wu (2013) state that a rising glide path is better, while Pfau and Kitces (2014) argue for a U-shaped path and Estrada (2016) recommends an inverted U-shape.

In the context of life-cycle investing, the rationale for a downward-sloping glide path is based on a trade-off between human and financial capital. Individuals in the early stages of their careers have high earning potential or human capital and likely just a marginal amount of accumulated financial capital. Human capital, or future income from work, is a bond-like asset: Investors earn a paycheck similar to a bond's coupon. This bond-like human capital diversifies equity risk in financial assets; thus, early in the life cycle one can take on more financial risk.

As careers progress, human capital reduces and financial wealth increases. As the consumption stage approaches in the later years of the investing life cycle, theory suggests one should increase the allocation to fixed income and decrease the allocation to risk assets. In other words, the glide path slopes downward.

Notes on risk

All investing is subject to risk, including the possible loss of the money you invest. There is no guarantee that any particular asset allocation or mix of funds will meet your investment objectives or provide you with a given level of income. Investments in bonds are subject to interest rate, credit, and inflation risk. Investments in stocks or bonds issued by non-U.S. companies are subject to risks including country/regional risk and currency risk. Diversification does not ensure a profit or protect against a loss. Annuities are long-term vehicles designed for retirement purposes and contain underlying investment portfolios that are subject to investment risk, including possible loss of principal.

Investments in target-date funds are subject to the risks of their underlying funds. The year in the fund name refers to the approximate year (the target date) when an investor in the fund would retire and leave the work force. The fund will gradually shift its emphasis from more aggressive investments to more conservative ones based on its target date. An investment in target date funds is not guaranteed at any time, including on or after the target date.

IMPORTANT NOTE: The projections and other information generated by the Vanguard Capital Markets Model® regarding the likelihood of various investment outcomes are hypothetical in nature, do not reflect actual investment results, and are not guarantees of future results. VCMM results may vary with each use and over time. The VCMM projections are based on a statistical analysis of historical data. Future returns may behave differently from the historical patterns captured in the VCMM.

More important, the VCMM may be underestimating extreme negative scenarios unobserved in the historical period on which the model estimation is based.

However, while this life-cycle theory reasoning is broad and generic, multiple other specific factors define the exact shape of the glide path for a particular investment objective. These include:

- The nature and magnitude of the investment goal itself (such as a lump-sum spending amount or sustained income for replacement purposes, funding of a limited-time liability such as four-year college tuition, or bequest goals).
- The investor's individual circumstances, such as savings rate, length of accumulation period, spending horizon, retirement age (if retirement is the goal), availability of income from pension plans, outside plan assets, expected growth and volatility of labor income compensation, labor market risks, and health status risks.
- The investor's subjective preferences or attitudes toward investment risk, such as risk tolerance, aversion to losses, and time preference (ability to postpone spending until later).

Without a framework or model in place, the infinite combinations of these factors would make answering the complex questions difficult. Luckily, researchers have studied the topic of life-cycle investing for decades and have proposed quantitative frameworks to address these types of investment problems.

VLCM is based on this extensive body of academic and industry research. It combines the best thinking and insights into a software-based quantitative algorithm that can be easily deployed toward a wide array of real-world goals-based investment applications. The VLCM allows for a variety of input parameters, including multiple goal definitions, different investor characteristics, and a full range of risk preferences. This level of analysis can provide unique investment solutions tailored to a large number of very specific investor situations.

Applications of VLCM include:

- **Individual advice:** VLCM is used to generate highly personalized one-to-one investment solutions in an individual advice setting, including glide paths, various portfolio analytics, and insights for retirement and non-retirement goals. Applications include Vanguard's Personalized Glide Path (PGP), used in our Digital Advisor offer and our 401(k) Individual Advice Service.
- **Plan sponsor glide-path customization:** VLCM is used in the design of glide paths for participants by plan sponsors seeking a certain level of customization. Applications include our Investment Solutions DC advisory services in the U.S. and many international pension plans featuring tailored target dates.
- **Design of "off-the-shelf," single-fund solutions such as target-date funds and 529 college savings plans:** VLCM is used by Vanguard's Strategic Asset Allocation Committee for the selection and oversight of all glide paths in Vanguard's goals-based multi-asset funds, such as our global Target Retirement Fund (TRF) franchise, and in products such as our 529 college savings plan. Glide-path construction and due diligence for these products is based on inputting into VCLM a broad range of population demographic and economic and market data most relevant to potential investors in these funds.

The remainder of the paper is divided into four sections. First, we describe the model framework. The next section discusses the sensitivity of the glide path to various factors. We then elaborate on practical case studies and highlight key insights obtained from the model. Finally, we lay out the caveats of the VLCM.

Vanguard’s Life-Cycle Investing Model

Vanguard’s Life-Cycle Investing Model is a proprietary, goals-based glide-path construction model developed by Vanguard’s Investment Strategy Group. It has several practical benefits.

- It provides a rigorous quantitative framework for the construction of personalized glide paths based on an investor’s specific circumstances and goals. The degree of customization in the model enables VLCM to solve for glide paths serving both retirement and nonretirement goals.
- It quantifies the benefits of customization to investors based on their risk tolerance and unique investment constraints using a utility-function-based framework. Any glide-path customization analysis should be done in the context of quantifying incremental costs and benefits and weighing investment trade-offs.
- Combined with long-term asset return expectations derived from the Vanguard Capital Market Model (VCMM), the VLCM is a powerful simulation tool for retirement portfolios through various market scenarios or changing economic conditions, calculating key metrics of investment success such as retirement income sufficiency and longevity risk.
- It can facilitate a deeper understanding of the glide path and asset allocation of goals-based multi-asset funds such as TRFs and products such as 529s in the context of regular due diligence. This process is an important element of the ongoing oversight that investment committees and plan sponsors should perform.

At its core, the VLCM generates optimal glide paths by assessing the trade-offs between the expected (median) lifetime spending that can be funded from a portfolio and uncertainty about that spending due to market risk. The model evaluates this trade-off for thousands of potential glide paths and selects the one that offers the best balance between level and volatility of lifetime spending.

The main principle behind life-cycle investing and VLCM is to maximize the expected lifetime utility of spending and wealth. Rational investors attempt to do this by choosing optimal actions. In the context of portfolio construction, these actions include selecting the asset allocation that provides the right balance between the portfolio’s expected return and risk.

One of the main advantages of a utility theory is that it explicitly accounts for an investor’s risk preference or risk aversion.The VLCM ranks different glide-path options by applying the risk-tolerance criteria embedded in the utility function. This function works as a scoring system that ranks all possible portfolio options based on their risk and return characteristics. Thousands of glide paths result in thousands of utility scores, and the glide path with the highest score (the one that strikes the optimal balance between expected return and risk) is the best solution for the investor’s preferences, circumstances, and goal.

As shown in **Figure 1**, VLCM combines four sets of inputs:

1. **Investor goal and investment horizon** (retirement or nonretirement).
2. **Asset-class return projections** from our proprietary VCMM, an asset return distribution-forecasting engine.
3. **Investor circumstances** such as savings rate, length of accumulation period, additional sources of income or assets for funding the goal, and consumption horizons.
4. **Investor preferences** such as risk aversion, shortfall risk aversion, loss aversion, and preference related to timing of spending.

Along with the optimal glide path, the VLCM generates a wide range of portfolio metrics such as a full statistical distribution of spending and wealth outcomes over any investment year, probability of success relative to the investor’s goals, risk and return analytics, and probability of loss.

Investor goal and investment horizon

The glide-path optimization methodologies for retirement and nonretirement goals have many similarities. However, the retirement objective is nuanced, requiring more elaborate inputs.

Retirement goals typically have a post-retirement subsistence level of income objective (covering basic living expenses) but can optionally include discretionary spending and bequests. All of these goals can be accounted for in the VLCM framework.

Figure 1. The VLCM process

Inputs

Investor circumstances for retirement

- Savings rate
- Compensation
- Defined benefits
- Social Security
- Starting age
- Spending strategy
- Retirement age
- Employee contributions
- Wage growth
- Industry-based wage growth
- Replacement ratio
- Mortality rate
- Annuity
- Social Security withdrawal age
- External cash flows

Investor circumstances for nonretirement

- Initial capital
- Accumulation time horizon
- Decumulation time horizon
- Contribution rate

Behavioral preferences

- Myopic loss aversion sensitivity
- Income shortfall aversion sensitivity

Rational preferences

- Risk aversion
- Preferences toward timing of consumption

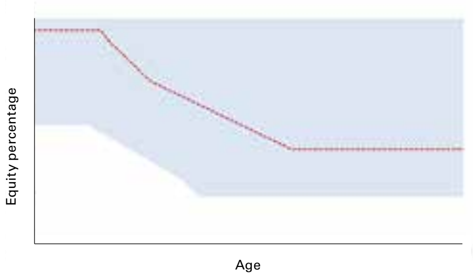
VCMM asset class return projections

- Domestic market equity
- International equity
- Domestic market fixed income
- International fixed income
- Inflation-linked bonds (short, intermediate, broad)
- Government bonds (short, intermediate, long, broad)
- Commodities
- Inflation

→ **VLCM** →

Output

Custom glide path



Portfolio analytics

- Simulated wealth distributions through time
- Simulated consumption distributions through time
- Risk metrics such as portfolio return volatility, consumption volatility, and wealth volatility
- Probability of success, given a goal
- Potential benefit of customization (certainty fee equivalent)—quantifies the benefit of a custom glide path versus an alternative glide path in units of expense ratio or fee

Source: Vanguard.

VLCM allows for different spending policies in accordance with investment goals. For example, a sizeable bequest goal should be paired with a relatively low spending assumption that fulfills the investor's basic living expenses and discretionary spending needs without depleting the portfolio. Thus, for a large bequest goal, low fixed real spending relative to portfolio wealth or low percentage-of-portfolio spending may be appropriate. If leaving behind a legacy is not an objective, then high percentage-of-portfolio spending may be preferable to cover discretionary spending above and beyond basic expenses.

Nonretirement goals may be a lump-sum payment or a sequence of withdrawals over a specified time horizon, for example, for car payments or a child's college tuition. The model is flexible enough to allow for a wide array of possible scenarios.

Asset-class return projections

The VLCM inherits the distributional forecasting framework of the VCMM (see Davis et al., 2014) and uses asset return simulations to calculate consumption and wealth outcomes for any glide path. VCMM simulations match the investment horizon of the portfolio. For instance, the retirement investment objective requires longer horizons compared to nonretirement goals, which tend to have an intermediate horizon, such as 5 to 30 years.

Investor circumstances

Retirement goals

Investing for retirement involves saving regularly, investing the savings appropriately to balance growth potential with investment risk, and then spending the invested wealth over the retirement period. VLCM is centered on calculating the distribution (or uncertainty) of spending and wealth during each year of retirement.

In the retirement goal framework, it's important to use a broader retirement income concept that considers additional sources beyond the portfolio itself. As shown in **Figure 2**, an investor can derive utility from four sources of income and wealth during retirement: the retirement portfolio, Social Security payments, external sources, and a defined-benefit (DB) pension plan.

In general, the availability of DB-like income will lead to a more aggressive glide path with a higher equity proportion. Income from sources such as Social Security or a pension plan could potentially allow a retiree to take on more risk with the retirement portfolio.

VLCM also has the capability to handle annuities in retirement portfolios: It can solve for the optimal equity-bond split in the glide path considering full or partial annuitization. Moreover, if desired, it can actually solve for the optimal level of annuitization based on an investor's risk tolerance and the relative importance attached to different goals (funding spending during retirement versus legacy).

Nonretirement goals

The framework for nonretirement investing is simpler because fewer factors affect the income from investments during the spending phase, as shown in **Figure 3**.

Investor preferences

Rational preferences

Because investors exhibit different risk tolerances, economists have developed a utility theory that uses a risk-aversion (RA) coefficient to analyze preferences in a consistent and rational way.

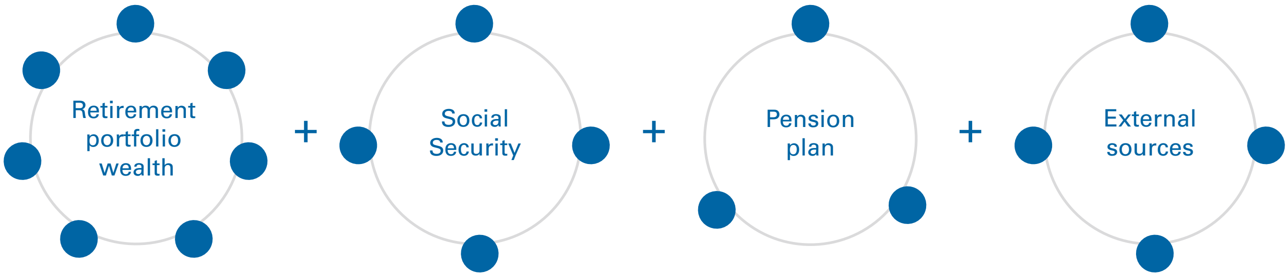
The VLCM annuities module

Purchasing annuities alongside an investment portfolio can be beneficial for certain types of investors. Annuities allow them to exchange a percentage of their net wealth for guaranteed yearly income payments following a predefined schedule. This can help reduce the risk of an income decrease during a market downturn.

The periodic income received from an annuity is a function of the annuity rate, which is set by the provider at the time of purchase. This process, known as annuitization, provides income security to the investor and hence reduces income fluctuation as well as hedging against longevity risk—the risk of outliving one's assets. Annuities can be valuable to investors who place a relatively high value on having stable income to cover their basic living expenses during retirement.

The VLCM incorporates fixed annuities into our life-cycle portfolio construction process. It allows us to model any annuitization rate and income payment schedule an investor might choose, in real or nominal terms. Multiple cases may be run with varying rates and schedules to analyze the pros and cons of various annuities, such as measuring the impact on net retirement spending, portfolio wealth, or the size of a bequest to an heir.

Figure 2. Factors that affect spending and wealth distribution during retirement years



Retirement portfolio wealth

- Time horizon
- Spending requirement
- Contribution rate
- VCMM asset return projections
- Glide path
- Compensation growth
- Compensation level

Social Security

- Retirement age
- Compensation level and scale
- VCMM asset return projections
- Mortality table

Pension plan

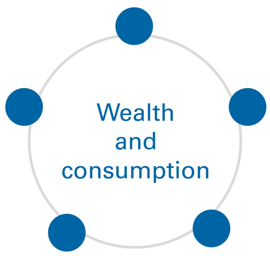
- Retirement age
- Compensation level and scale
- Pension plan specifics

External sources

- Rental income
- Licensing income
- Annuities
- Other income sources

Source: Vanguard.

Figure 3. Factors that affect consumption for nonretirement goals



- VCMM asset return projections
- Accumulation horizon
- Consumption horizon
- Contribution rate
- Initial capital

Source: Vanguard.

The RA coefficient measures the investor's degree of tolerance for market uncertainty. Finding out the correct RA coefficient for an individual in VLCM is equivalent to asking what the adequate policy benchmark for that investor would be. Is it the average equity/bond weight, 60%/40%? Or 80/20? Or 20/80? Advisors and consultants regularly answer this question when recommending portfolios to their clients. There is a one-to-one mapping between the riskiness of the benchmark and VLCM's RA coefficient.

Another important concept in the realm of rational preferences is time preference, or patience. All investors value receiving a payoff sooner rather than later, which is why markets need to compensate those who postpone their spending with a return (time value of money). However, investors differ in their degrees of patience. Along with the RA, this measure can be captured by analyzing the responses to a series of questions related to the subjective assessment of the time value of money.

Behavioral preferences

The utility-based approach also allows for the incorporation of behavioral considerations. Investors seldom exhibit entirely rational behavior. Their aversion to shortfall risk or to market losses often affects decision-making. Accounting for them can be extremely valuable.

Investors are often averse to falling short of their mental expectation of a certain dollar spending target. The disappointment of doing so can lead to portfolio changes that depart from the fully rational optimal glide path. VLCM's utility function has been modified to accommodate such a response. The model allows for specifying different spending targets to match the mental subjective expectation of a certain dollar amount. Appendix 3 describes how shortfall aversion is embedded into the utility function.

Another common form of loss-aversion bias happens when investors making portfolio decisions place a higher weight on the risk of experiencing negative market returns, especially large corrections or bear markets. This aversion is largely behavioral and not rational, in that it ignores actual statistical probabilities of such occurrences. Negative-return events may be much more infrequent and short-lived than investors fear. For instance, an individual may be oversensitive to a short-term period of negative returns early on even if it is unlikely to persist and have a significant long-term impact on wealth accumulation or the probability of success in retirement. The VLCM's utility function has been modified to incorporate such myopic loss aversion, and the resulting glide path exhibits sensitivity to temporary negative portfolio returns. In summary, VLCM accounts for both rational and behavioral investor preferences in calculating optimal glide paths.

Sensitivity of the glide path

In goals-based investing, the goal is never to achieve maximum returns or maximum wealth with no consideration for a portfolio's risk profile. The key problem for portfolio construction is to find the asset mix that strikes the right balance between investment risks and expected rewards. Therefore, the VLCM optimal glide paths are not necessarily the ones that can achieve the highest wealth accumulation (or even maximum success metrics) if that were to come at the expense of unbearable volatility.

Ultimately, success is more likely with a personalized portfolio that encourages investors to continue a steady flow of lifetime contributions throughout the normal ups and downs of the markets than with a high return-high risk option disconnected from the true degree of risk tolerance and loss aversion of the investor. Thus, portfolio optimization is not about finding the tactical asset allocation that results in outperformance of the portfolio relative to a benchmark or that can achieve higher wealth accumulation with less savings.

Perhaps the best way to quantify the benefits of a customized, optimized glide path is through the concept of a certainty fee equivalent (CFE), or the estimated benefit of customization. This refers to the fee (measured in basis points of return) an investor would be willing to pay to be placed on the optimized glide path versus staying with a non-optimal or ad hoc alternative.

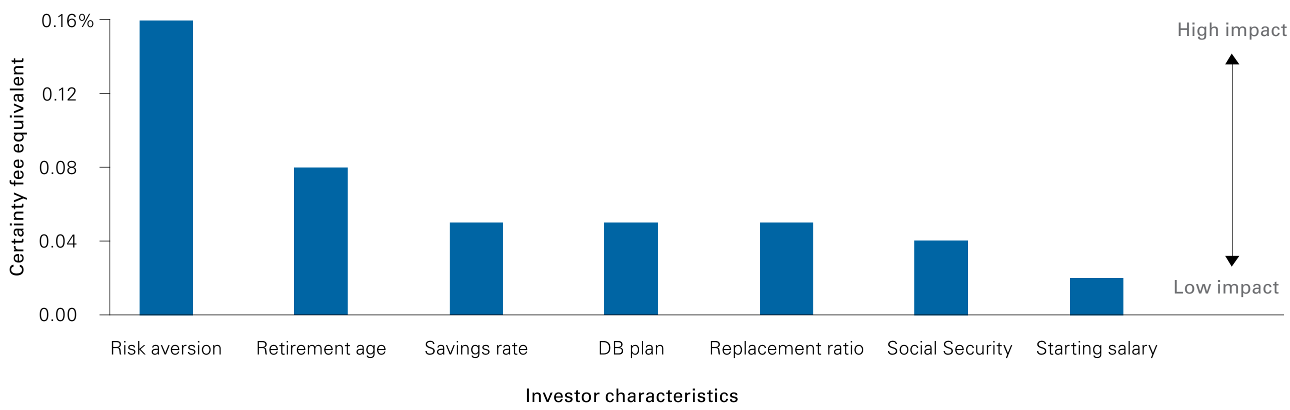
The higher the CFE, the greater the benefit of VLCM glide-path optimization (the benefit of striking the right risk-return balance given the investor's risk and loss aversion). The VLCM calculates this fee using the utility framework.

Figure 4 displays the benefit of customization (CFE) of glide paths resulting from various potential differences in investor preferences and circumstances. Investors who benefit the most from glide-path personalization have a different risk aversion than the broad population, prefer to retire early, or have a significantly lower savings rate, a higher spending rate, or pension benefits.

Another dimension of glide-path customization that receives a lot of attention is changes to the sub-asset allocation lineup such as portfolio tilts, sector overweights, and the consideration of alternative asset classes (commodities, liquid alternatives, and private assets). The VLCM provides a useful framework to consider the quantitative and economic significance of such changes versus other aspects of customization.

Figure 5 compares the impact on the probability of success of certain investor characteristics vis-à-vis that from sub-asset-class decisions. Increasing the savings rate from a low level to medium (as illustrated in **Appendix 5**) brings a dramatic improvement in probability of success of about 8%. Other factors such as delaying retirement or lowering the replacement ratio (spending less) are beneficial, too. By comparison, sub-asset allocation changes such as adding commodities or increasing credit exposure have a much lower relative impact.

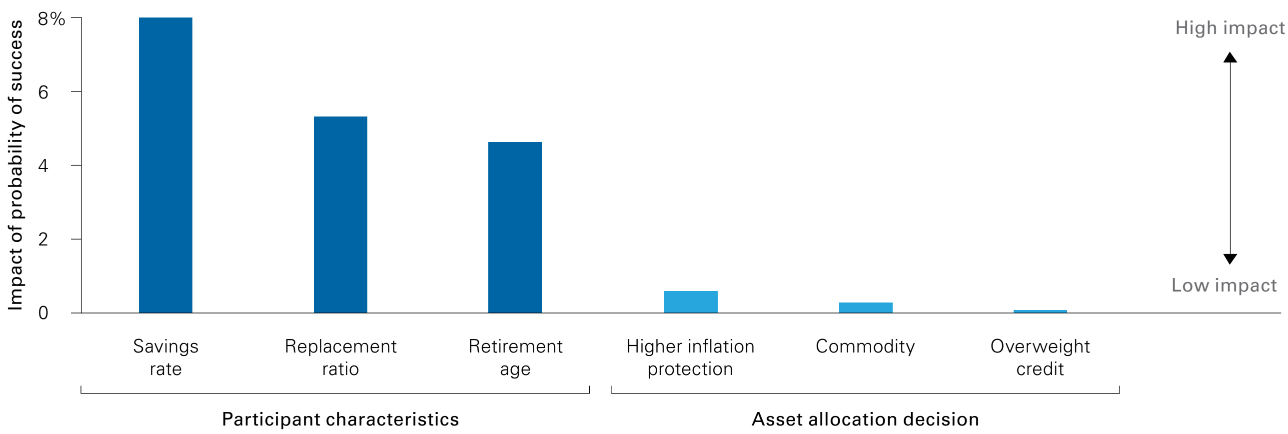
Figure 4. Quantifying the benefit of customization



Notes: The chart shows the impact of each population characteristic changing from low (25th percentile of broad population data) to medium (50th percentile). VCMM simulations are as of December 2019.

Source: Vanguard.

Figure 5. Sub-asset-class allocation decisions



Notes: The chart shows the impact of each population characteristic changing from low (25th percentile of broad population data) to medium (50th percentile). VCMM simulations are as of December 2019.

Source: Vanguard.

Case studies and insights

Insight 1: There is no one-size-fits-all solution

Potential differences in investor preferences and circumstances could result in a personalized glide path that differs from an off-the-shelf, ad hoc one. The implication of customization is most visible in the shape of the glide path: its average equity exposure and the pace and timing of equity de-risking. As shown in the hypothetical retirement goal analysis that follows, the VLCM can solve for customized glide paths for investors who are more or less risk-averse than the average investor (see **Figure 6**). These paths are more optimal from a utility standpoint than an off-the-shelf TRF and generate positive CFE (measured in basis points of return per year) relative to the traditional glide path.

In general, based on the model's sensitivity to inputs, we observe that:

- Increasing risk aversion leads to a more conservative VLCM-optimal glide path (see Figure 6a).
- Retiring earlier makes the optimal glide path more conservative during the accumulation phase and vice-versa (see Figure 6b).
- Lower spending leads to a more conservative optimal glide path and vice-versa (see Figure 6c).

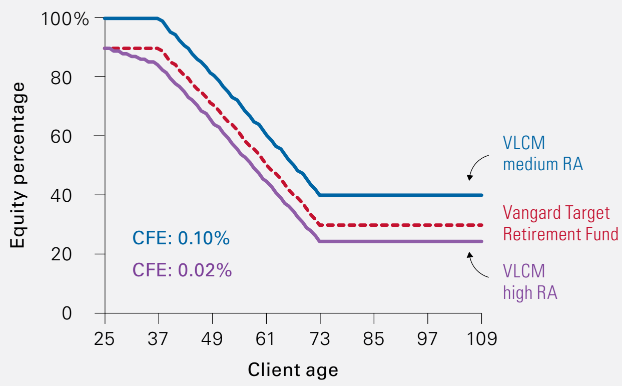
Insight 2: Don't ignore shortfall risk when it comes to nonretirement goals

VLCM can be used to solve for nonretirement goals such as education savings or buying a house. As shown in **Figure 7**, it can solve for the optimal glide path based on a different consumption horizon (one as opposed to four years). Both paths are optimal from a utility standpoint, assuming an investor contributes $1,000 each year and will get distributions past year 18. The blue bars show the dollar amount of consumption during the distribution period.

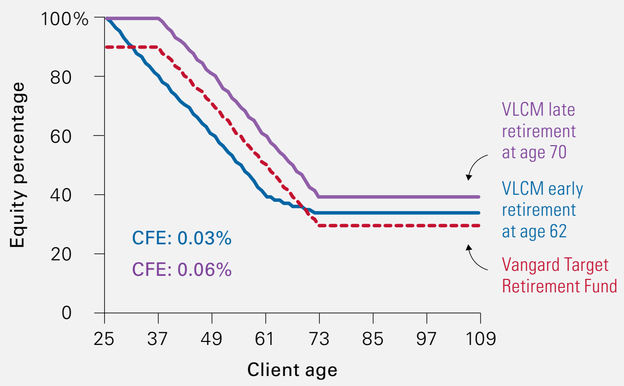
A common belief in the financial planning industry is that glide paths for nonretirement goals should "land" at very low or even zero equity levels.[2] The intuition behind this often-followed rule of thumb is that there is no need to take on market risk close to the end of the investment horizon. For instance, if an investor is saving to buy a house in ten years, the recommendation would be to have the glide path fully de-risked by year 9 to avoid the risk that a large negative market performance in the last year could unexpectedly erode portfolio wealth at the last minute.

Figure 6. Glide-path sensitivity and certainty equivalence fees

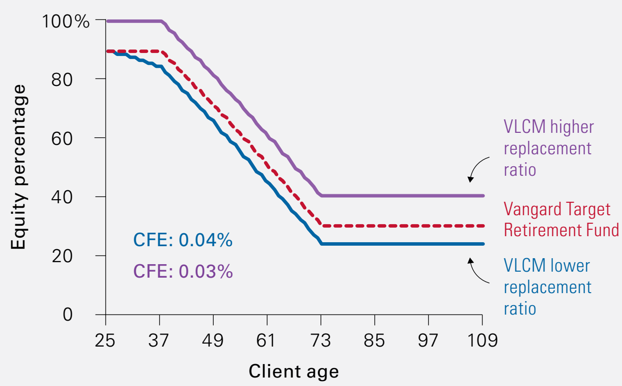
a. Risk-aversion sensitivity



b. Retirement age sensitivity



c. Replacement ratio sensitivity

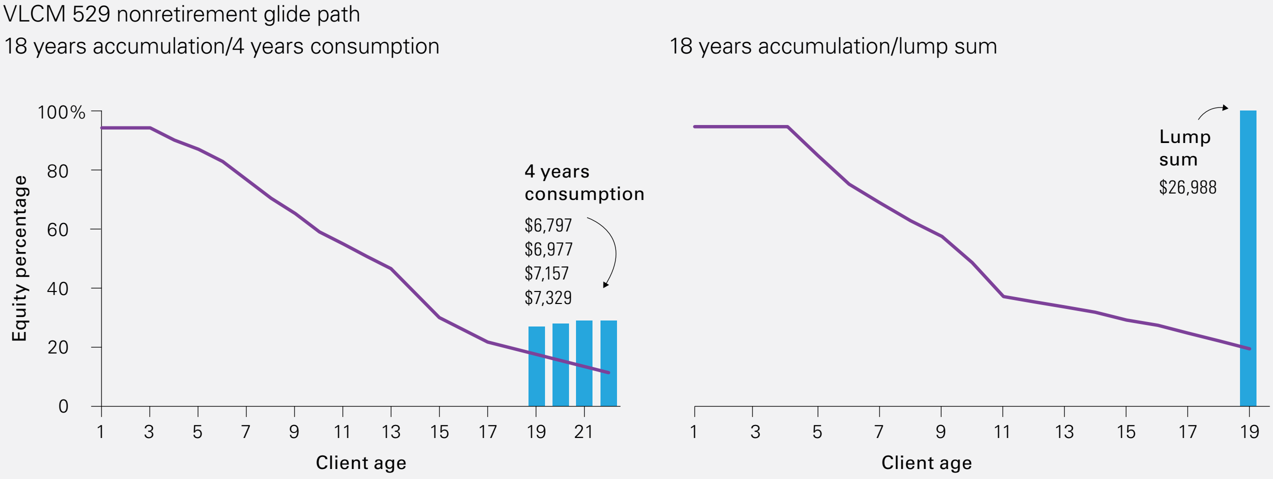


Note: Appendix 4 illustrates how changes in other preferences/parameters affect average equity exposure.

Source: Vanguard.

2 It is common for glide paths to move entirely to 100% cash when getting closer to the investment goal.

Figure 7. How VLCM solves for nonretirement goals such as saving for college



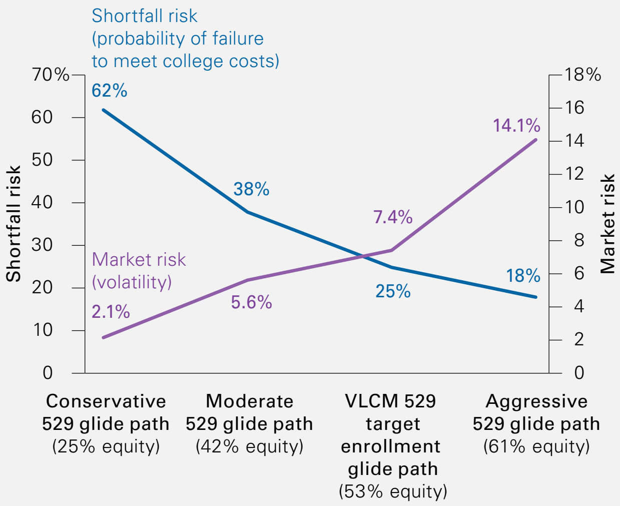
Source: Vanguard.

While the logic behind this recommendation seems compelling, it assumes with certainty that investors will be fully funded by year 9. In reality, such perfect foresight at the time of formulating the investment plan does not exist. At the beginning of the planning horizon, in year 1 of the glide path, it is unknown whether the portfolio will eventually achieve its goal or not. The probability of success may be high (say, 80%), but it is not 100%.

The problem with choosing a glide path that de-risks completely by year 9 is that it unintentionally increases the odds of falling short of the investment goal if the goal remains underfunded. After all, a more conservative glide path will yield a lower wealth accumulation. Thus, investors effectively face a trade-off: On the one hand, a path that de-risks fully might avoid last-minute market losses, but on the other hand, a more conservative landing point might increase significantly the odds of falling short of the goal.

Figure 8 illustrates this trade-off in the case of a college savings goal. It compares market risk to college funding shortfall risk for four different glide paths: three ad hoc paths with increasing landing points (equity weights) and one VLCM-derived optimal glide path. The upward-sloping purple line shows that market risk (portfolio volatility) increases with the equity level of the landing point of each path. The downward-sloping blue line shows that goal shortfall risk decreases for higher landing points. Out of the four paths, the VLCM's is optimal for balancing the trade-off between shortfall risk and market risk.

Figure 8. Optimal trade-off between market risk and shortfall risk



Source: Vanguard.

Insight 3: Early retirees benefit from a higher savings rate and, if their risk aversion is moderate to low, from glide-path customization

In the case of an early retirement, an investor with low or medium risk aversion may derive a greater benefit from customization and a personalized glide path identified through VLCM. Changes in circumstances such as demographic assumptions, retirement age, or savings rate will influence the glide path's outcome and probability of success.

Assuming an investor starts saving at age 25, retires early at 55, and wishes to replace 86% of his or her final salary, we compared the probability of success metrics using a Vanguard Target Retirement Fund (for an investor with high risk aversion) and two other VLCM-derived glide paths (for investors with low and medium risk aversion). The probability-of-success metric was based on the likelihood of the retiree meeting his or her spending needs at age 95.

Savings rate is one of the most critical factors an investor should leverage to increase the likelihood of retirement success. **Figure 9** illustrates that an investor who wants to retire early with a 20% savings rate is able to replace 86% of his or her age-55 salary with at least 80% success using any of the three glide paths. Because of the difference in risk profile, the two VLCM glide paths are not directly comparable to the TRF. Individuals have their own risk preferences; they are not interchangeable. Thus, VLCM can help advisors fine tune an investor's financial plan by providing important insights and analytics.

Insight 4: How much to save based on spending needs

A commonly referenced metric in goals-based investing is the probability of success. Usually, this is measured as the odds of fully funding a certain spending goal or need. For instance, in the case of retirement goals, the success metric is stated in terms of funding basic living expenses (not running out of cash) through age 95.

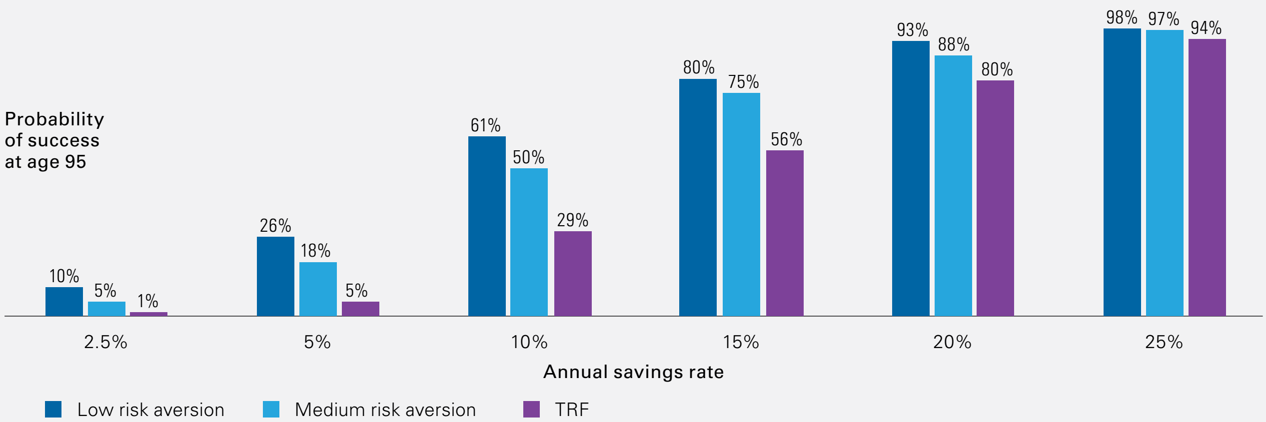
For any goals-based investment, there are four key determinants of the probability of success: potential asset returns and their uncertainty, asset allocation or glide path, savings, and spending needs. The exact mathematical relationship between these factors and the probability of success is built into the equations of the VLCM.

Thus, the VLCM can be used not only to derive the optimal glide path, but also to calculate the probability of success of any glide path (optimal or not). For instance, taking the TRF glide path as an example, the sensitivity table in **Figure 10** displays the probability of success for various replacement ratios (the ratio of portfolio income drawn during retirement to the final-year salary from the accumulation years), under various saving options. VLCM can provide analytical guidance on the saving level required for each desired spending level and creates a reference point for TRF investors to target a certain probability-of-success threshold (for instance, greater than 80%).

As shown in Figure 10, the probability of success at retirement is a function of the annual savings rate and spending level (replacement ratio). Lower spending and a higher savings rate contribute to a greater probability of success. For example, if an investor would like to

Figure 9. Early retirement reduces the overall probability of success, but VLCM-derived glide paths provide better outcomes

Early retirement at age 55: TRF versus VLCM glide paths



Note: The analysis above assumes an ending salary being spent during retirement, or a total replacement ratio of 86%, $26,600 starting salary, 47% retirement income coming from Social Security, a starting age of 25, and a retirement age of 55.

Source: Vanguard.

replace 98% of his or her age-65 salary, then the savings rate should be about 15% to result in an 80% or higher income sufficiency success rate up to age 95. Similar analysis can be conducted using a personalized glide path instead of the TRF.

Insight 5: How much to save based on spending needs and a bequest goal

How should savings rates change if an investor has a bequest goal? Again, for illustration purposes, we assume savings are invested in the TRF glide path.

A wealth multiple, or the ratio of terminal wealth to annual spending, provides a barometer of wealth levels available for bequest at age 95: 25th-, 50th-, and 75th-percentile outcomes are shown in **Figure 11**. For example, annual retirement spending of $40,000 with a wealth multiple of ten would mean a portfolio wealth of $400,000 at age 95 that could be potentially left to heirs.

As illustrated in Figure 11, leaving an amount of at least ten times annual spend to heirs at age 95 requires spending less than 80% of the investor's age-65 salary during retirement and saving 10% of annual income or higher starting at age 25. Leaving everything else the same but spending 86% of final income, a savings rate of 15% is more appropriate. VLCM provides valuable insights on appropriate saving rates for various levels of retirement spending rates, retirement ages, and bequest goal amounts.

Figure 10. How much should I save in my TRF based on my spending needs?

		Savings rate				
		2.5%	5.0%	10.0%	15.0%	25.0%
Replacement ratio	0.74%	15.9%	60.0%	96.8%	99.8%	100.0%
	0.80%	8.3%	41.4%	91.0%	99.1%	99.9%
	0.86%	4.8%	27.9%	81.4%	97.1%	99.6%
	0.92%	2.9%	19.2%	70.8%	93.9%	98.8%
	0.98%	1.9%	13.2%	60.2%	88.8%	97.3%

Notes: The table above shows probabilities of success based on varying savings rate and replacement ratios while keeping other assumptions such as starting salary, starting age, Social Security, and retirement age constant. This study assumes savings start at age 25 and retirement is at age 65. Salary and salary growth assumptions are based on broad U.S. demographic data. See Donaldson et al. (2015) for additional details.

Source: Vanguard.

Figure 11. How much should I save based on my spending needs (replacement ratio) and a bequest goal (wealth multiple)?

		Savings rate														
		2.5%			5.0%			10.0%			15.0%			25.0%		
	Percentile	25th	50th	75th	25th	50th	75th	25th	50th	75th	25th	50th	75th	25th	50th	75th
Replacement ratio	0.74%	1.2	1.6	2.4	2.6	5.5	15.2	17.6	31.2	51.5	36.0	56.7	88.3	54.5	82.4	124.9
	0.80%	1.1	1.5	2.2	2.2	3.5	9.8	12.4	24.6	43.3	29.3	48.2	77.3	46.4	72.1	111.2
	0.86%	1.0	1.4	2.0	2.0	2.9	5.6	7.8	19.0	36.2	23.6	41.2	67.6	39.5	63.0	99.2
	0.92%	0.9	1.3	1.9	1.9	2.7	4.2	5.0	14.2	30.0	18.6	34.9	59.3	33.4	55.3	88.9
	0.98%	0.9	1.2	1.7	1.7	2.5	3.7	4.1	10.0	24.7	14.4	29.3	52.2	28.2	48.7	79.7

Note: Wealth multiple is defined as total wealth at age 95 divided by annual spending. The 25th, 50th, and 75th percentiles are ranked forecast outcomes based on distribution of the wealth mutiple. For each savings rate, the blue boxes represent relatively higher wealth multiples and the purple boxes represent relatively lower ones. This study assumes that saving starts at age 25 and retirement is at age 65. Salary and salary growth assumptions are based on broad U.S. demographic data. See Donaldson et al. (2015) for additional details.

Source: Vanguard.

Caveats of the model

One limitation of the VLCM is that it cannot recommend optimal levels of spending and contribution rates. Rather, it optimizes the glide path for a specific customizable level of spending, growth rate of contributions, and other individual characteristics.

As in any model, the parameters used are subject to statistical uncertainty. While the model accounts for market uncertainty in its optimization, it does not formally account for model parameter uncertainty.

We have not tried to address the impact of health care shocks and the savings fluctuations investors are exposed to over their lifetime. Health care shocks due to changes in health needs have an associated cost that must be met, as do savings fluctuations arising from employment shocks and contribution variations during the accumulation years.

We expect eventually to provide a holistic life-cycle model that would optimize saving, investing, and spending strategies in the presence of a range of uncertainties faced by investors during their lifetime, such as asset returns, health states, and savings shocks. Furthermore, in future versions of VLCM we anticipate leveraging dynamic programming to have the model replicate dynamic decisions investors make in real time.

Finally, we would like to remind readers that, like any other model, VLCM is exposed to model specification risk. Although the model specification builds on a robust body of empirical evidence from both practitioners and academics in the field, it's important to acknowledge this risk.

Conclusion

Investment goals, saving, asset allocation, and spending are all interconnected. VLCM is a proprietary model created by our Investment Strategy Group to provide investors with glide-path construction personalized to their characteristics and preferences to help them meet their retirement or nonretirement investment goals.

The VLCM has multiple research and business applications. From an advice business perspective, one of the main benefits of its quantitative framework is that it can be used on multiple advice and digital technology platforms. The model allows for *full customization* of goals-based investing portfolios while at the same time preserving *scalability* in mass service offerings through technology implementations and also ensuring *consistency* of the underlying investment methodology for different clients and glide paths. Customization, scalability, and consistency are the three key advantages of ISG's quantitative models of portfolio construction.

From a due diligence and regulatory perspective, the quantitative methodology underpinning VLCM adds more transparency to advice methodology and implementation. Whether the model is used on an advice platform or within investment committees, its quantitative framework leads to more straightforward oversight and review processes of the resulting glide-path recommendations. After all, the model's methodological underpinnings are based on well-established theories in the academic literature on portfolio choice and household finance.

From a behavioral investment perspective, there are advantages to using the model to solve a goals-based investing problem. Its quantitative framework requires explicit inputs from the investor such as savings committed, realistic spending targets, expected timing to goal, and attitude toward market risk. It provides the client and the advisor or consultant with a powerful quantitative tool to estimate the impact of many decisions. This enables a conversation between advisors and investors about the realism of the explicit choices that must be made and that are critical to success in achieving the desired goal. An ad hoc glide path offers no explicit way to connect those choices to its design and ultimately evaluate the success of the plan.

A common misconception among practitioners is that the challenges involved in providing quantitative estimates for investors' choices, including degree of risk aversion, are unique to models such as VLCM. In reality, any glide-path recommendation, whether derived from a model or not, entails making all kinds of assumptions about savings, spending, and investor risk attitude. The only difference between "model-free" glide paths and quantitative models such as VLCM is that with the latter, such assumptions are explicit, which makes them transparent and more easily scrutinized.

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Appendix 1. Vanguard Capital Markets Model

IMPORTANT: The projections and other information generated by the Vanguard Capital Markets Model regarding the likelihood of various investment outcomes are hypothetical in nature, do not reflect actual investment results, and are not guarantees of future results. VCMM results will vary with each use and over time.

The VCMM projections are based on a statistical analysis of historical data. Future returns may behave differently from the historical patterns captured in the VCMM. More important, the VCMM may be underestimating extreme negative scenarios unobserved in the historical period on which the model estimation is based.

The VCMM is a proprietary financial simulation tool developed and maintained by Vanguard's Investment Strategy Group. The model forecasts distributions of future returns for a wide array of broad asset classes. Those asset classes include U.S. and international equity markets, several maturities of the U.S. Treasury and corporate fixed income markets, international fixed income markets, U.S. money markets, commodities, and certain alternative investment strategies. The theoretical and empirical foundation for the Vanguard Capital Markets Model is that the returns of various asset classes reflect the compensation investors require for bearing different types of systematic risk (beta).

At the core of the model are estimates of the dynamic statistical relationship between risk factors and asset returns, obtained from statistical analysis based on available monthly financial and economic data. Using a system of estimated equations, the model then applies a Monte Carlo simulation method to project the estimated interrelationships among risk factors and asset classes as well as uncertainty and randomness over time. The model generates a large set of simulated outcomes for each asset class over several time horizons. Forecasts are obtained by computing measures of central tendency in these simulations. Results produced by the tool will vary with each use and over time.

Appendix 2. The rational objective function for a retirement goal

The main principle behind life-cycle investing and VLCM is to maximize expected lifetime utility (or derived value) of consumption and wealth, $\overline{U_{Rational}}$, given by:

$$\overline{U_{Rational}} = U_{66} + U_{67} + \cdots U_{119}$$

In other words, lifetime utility is the sum of the utility scores of consumption and terminal wealth at each age postretirement for each year utility is received from consumption if the investor is alive, or from a hypothetical bequest if the investor is no longer alive. The model calculates each year's utility as the mortality probability-weighted utility for the full distribution of VCMM simulations.

Additionally, periodic consumption is the sum total of consumption from the portfolio, Social Security payments, and defined benefit plan payments and income from external sources such as rental income, if applicable. The rational objective function at time t is below:

$$U_t = \beta^{t-65}\, S_{t-1}[P_t\, E[U(C_{pt,t} + C_{ss,t} + C_{DB,t} + C_{EI,t})]] + (1-P_t)\, E[U(W_{t-1}) * (1+R_{t-1}))]$$

$$\beta = \frac{1}{(1 + r)}$$

β: investor's time preference (a behavioral preference,

r: investor's subjective discount factor parameter

P_t: conditional probability of survival to the end of period t

S_t: probability of survival to the end of the period t

$C_{pt,t}$: consumption from the portfolio during year t

$C_{SS,t}$: consumption from Social Security payments during year t

$C_{DB,t}$: consumption from defined benefit plan payments during year t

$C_{EI,t}$: consumption from external income payments during year t

W_{t-1}: portfolio wealth during yeat t–1

R: periodic portfolio return

Appendix 3. The behavioral component for income shortfall aversion

Income shortfall aversion captures the pain felt by investors when their income falls below a certain threshold. Utility functions can be modified to accommodate such preferences by overweighting the lower utility outcomes when consumption is below a target, thus avoiding solutions that are likely to fall short of the expected consumption targets. In other words, income shortfall aversion introduces a kink in the utility function.

In the case of a retirement goal, the threshold is applied to the replacement ratio, which is the percentage of ending salary that must be replaced by Social Security or other forms of income. This, in effect, represents the client's basic standard-of-living need. Any drop below this will warrant a large drop in utility. The calculation occurs for the full range of VCMM market return forecasts. Thus, income shortfall aversion is embedded in the rational objective functions A2 and A3.

$$E^*[U(C_t)] = \frac{(\sum_{i=1}^{n} A(U(C_i)))}{\sum_{i=1}^{n} A}$$

Where:

$$A = \begin{cases} (1-\alpha), & if\ C_i \geq \bar{C} \\ \alpha, & if\ C_i < C \end{cases}$$

C: actual periodic consumption

$\bar{C}$: spending threshold for shortfall aversion

α: shortfall loss aversion parameter

U: CRRA utility function

i: forecasted path of market returns out of 10,000 simulations

Appendix 4. Glide-path sensitivity

While the key criteria for glide-path optimization are embodied in the fee equivalence, the implication of customization is most visible in the shape of the glide path: the average equity exposure and the pace and timing of equity de-risking. The table below describes how an increase in each of the investor characteristics considered is expected to affect the level of equity exposure when the other characteristics are similar to the average of the broad population. Equity glide-path and fee equivalence differences are shown.

Expected impact on glide path

Increase in preference/ parameter	Average equity exposure	Reason
Risk aversion	Decreases	Risk aversion defines an investor's attitude toward the short-term volatility of the retirement portfolio. More aversion to risk (or a lower risk tolerance) means that an investor would rather give up a portion of the portfolio return potential for lower return volatility during the accumulation phase. If the investor's risk aversion increases, the glide path's equity level should decrease.
Savings rate	Decreases	A higher savings rate means faster wealth accumulation through working life, which means that risk-averse investors can afford to de-risk faster and earlier than otherwise.
Retirement age	Increases	As retirement age increases, human capital—typically a bond-like asset—also increases; hence, plan participants can afford a higher equity exposure in their glide path.
Income shortfall aversion	Decreases	This behavioral preference results in avoiding drops in income throughout retirement, which will generally in effect de-risk the glide path.
Myopic loss aversion	Decreases	The higher the myopic loss aversion, the less willing an investor is to tolerate loss during the distribution years. This will generally result in the avoidance of highly risk-seeking glide paths.

Note: The table above assesses the expected impact of only the specified characteristic changing, rather than multiple characteristics changing simultaneously. As an example, it does not cover a scenario where the presence of a DB plan (or large initial financial capital) in turn justifies an increase in risk aversion. Additionally, the expected impact on the glide path is based on the utility maximization framework for the VLCM. Under other utility functions and retirement objective functions, it could vary.

Source: Vanguard.

Appendix 5. Investor characteristics

Details of the investor characteristics needed to model wealth outcomes in VLCM are as follows.

Custom characteristics

Characteristic	Description	25th	50th	75th
Risk aversion	Risk aversion can be defined as aversion to uncertainty of outcomes. In other words, a risk-averse investor dislikes uncertain outcomes and prefers a degree of certainty. A low-level risk-averse investor would tolerate uncertainty for a better outcome, and an extremely risk-neutral investor would only care about the best outcomes and be indifferent toward uncertainty.	Low	Medium	High
DB plan income	DB plan income is computed by: • Defined benefit replacement ratio: the typical proportion of a final-year salary that a defined benefit will cover, or • Defined benefit formula: the calculation used by the plan sponsor to contribute to a DB plan.	NA	No DB	Yes (20% RR)
Savings rate	Savings rates typically differ by age; investors save relatively less when they are young and more as they approach retirement. Based on information from Alling et al. (2020), the average investor starts out at age 25 with an 8.8% savings rate and ends at age 65 with a 12.0% savings rate, including an employer match.	5.0%–8.0%	8.8%–12.0%	12.7%–16.8%
Starting salary	The investor's starting salary in dollars.	$26,600	$45,000	$65,000
Retirement age	The average age at which the investor leaves the workforce.	NA	65	70
Starting age	Starting age of investor.	25	25	25
Behavioral preferences	• Myopic loss aversion: how the investor perceives short-term market losses. • Income shortfall aversion: how the investor perceives a fall in income below a physiological threshold. • Time preference: the preference to consume now versus later.	Low	Medium	High
Spending	Spending (or consumption) is a direct function of wealth. The model will spend down wealth by following a range of different spending rules. These include: • Fixed-dollar spending (hybrid): The investor will spend a fixed dollar amount each year in retirement until wealth hits below a threshold, in which case spending is converted to percentage-of-portfolio. • RMD spending: The investor will draw down the portfolio in accordance with the Required Minimum Distribution starting at age 72. Post-retirement and before age 72, the investor will spend the first RMD percentage for age 72. • Percentage-of-portfolio spending: The investor will spend a fixed percentage every year in retirement. • Dynamic spending with a ceiling and a floor: The same as percentage-of-portfolio spending except that the investor cannot spend more than a specified ceiling or less than a specified floor of last year's spending.	Fixed-dollar spending (hybrid) with a replacement ratio of 0.81	Fixed-dollar spending (hybrid) with a replacement ratio of 0.86	Fixed-dollar spending (hybrid) with a replacement ratio of 0.91

Source: Vanguard.

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