Long-Dated Call Options in Defined Contribution Plans: A Superior Alternative

Working Paper (January 2026)

Not for citation; comments welcome

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We would like to thank the Options Institute, Cboe, and SpiderRock Advisors (the sponsor) for the research grant awarded for this study. We are grateful to Alexandra Szakats, Raj Shah, Florian Huchede, Eric Metz, Fred Sloneker, John Haffner, Kevin Nichols, Nishank Modi, and Bryan Fregeau for their comments and assistance at different stages of the project. We also want to express our gratitude to Bill O'keefe (Cboe Global Markets) and John Hiatt (Cboe Labs) for preliminary conversations leading to this study.

Abstract

We evaluate whether long-dated call options can address documented design flaws in target date funds (TDFs), currently the most popular investment vehicles in Defined Contribution (DC) plans. TDFs provide insufficient dollar-weighted equity exposure during early working years despite high percentage allocations. Using 96 years of historical S&P 500 data (1928–2024) and 1,000 simulated market scenarios, we analyze six accumulation strategies incorporating various option leverage and de-risking approaches over 20-year horizons. Two strategies emerge as superior: Blended (immediate option profit conversion to equities) achieves 84% outperformance frequency versus the S&P 500 benchmark with 11.24% median IRR, while Split Profit (conditional conversion based on realized gains) achieves 77% outperformance with 11.22% median IRR. Both strategies maintain downside risk comparable to passive equity investment while proving robust under pessimistic return assumptions. In contrast, aggressive continuous-leverage strategies underperform despite higher average returns driven by tail outcomes. The results support option-based leverage as a practical mechanism for improving younger participants' retirement outcomes while maintaining behavioral and financial suitability through balanced de-risking. We conclude that option-enhanced lifecycle strategies warrant serious policy consideration as superior alternatives to conventional TDF design.

Keywords: *Lifecycle investing, target date funds, leverage, long-dated options, defined contribution plans*

JEL Classification: G11, G23, J32

The growth of defined contribution (DC) retirement plans over recent decades has fundamentally altered how American households accumulate retirement savings. Whereas traditional defined benefit pensions placed responsibility for investment decisions with professional managers, the shift toward DC plans has devolved this responsibility to individual workers, many of whom lack the expertise, time, or inclination to make sophisticated portfolio choices. This shift prompted regulatory and industry responses designed to simplify retirement saving through automated investment vehicles.

Target Date Funds (TDF) have emerged as the dominant solution to this coordination problem. By 2024, TDFs has captured over $3.5 trillion in assets and represented the standard default investment option in 401(k) plans across the United States. TDFs embody the principle of lifecycle investing—the notion that younger investors with longer time horizons should maintain more aggressive equity allocations, gradually shifting toward conservative investments as retirement approaches. This principle has considerable theoretical appeal, rooted in the human capital framework developed by Bodie, Merton, and Samuelson (1992), wherein younger workers possess substantial human capital (the present value of future labor earnings) that functions as a bond-like asset. Maintaining constant overall risk exposure requires that financial capital hold higher equity allocations when human capital dominates total wealth, declining as human capital depletes and financial capital accumulates.

Yet despite this theoretical foundation, substantial evidence suggests that conventional TDF implementation suffers from a fundamental flaw. As Shiller (2005) points out and Ayres and Nalebuff (2010; 2013) demonstrate, the dollar-weighted equity exposure embedded in TDFs differs markedly from the time-weighted allocation typically advertised. Young workers contribute small amounts to initially large allocations toward equities, generating minimal absolute dollar exposure to growth assets. As portfolios accumulate through both continued contributions and investment returns, the same or lower percentage allocations generate increasingly substantial dollar exposure to equities. This creates a conundrum: the largest portfolio balances - accumulated in later career years—receive exposure to less risky assets precisely when the portfolio's size would permit greater equity market participation (Basu and Drew, 2009). Furthermore, average TDFs maintain roughly 50% equity allocation at their target retirement date, providing limited downside protection from market shocks. The 2008–2009 financial crisis provided stark evidence of this limitation, as 2010-target TDFs experienced losses averaging 25–30%, disappointing investors who believed their portfolios had been appropriately de-risked.[1] It is paradoxical that despite having a long investment horizon, the retirement plan investor's dollar weighted risk exposure is not evenly spread but concentrated heavily towards the final years before retirement. Therefore, the dual objectives of lifecycle investing – portfolio growth in early years and protection from market downturns in later years – are not realized.

For the younger investor, the lack of investable capital acts as a binding constraint on their exposure to equity market. Ayres and Nalebuff (2008; 2010) identified this problem and proposed an alternative framework wherein younger investors employ leverage to maintain constant allocation of the present value of combined current and future retirement savings in stocks. Their historical backtesting across multiple decades and international markets demonstrated that such leveraged lifecycle strategies substantially outperformed conventional TDFs in terms of both accumulated wealth and risk-adjusted returns. However, their analysis focused primarily on margin borrowing as a leverage mechanism and did not conduct detailed empirical analysis using actual option prices. This gap represents a significant limitation, as long-dated options offer distinct advantages over alternative leverage mechanisms for retail retirement investors: unlike margin loans, options provide defined maximum loss; unlike futures, they require no constant collateral monitoring; and unlike leveraged ETFs, they avoid daily rebalancing friction and volatility decay.

There has been scant research done on the use of leverage in the retirement investor's portfolio. Few studies such as Willen and Kubler (2006) and Ayres and Nalebuff (2010; 2013) which have delved in the topic have used an average interest cost linked with broker 'call money' rates as margin cost for leveraged portfolios in simulating their outcomes. The Australian study of Dunn et al (2009) on leveraged strategies also uses a borrowing cost that applies a fixed spread on the 10-year government bond rate. Ayres and Nalebuff (2010) suggest buying call options on broad market indices such as S&P500 or tracking exchange traded funds such as SPDR as a desirable

[1] Congressional inquiries following the crisis questioned whether TDF marketing and disclosure adequately communicated risks to participants. The persistence of these design flaws in the years since the crisis suggests that industry-standard glide paths may not represent optimal solutions.

leverage mechanism after considering the implicit borrowing costs of different Long Term Equity Anticipation Securities (LEAPS). However, no study till date has used option prices directly in testing the performance of leveraged lifecycle portfolios and estimating the excess payoff for retirement savers. This paper addresses this gap in the literature by providing the first comprehensive empirical analysis of retirement portfolio strategies directly incorporating long-dated (2-year) call option prices. We construct historical option price series spanning 1928–2024 by combining observed market data from 2005–2024 with synthetically reconstructed option prices for earlier periods using Vector Autoregression (VAR) models. We then simulate six distinct investment strategies—ranging from pure equity investment to aggressive continuous leverage—across rolling 20-year accumulation horizons representing the first half of working life of the retirement plan investor. We evaluate the strategies under both historical market conditions and simulated scenarios designed to test robustness. Our analysis incorporates 889 distinct rolling windows covering the historical period between 1928 and 2024 and 889,000 simulated windows, enabling robust statistical inference regarding strategy distributions and relative performance.

Our principal findings suggest that successful option-based leverage strategies must balance two competing objectives: multiplying gains from equity risk premiums through leverage while minimizing substantial capital losses. Strategies that maintain continuous leverage throughout the 20-year window fail to achieve acceptable reliability. Instead, two middle-ground approaches - one that perpetually converts option payoffs into unleveraged equity positions (Blended strategy) and another that conditionally converts payoffs based on realized gains or losses (Split Profit strategy) - achieve significant success in outperforming the equity market, respectively, while maintaining acceptable downside risk profiles. These findings are validated across different market environments and even under pessimistic assumptions.

The remainder of this paper is organized as follows. Section 2 reviews the theoretical foundations of lifecycle investing, examines existing critiques of Target Date Fund design, and situates our contribution within the broader literature on leverage and options in retirement portfolios. Section 3 details our methodology, including our approach to reconstructing historical option prices and generating simulated scenarios, and describes the six investment strategies evaluated in our study. Section 4 and 5 report the results from our analyses with historical and simulated S&P data, organized around key performance dimensions: wealth accumulation, success rates and reliability, and downside protection. Section 6 summarizes the results of further robustness checks under different market regimes and longer expiry options. Section 7 concludes.

2. Lifecycle Investing, Target Date Funds, and the Case for Leverage

The theory of optimal lifecycle portfolio choice originates with Samuelson (1969) and Merton (1969, 1971), who applied continuous-time dynamic programming to derive optimal consumption and investment rules under uncertainty. Their foundational result demonstrated that, with constant relative risk aversion preferences and time-independent investment opportunities, the optimal equity allocation should remain constant throughout an investor's lifetime rather than declining with age. This counterintuitive finding follows directly from the mathematical structure of their models: when investment opportunities present identical characteristics regardless of the investor's age or remaining time horizon, optimal risk-taking should not decline with age alone.

However, Bodie, Merton, and Samuelson (1992) demonstrated that this prescription changes fundamentally when human capital is incorporated. Younger workers possess substantial human capital—the present value of future labor earnings—which functions as a large, bond-like asset providing relatively stable cash flows over the working career. As individuals age and progress through their careers, human capital gradually depletes while financial capital accumulates through savings and investment returns. Maintaining constant overall risk exposure across the combined portfolio of human capital and financial capital requires that equity allocations in the financial portfolio start high when human capital dominates total wealth and decline as human capital diminishes and financial capital grows. This human capital framework provides theoretical justification for the glide path concept underlying Target Date Funds.

Despite the practical appeal of lifecycle investing and TDFs, empirical research has identified systematic flaws in conventional TDF implementation. Basu, Byrne, and Drew (2009, 2011) documented that the effective dollar-weighted equity exposure in TDFs falls substantially short of time-weighted allocations commonly reported in fund prospectuses. Through careful analysis of popular TDF families, they demonstrated that while funds maintain 80–90% equity allocations for young investors, the absolute dollar amounts exposed to equities remain minimal due to small portfolio balances. Twenty years into the accumulation phase, when portfolios have grown substantially, the same or lower percentage allocations generate vastly larger dollar exposure to growth assets. Paradoxically, young workers whose portfolios are small (when leverage would have greatest benefit per dollar of exposure) receive minimal dollar exposure, while workers approaching retirement (when large capital losses would prove most harmful) receive substantial equity exposure.

Ayres and Nalebuff (2010) proposed an alternative framework addressing these criticisms. Rather than maintaining constant percentage allocations that yield time-weighted but not dollar-weighted equity exposure, they advocated that younger investors employ leverage to maintain constant allocation of the present value of current and future retirement savings in equities. In their framework, an investor in the first year of a 40-year career might employ 2:1 leverage to maintain 100% equity exposure (in present value terms) while gradually de-leveraging toward 1:1 as retirement approaches. They demonstrated through extensive backtesting on U.S. market data from 1871–2009 that this leveraged lifecycle approach would have outperformed conventional strategies across every 30-year investor cohort, in terms of both accumulated wealth and risk-adjusted performance metrics.

Ayres and Nalebuff's analysis extended to United Kingdom and Japanese markets with similar conclusions, and results proved robust even under substantially more conservative assumptions regarding future equity risk premiums (30% below historical experience) and return volatility (50% above historical levels). Importantly, Ayres and Nalebuff also discussed Long-Term Equity Anticipation Securities (LEAPs) as a potential implementation mechanism, noting that the effective interest rates implicit in option pricing often proved more favorable than margin loan rates, particularly for smaller investors facing higher marginal borrowing costs.

Despite the theoretical underpinnings and promising historical simulation results, Ayres and Nalebuff (2010) did not provide detailed empirical analysis using actual historical option prices. Their analysis relied primarily on margin borrowing cost assumptions rather than explicitly simulating retirement portfolio outcomes using real option price data. As they acknowledged, direct analysis using option price data represented an important avenue for future research - a gap this paper directly addresses.

Call Options, especially those with longer expiry, offer several compelling advantages over alternatives leverage mechanism available to individual investors. First, unlike margin loans that require ongoing (and often prohibitively high) interest payments and expose investors to margin calls during market downturns, long-dated options limit maximum loss to the premium paid. This feature provides psychological and financial protection during volatile markets when forced liquidations would prove most harmful. Second, unlike futures contracts that demand constant collateral monitoring and require frequent rolling as contracts approach expiration, long-dated options provide ample time for markets to recover from temporary dislocations without requiring active management. Third, unlike leveraged exchange-traded funds that suffer from daily rebalancing friction and compounding effects of daily reset mechanisms over extended horizons, long-dated options maintain consistent leverage ratios and avoid volatility decay. Finally, long-dated options may benefit from favorable tax treatment in retirement accounts. While we do not conduct detailed tax analysis given the complexity of option taxation in qualified plans, the potential for favorable tax treatment compared to margin interest constitutes an additional advantage worthy of consideration.

3. Methodology

3.1 Constructing Historical Option Price Data Series

Our analysis utilizes daily observations spanning January 1928 through December 2024, representing 96 complete calendar years and approximately 24,000 trading days. This extended sample encompasses numerous complete market cycles—the Great Depression and subsequent recovery, the post-war economic expansion, the stagflation era of the 1970s, the technology boom and bust of the late 1990s and early 2000s, the 2008–2009 global financial crisis, and the recent decade's remarkable equity market performance. The breadth of this sample provides substantial variation in market conditions essential for evaluating strategy robustness across different economic regimes.

Historical S&P 500 index data originate from Robert Shiller's online database, which carefully constructs a consistent historical series by linking the modern S&P 500 index with its predecessor indices during earlier periods. The data include dividend reinvestment and appropriate adjustments for index methodology changes. We compile daily prices into monthly series representing closing values on the first trading day of each month, consistent with our strategy implementation wherein monthly contributions occur and option purchases execute at observed market prices.

The main reason behind prior research not exploring options in leveraging portfolios is that the market is relatively new (and LEAPS even newer) compared to the stock market, which makes it difficult to test the strategy over historical periods that predates the advent of index options. We address this issue by employing a method that simulates SPX call option prices for modelling the expected outcomes for different cohort of retirees going back in history.

Constructing historical option data series for our entire sample period presents a significant challenge given that trading of exchange-traded index options commenced only in 1983 and long-dated options traded actively only from the mid-2000s forward. To address this problem, we reconstruct historical implied volatility surfaces using Vector Autoregression models estimated on the 2005–2024 period, then extend these models backward using historical equity returns and realized volatility as exogenous inputs. We model the implied volatility surface using a two-dimensional grid defined by option delta (moneyness) and time to expiration. Specifically, we construct surfaces across five delta values (0.1, 0.25, 0.5, 0.75, 0.9) and five expiration horizons (0.25, 0.5, 1.0, 1.5, 2.0 years). For each trading day in the 2005–2024 observed sample, we interpolate observed implied volatilities onto this standardized grid, yielding 25 implied volatility observations.

For the period 2005–2024, we utilize comprehensive US market option data from Cboe, which provides complete daily records of bid-ask prices, implied volatility, delta, and other characteristics for actively traded S&P 500 index options (SPX). For each date, we compute time to expiry T, index price, delta Δ, and implied volatility $IV_{T,t}^{\Delta}$for call options. These are then used to compute an IV surface across the grid of delta and time to expiry. A Vector AutoRegression with exogenous variables (VAR-X) model is then estimated with the following specification:

$$y_t = c + \sum_{i=1}^{3} \phi_i \, y_{t-1} + \psi \, x_{t-1} + \varepsilon_t \qquad (1)$$

$y_t = [IV_{1,t}^{0.1},\ IV_{1.5,t}^{0.1},\ IV_{2,t}^{0.1},\ IV_{1,t}^{0.5}, IV_{1.5,t}^{0.5},\ IV_{2,t}^{0.5},\ IV_{1,t}^{0.9}, IV_{1.5,t}^{0.9}, IV_{2,t}^{0.9}]'$, $\boldsymbol{c}$ is a vector of constants, ϕ_i are square matrices of coefficients. ψ is a coefficient matrix. $x_{t-1} = [r_{t-1},\ \overline{\sigma}_{t-1:t-22}]$ contains lagged index returns and a 22-day moving average of a OHLC volatility estimator:

$$\sigma_t = \sqrt{\frac{1}{2}\, ln\left(\frac{H_t}{L_t}\right)^2 - (2l\,n(2) - 1)n\left(\frac{C_t}{O_t}\right)^2} \qquad (2)$$

ε_t is a vector of residuals.

Using 1928-2024 observations for S&P 500 returns and volatility used in $\boldsymbol{x_{t-1}}$, $\boldsymbol{y_t}$ is recursively simulated using the VAR coefficient estimates. This process produces a complete daily series of synthetic implied volatility surfaces extending back through the full sample period. The simulated $IV_{2,t}^{0.5}$is selected and combined with the observed 2005-2024 sample to give an IV for the full 1928-2024. For 2-year call options (the primary analysis focus), we extract the synthetic implied volatility at 2.0 years maturity and 0.5 delta (approximately at-the-money). From the generated surface based on the simulated $IV_{2,t}^{0.5}$, 2-year call option prices $C_{2,t}^{0.5}$ are computed using the Black-Scholes model. These are combined with the observed prices for 2-year options to give a call option price series for the full 1928 to 2024 period.

For 5-year options, we employ a two-stage approach: for 2012–2024 (when some trading occurred in longer-dated options) we extract observed implied volatilities for options with close to 5-year maturity and 0.5 Delta We then estimate the following regression:

$$IV_{5,t}^{0.5} = \alpha + \beta_1 IV_{0.25,t}^{0.5} + \beta_2 IV_{0.5,t}^{0.5} + \beta_3 IV_{1,t}^{0.5} + \beta_4 IV_{1.5,t}^{0.5} + \beta_5 IV_{2,t}^{0.5} + \varepsilon_t \qquad (3)$$

Using the estimated coefficients, we predict 5-year implied volatility $IV_{5,t}^{0.5}$ for 2005-2011 from contemporaneous shorter-maturity implied volatilities and the observed $IV_{0.25,t}^{0.5}$, $IV_{0.5,t}^{0.5}$, $IV_{1,t}^{0.5}$, $IV_{1.5,t}^{0.5}$, $IV_{2,t}^{0.5}$ during that period. With an estimate of $IV_{5,t}^{0.5}$ for the full 2005-2024 period, the same process for 2-year options as described above was followed to obtain $IV_{5,t}^{0.5}$ for the 1928 to 2004 period. We then apply the Black-Scholes option pricing model using this complete implied volatility series, observed S&P 500 index levels, and historical short-term interest rates to generate daily series of synthetic 5-year option prices covering the full 1928–2024 period.

From the full 1928-2024 period, $IV_{2,t}^{0.5}$ and $IV_{5,t}^{0.5}$ are used to construct price paths of every 2-year and 5-year call options. $C_{2,t}^{0.5}$ and $C_{5,t}^{0.5}$ are calculated (initially at-the-money at the start of each 2-year and 5-year windows) using the relevant S&P 500 index price for each month, expiring at the end of the window. For example, the price of first 2-year option is generated from January 1928 till it expires in February 1930.

3.2 Simulation Framework for S&P 500 & Option Price Paths

While historical analysis provides insights into actual realized outcomes across numerous market regimes, any single historical path represents just one draw from the distribution of potential futures. Monte Carlo simulation enables exploration of strategy performance across a broad range of alternative market scenarios. We develop a comprehensive simulation framework generating complete alternative market histories spanning the 1928–2024 period.

To generate a single simulated market history, we initialize at the beginning of the sample period with the observed historical S&P 500 index level, then recursively generate daily returns. The foundation of our simulation involves modeling daily equity returns through a GARCH(1,1) specification capturing both unconditional mean returns and time-varying conditional volatility. To simulate index prices through time, accounting the time-varying volatility, returns are simulated under the following GARCH(1,1) process:

$$\sigma_t^2 = \gamma + \alpha r_{t-1}^2 + \beta \sigma_{t-1}^2, \quad r_t \sim N(\mu, \sigma_t) \qquad (4)$$

where the mean return, μ is simply set the be the long-run average over the full sample. Simulated returns are used to construct simulated index price through time based on the same initial S&P500 price as at the start of the sample. The length of simulated series is set to be equal to that of the historical sample (1928-2024), generating a complete alternative 96-year market history.

The simulated returns are used to construct volatility (monthly moving average of squared daily simulated returns in this case as OHLC prices are not available), which are then used to simulate $IV_{2,t}^{0.5}$ and $IV_{5,t}^{0.5}$ using the VAR model, in the same manner as described above. These IV are then used to compute simulated price paths of every 2-year and 5-year call options $C_{2,t}^{0.5}$ and $C_{5,t}^{0.5}$. This process is then repeated 1,000 to generate 1,000 independent simulated market histories, each representing a complete alternative realization of 96 years of market dynamics. Each simulation preserves important features of historical data including mean return levels, volatility clustering patterns, and relationships between realized and implied volatility, while allowing the specific timing, magnitude, and sequencing of bull markets, bear markets, and volatility episodes to vary across simulations.

3.3 Investment Strategies: Design and Rationale

We evaluate six distinct investment strategies spanning the spectrum from no leverage (pure equity) to continuous maximum leverage. All strategies share the foundation of same monthly contributions (inflation-adjusted annually) extending over precisely 20 years but differ in how they allocate new contributions and reinvest proceeds from maturing options.

i) S&P 500 Only (Benchmark): This strategy serves as our benchmark, representing conventional unleveraged equity investment. Every monthly contribution throughout the entire 20-year horizon purchases S&P 500 index shares at prevailing market prices. This strategy mirrors a traditional equity-focused TDF portfolio for young investors.

ii) Rolling Options (Maximum Leverage)" This strategy implements the most aggressive approach to leverage, maintaining continuous exposure to 2-year call options throughout the investment horizon. Each monthly contribution purchases a new 2-year at-the-money call option. When options mature, proceeds immediately roll into new 2-year call options. This continuous rolling maintains leveraged exposure, with only a brief exception during the final 24 months when new options cannot mature within the 20-year window. At that point, new contributions and maturing proceeds shift to S&P 500 index purchases. This strategy tests the maximum potential benefit of sustained leverage during accumulation, accepting substantial volatility in pursuit of maximum wealth accumulation.

iii) Blended (Immediate De-leveraging): This strategy represents a more conservative approach to leverage implementation, using options to gain initial leveraged exposure but immediately converting all option payoffs into unleveraged equity. Each monthly contribution purchases 2-year options identical to the Rolling Options strategy. However, when any option matures, proceeds immediately and permanently invest in the S&P 500 index rather than purchasing new options. Similar to Rolling Options, contributions during the final 24 months invest in the S&P 500 index. This strategy tests whether capturing option leverage benefits during the accumulation phase while locking gains into safer index holdings produces superior risk-adjusted returns compared to continuous rolling.

iv) Lifecycle (Time-Based De-leveraging): This strategy implements explicit glide-path de-risking by dividing the 20-year horizon into distinct phases. During the first ten years (months 1–120), the strategy operates identically to Rolling Options—new contributions purchase 2-year options and maturing proceeds roll into new options, maintaining aggressive leverage while portfolios remain relatively small. At the ten-year midpoint, the strategy pivots toward de-risking. During the second decade, the strategy operates identically to Blended—new contributions continue purchasing options until month 216, after which all further contributions and maturing proceeds invest in the S&P 500 index. This creates explicit lifecycle progression where leverage concentrates in early years and automatically de-risks as portfolios grow and approach the accumulation period's end.

v) Lifecycle Split Profit (Asymmetric Profit Realization): This strategy introduces asymmetric treatment of profitable versus unprofitable option outcomes during the first ten years. When options mature, the strategy examines realized returns. If the option generated a profit, the strategy splits proceeds—the original principal rolls into a new 2-year option maintaining leverage, while the profit invests permanently in the S&P 500 index to lock gains. If the option resulted in a loss, all proceeds roll into a new 2-year option. During years 11–20, the strategy operates identically to Lifecycle. This asymmetric reinvestment rule reflects behavioral finance insights regarding loss aversion while implementing systematic profit-taking discipline.

vi) Lifecycle Profit Rolled (Inverted Asymmetric Treatment): This strategy inverts the asymmetric logic while maintaining the ten-year lifecycle pivot. During years 1–10, when options generate profits, the original principal invests permanently in the S&P 500 while the profit increment rolls into new options. The logic reflects a momentum perspective—profitable options suggest favorable conditions warranting continued leverage on gains. Conversely, when options result in losses, all proceeds invest immediately in the S&P 500, de-risking capital that failed to benefit from leverage. During years 11–20, all proceeds invest in equities similar to other lifecycle variants.

3.4 Rolling Window Portfolio Simulation Framework

Having constructed complete price series for equities and options spanning 1928–2024 in both historical and simulated data, we evaluate retirement investment strategies using a rolling window methodology. We initiate a new 20-year investment period on the first trading day of every month beginning in January 1928. Each window represents the experience of a hypothetical cohort beginning their retirement savings program at that specific date and contributing monthly for precisely 20 years. The choice of 20 years as the investment horizon is deliberate and important in the context of the 'lifecycle conundrum' discussed earlier in the paper. The objective of using options-based strategies is to build significant wealth for young investors by the time they reach the middle of their working life so that they can afford to de-risk their portfolio aggressively well ahead of their retirement without sacrificing their retirement lifestyle. A time period of 20 years roughly represents the midpoint of most people's career. Therefore, the accumulation at the end of this horizon would be an appropriate comparator to assess the suitability of the strategies as default investment vehicle for young employees joining retirement plan.

Common assumptions across all strategies include initial monthly contributions of $100 beginning in the first month of each window, with contributions growing annually at the rate of inflation observed during the corresponding historical or simulated period. We compound this inflation adjustment annually, so all years within a given window maintain constant real contribution values. Contributions occur on the first trading day of each month, with immediate investment according to each strategy's rules using option or equity prices prevailing at that time.

Our analysis produces 889 distinct rolling 20-year windows from historical data, with the first window beginning January 1928 and ending December 1947, and the final window beginning November 2004 and ending October 2024. In simulated data, each of the 1,000 simulated market scenarios generates these same 889 rolling windows, producing 889,000 total simulated window observations. For each window and each strategy, we track all contributions, option purchases, option maturities, equity positions, and final balances. We calculate multiple performance metrics including final portfolio value, internal rate of return accounting for timing and size of cash flows, and relative performance compared to a pure S&P 500 benchmark strategy.

4. Historical Performance Analysis

We analyze historical performance across 889 rolling 20-year windows spanning 1928-2024. Results are presented in logical progression: starting with a visual examination of the rolling window accumulation outcomes, then examining distribution characteristics, following by relative performance and downside risk analysis.

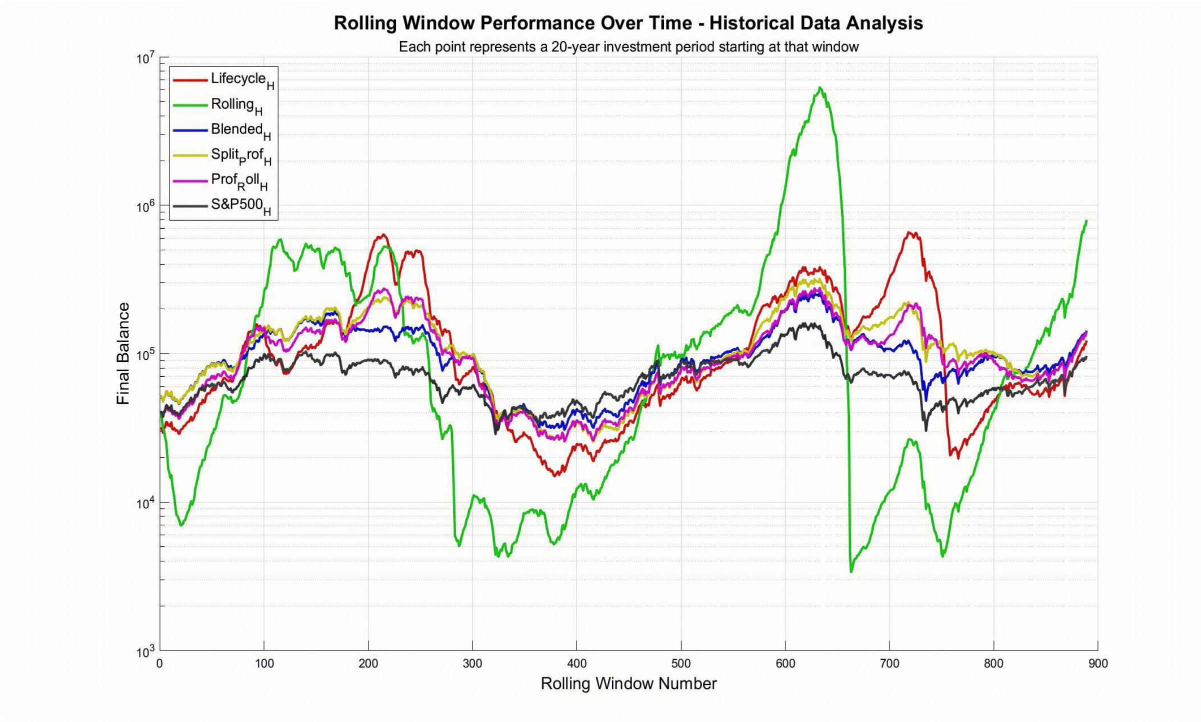

FIGURE 1: Accumulation over Rolling 20-year periods (from Jan, 1928)

Figure 1 displays the final accumulated wealth outcomes for each of the six investment strategies across 889 rolling 20-year investment periods beginning monthly from January 1928 through October 2024. Each point represents the terminal portfolio value for a hypothetical cohort that begins accumulation at that specific date and contributes monthly contributions (inflation-adjusted annually) over precisely 20 years. The temporal pattern reveals that cohorts beginning in recovery periods following market crashes (post-1932, post-1975, post-2008, post-2020) experience substantially higher accumulations across all strategies, demonstrating that accumulation outcomes depend critically on when within the market cycle individuals begin their investment program. Cohorts beginning in early 1928 experienced the entire Great Depression within their 20-year accumulation window, visible in the lower tail of outcomes, where both the S&P 500 benchmark and particularly the leveraged strategies show compressed returns reflecting the severe equity market contraction. Conversely, cohorts initiating savings in the mid-1950s through mid-1960s navigated the post-war economic expansion, evidenced by elevated outcomes across all strategies during this period. The clustering of lower outcomes visible in the 1970s-early 1980s reflects cohorts confronting the stagflation era mentioned in the paper, demonstrating that inflationary periods with moderate equity returns constrain option profitability and strategy effectiveness. Most visibly, cohorts beginning around 1999–2002 (dotcom bubble, bust and subsequent recovery) and 2007–2009 (financial crisis and subsequent expansion) demonstrate the volatility within the figure: the immediate market downturn compressed early-window returns while the subsequent strong recovery within the 20-year window generated elevated final accumulations.

The S&P 500 benchmark (gray line) exhibits relatively stable, predictable accumulation clustering in the $50,000–$75,000 range across all historical periods, reflecting consistent equity market resilience across diverse regimes. In stark contrast, the Rolling Options strategy (green line), and Lifecycle (red line) to some extent, demonstrates extreme regime dependence, with severe contractions during cohorts experiencing deflationary or stagnant markets (visible in the Great Depression and stagflation-era troughs), punctuated by spectacular peaks during recovery-dominated periods (visible post-2008 and post-2020). The Blended strategy (blue line) maintains consistently elevated outcomes throughout the historical period, clustering around $85,000–$105,000 with minimal sensitivity to regime transitions, demonstrating that immediate de-leveraging provides robustness across heterogeneous market environments. Lifecycle (red line) and its variants (Split Profit and Profit Rolled) occupy intermediate positions with moderate volatility relative to Rolling Options, though showing more pronounced sensitivity to regime classification than Blended. The Rolling Options' occasional spikes to $1,000,000+ are statistical outliers concentrated in favorable regime windows unlikely to characterize the typical investor's experience, whereas the Blended strategy's consistent elevated outcomes across all historical periods represent the realistic experience most participants would encounter regardless of entry timing within the historical sample.

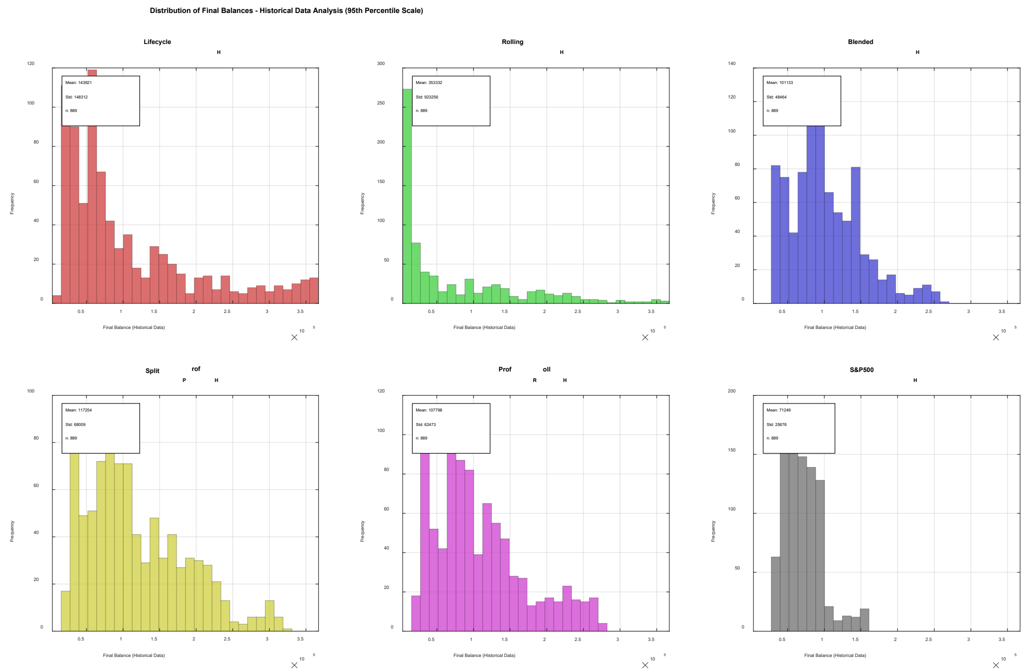

FIGURE 2: Distribution of Final Balances - Historical Data Analysis

Figure 2 visually demonstrates accumulated wealth distributions of the six strategies. The S&P 500 benchmark strategy shows a tight distribution of outcomes centered around $69,000 with slight right skewness. Rolling Options (green histogram) extends far to the right with extreme rightward skew, revealing frequent low outcomes alongside occasional massive gains exceeding $1,000,000. Similarly, Lifecycle strategy shows extreme right skewness with modal outcomes below $70,000 but occasional tail outcomes exceeding $500,000-$1,000,000. The skewness of these strategies creates a disconnect between mean (pulled upward by rare exceptional cases) and median (reflecting typical outcomes). Participants in these strategies cannot reliably count on mean returns; they must plan for lower median outcomes. Blended (blue histogram) concentrates tightly around $90,000, showing that typical outcomes closely are well above the benchmark's accumulation. Similarly, the two Lifecycle variants - Split Profit and Profit Rolled - show more concentrated and less skewed distributions compared to the Lifecycle startegy. This visual representation clarifies why median outcomes prove more important for retirement planning than means—individuals must plan for typical outcomes, not statistical averages.

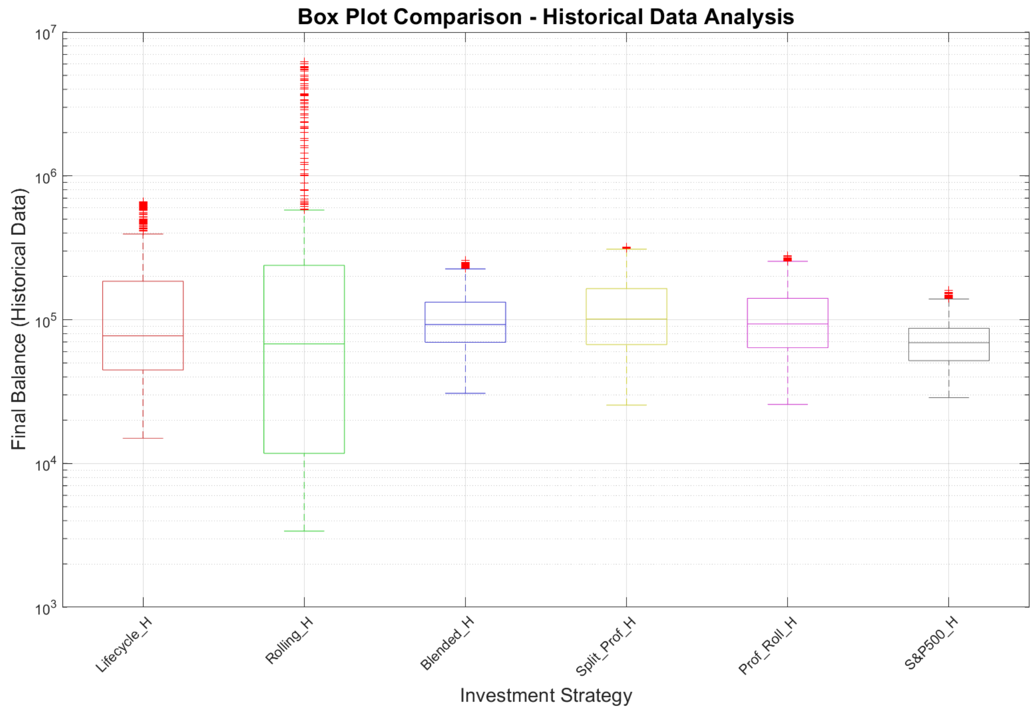

FIGURE 3: Box Plot Comparison - Historical Data Analysis

Box plots in Figure 3 illustrate quartile structures and outliers. Again, the benchmark has the tightest interquartile range (IQR) and bare any outlier outcome. In contrast, Rolling Options (green) displays extreme outliers extending far above the IQR, confirming extreme skewness where occasional extraordinary gains pull the mean upward while frequent poor outcomes keep the median low. Blended (blue) exhibits a compact box indicating that 50% of outcomes fall within a tight range, with minimal outliers beyond expected variation. This visual consistency distinguishes Blended as reliable compared to the highly variable Rolling Options approach. The Lifecycle has a wider IQR (more than twice the benchmark) and a number of outliers whereas its conditional variants – Split Profit and Profit Rolled – have a more compact box with a few outliers.

TABLE 1: Summary Statistics of Terminal Wealth Outcomes (in $) over 20-Year Horizon Using Historical S&P 500 Data (1928-2024)

Strategy	Mean	Median	Maximum	Minimum	Standard Deviation	5th Percentile
S&P 500	71,249	69,166	160,259	28,699	25,676	35,518
Rolling Options	353,332	67,857	6,209,934	3,382	923,256	5,232
Blended	101,133	91,254	258,560	30,734	48,464	40,218
Lifecycle	143,921	69,842	658,692	14,978	187,654	21,489
Split Profit	117,254	99,876	318,959	25,439	62,341	30,726
Profit Rolled	112,843	87,234	277,208	28,456	58,923	31,256

Table 1 reports summary statistics of the final wealth outcome distributions for all six strategies across 889 rolling windows. Mean outcomes reveal dramatic differences. Rolling Options achieves $353,332 mean wealth—five times the S&P 500 benchmark's $71,249. However, the median outcomes tell a different story. While Rolling Options' mean is highest among all six strategies, its median of $67,857 (below the benchmark's $69,166) is the lowest among all strategies. The Rolling Options' mean IRR of 21.91% pairs with median IRR of only 7.57%, a 14.34 percentage point gap revealing an extremely skewed distribution (Table 2). In contrast, Blended's 11.24% mean IRR pairs with 10.43% median IRR (only 0.81 percentage point gap), indicating symmetric, reliable outcomes where typical participants experience near-average returns. The Lifecycle strategy results in the second highest mean outcome, but the median outcome barely matches the benchmark. In comparison, both Split Profit and Profit Rolled generate mean and median outcomes that are significantly above that of the benchmark. The average accumulations of these strategies are also well above that of the Blended. In terms of median outcome, Split Profit exceeds Blended whereas Profit Rolled is slightly lower.

TABLE 2: Internal Rates of Return over 20-Year Horizon Using Historical S&P 500 Data (1928-2024)

Strategy	Mean IRR (%)	Median IRR (%)	Mean-Median Gap (%)
S&P 500	8.03	7.75	0.28
Rolling Options	21.91	7.57	14.34
Blended	11.24	10.43	0.81
Lifecycle	14.34	8.79	5.55
Split Profit	12.55	11.22	1.33
Profit Rolled	12.12	10.53	1.59

Next, we look at the variability of the outcomes from individual strategies. The benchmark has the lowest standard deviation implying a high predictability of accumulation at the end of the 20-year horizon. reveals outcome concentration. Rolling Options' standard deviation of $923,256 exceeds its mean of $353,332, indicating outcomes cluster at extremes rather than around the center. Blended's standard deviation of $48,464 relative to its mean of $101,133 indicates concentrated, predictable outcomes. Split Profit (std dev $62,341) and Profit Rolled (std dev $58,923) show similar tightness, while Lifecycle (std dev $187,654) exhibits problematic variability. These distributional characteristics fundamentally determine whether retirement planning can rely on typical outcomes matching expectations.

Beyond central tendencies, the magnitude of potential losses critically determines behavioral suitability. Young savers experiencing catastrophic losses may abandon strategies precisely when long-term discipline matters most, undermining theoretical advantages regardless of positive expected value. Evaluating minimum outcomes and low percentile results reveals whether worst-case scenarios remain psychologically and financially acceptable.

Rolling Options presents unacceptable downside risk through its minimum outcome of $3,382 representing approximately total capital loss despite 240 months of $100 contributions. The 5th percentile outcome of $5,232 confirms that even favorable outcomes among the worst 5% of cases produce disastrous results. A young saver experiencing such catastrophic losses would likely abandon the strategy, destroying its long-term effectiveness regardless of positive expected value in other scenarios. This behavioral reality makes Rolling Options unsuitable despite its theoretical appeal.

In sharp contrast, Blended's minimum wealth of $30,734 exceeds the benchmark's $28,699, while its 5th percentile of $40,218 remains within normal equity investor expectations. Lifecycle shows concerning downside with 5th percentile of $21,489 and minimum of $14,978. Split Profit (5th percentile $30,726) and Profit Rolled (5th percentile $31,256) maintain acceptable downside comparable to benchmark risk. This downside analysis identifies the suitability boundary: strategies maintaining manageable worst-case scenarios (Blended, Split Profit, Profit Rolled clustering near $30,000 minimums) differ fundamentally from catastrophic strategies (Rolling Options below $4,000).

The IRR analysis reinforces distributional insights. Rolling Options' 14.34 percentage point gap between mean and median IRR confirms that the typical investor experiences only 7.57% IRR despite the 21.91% mean return—reflecting the 50% probability of underperformance. Blended's 0.81 percentage point gap indicates median outcomes closely track expectations, providing confidence that the stated success rate reflects what investors will typically experience.

While distribution characteristics describe outcome shapes, we need to quantify the downside risk of the strategies: (i) how often a strategy falls short of achieving the accumulation generated by the passive equity benchmark over rolling 20-year windows and (ii) to what extent does it fall short in such scenarios. Similarly, we also need to be attentive to the upside potential of the strategies with respect to (i) how often a strategy is able to exceed the accumulation from benchmark strategy and (ii) when it does, what is the magnitude of such outperformance. We compute the relative frequency of underperformance (outperformance) of each strategy relative to the benchmark strategy as well as the magnitude of their underperformance (outperformance). Finally, we assess overall attractiveness of each strategy by scaling their upside potential against their downside risk by computing a ratio of the expected value of the outperforming outcomes and the expected value of the underperforming outcomes. We call this measure the Asymmetric Pay-off Ratio.

TABLE 3: Performance Relative to S&P 500 Benchmark (Historical Data)

Strategy	Underperformance		Outperformance		Asymmetric Pay-off Ratio
	Relative Frequency	Magnitude (%)	Relative Frequency	Magnitude (%)	
Rolling Options	0.50	67.07	50%	512.26	17.17
Blended	0.16	12.58	84%	47.80	29.92
Lifecycle	0.44	28.58	56%	187.85	11.89
Split Profit	0.23	20.25	77%	82.13	19.28
Profit Rolled	0.28	16.38	72%	72.06	15.83

The results reveal stark differences between the leveraged strategies in their ability to outperform the benchmark. The Rolling Options strategy achieves exactly 50% success rate—participants experience better outcomes than the S&P 500 benchmark in only 444 of 889 rolling windows, while underperforming in the remaining 445. This coin-flip reliability makes the strategy unsuitable for retirement planning despite superior mean returns. The Lifecycle strategy achieves only 56% success (496 windows), marginally better than even odds. In sharp contrast, Blended achieves 84% success (747 windows), with Split Profit at 77% (686 windows) and Profit Rolled at 72% (639 windows). This gap from 50% to 84% success represents the boundary between unsuitable and suitable retirement strategies.

When Rolling Options underperforms the benchmark, average underperformance is -67.07%, creating significant portfolio setbacks. However, when it outperforms, average outperformance reaches +512.26%, creating 17:1 asymmetric pay-off ratio. While superficially attractive, the 50% underperformance frequency and the significantly large size of underperformance make this unsuitable for retirement planning - investors cannot reliably achieve the positive asymmetry. Blended maintains almost 30:1 asymmetric pay-off ratio while underperforming only 16% of the time, achieving superior reliability. When Blended underperforms, the magnitude of underperformance averages only 12.58% below the benchmark's accumulation, while outperformance averaging +47.80% produces a favorable asymmetric ratio. Split Profit's 19:1 ratio combined with 77% outperformance frequency also provides attractive risk-return characteristics. These metrics quantify the fundamental tradeoff: Rolling Options offers potential of extremely high pay-offs but with extremely large downside, while Blended and lifecycle variants like Split-profits offers better asymmetric pay-off with much higher reliability.

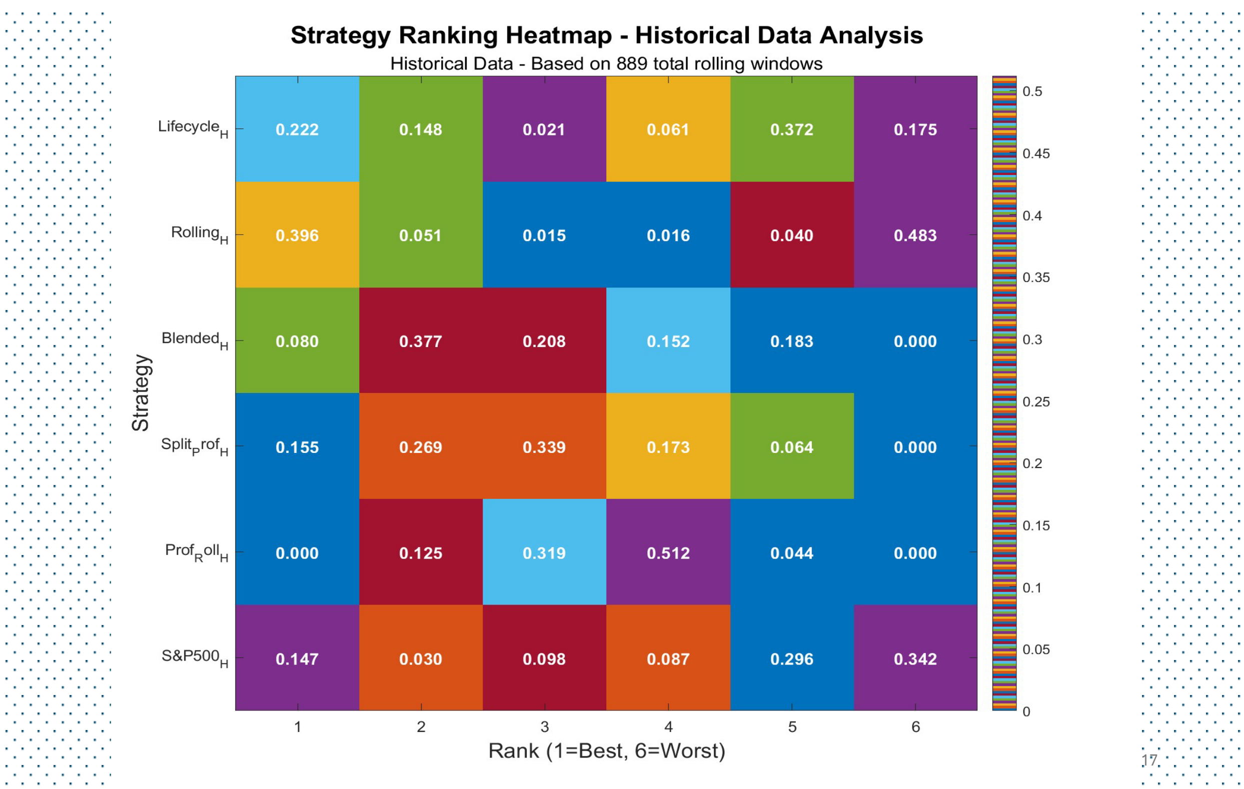

FIGURE 4: Strategy Ranking Heatmap - Historical Data Analysis

The strategy ranking heatmap is shown in Figure 4. It reveals consistent performance patterns across rolling windows. Collectively, the leveraged strategies outperform the benchmark strategy in more than 85% of the rolling 20-year windows. Looking at the individual leveraged strategies, Rolling Options shows extreme bimodality, concentrating in rank 1 (best, 39.6%) and rank 6 (worst, 48.3%), indicating its performance depends entirely on market conditions without consistency. In contrast, Blended never ranks last place while concentrating in ranks 2-3 (close to 60%), indicating it reliably performs near-best across diverse conditions without depending on favorable market timing. Split Profit similarly concentrates in ranks 2-3 (>60%), while Profit Rolled shows comparable consistency. This heatmap visually demonstrates why Blended achieves its high 84% success rate: it performs reliably well regardless of market environment, while Rolling Options' 50% success reflects its unpredictable bimodal performance pattern. Noticeably, the Lifecycle strategy shows extreme variability compared to its conditional variants – Split Profit and Profit Rolled – as it ranks highest in 22% of the rolling windows but also ends up in the bottom two positions in nearly 55% of the same.

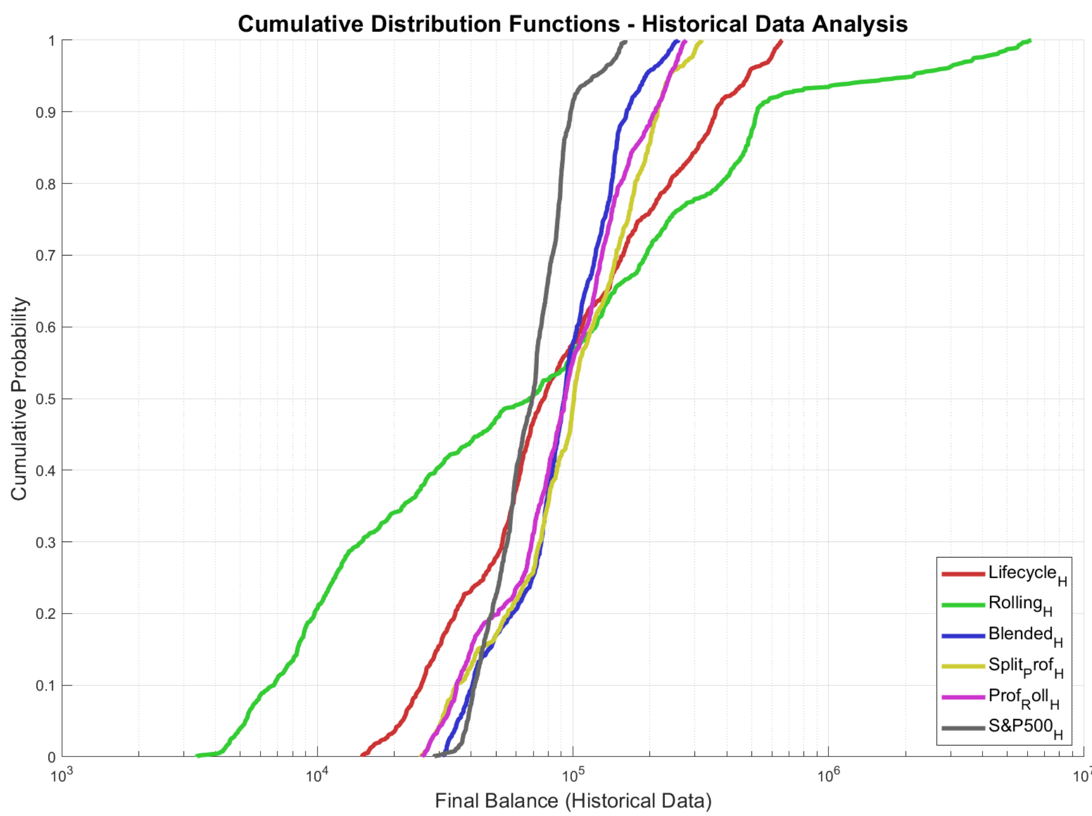

FIGURE 5: Cumulative Distribution Functions - Historical Data Analysis

Cumulative distribution functions (CDFs) directly show the probability of achieving specific outcome levels—the probability function most relevant for retirement planning. These show the likelihood of reaching various wealth targets crucial for retirement adequacy. The CDF in Figure 5 reveals critical insights into achievable outcomes. S&P 500's (gray) curve shows steep left-shift, indicating high probability (>80%) of reaching $60,000, reflecting predictable distribution. Blended's (blue) steep curve shows 50% probability of reaching approximately $92,000. In stark contrast, Rolling Options' (green) gradually rising curve indicates outcomes spread across an extremely wide range—only 50% probability of reaching $70,000 despite much higher mean. Split Profit and Profit Rolled show curves between these extremes, indicating good probability of achieving significantly higher outcomes (compared to the benchmark) with manageable tail risk. These CDF visualizations clarify that participants choosing Rolling Options may be confronting lottery like outcomes (small probability of achieving extremely high accumulations) while strategies like Blended and conditional lifecycle variants provide significantly greater certainty of obtaining moderately higher outcomes compared to the benchmark S&P500.

The comparison between Blended (immediate de-leveraging) and Lifecycle (ten-year partial leverage) reveals another important dynamic challenging intuition. Blended achieves higher success rates (84% versus 56%) and substantially higher median outcomes. Why does immediate de-leveraging outperform the delayed approach? The explanation appears to involve compounding and volatility interaction dynamics. When leveraged positions are maintained for extended periods like in Lifecycle's ten-year first phase, temporary downturns can erode gains faster than those same downturns affect unlevered positions. Volatility amplification compounds this problem—a 10% market decline impacts leveraged portfolios asymmetrically compared to unlevered ones. By immediately converting option gains to equities as Blended does, the strategy 'locks in' the benefits of leverage while avoiding the risk that leverage amplifies subsequent volatility-driven losses. Lifecycle's continued leverage through year ten exposes accumulated gains to ongoing volatility, partially reversing previous years' leverage benefits. In this interpretation, the optimal strategy balances two competing objectives: capturing leverage benefits during initial accumulation when absolute exposure remains manageable, and rapidly de-leveraging to preserve accumulated capital from amplified losses during subsequent volatility. The immediate-conversion approach better balances these objectives than time-based approaches that maintain leverage based on calendar time.

5. Performance Analysis with Simulated S&P 500 data

While historical analysis describes actual realized outcomes across numerous market regimes, any single historical path represents just one draw from an infinite distribution of potential states of the world. To examine a varied set of possible outcomes for our stylized investment strategies, we simulate S&P 500 return paths which enable stress-testing strategies under alternative scenarios that can test their robustness to unfavorable market conditions. The method for generating simulated S&P 500 index data and corresponding option prices have already been described in Section 3.

TABLE 4: Simulated vs Historical Market Characteristics

	Simulated	Historical	Difference
S&P 500 Mean Return (Annualized)	5.89%	7.63%	-1.74%
Volatility (Annualized)	21.50%	18.84%	+2.66%
Worst Monthly Return	-67.96%	-31.49%	-36.47%
Best Monthly Return	203.51%	43.47%	160.04%
2-Yr Calls In-The-Money	63%	76%	-13%
2-Yr Calls Profitable at Maturity	43%	59%	-16%
5-Yr Calls In-The-Money	67%	80%	-13%
5-Yr Calls Profitable at Maturity	48%	66%	-18%

Before evaluating outcomes of investment strategies using simulated S&P 500 data and comparing them to the results of those with historical data, we need to compare historical return distribution with that using simulated data. Table 4 presents equity return characteristics and option performance metrics using simulated and historical S&P 500 data.

Historical S&P 500 monthly returns exhibit a mean of 0.636%, corresponding to annualized returns of 7.63%, with standard deviation of 5.439% (annualized: 18.84%). These figures align well with widely cited long-run equity market statistics. The historical distribution displays slight positive skewness (0.176) and excess kurtosis (9.158), revealing fat tails with frequent extreme returns exceeding normal distribution predictions. The worst historical monthly return equals -31.49% (Great Depression era) and the highest equals 43.47% (recovery period).

In contrast, the simulated data overall exhibits a far pessimistic view of the equity markets: mean returns of 5.89% represent a 1.74 percentage point annual shortfall versus 7.63% historical average. Volatility of 21.50%, on the other hand, exceeds historical estimate by 2.66%, indicating more uncertainty. The simulated data also has remarkably extreme returns including monthly observations of -67.96% and +203.51% (outliers that may be considered implausible) suggesting GARCH process occasionally generates scenarios inconsistent with real-world constraints. These differences create ideal stressed conditions for our strategy evaluation.

The depressed and more volatile simulated equity market returns have implications for profitability of options and leveraged investments. For 2-year call options, simulated profitability rate declines from 59% (historical) to 43% (simulated), a 16 percentage point deterioration. The decline is even higher (18 percentage point) for 5-year call options. This stressed scenario tests whether strategy conclusions depend critically on optimistic historical assumptions or reflect fundamental strategy characteristics robust to materially adverse conditions.

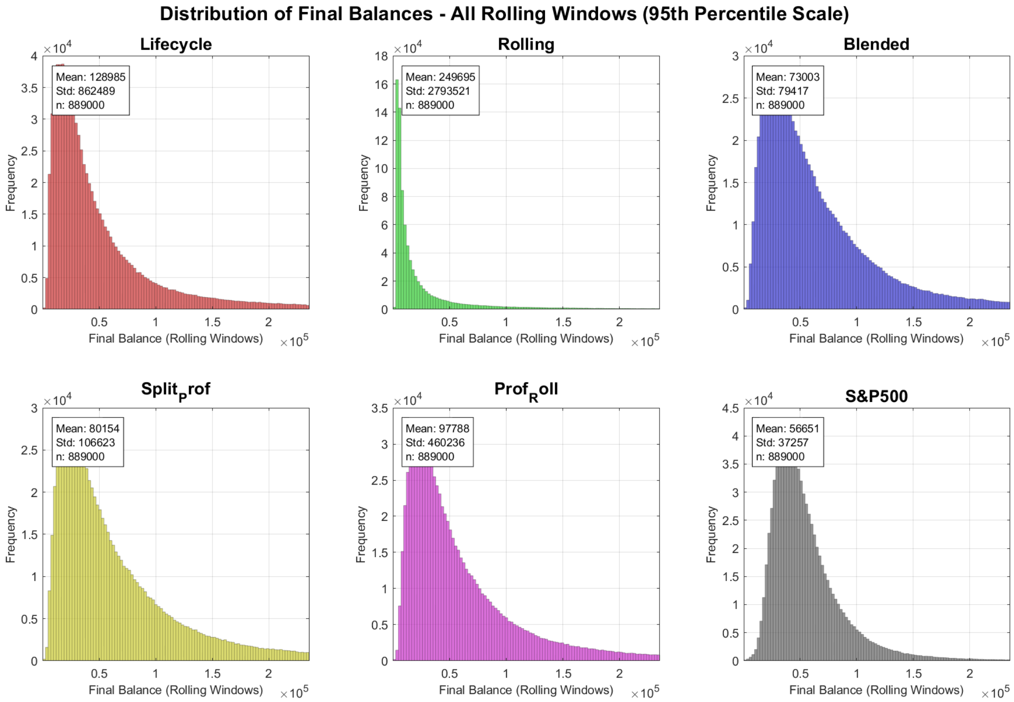

FIGURE 6: Distribution of Final Balances - Simulated Data

Simulated outcome distribution shift dramatically compared to historical outcome distribution as shown in Figure 6. All strategies show downward shifts reflecting reduced expected returns. Rolling Options' distribution becomes even more extremely skewed, with modal outcomes in the low thousands while rare outcomes reach millions. Blended and Split Profit maintain relative concentration, though shifted downward.

Box plots for simulated data (Figure 7) using logarithmic scale reveal that despite stressed conditions, Blended (blue) and variants of the lifecycle strategies maintains tight interquartile distributions. The same could not be said about the Rolling Options (green) which shows a wider interquartile range. Interestingly, the third quartile outcome of the Rolling Options is not too far from the first quartile outcomes of the Benchmark as well as the other strategies. The number of outlier outcomes are higher for all strategies (including the Benchmark) compared to their historical distribution. Again, the Rolling Options strategy results in significantly larger outlier results compared to the other strategies.

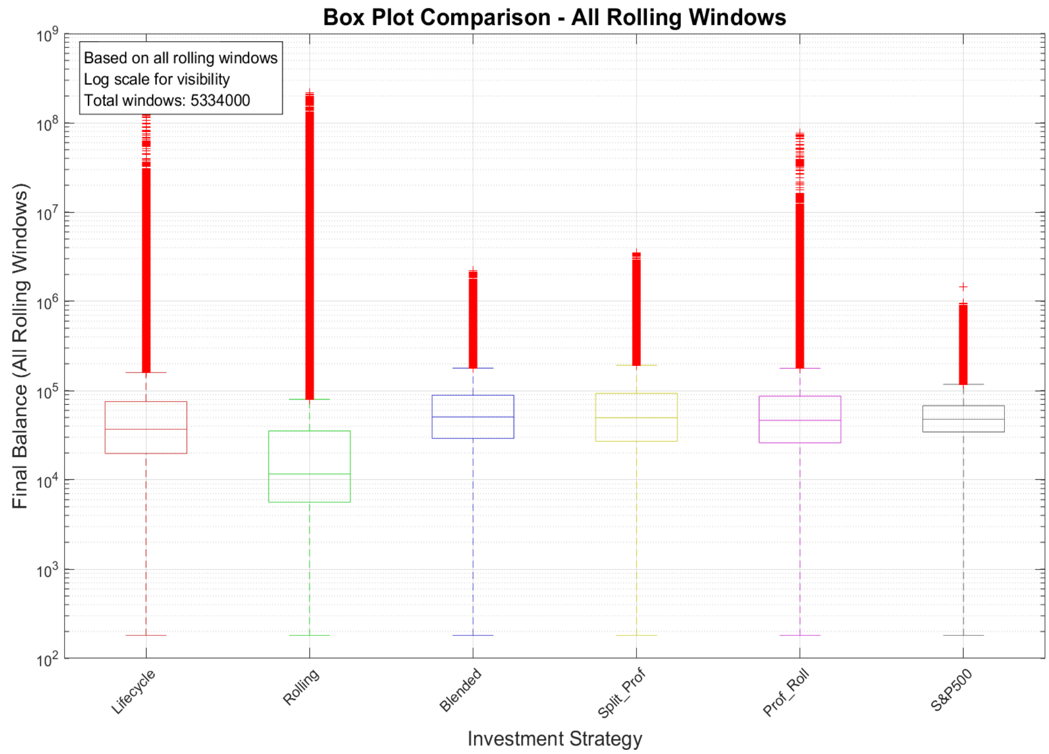

FIGURE 7: Box Plot Comparison - Simulated Data (Log Scale)

Table 5 reports the aggregated summary statistics of wealth outcomes for all 1,000 simulations. Expectedly, performance of all strategies deteriorates under simulated pessimistic conditions. The benchmark's median wealth declines from $69,166 (historical) to $47,781 (simulated)—a 31% reduction reflecting lower expected returns. Rolling Options' median collapses from $67,857 to $11,620 - 83% deterioration—while its mean-median gap persists at enormous magnitude, confirming continued distribution skewness. Most troublingly, median IRR becomes negative (-13.74%), indicating typical outcomes represent losses (Table 6). Critically, Blended's median of $50,716 remains slightly above benchmark despite absolute returns falling 32%, demonstrating that Blended's relative advantage persists. Split Profit's median of $49,658 similarly maintains slightly above-benchmark positioning. This pattern of relative robustness despite absolute deterioration validates that strategy rankings reflect fundamental characteristics rather than optimistic return assumptions.

TABLE 5: Summary Statistics of Terminal Wealth Outcomes (in $) of 20-Year Accumulation Horizon Using Simulated S&P 500 Data (1,000 simulations)

Strategy	Mean	Median	Maximum	Minimum	Standard Deviation	5th Percentile
S&P 500	$56,651	$47,781	$1,449,798	$181	$37,257	$21,442
Rolling Options	$249,695	$11,620	$219,484,234	$181	$2,793,521	$3,863
Blended	$73,003	$50,716	$2,203,666	$181	$79,417	$13,194
Lifecycle	$128,985	$36,827	$133,295,979	$181	$862,489	$8,685
Split Profit	$80,154	$49,658	$3,520,764	$181	$106,623	$11,819
Profit Rolled	$97,788	$46,381	$76,848,287	$181	$460,236	$11,806

TABLE 6: Internal Rate of Return - Simulated Data

Strategy	Mean IRR (%)	Median IRR (%)
S&P 500 Only	5.80%	4.12%
Rolling Options	18.90%	-13.74%
Blended	8.20%	4.72%
Lifecycle	13.30%	1.44%
Split Profit	9.06%	4.51%
Profit Rolled	10.86%	3.82%

Next, we look at the performance of options-based strategies relative to the benchmark as reported in Table 7. Under simulated stress, success rates decline substantially but in patterns confirming earlier conclusions. Rolling Options outperformance frequency over benchmark collapses from 50% in historical data to 15%, suggesting extremely poor performance when conditions are much less favorable. Alarmingly, under such conditions, they fall short of the benchmark's accumulation by 70.13% on average. In the 15% of total simulations when they outperform the benchmark, they do so by a staggering 459% (on average) which confirms its lottery like pay-offs for the investor.

TABLE 7: Performance Relative to S&P 500 Benchmark (Simulated Data)

Strategy	Underperformance		Outperformance		Asymmetric Pay-off Ratio
	Relative Frequency	Magnitude (%)	Relative Frequency	Magnitude (%)	
Rolling Options	0.85	70.13	0.15	458.60	17.17
Blended	0.44	23.93	0.56	38.71	29.92
Lifecycle	0.70	38.03	0.30	212.07	11.89
Split Profit	0.48	28.77	0.52	58.56	19.28
Profit Rolled	0.55	27.20	0.45	82.34	15.83

Blended still outperforms benchmark 56% (down from 84% historically) while Split Profit's success in outperforming benchmark is 52% (down from 77%), showing significant deterioration but still outperforming the benchmark slightly more often than not. Importantly, the size of the average outperformance for both strategies is significantly higher than their respective average underperformance. This results in Lifecycle outperforms the benchmark in only 30% of the simulations, confirming that time-based glide paths underperform immediate de-risking in adverse scenarios. This pattern validates that suitability conclusions regarding Blended and Split Profit superiority remain sound even under pessimistic assumptions—these strategies maintain relative advantage despite significant decline in their rate of success in outperforming the benchmark.

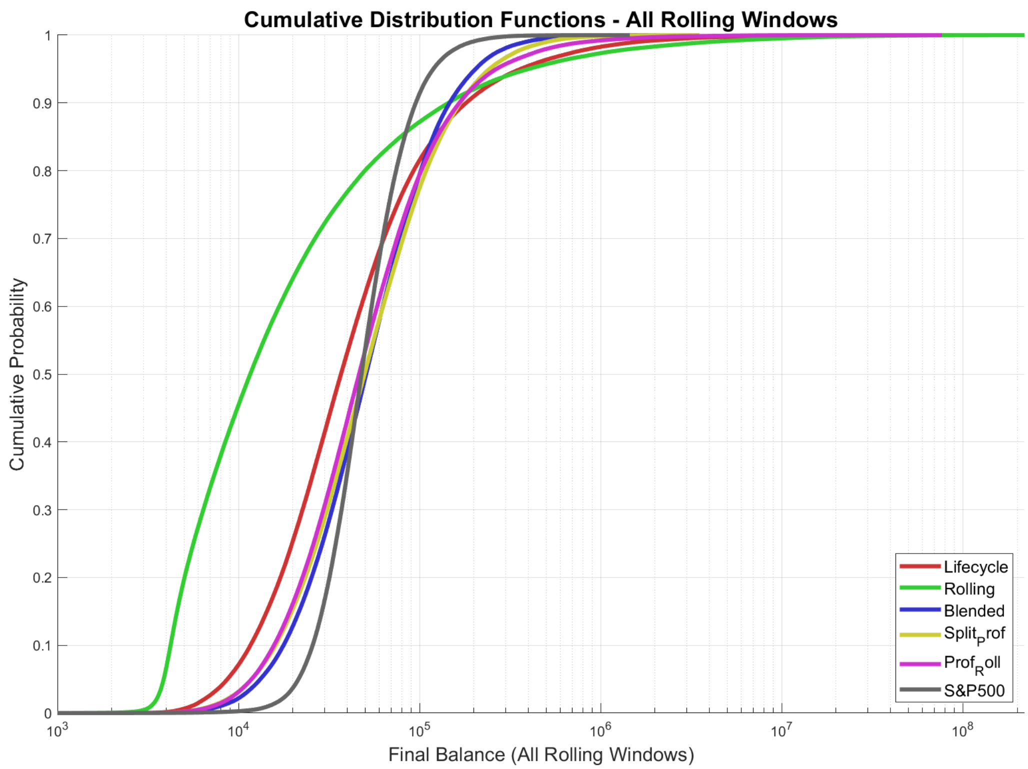

FIGURE 8: Cumulative Distribution Functions - Simulated Data

The CDF for simulated wealth outcomes is presented in Figure 8. Compared to our analysis with historical rolling windows, this plot is much smoother here as the number of rolling windows is 1,000 times greater. The CDF shows compressed outcome ranges reflecting lower expected returns and higher volatility. S&P 500 (gray) and Blended (blue) maintain steep, left-shifted curves indicating concentration around modal outcomes. Rolling Options (green) and Lifecycle (red) show gradual slopes and extended right tails indicating probability spread across wide ranges, with substantial probability of very poor outcomes (below $20,000). In other words, the benchmark S&P500 provides more certainty in achieving low terminal wealth outcomes. However, if the investors aim for higher accumulation (but not extreme payoffs) at the end of the horizon, the likelihood of doing so would increase by employing the options-based strategies. The Blended, followed by Split Profit, appears to fare well in this respect as their CDF plots mostly remain under that of other strategies for the vast majority of middle outcomes.

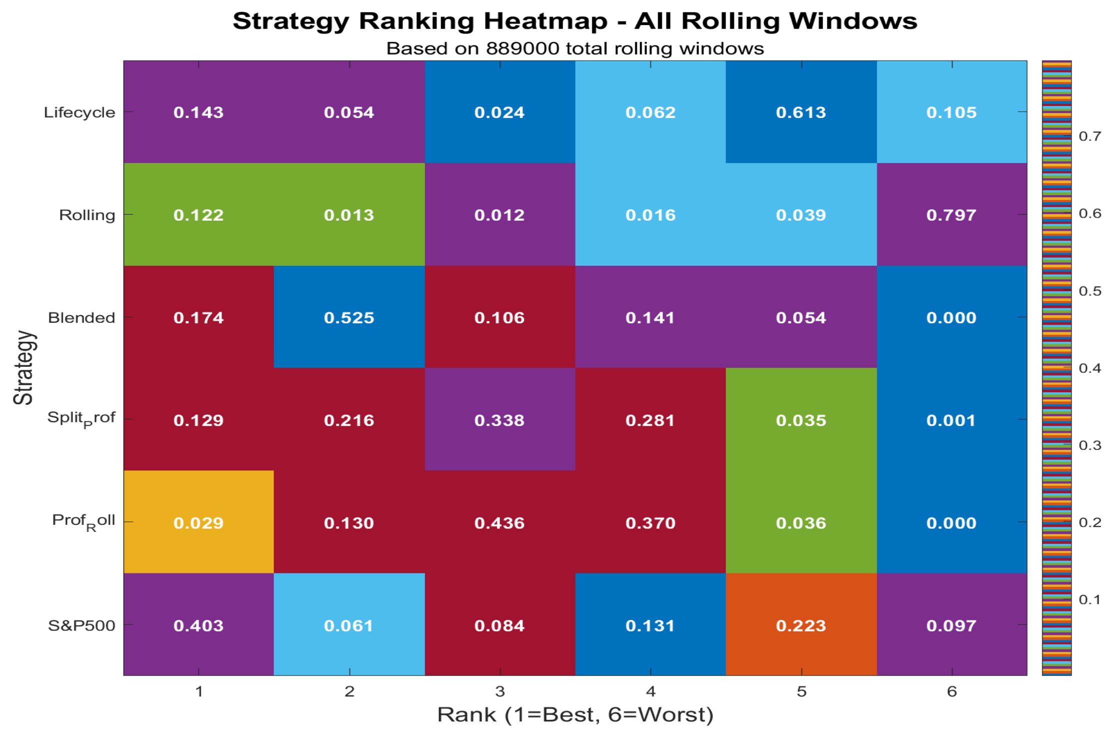

FIGURE 9: Strategy Ranking Heatmap - Simulated Data

Ranking distribution for simulated data (Figure 9) shows that the benchmark S&P 500 performs relatively much better under the unfavorable equity market conditions thrown up by the simulated data and outperforms all options-based strategies in 40.3% of all simulations. Yet, it also features in the bottom two rankings in 32% of the simulations. Rolling Options strategy rankings concentrate heavily (almost 80% frequency) in the worst rank, confirming catastrophic failure under stress. Similarly, Lifecycle on concentrates on the lower rankings. In contrast, Blended concentrates in the top two ranks (70% frequency) and as in the results with historical data, never ended up in the last rank. Split Profit and Profit Rolled has a balanced distribution across the top and middle ranks.

The fact that simulated conditions deliberately create pessimistic returns (5.89% vs 7.63% historical), elevated volatility (21.50% vs 18.84%), and reduced option profitability (43% vs 59%) provides valuable stress-testing precisely because strategies must perform under adverse conditions. The critical finding is that relative strategy rankings prove robust despite dramatic absolute performance deterioration. Rolling Options maintains its categorical unsuitability (15.2% success, negative median IRR, 80% worst-rank frequency). Blended and Split Profit maintain relative advantage despite 30+ percentage point success rate declines. This pattern suggests conclusions reflect fundamental strategy characteristics rather than specific market return assumptions. The relative performance under stress provides confidence that strategy recommendations are not artifacts of favorable historical conditions but robust across regimes.

6. Further Robustness Checks

We conduct further robustness checks to determine whether relative standings of the strategies get altered or remain unchanged under (i) different market regimes and (ii) options with longer expiry. While we do not provide the results here in the interest of brevity, we summarize the main findings below.

6.1 Market Regimes

To evaluate how investment strategies perform across different market conditions, we employ a six-regime classification system that categorizes each 20-year rolling window based on S&P 500 performance characteristics. This classification distinguishes between market environments by examining both temporal performance patterns and volatility dynamics. The approach recognizes that the sequence and magnitude of returns matter critically for retirement planning—a market that recovers strongly late in the accumulation period presents fundamentally different challenges than one that weakens in the final years, even if the total return is identical.

The regime classification operates on three performance dimensions. First, we evaluate early-period performance (years 1–5) and late-period performance (years 16–20), categorizing each as strong (>15% return), poor (<−5% return), or moderate (between −5% and +15%).

Second, we measure monthly volatility across the entire 20-year window, with high volatility (>8% monthly standard deviation) taking precedence in classification as it fundamentally alters risk characteristics regardless of directional performance. Third, we identify steady-growth scenarios, which require moderate performance in both early and late periods combined with total portfolio return exceeding 5% and monthly volatility below 5%. This produces six distinct regimes: Bear-Bull (poor early, strong late), Bull-Bear (strong early, poor late), Bear-Bear (poor performance in both early and late periods), Bull-Bull (strong performance in both periods), Steady-Growth (moderate performance throughout with low volatility and positive total returns), and High-Volatility (turbulent conditions regardless of direction). This classification framework enables regime-specific performance analysis, allowing us to assess whether strategies demonstrate consistent outperformance across market conditions or exhibit regime-dependent effectiveness.

The average outcomes of all the strategies are above that of the benchmark under all six regimes. The aggressive strategies have average accumulations that are many times that of the S&P500. For example, the aggressive Rolling Options' accumulations range from 1,115 x the benchmark's accumulation in High Volatility regime to 144 x in a Bull-Bull regime. In contrast, a relatively conservative Blended strategy's average accumulations outperform the benchmark by a more modest margin (1.52 x in High Volatility and 1.39 x in Bull-Bull regimes). However, looking at the median outcomes across the strategies reveals a different picture. Rolling Options exhibits the worst performance, underperforming S&P 500 in all six regimes with medians ranging from -52.2% (Bear-Bull) to -85.7% (Bull-Bear) and -81.9% (Bear-Bear). Similarly, Lifecycle underperforms across all regimes, ranging from -13.8% (Bull-Bull) to -46.8% (Bear-Bear), despite its higher mean returns driven by favorable outliers. Profit-Rolled underperforms or marginally outperforms in five of six regimes, with meaningful underperformance in three regimes (-38.3%, -38.1%, -10.7%). In contrast, Blended and Split Profit emerge are the only strategies achieving positive median outperformance in favorable conditions: both strategies outperform in Bull-Bull (Blended +18.8%, Split Profit +18.4%) and High Volatility (Blended +14.6%, Split Profit +10.2%), while remaining near breakeven in Bear-Bull and Bull-Bear markets. Although both underperform the benchmark in Steady Growth (Blended -27.5%, Split Profit -33.6%) and Bear-Bear (Blended -32.4%, Split Profit -38.1%) regimes, the absolute dollar penalty for underperformance in these markets is similar to the dollar gains in bullish and high volatility regimes.

In summary, the option strategies amplify gains in favorable conditions but incur contained penalties in adverse ones. They demonstrate strong relative performance in bull-dominated and recovery regimes, with some of them having substantial absolute differences versus the S&P 500 benchmark. However, in bearish and steady regimes, their likelihood of underperformance increases although the shortfall amounts are not catastrophic in absolute terms. It is instructive that nearly half (48%) of the 20-year rolling windows in the historical S&P500 dataset fell into the Bull-Bull category whereas only 12% of these rolling windows experienced Bear-Bear conditions. It explains why many option-based strategies were very successful in enhancing wealth outcomes. The results here also validate that why Blended and Split Profit strategies could be more appealing to younger investors who are looking for more reliable performance that has a higher likelihood of generating decent gains while lowering the risk of falling below the broader market index.

6.2 Longer Expiry (5-year) Options

While the results reported in this paper are for strategies using 2-year options, we tested the same strategies with longer expiry (5-year) options to assess whether they are more (or less) suitable to meet the 20-year wealth accumulation goals of the retirement investor. New contributions and maturity proceeds are invested exactly by the same principles but with 5-year options instead of 2-year options till such time when new options can no longer mature within the 20-year horizon. In other words, when the remaining investment horizon is less than 60 months, all new contributions and proceeds from maturing options are allocated to S&P 500 index.

The simulation results using 5-year equity call options reveal a clear pattern: all five option-enhanced strategies (Lifecycle, Rolling Options, Blended, Split Profit, and Profit Rolled) deliver higher average final portfolio balances than a pure S&P 500 index strategy over 20-year rolling investment horizons. Mean balances range from $64,962 (Blended) to $78,034 (Rolling Options) compared with $54,760 for the benchmark, representing a 19–42% improvement in expected terminal value from the same $100 monthly contributions (adjusted for salary growth).

However, this edge comes with significantly higher volatility — standard deviations are 2.0× to 5.1× higher than the benchmark's $30,914 — and pronounced positive skewness. Median balances are lower than the benchmark in most cases (except Blended and Split Profit), highlighting that the superior mean is driven by infrequent but very large outperformance events rather than consistent gains.

Relative to the S&P 500 benchmark, the option strategies exhibit strong payoff asymmetry. When they outperform, the average dollar gain is 3.4× to 7.0× larger than the average dollar loss when they underperform. For example, Rolling Options shows a 6.96× asymmetry ratio ($120,911 average outperformance vs. $17,375 average underperformance), while Blended shows a more conservative 3.43× ratio. After weighting by the proportion of windows in which each strategy beats the benchmark (41–56% across strategies), the net expected value per 20-year window remains positive for all five approaches, ranging from +$10,198 (Blended) to +$23,282 (Rolling Options). This suggests that, despite more frequent underperformance in some cases, the magnitude of the wins can produce meaningful long-term advantage.

However, compared to 2-year options, the pay-off asymmetry is subdued. 5-Year option-based strategies yield lower means/medians, with lower dispersion than their 2-year options counterparts. This possibly happens due to fewer reinvestment cycles for 5-year options, smoothing outcomes but also capping compounding of returns. The net effect is higher (lower) proportions of underperformance (outperformance) of benchmark S&P 500 by 5-year option-based strategies. However, what is more interesting in the context of our study is that relative performance of leveraged strategies remains similar to what we observed in our results for strategies employing 2-year options. Blended and Split Profit remain the most reliable top performers. Rolling Options offers the highest upside but is also the most inconsistent, followed by Lifecycle strategy. Both strategies show bipolarity in rankings with some extremely large outcomes but also a larger proportion of very poor outcomes.

7. Conclusion

The principle of lifecycle investing—maintaining higher equity exposure when investors are young with abundant stock of human capital, and gradually de-risking as retirement approaches – has appealed to many retirement plan sponsors resulting in widespread adoption of TDFs as default investment vehicles within DC plans. Yet substantial evidence from both academic research indicates that conventional TDF implementation produces suboptimal dollar-weighted equity exposure for younger workers and leaves workers approaching retirement unnecessarily vulnerable to market shocks. Young workers benefit very little from minimal dollar-weighted equity exposure in their early accumulation years despite high percentage allocations.

This paper evaluates whether long-dated call options offer a practical solution to these documented design problems. Through comprehensive historical analysis covering 96 complete years of market data spanning 1928–2024 and extensive simulations stress-testing of options-based strategies under less favourable conditions, we identify two option-based strategies achieving substantially higher reliability than both aggressive continuous-leverage approaches and while outperforming conventional unlevered strategies with a high likelihood.

The Blended strategy, which converts option gains into unlevered equity positions immediately upon maturity, achieves 84% success in outperforming passive equity benchmarks across 889 rolling 20-year accumulation periods. Median returns reach 11.24% IRR (annualized), substantially exceeding the S&P 500's 7.75% median IRR. The Split Profit strategy, which conditionally converts option gains into unlevered equity positions based on realized gains or losses, achieves 77% success in outperforming benchmarks with median IRR of 11.22%. Both strategies maintain downside risk profiles comparable to traditional equity investment, with 5th percentile outcomes that are similar to the benchmark's.

Critically, both strategies prove relatively robust to very pessimistic market assumptions in comprehensive stress-testing simulations. Even when underlying market return assumptions become substantially less favorable than historical averages (5.89% vs 7.63% mean returns, 21.50% vs 18.84% volatility), Blended maintains 55.7% success (down from 84%) and Split Profit maintains 52% (down from 77%). While the likelihood of outperforming the benchmark index reduces significantly under these conditions, the asymmetricity in the size of gains relative to losses make the expected pay-off still very favorable for these strategies. This relative robustness provides confidence that strategy recommendations reflect their fundamental merit rather than temporary historical advantages.

These successful strategies balance two competing objectives: capturing leverage benefits during early accumulation years when absolute exposure and portfolio volatility prove manageable, and progressively de-leveraging to preserve accumulated capital from amplified losses during subsequent volatility episodes. Strategies maintaining continuous leverage throughout the 20-year horizon have less success and reliability making them unsuitable for retirement planning. Strategies immediately eliminating leverage fail to capture meaningful leverage benefits. The middle-ground approaches embodied in Blended and Split Profit capture the best of both worlds. The fact that relative strategy rankings prove stable even under pessimistic market conditions, with Blended and Split Profit maintaining substantial advantage over both more aggressive and more conservative approaches, suggests that these option-based leverage strategies warrant serious consideration as practical policy solutions to long-standing criticisms of conventional TDF design.

We expected option maturity selection to significantly impact outcomes. Five-year options demonstrate substantially superior in-the-money (80% vs 76%) and profitability rates (66% vs 59.1%) compared to 2-year options, suggesting higher maturity options would improve strategy performance. However, this didn't materialize in our simulations, clearly because 5-year options had less reinvestment cycles within the 20-year rolling windows as per our strategy specification. An alternative specification where new contributions and maturity proceeds were always reinvested in new options irrespective of whether the options could be held till maturity is likely to produce better outcomes for 5-year options. Conversely, very short maturities (under 6 months) would likely perform poorly due to option decay acceleration as expiration approaches.

For practitioners and policymakers seeking to improve retirement outcomes for younger workers relying on DC plans, option-based leverage strategies deserve consideration as serious complements to or alternatives for conventional TDFs. Long-dated call options offer a promising mechanism for building leverage in retirement portfolios of younger investors that address documented shortcomings of conventional Target Date Fund design. The concentration of leverage in early accumulation years, combined with progressive de-risking through option maturity and conversion to equities, creates a risk-return profile superior to conservative unleveraged strategies for younger investors joining retirement plans.

Plan sponsors considering option-based approaches would benefit substantially from piloting these strategies with targeted younger participant subpopulations before broader rollout. However, clear communications regarding strategy mechanics and realistic outcome expectations are essential. Options create a more transparent mechanism for understanding and communicating strategy risk compared to other instruments of leveraging equity portfolios. Participants may find it easier to understand that options expire and provide defined maximum loss.

Regulatory framework development could substantially facilitate adoption among younger participants in retirement plans. Department of Labor safe harbor provisions specifically addressing option-based leverage strategies would address fiduciary concerns currently preventing plan adoption of sophisticated strategies with sound economic foundations. Clear regulatory guidance distinguishing sophisticated option-based leverage from speculative options trading would facilitate broader implementation and participant acceptance. Such guidance could establish that option-based leverage, when implemented with automatic enrollment and restricted switching, represents fiduciary-appropriate strategy innovation rather than speculative excess.

Our study has several important limitations. First, our synthetic reconstruction of pre-2005 option prices introduce estimation uncertainty. The VAR-X model captures relationships observable in recent data (2005-2024) but underlying relationships may have differed substantially during earlier eras when option market structures, participant bases, and trading mechanisms looked substantially different. Second, alternative simulation frameworks incorporating regime-switching dynamics, jump processes, or other mechanisms specifically designed to capture tail risk might generate different results, particularly regarding extreme outcomes and strategy robustness to unprecedented market conditions. Third, our focus on 2-year and 5-year options reflects practical availability constraints but may not represent optimal maturities for retirement implementation. Intermediate maturities (3-4 years), adaptive maturity selection strategies that vary maturity based on portfolio characteristics, or partial laddering strategies using multiple maturities might produce superior results. Fourth, we do not consider costs for option trading and administrative expenses that would reduce net returns compared to our analysis.

Future research can extend this analysis in several important directions. First, analysis of adaptive strategy designs - dynamically adjusting leverage based on portfolio growth, participant age, or market conditions rather than fixed schedules - might identify more sophisticated approaches achieving even superior risk-adjusted returns. Second, integration of detailed tax analysis and fee structures would illuminate the practical economics of real-world implementation. Third, analysis of actual participant behavior—including switching patterns, contribution timing, and risk tolerance dynamics—would provide insights into real-world outcomes versus theoretical predictions. Fourth, international evidence from markets with different option market structures and regulatory frameworks would test the generality of these findings across jurisdictions.

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