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Considering the Past and the Future in Asset Simulation

A systematic modelling process to simulate potential asset returns for portfolio construction.

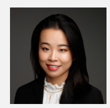
November 2022

EXECUTIVE SUMMARY

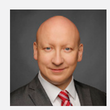
Modelling future expectations is a key component of portfolio construction that helps asset allocators to assess the risk and return of different portfolio designs.

We have developed an intuitive process to explicitly embed both long-term historical asset behaviours and investor expectations of future performance when simulating asset returns.

Our three-step process: (1) expands the market return history to cover multiple business cycles, (2) recalibrates historical returns with the investor's forward-looking expectations and (3) seeks to generate simulations that preserve the salient characteristics of asset returns.



Eva Wu
Solutions Analyst



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Solutions Strategist

A robust portfolio construction process, overlaid with rigorous risk assessment, is crucial for designing and managing portfolios. Though challenging, it is important to properly assess the risk and return characteristics of various asset classes in different market environments, particularly when historical data are limited. Simulations are often used to analyse and stress-test portfolios—however, the available simulation approaches have their limitations.

Two popular simulation approaches are Monte Carlo modelling and historical resampling (their definitions and details are explained below). Each approach has its advantages and shortcomings. At T. Rowe Price, we have developed a process that seeks to bridge the two methods by creating a historically informed but forward-looking simulation. This process can not only exhaustively explore possible trajectories of asset performance under user-defined return expectations, but also maintain important information gleaned from history, such as month-to-month asset movements and cross-sectional volatilities over different market cycles.

"...the available simulation approaches have their limitations.

Below, we provide an overview of the following three-step process: (1) expand history, (2) recalibrate the past with the future and (3) generate path-dependent simulation. Throughout the paper, we use a case study to illustrate how this would work in practice with a hypothetical multi-asset portfolio.

Step 1: Expand History

As with most returns-based analytical frameworks, our process begins with preparing the available set of historical returns. For illustration, we use two representative asset classes: the MSCI All Country World Index (ACWI) for global equities and the Bloomberg Global Aggregate Index for fixed income. These are commonly used indices, representing market returns for the two major global liquid asset classes. However, investors can choose different and/or additional indices to fit their modelling needs.

These indices include just over three decades of historical returns (Figure 1), which may be too short a time horizon to properly reflect the asset behaviour over multiple business cycles and different market conditions. For instance, the 10-year US Treasury yield has been declining overall since peaking at around 16% in 1981, despite trending upwards over the previous 20 years. If investors were to take the more recent two decades of the entire four-decade period, they would likely miss information and test their portfolio over market conditions of mostly falling bond yields.

While widely recognised measures for the returns on global equities and fixed income only go back a little over 30 years, the return history of US equities and bonds extends back to the 1920s. These return series span the Great Depression, several wars, periods of inflation and deflation, and various financial crises. This allows us to use the MSCI World Index and the S&P 500 Index, which go back to 1970 and 1928, respectively, to backfill return data for global equities prior to the start date of the MSCI ACWI. The SBBI 5-Year US Government Bonds series[1] and the Bloomberg US Aggregate Bond Index are used to backfill for global fixed income, prior to the start date of Bloomberg Global Aggregate Bond Index. Figures 2 and 3 summarise the asset return breakdown by backfilled periods and the corresponding proxy indices.

Our approach to expanding available return series and addressing the limited past data is to use a backfill method[2] to extend the history of the selected indices. This method combines the Maximum Likelihood Estimation (MLE) approach of Stambaugh (1997)[3] with conditional sampling to backfill missing data of the short sample using the long sample as the explanatory variable (Figure 4).

Indices Provide Limited Historic Data

(Fig. 1) This makes it difficult to assess long-term asset behaviour

Index	Start Date
MSCI ACWI	January 1, 1988 (see Additional Disclosures)
Bloomberg Global Aggregate Bond Index	January 1, 1990 (see Additional Disclosures)

For illustrative purposes only.
Sources: Bloomberg Finance L.P. and MSCI.

Global Equity Return Breakdown by Backfilled Periods

(Fig. 2) The S&P 500 Index, MSCI World Index and MSCI ACWI

Global Equity	From	To
S&P 500 Index	January 1, 1928	December 31, 1969
MSCI World Index	January 1, 1970	December 31, 1987
MSCI ACWI	January 1, 1988	June 30, 2022

As of June 30, 2022.
For illustrative purposes only.
Source: Index data sourced from Bloomberg Finance L.P., MSCI and S&P (see Additional Disclosures).

Global Fixed Income Return Breakdown by Backfilled Periods

(Fig. 3) The SBBI 5-Year U.S. Government Bonds, Bloomberg U.S. Aggregate Bond Index and Bloomberg Global Aggregate Bond Index

Global Fixed Income	From	To
SBBI 5-Year U.S. Government Bonds	January 1, 1928	December 31, 1975
Bloomberg U.S. Aggregate Bond Index	January 1, 1976	December 31, 1989
Bloomberg Global Aggregate Bond Index	January 1, 1990	June 30, 2022

As of June 30, 2022.
For illustrative purposes only.
Sources: Bloomberg Finance L.P. and SBBI (see Additional Disclosures). We aimed to pick the closest proxy, despite recognising that there is some duration mismatch among the selected bond indices—modified durations for the Bloomberg Global Aggregate Bond Index and the Bloomberg U.S. Aggregate Bond Index were 7.0 years and 6.6 years, respectively, at the time of writing.

[1] Ibbotson, R. G., Sinquefield R. A. (1989) 'Stocks, Bonds, Bills and Inflation'. CFA Institute Research Foundation Books.
[2] Page, S. (2013) 'How to Combine Long and Short Return Histories Efficiently', Financial Analysts Journal.
[3] Stambaugh, R. F. (1997) 'Analyzing Investments Whose Histories Differ in Length'. Journal of Financial Economics, vol. 45, no. 3 (September): 285–331.

Our method uses the period of common returns (the short sample) to estimate the average differences in returns and covariance information for both indices. These estimates, along with the available returns for the remainder of the long sample, can be used to construct the desired longer return series.

For instance, in our previous equity example, the means and covariance information for MSCI ACWI and MSCI World returns over the period from January 1988 to June 2022 would be combined with the MSCI World returns from January 1970 to December 1987 to create estimated returns for the MSCI ACWI over the 'missing' 18-year period from 1970 to 1987.

We make a further adjustment to allow for the non-normal nature of financial asset return data (Figure 5). Instead of assuming the noise term is normally distributed over the entire period (i.e., the out-of-sample noise term), the model recycles residuals from the short sample (i.e., the in-sample noise term) and uses these to adjust the estimated returns for the period of missing data. This adjustment allows us to efficiently capture non-normal skewness and kurtosis in the data.

Index History Can Be Extended by Backfilling

(Fig. 4) Short sampling is used to complete missing data

For illustrative purposes only.
Source: T. Rowe Price.

Financial Assets Often Exhibit Non-normally Distributed Returns

(Fig. 5) Non-normal skewness and kurtosis need to be captured

Index	Skewness	Kurtosis
MSCI ACWI (see Additional Disclosures)	-0.6	1.5
Bloomberg Global Aggregate Bond Index	-0.5	2.5
Normal distribution	0.0	3.0

As of June 30, 2022.
Past performance is not a reliable indicator of future performance. For illustrative purposes only.
Skewness is a statistical measure to describe the degree of asymmetry observed in probably distribution of assets, while kurtosis is a statistical measure to describe the "fatness" of the tails found in probability distribution of assets. A normal distribution has a skewness and kurtosis of 0.0 and 3.0 respectively.
Sources: Bloomberg Finance L.P. and MSCI. Figures are calculated in USD. Based on monthly total returns. For MSCI ACWI from January 1988 through June 2022. For Bloomberg Global Aggregate Bond Index from January 1990 through June 2022.

Backfill Result for Global Equity

(Fig. 6) The return decreased over the extended period

Period		MSCI ACWI (Backfilled)	S&P 500 Index	MSCI World Index	MSCI ACWI (Not Backfilled)
From January 1928 through June 2022	Return	6.8%	9.4%	N/A	N/A
	Volatility	17.2%	18.8%	N/A	N/A
	Skewness	–	0.1	N/A	N/A
	Kurtosis	6.5	7.7	N/A	N/A
From January 1970 through June 2022	Return	7.5%	10.5%	7.6%	N/A
	Volatility	15.0%	15.3%	14.8%	N/A
	Skewness	-0.5	-0.4	-0.5	N/A
	Kurtosis	1.7	1.8	1.6	N/A
From January 1988 through June 2022	Return	7.3%	10.6%	7.4%	7.3%
	Volatility	15.1%	14.6%	15.0%	15.1%
	Skewness	-0.6	-0.6	-0.6	-0.6
	Kurtosis	1.5	1.2	1.4	1.5

Figures refer to simulated past performance and that past performance is not a reliable indicator of future performance. For illustrative purposes only.
Please see Appendix Disclosures for additional important information on this analysis.
Sources: Bloomberg Finance L.P., MSCI and S&P. Figures are calculated in USD. Based on monthly total returns, gross of fees. Calculated returns and volatilities are annualised. Volatility is measured by the annualised standard deviation of monthly returns.

Backfill Result for Global Fixed Income

(Fig. 7) Returns increased slightly over the extended period

Period		Bloomberg Global Aggregate Bond Index (Backfilled)	SBBI 5-Year U.S. Government Bonds	Bloomberg U.S. Aggregate Bond Index	Bloomberg Global Aggregate Bond Index (Not Backfilled)
From January 1928 through June 2022	Return	4.8%	4.9%	N/A	N/A
	Volatility	5.2%	4.4%	N/A	N/A
	Skewness	0.5	0.9	N/A	N/A
	Kurtosis	7.5	8.7	N/A	N/A
From January 1976 through June 2022	Return	6.3%	6.4%	6.8%	N/A
	Volatility	6.6%	5.3%	5.3%	N/A
	Skewness	0.3	0.8	0.7	N/A
	Kurtosis	4.7	6.9	7.1	N/A
From January 1990 through June 2022	Return	4.6%	4.9%	5.3%	4.6%
	Volatility	5.6%	4.2%	3.7%	5.6%
	Skewness	-0.5	–	-0.3	-0.5
	Kurtosis	2.5	0.5	1.0	2.5

Figures refer to simulated past performance and that past performance is not a reliable indicator of future performance. For illustrative purposes only. Please see Appendix Disclosures for additional important information on this analysis.

Sources: Bloomberg Finance L.P. and SBBI. Figures are calculated in USD. Based on monthly total returns, gross of fees. Calculated returns and volatilities are annualised. Volatility is measured by the annualised standard deviation of monthly returns.

A similar approach is used for both the equities and fixed income return series described here.

After backfilling the data, we expanded the 'raw' market return history from around 30 years to 94 years, for the Global Equity and Global Fixed Income. Figures 6 and 7 include return and risk characteristics of the indices over different time periods. For example, the return of the backfilled global equity index has decreased over the extended full period, balancing out the exuberant equity market over the past three decades. Investors can also choose proxy indices across asset classes to backfill the desired assets.

Step 2: Recalibrate the Past With the Future

As well as extending the historical data, another key characteristic of these simulations is that they reflect the expected forward-looking risk and return characteristics of assets. Two popular simulation approaches are Monte Carlo modelling and historical resampling. Monte Carlo models asset performance by generating future paths of random asset returns derived from a distribution. In other words, forward-looking expectations are incorporated to inform the shape of the distribution of returns, while each draw of the return streams inherently introduces randomness to the process.

By contrast, historical resampling arbitrarily extracts a subset of data points from the raw historical returns without explicitly reflecting the investors' expectations—instead, the model implicitly assumes that historical experience reflects possible future experience. Historical resampling is also subjective to the common periods of the available asset returns in consideration. This might not be sufficiently reflective of the current market environment.

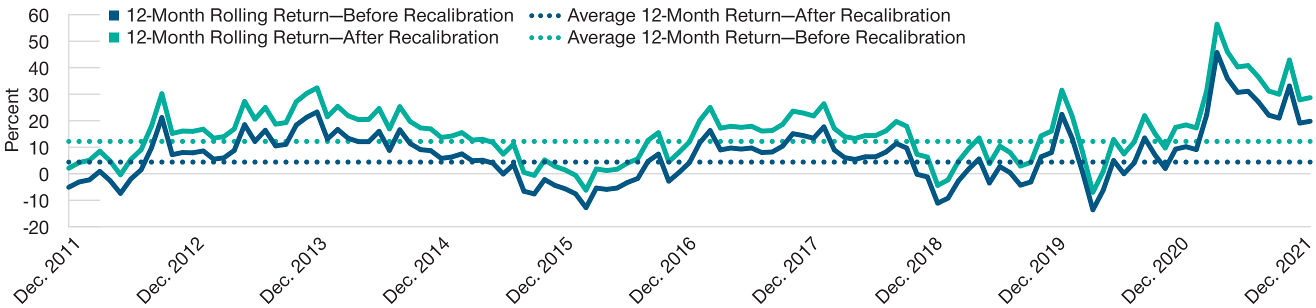
"Our approach rescales historical return data series to match forward-looking return assumptions.

Our process seeks to bridge the gap between the two methods by creating a historically informed, forward-looking simulation framework. Not only does it explore many possible trajectories of asset performances under user-defined return expectations, it also avoids losing important information in translation, such as the historical autocorrelation of asset movements and correlation between different assets over time.

Our approach rescales historical return data series to match forward-looking return assumptions. For example, according to our backfill result, the Bloomberg Global Aggregate Bond Index has an average annual return of about 5.0% per annum over nearly a century. However, according to the T. Rowe Price

12-Month Rolling Asset Returns Before and After Recalibration

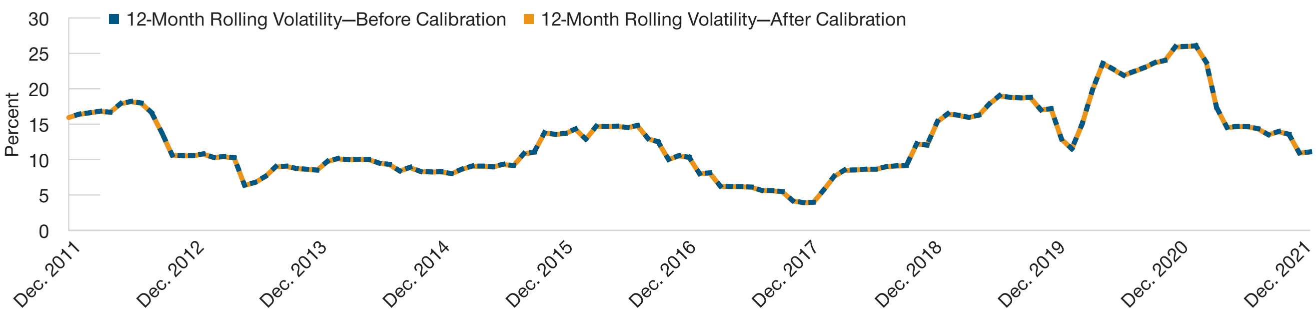
(Fig. 8) Asset returns are shifted directionally



Past performance and hypothetical performance are not reliable indicators of future performance. Actual outcomes may differ materially from estimates and forward-looking assumptions. For illustrative purposes only. Please see Appendix Disclosures for additional important information on this analysis. Sources: Bloomberg Finance L.P. and T. Rowe Price. Figures are calculated in USD. Based on monthly total returns. This chart shows the 12-month rolling returns of the S&P 500 Index before and after recalibrating it to the T. Rowe Price 2022 CMA for U.S. Large-Cap. Using asset returns over the period from December 2010 through December 2021.

12-Month Rolling Asset Volatilities Before and After Recalibration

(Fig. 9) Volatility remains intact



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Capital Market Assumptions (CMAs)[4] for the next five years, the Bloomberg Global Aggregate Bond Index was expected to deliver 0.3% per annum at the beginning of 2022. This is because bond returns have typically been highly correlated to the initial level of yield, which was at a very low level. To reflect this expectation, we scale down the historical return series such that the average of all rolling five-year monthly returns equals the forward-looking return assumption of 0.3% per annum, while maintaining the volatility and covariance characteristics of the historical return series. The scaling approach retains the volatility, original month-to-month trajectory of asset returns, as well as cross-sectional volatility among different assets. In the meantime, it shifts directionally to reflect the investors' return expectations over the selected investment horizon.

When discussing investors' expectations for expected returns, volatility and correlations over the rest of this paper, these will reflect the T. Rowe Price 2022 CMAs. However, portfolio managers at T. Rowe Price or external investors can instead include their own assumptions for these elements when using the methodology. We will use the term 'investors' interchangeably for these different groups of potential users throughout the remainder of this paper.

Figures 8 and 9 illustrate how this plays out in practice: Asset returns are shifted directionally while the volatilities remain intact.

For assets with pure market exposures (beta), such as passive index tracking funds, the above procedure is sufficient for the next stage of the simulation. However, for actively managed strategies with idiosyncratic return sources from active management (alpha), as well as alternative strategies

[4] 'Capital Market Assumptions Five-Year Perspective 2022', T. Rowe Price.

that offer return streams that are imperfectly correlated with markets, additional steps are required to try to ensure that the simulation captures the varying nature of relative returns from active strategies.

Below, we share the four sub step process for modelling active strategies:

Sub step 1: Estimate asset exposure to the relevant market indices using historical asset data

- We first determine the most relevant market indices for the active strategy. Using regression between the active strategy and the selected market indices, we map the strategy's exposure to them. For example, an actively managed global fixed income strategy could have exposure to the Global Aggregate Bond Index as a source of market returns. Based on historical asset performance, we assess how much of the strategy's returns comes from its exposure to the index.
- Subjective adjustment can be imposed on top of the historical evaluation, especially in situations where only limited data history is available to run any meaningful, stable regression for the active strategy.

Sub step 2: Match backward-looking market return with forward-looking assumptions

- We then recalibrate the selected market indices historical series with the investor's forward-looking return expectations as elaborated in the previous section. In our example, the monthly returns of the Global Aggregate Bond Index can be rescaled to reflect the investor's view on global bonds' future performance. In this paper, we use the T. Rowe Price CMAs for 2022 for this element.

Sub step 3: Estimate asset historical alpha and the alpha volatility

- Estimate the strategy's return from its exposure to market risks by multiplying the corresponding asset exposures (from sub step 1) with the rescaled market index monthly returns (from sub step 2).
- Subtract the calculated market exposure returns from the total returns of the strategy, deriving the unexplained return series (i.e., the 'alpha' term). For example, assume the actively managed global fixed income strategy returned 0.8% in May 2020, while the recalibrated Global Aggregate Bond Index returned 0.6% in the same month. If the strategy has an exposure of 0.7 to the Global Aggregate Bond Index, then the alpha term for the month equals 0.4% (0.8% - (0.6%*0.7)).
- Calculate the average monthly return and volatility of the alpha term series.

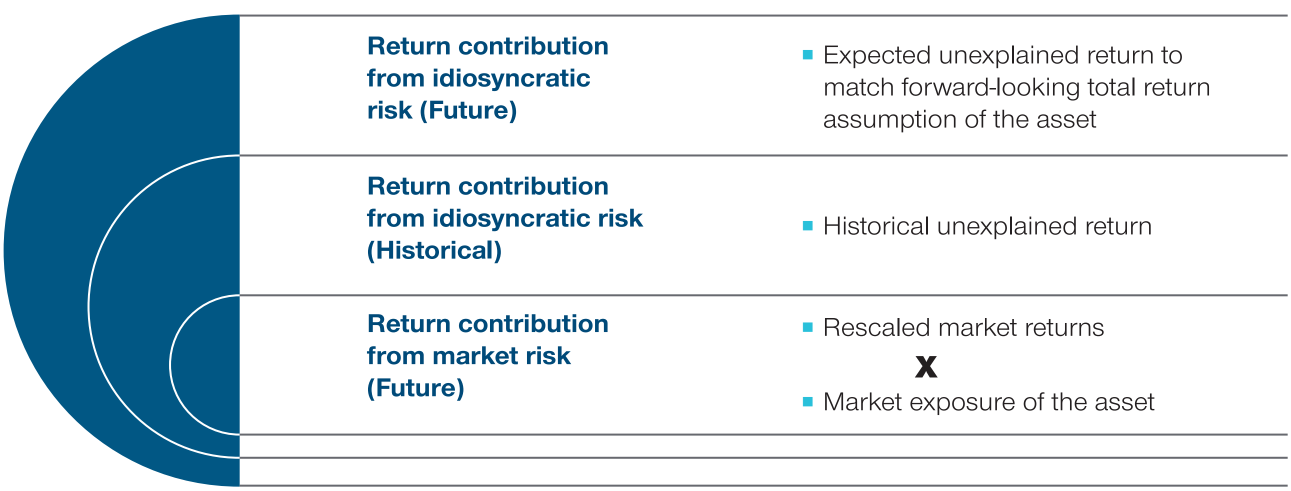
Sub step 4: Calculate the forward-looking alpha assumption

- Calculate monthly asset returns by summing up the strategy's monthly returns derived from its exposure to market risk, and the estimated average historical alpha term (from sub step 3).
- Reiterate the recalibration process described in the previous section, to calculate the forward-looking alpha term that help ensure the strategy's total return matches the investor's forward-looking total return assumption for the active strategy. This is also an opportunity of checking internal consistencies of the investor's assumptions. Again, the T. Rowe Price CMAs for 2022 are used here.

Figure 10 illustrates how this works.

Calculating the Forward-Looking Alpha Assumption

(Fig. 10) Match backward-looking return with forward-looking assumptions for active strategies



For illustrative purposes only. Actual future outcomes may differ materially from estimates and forward-looking assumptions. Please see Appendix for additional important information regarding forward-looking assumptions and their limitations.
Source: T. Rowe Price.

Step 3: Generate Path-Dependent Simulation

Instead of drawing random data points to compose return paths as commonly done in Monte Carlo simulation and historical resampling, our process deliberately retains the actual pattern of month-to-month asset movements in each simulated scenario.

> We model possible extreme events by constructing rolling windows across the expanded data history....

It is important to preserve the original characteristics of an asset's returns during the simulation, especially to recognise extreme tail risk occurrences in actual historical context. For example, let's assume that an investor believes that over the next business cycle the market will trade similarly to the conditions at the beginning of 1973—i.e., with high inflation and restrictive monetary policy. The question then is how to position the portfolio in seeking to withstand such a headwind, based on the asset dynamics in a similar market environment. For long-term investors, it is also critical to consider multiple possible drawdown scenarios when designing the portfolio's long-term asset allocation.

We model possible extreme events by constructing rolling windows across the expanded data history, reflecting the desired investment horizon. By doing so, we exhaustively include all available asset performance trajectories over any given investment time scale. The available number of simulated paths depends on the length of the data history available. For example, step 1 of our process has generated 94 years of available data history for global equities and fixed income. This means we would have 1,117 ((93*12) + 1) possible simulations of monthly performance over a one-year time window. In addition, step 2 of our process enables us to expand active strategies' available data history while incorporating both historical information and future expectations.

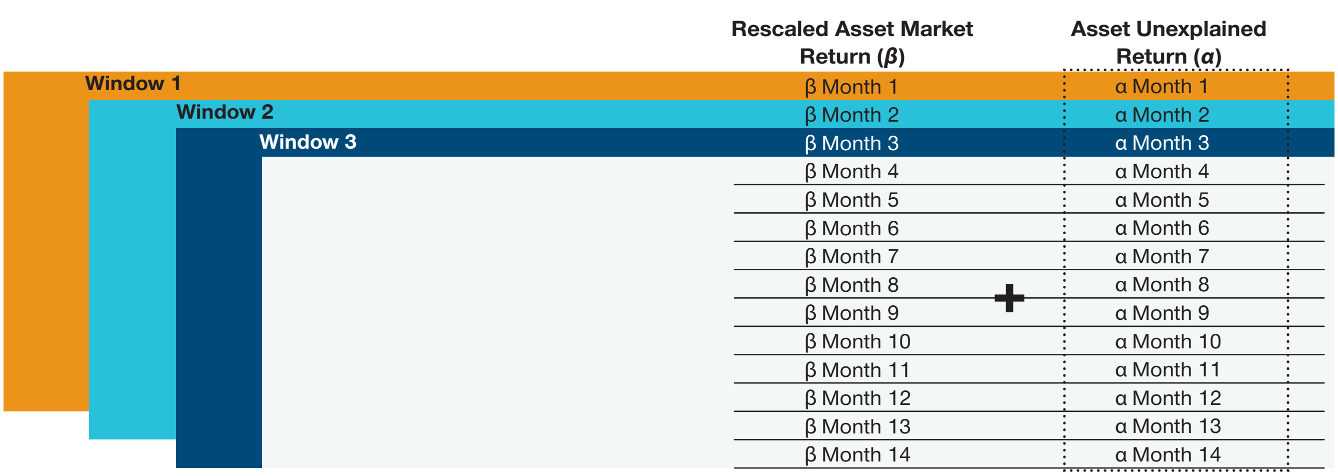
For assets with additional unexplained returns (alpha) on top of market exposures (beta), random excess return terms (alpha) are generated under the constraints of expected average and historical risk estimates (from sub step 3 and sub step 4 above). This essentially manufactures thousands of alpha series that are consistent with historical patterns while considering the unpredictable nature of this noise term. During the simulation process, one random alpha term is generated for each month within each scenario. By doing so, it reduces the model sensitivity to the alpha term assumptions.

Combining the simulated rolling historical returns with the realisations of random alpha terms creates a rich set of asset returns. The path-dependent nature of this simulation framework inherently keeps the varying cross-sectional volatility among different assets over time.

Figure 11 demonstrates an example of simulating one-year performance of an actively managed strategy.

Simulating One-Year Performance of an Actively Managed Strategy

(Fig. 11) It combines simulated historical returns with the realisations of random alpha terms



Figures refer to simulated past performance and that past performance is not a reliable indicator of future performance. For illustrative purposes only.
Source: T. Rowe Price.

Empirical Application of the Process

Our simulation process can be used to model a multi-asset portfolio to demonstrate how it would have performed in different market conditions reflective of historical experience, while incorporating the investor's expectations for the future.

We consider the possible experience of a multi-asset portfolio over a 20-year investment horizon. The portfolio is made of three building blocks: global equity, global fixed income, and an actively managed conservative fixed income strategy (Active Fixed Income Strategy) strategy.[5] The strategic allocation is 60% MSCI ACWI, 10% Bloomberg Global Aggregate Bond Index and 30% Active Fixed Income Strategy.

Three different simulation approaches, as typically practiced, are used to assess this portfolio:

(1) CMA-based simulation (Monte Carlo modelling (see Appendix)): Using Multi-Variate Normal distribution to simulate asset class returns, taking the T. Rowe Price CMAs (see Appendix) of return, volatility and correlations as distribution parameters.

(2) Historical resampling: Using available unadjusted historical monthly return series, with values randomly sampled to generate asset and portfolio behaviour. For global equities, this would involve randomly sampling returns from January 1989 to June 2022. For active strategies, random samples of monthly returns would be taken from the available track record.

(3) Historical informed simulation: The process we present in this paper, using historical backfilled asset returns, as well as user-defined, forward-looking return assumptions to simulate asset and portfolio behaviour. The forward-looking assumptions include both T. Rowe Price CMAs on traditional asset classes and investors' judgement on active strategies, such as the Active Fixed Income Strategy used here.

In looking to generate the necessary analysis over a 20-year horizon, one benefit of the historical informed simulation approach becomes clear. Historical resampling, as typically practiced, can only reflect the assets' past performances over periods where common returns for all included assets are available. In our case, the common period for the MSCI ACWI, Bloomberg Global Aggregate Bond Index and Active Fixed Income Strategy is February 2015 through June 2022—a time period that witnessed unusual market volatility and challenging returns at the portfolio level. Actual longer-term track records are unlikely to be available for actively managed strategies for modelling purposes.

As Figure 12 shows, our process and the CMA-based approach both suggest an average annualised return of 4.7%, and similar levels of volatility for the portfolio of 8.7% and 9.0% respectively, while the historical resampling indicates a much lower risk and return profile. This is mainly because the former two approaches incorporate user-defined future return assumptions as well as longer historical backfilled data.

Simulated Portfolio Return and Volatility

(Fig. 12) Our process and the CMA-based approach suggest similar returns and volatility

	Return*	Volatility
CMA-based	4.7%	8.7%
Historical resampling	2.4%	3.5%
Historical informed	4.7%	9.0%

As of June 30, 2022.

Past performance and hypothetical performance are not reliable indicators of future performance. Actual outcomes may differ materially from estimates and forward-looking assumptions. For illustrative purposes only. Please see Appendix Disclosures for additional important information on this analysis.

*Gross of fees.

Sources: Bloomberg Finance L.P., MSCI, SBBI and T. Rowe Price. Figures are calculated in USD. Based on monthly total returns, gross of fees. For CMA-based, uses T. Rowe Price 2022 CMAs. For historical resampling, uses asset returns over the period February 2015 through June 2022. For historical informed, uses backfilled asset returns over the period January 1928 through June 2022. Calculated returns and volatilities are annualised.

[5] The conservative fixed income strategy is based on a strategy managed by T. Rowe Price Dynamic Global Bond. For historical resampling, we use actual gross-of-fee strategy returns from the inception date of February 2015 through June 2022. For the analysis, we use this as a sample active strategy because of the diversification properties if offers to both equity and fixed income markets. The strategy has an objective as follows: Seeks to outperform the ICE BofA 3 Month T Bill index by 300 basis points per annum over a full market cycle. This is used as the forward assumption for the conservatively managed fixed income component of our analysis. The data presented herein is hypothetical and not representative of actual strategy performance. This information is for illustrative purposes only and is not a promotion of any specific strategy nor is this investment advice or a recommendation to buy or sell any security.

Appropriate Risk Measure

Multiple research papers argue that volatility is not an appropriate measure of risk because it is an unreliable way to predict permanent capital losses. Drawdown, in this case, may be a better way to evaluate downside risk for investors, who may see it as a preferred driver of portfolio construction decisions.[6]

By definition, a drawdown is the drop in portfolio value compared to the maximum value of the portfolio achieved in the past. We can define drawdown in absolute or relative (percentage) terms. For example, if the present portfolio value is USD 8 million and its highest value in the past was USD 10 million, we can say that the drawdown is USD 2 million in absolute terms, or 20% in relative terms. A peak-to-trough drawdown reflects the largest loss of portfolio value over the invested period. A 95% peak-to-trough drawdown marks the 95th percentile of the maximal loss compared to its highest value over the invested period across all the simulated scenarios.

Despite having almost identical results of return and volatility, CMA-based simulation suggests much smaller peak-to-trough drawdown compared to our historical informed simulation (Figure 13). This is because the CMA-based Monte Carlo simulation approach assumes constant values for asset volatility and correlations across all market conditions. Periods of market turbulence tend to result in sharp changes in these characteristics. Our approach, on the other hand, has picked up asset behaviour over volatile market environments historically.

Further evidence of this is provided in Figure 14, which plots portfolio risk and return, and Figure 15, which draws distribution of portfolio peak-to-trough drawdowns under the CMA-based and historical informed simulation methods. In Figure 16, we calculated probability of loss for the simulated portfolios over

Simulated Portfolio Return, Volatility and Drawdowns

(Fig. 13) Our approach suggests a higher peak-to-trough drawdown than the CMA-based simulation

	Return*	Volatility	95% Peak-to-Trough Drawdown
CMA-based	4.7%	8.7%	-34.8%
Historical resampling	2.4%	3.5%	-12.9%
Historical informed	4.7%	9.0%	-43.5%

As of June 30, 2022.

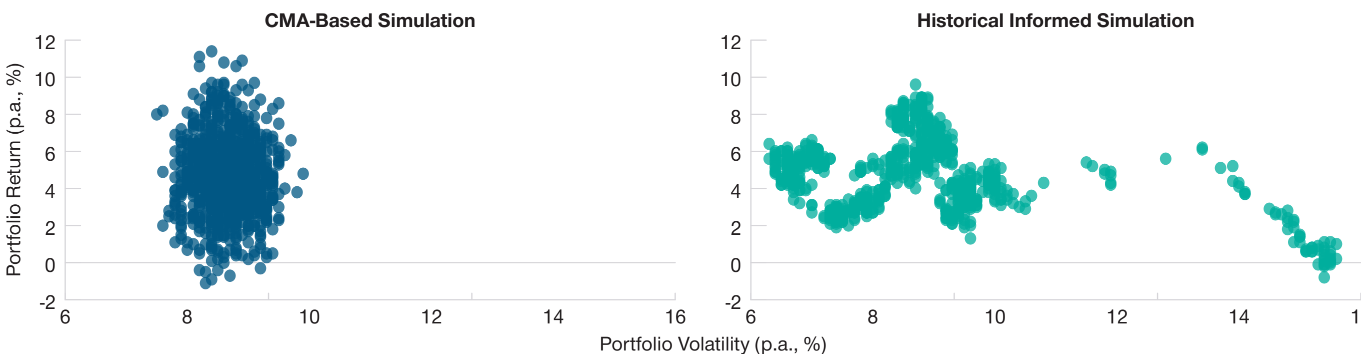
Figure incorporates simulated past performance and that past performance is not a reliable indicator of future performance. It also incorporates forward-looking assumptions. Actual outcomes may differ materially from estimates and forward-looking assumptions. For illustrative purposes only. Please see Appendix Disclosures for additional important information on this analysis.

*Gross of fees.

Sources: Bloomberg Finance L.P., MSCI, SBBI and T. Rowe Price. Figures are calculated in USD. Based on monthly total returns, gross of fees. For CMA-based, uses T. Rowe Price 2022 CMAs. For historical resampling, uses asset returns over the period February 2015 through June 2022. For historical informed, uses backfilled asset returns over the period January 1928 through June 2022. Calculated returns and volatilities are annualised.

Portfolio Risk and Return

(Fig. 14) Our simulation produced a broader range of outcomes



As of June 30, 2022.

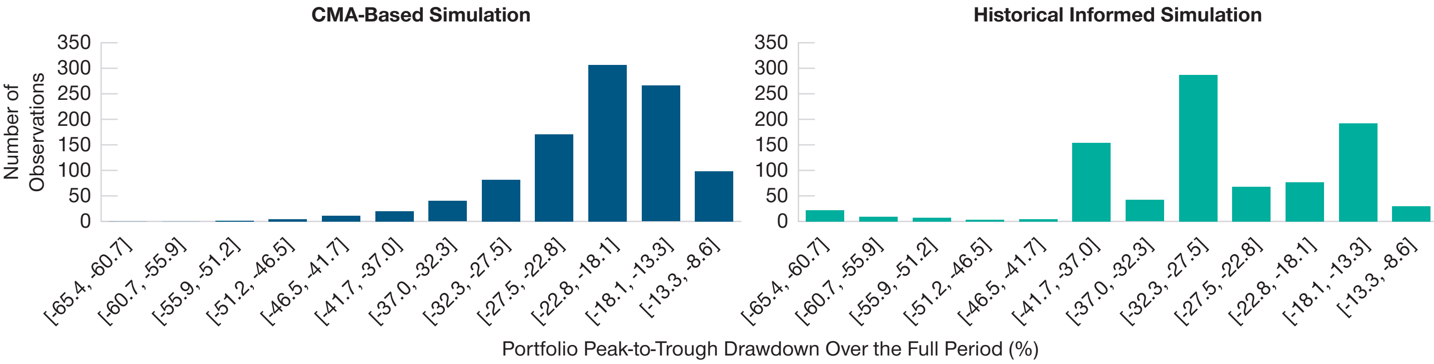
Figure incorporates simulated past performance and that past performance is not a reliable indicator of future performance. It also incorporates forward-looking assumptions. Actual outcomes may differ materially from estimates and forward-looking assumptions. For illustrative purposes only. Please see Appendix Disclosures for additional important information on this analysis.

Sources: Bloomberg Finance L.P., MSCI, SBBI and T. Rowe Price, analysis by T. Rowe Price. Figures are calculated in USD. Based on monthly total returns. For CMA-based, uses T. Rowe Price 2022 CMAs. For historical informed, uses backfilled asset returns over the period January 1928 through June 2022.

[6] Chekhlov, A. (2005) 'Drawdown Measure in Portfolio Optimization', International Journal of Theoretical and Applied Finance, 8(1): 13–58.

Portfolio Peak-to-Trough Drawdown Distribution

(Fig. 15) Our simulation and the CMA simulation produce different patterns



As of June 30, 2022.

Figure incorporates simulated past performance and that past performance is not a reliable indicator of future performance. It also incorporates forward-looking assumptions. Actual outcomes may differ materially from estimates and forward-looking assumptions. For illustrative purposes only. Please see Appendix Disclosures for additional important information on this analysis.

Sources: Bloomberg Finance L.P., MSCI, SBBI and T. Rowe Price, analysis by T. Rowe Price. Figures are calculated in USD. Based on monthly total returns. For CMA-based, uses T. Rowe Price 2022 CMAs. For historical informed, uses backfilled asset returns over the period January 1928 through June 2022.

Probability of Loss of Simulated Portfolios Over Different Time Horizons

(Fig. 16) Our simulation suggests a wider range of volatilities

	3 Months	1 Year	3 Years	5 Years	7 Years	10 Years
Loss threshold*	(-5.9%)	(-9.5%)	(-3.9%)	(-2.0%)	(-1.1%)	(-0.2%)
CMA-based	5.0%	5.0%	5.0%	5.0%	5.0%	5.0%
Historical resampling	0.0%	0.0%	0.1%	0.3%	0.5%	0.9%
Historical informed	6.8%	6.9%	6.6%	3.8%	2.6%	2.8%

Figure incorporates simulated past performance and that past performance is not a reliable indicator of future performance. It also incorporates forward-looking assumptions. Actual outcomes may differ materially from estimates and forward-looking assumptions. For illustrative purposes only. Please see Appendix Disclosures for additional important information on this analysis.

*Loss threshold takes the 95th percentile return of the CMA-based simulation results over different time horizons, as the 95th percentile return is a threshold commonly used by investors.

Sources: Bloomberg Finance L.P., MSCI, SBBI and T. Rowe Price. Figures are calculated in USD. Based on monthly total returns. For CMA-based, uses T. Rowe Price 2022 CMAs. For historical resampling, uses asset returns over the period February 2015 through June 2022. For historical informed, uses backfilled asset returns over the period January 1928 through June 2022.

different time horizons. The historical informed simulation has the widest range of volatilities of portfolio returns. This is perhaps more realistic, especially for a 20-year investment period where multiple varied market environments are likely to occur.

The historical informed simulation exhibits a non-normal distribution curve of drawdowns, with a fatter tail and a negative skewness. This is more in line with the consensus view that financial assets are not normally distributed. It is interesting to note generally higher probabilities of capital loss implied by the historical informed simulation than the ones implied by both the CMA-based and historical resampling simulations. We believe these distinct characteristics of our process are especially important when designing solutions for investors who have a particular sensitivity to tail risk and capital loss.

Assume the investor was looking for a portfolio with a return target of about 4%–5% per annum over the long term but was mindful of potential of drawdowns. The CMA-based simulation would suggest an asset allocation of 10% Bloomberg Global Aggregate Bond Index, 60% MSCI ACWI and 30% Active Fixed Income Strategy as originally stated in Figure 17. However, our framework shows that such an allocation mix would pose a much more severe risk of capital loss, and a higher probability of loss over short to medium time horizons, than initially anticipated, as shown in Figures 14, 15 and 16. Therefore, the investor should consider reducing the allocation to risky assets such as global equity, which has experienced much more severe and abrupt drawdowns historically compared to fixed income.

Assessing Different Portfolio Allocations

(Fig. 17) Four stock/bond weighting combinations

	Bloomberg Global Aggregate*	Active Fixed Income	MSCI ACWI*
Portfolio 1 (original)	10.0%	30.0%	60.0%
Portfolio 2	10.0%	35.0%	55.0%
Portfolio 3	10.0%	40.0%	50.0%
Portfolio 4	10.0%	42.5%	47.5%

Figures refer to simulated past performance and that past performance is not a reliable indicator of future performance. For illustrative purposes only.
*Assume the following investment constraints: 10% maximum allocation to Bloomberg Global Aggregate Bond Index, MSCI All Country World Index. Portfolios are assumed to be rebalanced monthly.
Source: T. Rowe Price.

A Reduced Allocation to Risky Assets Cushioned Volatility

(Fig. 18) Simulated returns are only marginally lower

20-year Simulated Window	Return	Volatility	95% Peak-to-Trough Drawdown
Portfolio 1 (original)	4.7%	9.0%	43.5%
Portfolio 2	4.5%	8.3%	40.4%
Portfolio 3	4.4%	7.6%	37.1%
Portfolio 4	4.4%	7.2%	35.4%

As of June 30, 2022.
Figure incorporates simulated past performance and that past performance is not a reliable indicator of future performance. It also incorporates forward-looking assumptions. Actual outcomes may differ materially from estimates and forward-looking assumptions. For illustrative purposes only. Please see Appendix Disclosures for additional important information on this analysis.
Sources: Bloomberg Finance L.P., MSCI, SBBI and T. Rowe Price. Figures are calculated in USD. Based on monthly total returns. Uses backfilled asset returns over the period January 1928 January through June 2022. Calculated returns and volatilities are annualised.

A Greater Bond Weighting Reduced the Probability of Capital Loss

(Fig. 19) Six different time horizons

	3 Months	1 Year	3 Years	5 Years	7 Years	10 Years
Loss threshold*	(-5.9%)	(-9.5%)	(-3.9%)	(-2.0%)	(-1.1%)	(-0.2%)
Portfolio 1 (original)	6.8%	6.9%	6.6%	3.8%	2.6%	2.8%
Portfolio 2	5.7%	5.5%	5.3%	2.8%	2.0%	2.2%
Portfolio 3	4.5%	4.5%	4.2%	2.1%	1.6%	1.8%
Portfolio 4	3.9%	4.0%	3.7%	1.9%	1.4%	1.6%

As of June 30, 2022.
Figure incorporates simulated past performance and that past performance is not a reliable indicator of future performance. It also incorporates forward-looking assumptions. Actual outcomes may differ materially from estimates and forward-looking assumptions. For illustrative purposes only. Please see Appendix Disclosures for additional important information on this analysis.
*Loss threshold takes the 95th percentile return of the CMA-based simulation results over different time horizons. Measure shown is the probability of capital loss over the stated threshold.
Sources: Bloomberg Finance L.P., MSCI, SBBI and T. Rowe Price. Figures are calculated in USD. Based on monthly total returns. Uses backfilled asset returns over the period from January 1928 through June 2022.

Impact of Different Portfolio Allocations on Drawdowns

(Fig. 20) Hypothetical portfolio peak-to-trough drawdowns over the whole period

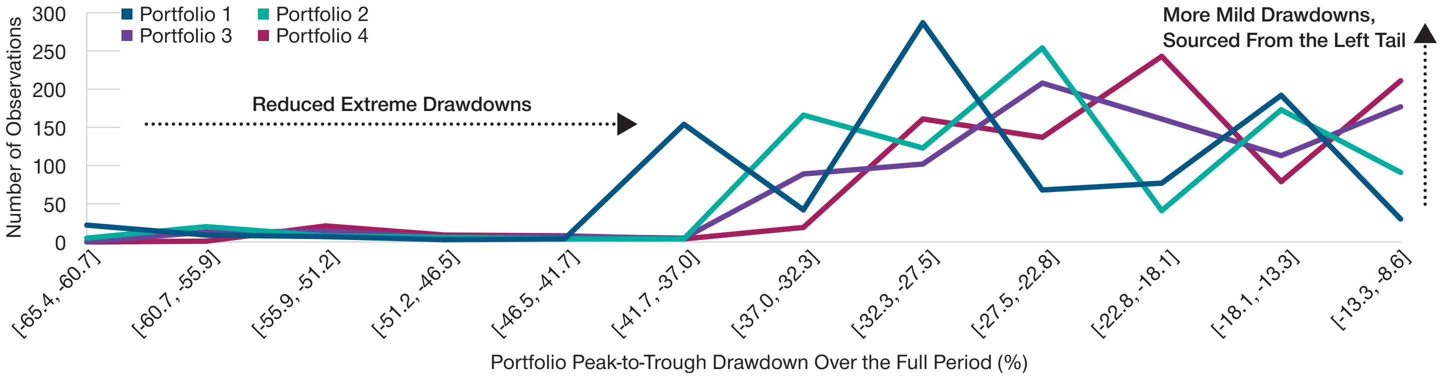


Figure incorporates simulated past performance and that past performance is not a reliable indicator of future performance. It also incorporates forward-looking assumptions. Actual outcomes may differ materially from estimates and forward-looking assumptions. For illustrative purposes only. Please see Appendix Disclosures for additional important information on this analysis. This is not to be construed as investment advice or a recommendation to buy or sell any security.

Sources: Bloomberg Finance L.P., MSCI, SBBI and T. Rowe Price. Figures are calculated in USD. Based on monthly total returns. Uses backfilled asset returns over the period from January 1928 through June 2022.

After testing different portfolio allocations with the new process, Portfolio 4 in Figure 17 should not experience peak-to-trough drawdowns worse than 35%, 95% of the time, while giving up about 0.3% return per annum as desired by the investor as shown in Figure 18. Portfolio 4 would also significantly reduce the probability of capital loss over a pre-defined threshold across a spectrum of various time horizons as detailed in Figure 19.

> A robust simulation process can often serve as a key tool to model portfolio behaviour.

Conclusion

A robust simulation process can often serve as a key tool to model portfolio behaviour. Our framework explicitly embeds both historical asset behaviours and the investor's expectation of future performance when simulating asset and portfolio returns.

We believe our approach is intuitive and based on proven processes that investors may use in constructing multi-asset portfolios.

Appendix:

Important Information—Backfilling Methodology:

- Our approach assumes that all data from the long sample is equally valuable in simulating future returns.
- Our approach assumes that relationships between the existing factors and the missing factors do not change, which is not necessarily realistic.
- There is a limit to how much missing data can be backfilled. If a large portion of the data is missing, it might be better to simply use the shorter, common sample. In general, the higher the correlations, and the more stable the distribution's moments, the more data can be backfilled.
- Our approach does not impose economic constraints on the returns series produced—for example, there is no constraints on large positive returns to fixed income in a period of negative yields.
- If the true distribution of return series is multivariate normal, using more conventional approaches may be preferable because our approach relies on relatively small samples of realized residual returns.
- There may also be cases of corner relationships between returns on sets of assets which may be better modelled using more conventional approaches.

Important Information—Capital Market Assumptions

T. Rowe Price Capital Market Assumptions as of December 31st 2021: We adopt T. Rowe Price 5 year expected returns of 6.0% for global equities, 0.3% for Global Aggregate, 0.5% for GBP cash, while the return for Active Fixed Income is assumed to be GBP cash + 3.0%. Each forecast is gross of investment management fees.

The assumed correlations and volatilities for each asset class used in the Monte Carlo Simulation is shown below:

Correlations	Global Equities	GBP Cash	Active Fixed Income	Volatility (% p.a.)
Global Equities	1.00	-0.02	-0.04	14.1%
GBP Cash	-0.02	1.00	0.06	1.0
Active Fixed Income*	-0.04	0.06	1.00	4.0

*Active Global Fixed Income is represented by a strategy managed by T. Rowe Price, Dynamic Global Bond.

The information presented herein is shown for illustrative, informational purposes only. Forecasts are based on subjective estimates about market environments that may never occur. This material does not reflect the actual returns of any portfolio/strategy and does not guarantee future results. The historical returns used as a basis for this analysis are based on information gathered by T. Rowe Price and from third party sources and have not been independently verified. The asset classes referenced in our capital market assumptions are represented by broad based indices, which have been selected because they are well known and are easily recognizable by investors. Indices have limitations due to materially different characteristics from an actual investment portfolio in terms of security holdings, sector weightings, volatility, and asset allocation. Therefore, returns and volatility of a portfolio may differ from those of the index. Management fees, transaction costs, taxes, and potential expenses are not considered and would reduce returns. Expected returns for each asset class can be conditional on economic scenarios; in the event that a particular scenario comes to pass, actual returns could be significantly higher or lower than forecast.

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The gross model performance results do not reflect the deduction of investment advisory fees. Returns shown would be lower when reduced by the advisory fees and any other expenses incurred in the management of an investment advisory account. For example, an account with an assumed growth rate of 10% would realize a net of fees annualized return of 8.91% after three years, assuming a 1% management fee.

T. Rowe Price Methodology: Monte Carlo Analysis

Monte Carlo simulations model future uncertainty. In contrast to tools generating average outcomes, Monte Carlo analyses produce outcome ranges based on probability, thus incorporating future uncertainty.

Hypothetical in nature, the projections do not reflect actual investment results, and are not guarantees of future results. The simulations are based on assumptions. The materials present only a range of possible outcomes. Actual results are unknown—therefore results may be better or worse than the simulated scenarios. Investors should be aware the potential for loss (or gain) may be greater than demonstrated in the simulations.

Modelling Assumptions include:

The primary asset classes and return assumptions used for this analysis are as outlined in the paper and appendix. The analysis includes c. 1,000 simulations for each portfolio allocation. Portfolios are assumed to be rebalanced on a monthly basis for the forward-looking simulation.

Material Assumptions include:

The primary assumptions underlying the analysis are the historical period from which returns are resampled and the rate of return of each asset class. Underlying long-term rates of return for the asset classes are not directly based on historical returns. Rather, they represent assumptions that take into account, among other things, historical returns. They also include estimates for reinvested dividends, rebalancing frequency, and capital gains.

Material Limitations include:

The analysis relies on return assumptions of asset classes (not investment products), combined with a historical resampling period, to generate a wide range of possible return scenarios. There is no certainty the future path of asset class returns is within the range of outcomes modelled. As a consequence, the results of the analysis should be viewed as comprehensive, but not exhaustive. Users should also keep in mind that seemingly small changes in input parameters, may have a significant impact on results. This, as well as mere passage of time, may lead to considerable variation in results for repeat users.

Additional material limitations include:

- Extreme market movements may occur more often than in the model.
- Market crises can cause asset classes to perform similarly, lowering the accuracy of our projected return assumptions, and diminishing the benefits of diversification in ways not captured by the analysis. As a result, returns experienced by the investor may be more volatile than projected.
- Asset class dynamics, including but not limited to risk, return and the duration of ‘bull’ and ‘bear’ markets, can differ than those in the modelled scenarios.
- The analysis does not use all asset classes.
- Taxes, transaction costs, other potential expenses, potential for alpha from active management, and investment management fees are not taken into account.

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The results are not predictions but should be viewed as reasonable estimates.

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Bloomberg Finance L.P.

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