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September 2026

Vanguard Capital Markets Model

- The **Vanguard Capital Markets Model®** (VCMM) is Vanguard's proprietary financial simulation engine, powering our strategic investment outlook and asset allocation decisions. It has three main components: (1) a global, dynamic model of the fundamental drivers of asset returns—including yield curves and equity market valuations; (2) attribution models that map those drivers to asset class returns; and (3) a simulation engine that produces probability distributions of outcomes.
- Key features include a probabilistic framework, forward-looking assumptions anchored to Vanguard's macroeconomic views, sensitivity to current market conditions, and non-normal distributions that capture tail risk.
- The VCMM produces joint distributions of asset returns, volatilities, and correlations. These outputs serve two purposes. First, they support risk and return analytics—including return outlooks, scenario analysis, and evaluation of the trade-offs for different investment decisions. Second, they feed into portfolio optimization tools such as the **Vanguard Asset Allocation Model** (VAAM) and the **Vanguard Life-Cycle Model** (VLCM), which construct portfolios ranging from static and time-varying allocations to dynamic glide paths.

Authors

Kevin DiCiurcio, CFA

Lukas Brandl-Cheng, M.Sc.

Ian Kresnak, CFA

Acknowledgments: This paper is a revision of Vanguard research first published in 2014 as *Vanguard Global Capital Markets Model* by Joseph Davis, Ph.D., Roger Aliaga-Díaz, Ph.D., Harshdeep Ahluwalia, Frank Polanco, Ph.D., CFA, and Christos Tasopoulos. We acknowledge the various authors who have contributed to prior versions of this research.

The Vanguard Capital Markets Model is a proprietary financial simulation tool developed and maintained by Vanguard's Investment Strategy Group. It forms the basis for Vanguard's strategic global capital markets outlook. By blending statistical analysis with forward-looking macroeconomic assumptions—and by accounting for current market conditions and the non-normality of asset returns—the VCMM generates distributions of global asset returns, correlations, and volatility over different horizons. The VCMM is a powerful forecasting tool used for setting reasonable return expectations and evaluating the risk-return trade-offs inherent in portfolio decisions, such as the potential range of portfolio return outcomes and the probabilities of achieving return objectives or realizing downside-risk events.

The VCMM is grounded in the view that asset class returns reflect compensation for bearing systematic risk. Using decades of historical data, the VCMM establishes a forward-looking equilibrium of risk-free rates and risk premia. Near-term forecasts then vary around this equilibrium based on current market conditions. Next, the VCMM estimates a dynamic statistical relationship among risk factors and asset returns. To account for what is left unexplained in the model, Monte Carlo simulation methods are used to simulate the uncertainty around modeled expectations. By explicitly accounting for important initial market conditions when generating its return distributions, the VCMM framework departs fundamentally from more basic Monte Carlo simulation techniques found in some financial software.

This paper explains how the VCMM works, describes its key assumptions, and shows how the model is applied in practice. We organize the discussion around the following topics: the model's forecast philosophy, its statistical architecture for the core and attribution modules, the forward-looking assumptions built into the VCMM, and the model's real-world applications.

Vanguard's approach to forecasting and notes on risk

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Investments are subject to market risk, including the possible loss of the money you invest. Bond funds are subject to the risk that an issuer will fail to make payments on time, and that bond prices will decline because of rising interest rates or negative perceptions of an issuer's ability to make payments. Diversification does not ensure a profit or protect against a loss in a declining market. **Performance data shown represent past performance, which is not a guarantee of future results.** Note that hypothetical illustrations are not exact representations of any particular investment, as you cannot invest directly in an index or fund-group average.

Forecast principles underpinning the VCMM

Three principles guide the VCMM's approach to forecasting asset returns.

1. **History informs but does not dictate.** As Bogle (2017) put it, "past stock market returns … are deeply flawed guides to what lies ahead … [but] if we can distinguish the reason the past was what it was, then we can establish reasonable expectations about the future." The VCMM takes this to heart. The model identifies the key fundamental drivers behind past returns of different asset classes and, together with explicit forward-looking assumptions, projects how they may evolve and may shape the future return environment.

2. **Fundamentals and sentiment both matter.** Any asset's return reflects two forces: the income and fundamental value the asset generates over time, and the price investors are willing to pay for that value. In the long run, fundamentals dominate. In the short run, sentiment can swing prices far from fair value. The VCMM models both forces jointly.

3. **Uncertainty is the point, not a limitation.** Because no one can predict the future with certainty, the VCMM produces a full distribution of possible outcomes rather than a single forecast number. These distributions use non-normal (heavy-tailed) shapes, assigning a higher probability to extreme events than a normal distribution would.

   Together, these principles distinguish the VCMM from simpler approaches that rely on historical averages, assume normal distributions, or ignore how starting conditions shape the path ahead. The rest of this paper shows how the model puts these principles into practice.

Vanguard Capital Markets Model

The VCMM is built on the principle that potential returns from an asset class are compensation for bearing the systematic risk (or beta) of that asset class. The VCMM uses both historical macroeconomic and financial market data to dynamically model the return behavior of these asset classes. Some of the variables include yield curves, inflation, and leading economic indicators. Using large datasets of quarterly frequency from as early as 1960, the VCMM estimates a dynamic statistical relationship between risk factors and asset returns. Based on these calculations, the model generates simulations using regression-based Monte Carlo techniques to project these relationships into the future.

As illustrated in **Figure 1** on the next page, the model has two main components:

- The **core module** captures relationships among macroeconomic and financial risk factors ("core variables") across geographic regions. This is done through a global Bayesian vector autoregression (BVAR) model, extending Villani (2009).
- The **attribution module** maps those core variables to asset class returns through a set of asset-class-specific models. Using regression-based Monte Carlo methods, it translates each simulated risk-factor path into a corresponding return path, producing a joint distribution of returns across all asset classes. This approach ensures the distribution of cross-asset performance is consistent across risk-factor paths, while also reflecting tail outcomes and quantifying their probability of occurrence.

The forecasts from the VCMM are anchored to Vanguard's near-term macroeconomic outlook and to megatrends, such as technological change and structural fiscal deficits, through dynamic, forward-looking targets and equilibrium assumptions built into the model.[1]

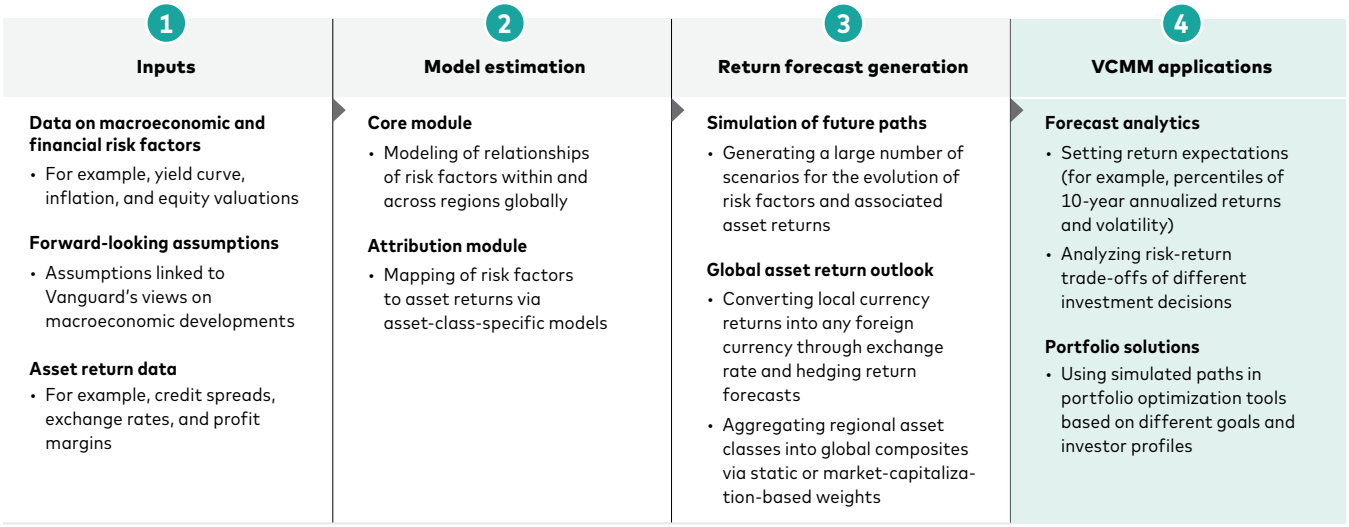
1 Megatrends are slow-moving forces such as technological progress, demographic changes, structural fiscal deficits, and developments in globalization that shape an economy's productive capacity and impact financial markets. For more details, see Davis, Brandl-Cheng, and Khang (2024) and Davis (2025).

The projections from both the core and attribution modules account for the uncertainty present in any forecast. Through jointly modeling variables from different regions, the model captures spillovers and feedback effects of shocks and reflects them in the forecasted asset returns accordingly—a key feature for using the VCMM return simulations to build diversified portfolios that span multiple regions and asset classes.

The attribution models incorporate draws from the core forecast distribution in a regression-based Monte Carlo framework. This approach accounts for the uncertainty around the mapping from risk drivers to returns due to the occurrence of shocks and generates a range of potential future returns.

FIGURE 1

An overview of the VCMM



Source: Vanguard.

Core module

The VCMM core module is a global statistical model of region-specific core variables. It determines, within and across regions, the relationships between these macroeconomic and financial risk factors. The core variables include government bond yield curves, the inflation rate, various measures of economic growth, equity valuations, and dividend payout ratios. These variables are modeled in a global BVAR—a statistical framework designed to capture the time-evolving behavior of interrelated time series.[2]

Estimating a large global model rather than separate, country-specific models improves the understanding of cross-country spillovers of shocks and global dynamics. To avoid overfitting the data, which would constrain suitability for forecasting, it is regularized through "Bayesian shrinkage." This keeps the curse of dimensionality for such a heavily parameterized model in check, while preserving its ability to capture meaningful relationships (Litterman, 1986). Research shows that large BVARs tend to outperform smaller models in both analysis and forecasting (Carriero, Clark, and Marcellino, 2019).

The VCMM's specification follows Villani (2009), which allows for the inclusion of "informative steady-state priors." This creates a systematic way to incorporate forward-looking assumptions such as Vanguard's views into macroeconomic variables or the output from other models that estimate the time-varying fair value of fundamentals for different financial variables.

Attribution module

The attribution module translates the risk factors from the core module into asset class returns using a collection of asset-class-specific models with region-specific adaptations. Depending on the asset class, these models take the form of aggregations of core variables, contemporaneous or lagged regressions, or error-correction models that balance long-run equilibrium relationships with short-run market dynamics.[3]

The attribution module includes foreign exchange models. Using forecasts from these models, the VCMM can express asset return forecasts in any of the modeled currencies. This is a critical step for building global portfolio views from the perspective of investors in different regions and is discussed further below.

All attribution forecasts are generated through regression-based Monte Carlo simulations. Each simulated path from the core module feeds into every attribution model, ensuring that the same economic scenario produces a consistent set of returns across asset classes. Correlations among asset class returns arise naturally from shared underlying risk factors and correlated residual shocks.

Every model simulation starts from current economic and financial market conditions ("initial conditions"). This means the VCMM naturally reflects market-consensus views embedded in current prices and captures how current dynamics can continue or correct toward forward-looking targets over the medium and long term.

2 A BVAR differs from a traditional frequentist vector autoregression in that it treats model parameters as random variables rather than as fixed values that the estimation process tries to identify. The model is estimated by combining prior information on the distribution of these random variables with the information provided by the data. This prior information can be specified in a way that shrinks weaker relationships in the data, with the effect of reducing the likelihood of overfitting and thereby capturing systematic dynamics instead of noise in the sample. For more details, see Dieppe, Legrand, and van Roye (2016) and Martin et al. (2024).

3 The VCMM forecasts an equity return by separately modeling the components and aggregating them back into the total return. A similar setup can be found in Ferreira and Santa-Clara (2011), which looks at equity returns through changes in the price/earnings ratio, earnings growth, and the dividend-to-price ratio. In the VCMM, we additionally split earnings growth into revenue growth and change in profit margins.

Forward-looking assumptions and global capital markets equilibrium

The medium-term, time-varying targets driven by estimates of fair value and the long-run equilibrium (steady state) embedded in the VCMM play a crucial role in formulating strategic asset return expectations that are truly forward-looking, as opposed to being confined by history. Moreover, where appropriate, the VCMM reduces reliance on the choice of historical data sample.

A purely statistical model would eventually revert its forecasts to historical averages.[4] However, sample means depend heavily on the sample period chosen and may lead to biased projections of future asset return expectations. As **Figure 2a** and **Figure 2b** show, simply extrapolating historical averages can produce misleading return expectations and, ultimately, poor portfolio decisions.

The VCMM addresses this by replacing raw historical averages with forward-looking assumptions over different horizons.

- **Medium-term targets** for the next five to 10 years reflect Vanguard's views on fair valuations and macroeconomic trends, informed by current market conditions.
- **Long-run equilibrium targets** represent the prevailing conditions in equilibrium (steady state) or, equivalently, the return over very long horizons when cyclical effects largely offset one another.

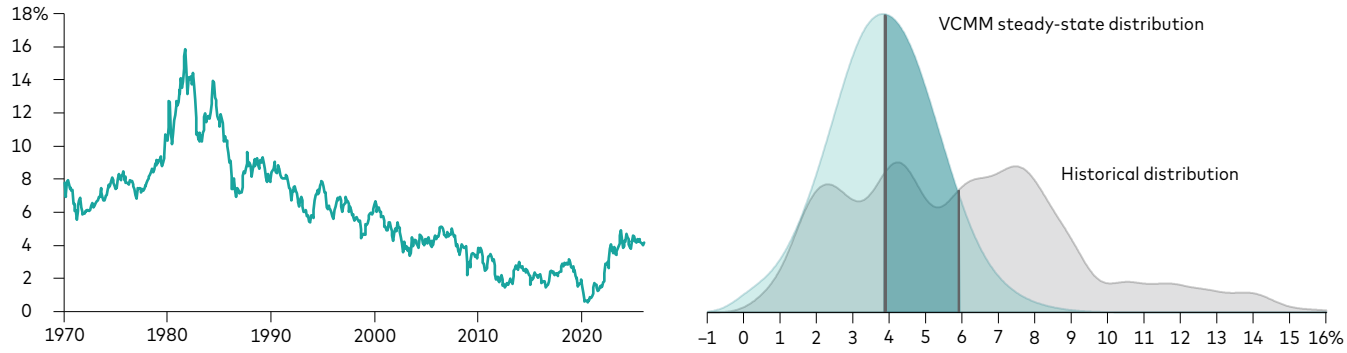
Together, these targets ensure the VCMM's forecasts are shaped by economic reasoning and financial theory, not anchored to an arbitrary slice of history.

FIGURE 2

Forward-looking assumptions to reflect structural economic and financial changes

a. 10-year U.S. Treasury yield

b. 10-year U.S. Treasury yield distribution



Notes: The chart on the left shows the 10-year U.S. Treasury yield from January 31, 1970, to December 31, 2025. The chart on the right shows the probability distribution of the historical 10-year U.S. Treasury yield compared with the long-run equilibrium distribution of the VCMM forecast as of December 31, 2025.

Sources: Vanguard calculations, based on data from Refinitiv, as of December 31, 2025.

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4 Mean reversion is a key feature of stationary series such as growth rates and asset returns.

Dynamic fair-value targets for the medium term

Over the medium term, the core and attribution model forecasts are informed by forward-looking targets that combine initial conditions with Vanguard's views on macroeconomic trends and estimates of fair values for different asset classes. This is implemented through time-varying steady-state priors in the core module, and asset return components such as credit spreads or equity factor valuations in the attribution module.

For equity valuations, the VCMM incorporates the fair-value cyclically adjusted price/earnings (CAPE) framework from Davis et al. (2018). Rather than assuming valuations revert to a fixed historical average, the VCMM estimates a dynamic, time-varying "center of gravity" for each region's valuation. **Figure 3** illustrates the change in this center of gravity for U.S. equity valuations over recent decades, from below 20 before 1995 to higher levels in the years thereafter—reflecting structural changes in the economy and corporate sector.

Figure 4a and **Figure 4b** on the next page demonstrate that this dynamic approach tracked realized valuation changes more accurately than a naïve rolling-average reversion in out-of-sample backtests.

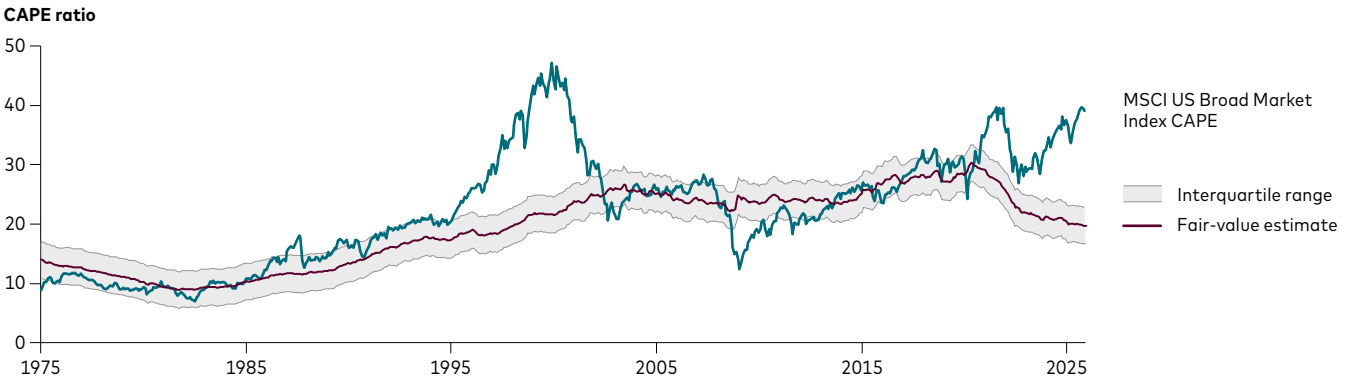
Through the dynamic targets, the VCMM further links to near-term, cyclical views on central bank policy rates and medium-term neutral rate estimates. This is a key component of the yield curve forecast for each region in the VCMM and in turn sets the risk-free rate on top of which risk premia for different assets build.

To model the entire yield curve in the core module, the VCMM reduces it to yield curve factors as in Diebold and Li (2006). The forecast for these factors is informed by the forward-looking view on policy rates, together with a process for the slope and curvature of the yield curve.

The resulting medium-term forecasts for different asset classes are therefore time-varying and impacted by initial conditions, the forward-looking targets, and the statistical relationships estimated in the core and attribution modules.

FIGURE 3

Dynamic fair-value-based targets for equity valuations



Notes: This chart shows the CAPE ratio for the MSCI US Broad Market Index, extended with the MSCI USA Index before data is available, along with our fair-value estimate and range, for the period from January 1975 through December 2025. The CAPE ratio is calculated as the equity market price divided by the 10-year inflation-adjusted average earnings.

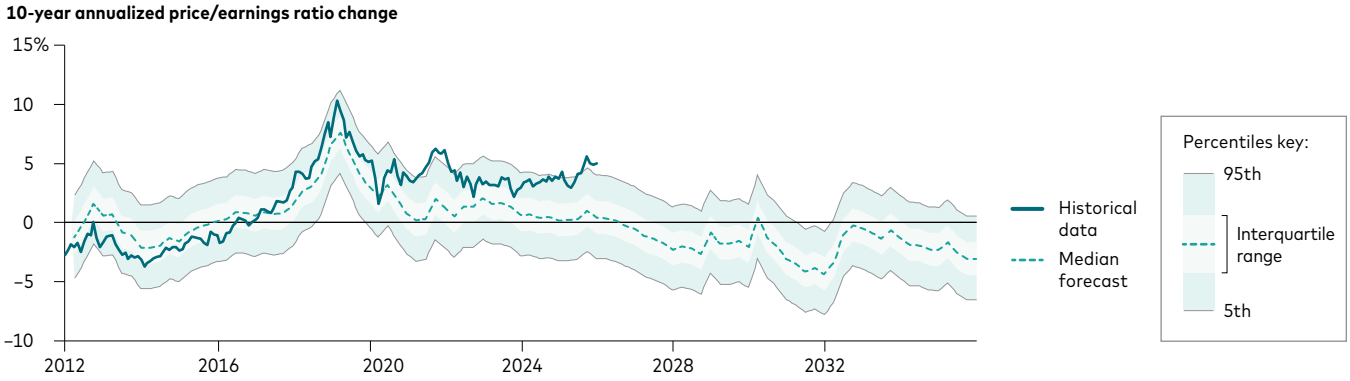
Sources: Vanguard calculations, based on data from Refinitiv, as of December 31, 2025.

Illustrative of model behavior and internal consistency rather than formal forecast evaluation exercises, any projections should be regarded as hypothetical in nature and do not reflect or guarantee future results. Past performance is not a reliable indicator of future results.

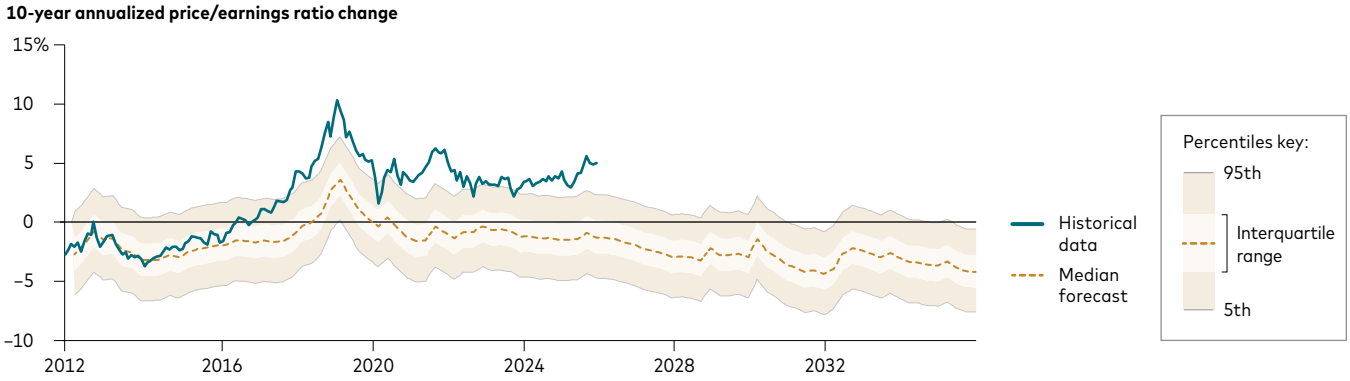
FIGURE 4

Dynamic valuation targets improve forecasts of valuation changes

a. Dynamic fair-value framework



b. Rolling-average reversion framework



Notes: These charts show the 10-year annualized change in the price-to-three-year average earnings (PE3) ratio of the MSCI US Broad Market Index and illustrative backtests at each quarter from March 31, 2002, (end date of 10-year period: March 31, 2012) to December 31, 2025, (end date of 10-year period: December 31, 2035) of the VCMM's dynamic fair-value-based targeting framework and of an approach with PE3 converging to its rolling 20-year historical average. The interquartile and 5th-to-95th percentile ranges are based on 10,000 simulations of the VCMM as of December 31, 2025.

Sources: Vanguard calculations, based on data from Refinitiv, as of December 31, 2025.

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Long-run equilibrium targets

Beyond the medium-term horizon over which these country-specific conditions and dynamics matter, the VCMM outlook is impacted by a set of "steady-state" assumptions. These assumptions reflect conditions in equilibrium or, equivalently, the return over very long horizons when positive and negative dynamics net out.

Figure 5 illustrates the conceptual framework to set these equilibrium targets. It reflects the assumption that investors are compensated for bearing different types of systematic risk that cannot be diversified away.

As investors move from cash to government bonds to corporate bonds to equities, risk rises and so does the equilibrium return that investors require for bearing systematic risks. This framework sets the long-run anchor for every asset class and region in the model. It is implemented through asset-class-specific risk premia while assuming that, under capital mobility, persistent country premia do not exist in steady state.

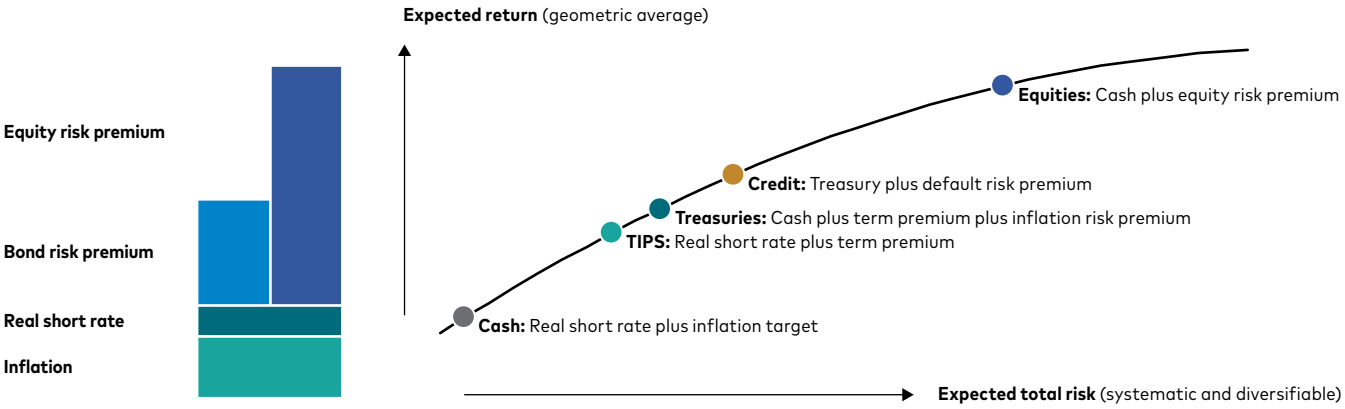
The starting point is the risk-free rate, which reflects broadly comparable monetary policy frameworks across regions. We assume long-run inflation at central bank targets and set the long-run real short rate at 1%, consistent with historical experience over extended horizons.[5] This implies a nominal cash rate in equilibrium of around 3% at the median for most developed markets in the VCMM.

From this 3% nominal risk-free rate, government bond returns embed a term premium consistent with upward-sloping yield curves. The yield curve slope is set at 1.2 percentage points from the short to the long end of the curve, based on average values observed across regions and during periods with inflation close to target.

Corporate bonds then add a credit risk premium consistent with long-run historical spreads. For equities, we assume a common equity risk premium of 5% across developed markets, implying a long-run nominal return of around 8%.

FIGURE 5

Conceptual framework: Global capital markets equilibrium assumptions



Notes: This figure provides an illustrative overview of how the VCMM's equilibrium assumptions are structured across asset classes. These assumptions are informed by theoretical and empirical research on different long-run risk premia. They serve as the equilibrium targets toward which the VCMM's forecasts converge in the long run.

Source: Vanguard.

5 For most developed markets covered in the VCMM, the inflation target is at 2%. Exceptions are the Reserve Bank of Australia and the Swiss National Bank, which target a range of 2% to 3% and 0% to 2%, respectively. We set the target for the median inflation rate at the midpoint of these target ranges: 2.5% for Australia and 1% for Switzerland. The central banks of Mexico and Brazil each target a range around 3%, which is the target in the VCMM.

Modeling exchange rates and aggregating forecasts into global composites

For any model that is global in nature, the modeling of exchange rates is a critical component. The VCMM models each region's assets in its local currency and uses the exchange rate forecasts to convert these returns into any other currency. This ability to convert local-currency-denominated asset returns is necessary for the bottom-up construction of cross-regional asset return benchmarks, such as global or developed markets equity indexes.

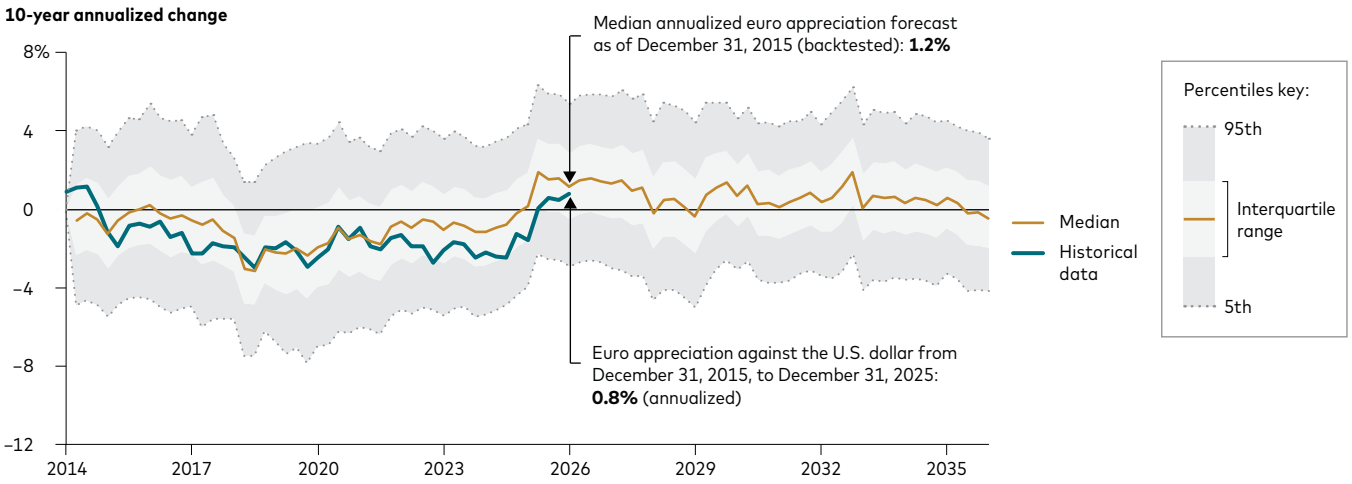
By definition, this approach ensures internal consistency within the VCMM. For example, the global equity return forecast is constructed as the market-capitalization-weighted average of the different underlying regional equity return forecasts, converted into a common currency.

The exchange rate model in the VCMM is a statistical model that adheres to economic theory in the long run and takes current market conditions into account. This approach balances the VCMM's two goals of constructing both accurate and explainable forecasts with clear intuition.[6]

Figure 6 illustrates the currency model in action with the euro (EUR)/U.S. dollar (USD) exchange rate. In 2015, the U.S. dollar appreciated sharply against the euro, partly on expectations of rising U.S. interest rates. When that appreciation exceeded what the model's fundamentals could explain, the VCMM identified the dollar as overvalued. Its forecast flipped from expecting further dollar appreciation to anticipating the euro to appreciate over the following decade until 2025—a shift that was broadly consistent with the subsequent realized currency moves.

FIGURE 6

The VCMM currency model: EUR/USD exchange rate



Notes: This figure shows the rolling 10-year annualized change of the EUR/USD exchange rate (realized and forecasted) for the period ending with the year indicated on the x-axis. The forecast range and median at each point in time correspond to the illustrative backtest of the VCMM using data up to the start date for each forecast. A positive value reflects appreciation of the euro and depreciation of the U.S. dollar.

Sources: Vanguard calculations, based on data from Refinitiv, as of December 31, 2025.

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6 In particular, the exchange rate model is a Bayesian error correction model that explains the long-run dynamics of exchange rates relative to differentials in productivity (real GDP growth per capita) and long-term real interest rates between two regions, and accounts for short-term impacts from relative changes in inflation rates, central bank policy rates, and economic growth. This approach links the long-term dynamics to the economic theories on purchasing power parity (PPP; identical goods should sell at the same price across regions when expressed in a common currency) and interest rate parity (IRP; differences in interest rates across regions should equal the expected change in their exchange rate) while accounting for the effects that changes in monetary policy globally have had on government bond yields.

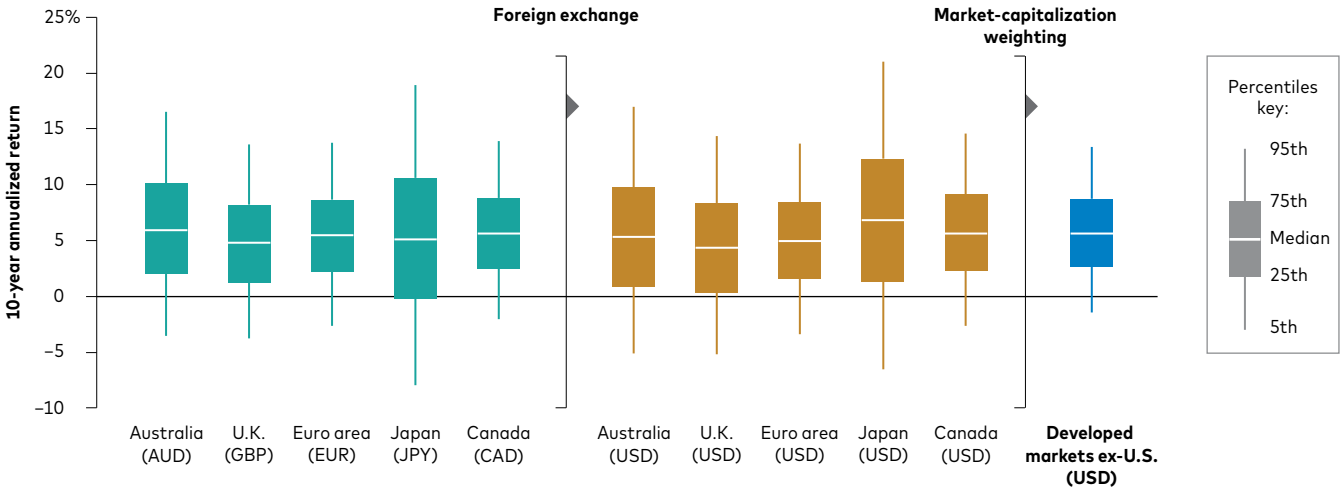
An additional feature of the VCMM currency model is that in the very long run, the exchange rate impact on the return component of any asset equals that of hedging the foreign currency exposure. Currency hedging is implemented in the VCMM through differences in short-term interest rates between the two concerned regions.

Having a forecast distribution for exchange rates (or hedging returns) then enables the conversion of any local currency return into a return in a different currency, and combining returns from individual assets into cross-regional composite returns or portfolios. **Figure 7** illustrates this with the example of the VCMM return forecast for developed markets ex-U.S. equities. The VCMM forecasts returns for different (sub-)asset classes across 13 regions. These returns can be combined to cover a representative share of the market capitalization of a range of cross-regional benchmarks, such as developed markets ex-U.S.

To construct forecasts for these benchmarks, the VCMM converts all building blocks into the target currency using the exchange rate (or hedging return) forecast and then aggregates the individual regional forecasts into the composite, based on market-capitalization weights.

FIGURE 7

Constructing cross-regional composite VCMM forecasts in any currency



Notes: This figure illustrates how the VCMM constructs a composite return forecast for developed markets ex-U.S. equities. Regional return forecasts, produced in local currency, are converted into a common currency using the exchange rate (or hedging return) forecast and then aggregated using market-capitalization weights.

Sources: Vanguard calculations, based on data from Refinitiv, as of December 31, 2025.

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Non-normal distributions and tail risk

Extreme outcomes, both good and bad, occur far more often than a normal distribution would predict.

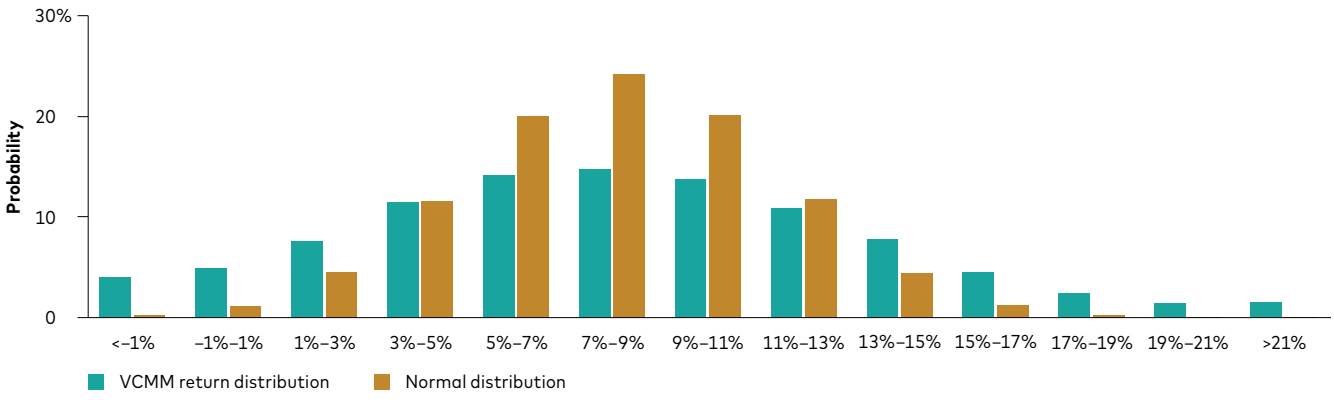
From the end of 1999 to the end of 2009, the Standard & Poor's 500 Index delivered a negative total return over a full decade. Looking at history since 1871, this happened in 3% of all rolling 10-year windows.[7] But under a normal return distribution, it would occur in fewer than 0.4% of simulated scenarios—roughly one-eighth as often as it actually has.

The VCMM explicitly allows for heavy-tailed distributions that assign realistic probabilities to these extreme events. This is implemented by modeling the shocks that drive the range of simulated returns using t-distributions rather than assuming normally distributed shocks.

These shocks are calibrated to replicate the historical frequency and magnitude of extreme outcomes observed in financial markets, ensuring that tail events occur in simulations at realistic rates. As **Figure 8** shows, this approach results in return distributions for U.S. equities with materially fatter tails than a normal distribution with the same average return and volatility.

FIGURE 8

Non-normal VCMM U.S. equity return distribution



Note: This figure shows the distribution of 10,000 equilibrium VCMM returns for U.S. equities and of 10,000 draws from a normal distribution with a mean of 8% and volatility of 18%.

Source: Vanguard calculations, as of December 31, 2025.

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7 The rolling 10-year windows constructed start with January 31, 1871, to January 31, 1881, and end with December 31, 2015, to December 31, 2025.

Applications of the VCMM

The VCMM's distributional output—joint distributions of returns, volatilities, and correlations across asset classes—supports two broad categories of applications: risk and return analytics, and portfolio optimization.

Risk and return analytics and scenario analysis

At its most fundamental level, the VCMM helps set reasonable return expectations. Rather than quoting a single number, the VCMM provides a full distribution that can be summarized by a median and an interquartile range across different horizons, while also conveying the probability of extreme outcomes.

Beyond return expectations, the VCMM enables analysis of the risk-return trade-offs inherent in any investment decision. For example:

- **Asset allocation trade-offs.** How does shifting a portfolio from 60% stocks and 40% bonds to 70% stocks and 30% bonds change the range of 10-year outcomes and portfolio risk? The VCMM can quantify both the upside potential and the increased drawdown risk.
- **Scenario analysis.** What happens to a diversified portfolio if inflation stays elevated for a decade or if interest rates fall sharply? The VCMM simulates thousands of macro-economic paths, and filtering for specific scenarios offers insight into how portfolios behave under stress. This builds on the relative-entropy scenario framework described in Robertson, Tallman, and Whiteman (2005), which provides a principled way to weight alternative scenarios without discarding the baseline outlook.
- **Regional diversification.** Because the VCMM models regions jointly and accounts for currency effects, it can illustrate the diversification benefits of adding international exposure (either currency hedged or unhedged) to a portfolio.

Portfolio optimization

The VCMM's simulated return distributions also serve as the foundation for Vanguard's portfolio optimization tools.

The Vanguard Asset Allocation Model (Aliaga-Díaz et al., 2024) uses VCMM output to construct optimized portfolios. By combining the VCMM's forward-looking return and risk estimates with an investor's objectives and constraints, the VAAM identifies allocations that balance risk and expected return in a rigorous, model-driven framework.

The Vanguard Life-Cycle Model extends this concept to dynamic, goal-based settings. It uses VCMM return distributions to design glide paths—asset allocations that evolve over time as an investor moves toward a specific goal, such as retirement. The VLCM accounts for the investor's full financial picture, including savings, spending, and the evolving trade-off between growth and capital preservation at different life stages.

Together, these V-models form an integrated suite: The VCMM models what markets might do, and the VAAM and VLCM translate those views into actionable portfolio decisions.

Limitations and caveats

The VCMM is an advanced and well-designed quantitative simulation engine. But as with any statistical model, it possesses limitations that are important to understand.

Limitations of the quantitative analysis

Projections generated by the VCMM rely on estimated relationships from historical data and on assumptions about risk characteristics. If future developments depart fundamentally from past patterns through unprecedented structural shifts, model accuracy may be impacted.

That is why Vanguard investment teams complement the VCMM's quantitative output with qualitative analysis. These qualitative adjustments are based on the professional judgment and industry experience of Vanguard

analysts, as well as market consensus and other information from external sources not captured within the VCMM.

The interdependence among the VCMM inputs is captured through the estimated covariance matrix in the global BVAR in the core module and the covariance matrix across the frameworks in the attribution module. Both steps assume that this covariance matrix is static.[8]

In reality, correlations evolve slowly over time. The VCMM compensates for this in several ways. One example is the use of non-normal innovations, which allow for fatter tails and more realistic extreme-event probabilities.

Sensitivity of VCMM forecasts to new dates and forward-looking assumptions

The VCMM is re-estimated quarterly, with additional historical observations becoming available. Each forecast, either when re-estimating the model coefficients or using the latest available coefficients for an intermediate update, then starts from the current available initial conditions of risk factors and asset returns. While the models are designed to capture stable relationships and don't change inexplicably quarter over quarter, the addition of new information to the model does introduce an additional source of change to the forecasts, alongside revisions to Vanguard's forward-looking views on the economy, financial markets, and long-run equilibrium conditions.

This time-dependency of the forecasts is a strength of the VCMM because current market conditions are directly incorporated into the forecasts. And since these forecasts are initialized to current market conditions (that is, to the most current quarter of available data), simulation results are heavily influenced by the most recent data point. This influence is especially true for shorter forecast horizons.

The long-term targets built into the model are additional strengths of the VCMM. As mentioned, the output targets are based on long-term observations but adjusted for structural changes in the financial markets.

For example, inflation in the 1970s was much higher than what might be expected as a long-term average for the future. Accordingly, when determining the steady state (that is, the long-term target) for inflation, we would want to moderate the effect of the high inflation levels experienced in the 1970s. Thus, the long-term targets affect the steady-state behavior of VCMM outputs.

Conclusion

The VCMM is Vanguard's proprietary model of the global capital markets, designed to help clients make effective investment decisions. This paper has highlighted four key features of the VCMM asset return simulation model.

First, by focusing on ranges of outcomes rather than on point forecasts, the VCMM can better incorporate statistical uncertainty into its forecasts. This approach provides investors with a powerful framework to assess unanticipated risks.

Second, the VCMM is forward-looking. Rather than relying solely on historical patterns, the VCMM builds its forecasts on economic fundamentals and Vanguard's macroeconomic outlook, ensuring that the model adapts as the market environment evolves.

Third, the VCMM explicitly accounts for current market conditions and allows for time-varying risk factors and risk premia. The long-term equilibrium conditions imposed on the VCMM are based on both quantitative and qualitative factors, which are determined by experienced analysts within Vanguard's Investment Strategy Group.

8 The global BVAR assumes a static covariance matrix over the forecast horizon. However, each simulated path is the result of the estimated covariance matrix corresponding to that path, which is obtained from a draw from the posterior distribution of the Bayesian model.

Fourth, the VCMM accounts for the non-normality of financial markets, with extreme events occurring more frequently than a normal distribution would imply. This is an important aspect when using the VCMM return forecasts for investment decisions such as portfolio optimization using the VAAM.

These features make the VCMM a powerful foundation for both risk and return analytics and portfolio optimization. The VCMM combines economic and financial variables to weigh many risk factors and set reasonable return expectations. Combined with the Vanguard Asset Allocation Model and the Vanguard Life-Cycle Model, the Vanguard Capital Markets Model helps investors navigate an uncertain world with reasonable return expectations.

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About the Vanguard Capital Markets Model

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

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

The VCMM is a proprietary financial simulation tool developed and maintained by Vanguard's primary investment research and advice teams. The model forecasts distributions of future returns for a wide array of broad asset classes. Those asset classes include U.S. and international equity markets, several maturities of the U.S. Treasury and corporate fixed income markets, international fixed income markets, U.S. money markets, commodities, and certain alternative investment strategies. The theoretical and empirical foundation for the VCMM is that the returns of various asset classes reflect the compensation investors require for bearing different types of systematic risk (beta). At the core of the model are estimates of the dynamic statistical relationship between risk factors and asset returns, obtained from statistical analysis based on available monthly financial and economic data from as early as 1960. Using a system of estimated equations, the model then applies a Monte Carlo simulation method to project the estimated interrelationships among risk factors and asset classes as well as uncertainty and randomness over time. The model generates a large set of simulated outcomes for each asset class over several time horizons. Forecasts are obtained by computing measures of central tendency in these simulations. Results produced by the tool will vary with each use and over time.

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