Capital Market Assumptions 2023

Our long-term return expectations for capital markets serve as key inputs into our strategic asset allocation process for multi-asset portfolios and provide context for shorter-term forecasting.

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Foreword

Our annual capital market forecasting process is always a time for looking ahead and looking back for our investment teams. Looking ahead to define the trends and underlying forces that will determine asset class returns over the next decade and looking back to see whether our forecasting methodology and statistical techniques are still relevant and cutting edge.

In this document, we present our 10-year ahead forecasts for risk, return and correlation of returns for mainstream asset classes in the global investable universe. This year, we have modified our process to incorporate climate change, a subsegment of environmental, social and governance (ESG) factors, into our return forecasts. We specifically choose climate change as the most tangible factor within ESG-related considerations, as it can affect consumer behavior, investment needs, financing, supply chain organization, cross-border trade and stranded assets. Climate change's effect on these variables flows directly into GDP growth and inflation, the magnitude of which will be partly driven by increases in productivity-enabling technologies. For further discussion of climate change in our capital market forecasts please see page 14.

Our analysis points to a decade of subdued returns for most major asset classes.

The return profile for many assets classes remains below historical averages. For example, global equities are forecast to have an arithmetic return of 6%. The economy being mired in a low productivity regime leaves equity in solid shape, but offering what most investors consider somewhat limited upside potential. By contrast, fixed income is forecast to deliver decent returns. Global fixed income assets are forecast to gain 3.6% and we expect US long government bonds to return 4.5%. The rationale behind stronger than previously forecast fixed income gains is the starting point for real yields, which are positive for the first time since 2009. The more normal investment environment that positive real yields bring to investors is a welcome development.

We hope that you find our capital market forecasts useful and look forward to the year ahead. We wish you the very best for a successful 2023.

Sincerely,

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Summary of findings

Compared to last year's projections, our 2023–2032 forecast calls for similar equity returns (6.0% for the S&P 500) and higher bond returns (4.2% for the US Agg).

Our capital market assumptions (CMA) 2023 report details our research on asset class returns, standard deviations of returns and correlations over the 10-year horizon from 2023 through 2032. These estimates represent key inputs into strategic asset allocation decisions for our multi-asset portfolios and provide context for shorter-term macroeconomic and financial forecasting.

Our forecasts were informed by historically low potential GDP growth, reduced labor supply and elevated inflation. To avoid using a single-point estimate forecast, we incorporate an alternative scenario, which has slightly better or worse macro inputs. This year, the alternative-case scenario was again based on inputs of marginally higher productivity and a lower terminal fed funds rate.

Some key results of our analysis:

- The next decade will likely be characterized by returns below historical averages across all major asset classes.
- Developed market equities are likely to deliver mid-single-digit returns, with returns for most non-US market assets lower than those for comparable US assets.
- Emerging market equities should outperform developed markets, albeit with higher expected volatility given a more uncertain path to growth than that of developed markets.
- Bond return assumptions have increased from last year but remain in the low single digits. These projections assume that moves in both bond term premiums and real interest rates will cap upside returns available to fixed income assets.

Forecast environment: Still a low-growth world, with upside for the US

Our forecast models an explicit process of convergence to a steady-state equilibrium for global economies and financial markets through 2032. In our modeling process, we worked with the economic consulting group at S&P Global, which provided quantitative support for our macro inputs.[1]

Cyclical fluctuations are an inevitable aspect of market economies, and we recognize that the steady-state equilibrium incorporated as the terminal point of our forecast is unlikely to be fully attained over any point-to-point 10-year period under real-world conditions. Nonetheless, we find that this theoretical construct is useful for anchoring the forecast. As a result, the forecast does not assume a recession or contraction over the 2023–2032 horizon.

Over the period covered by our forecasts, we believe the US will be constrained by labor force growth, but has the ability to move to a somewhat higher, sustained growth path than it experienced in the previous business cycle. The key is for the US to exit the current low-productivity regime that has constrained the economy.

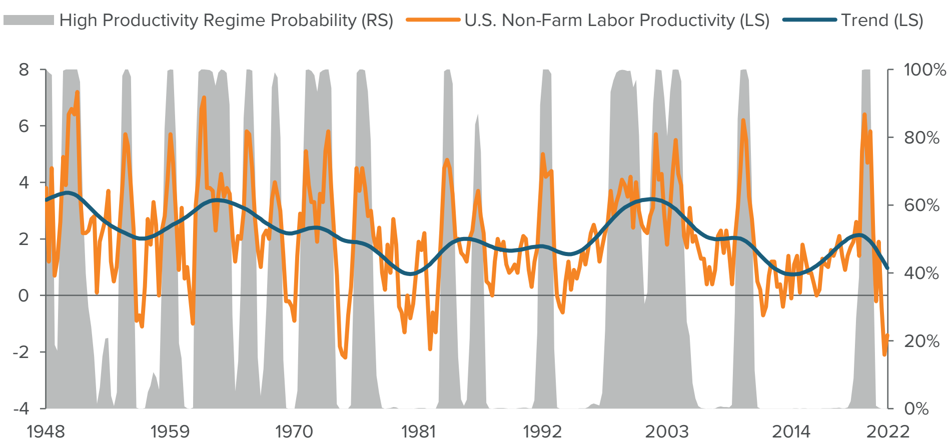
Productivity growth essentially comes from capital deepening and total factor productivity (TFP). The latter is an unobservable measure taken from the decomposition of real GDP growth — the remainder after accounting for the contributions of capital and labor, called the Solow residual. This residual could reflect improvements in technology, growth in the effectiveness of labor, strength in property rights and quality of labor. It also incorporates cultural attitudes, including risk and high levels of confidence in the outlook, which can contribute to a revival in productivity through the TFP channel.

[1] S&P Global is an independent research firm that provides a comprehensive global macroeconomic model, linking 68 individual country models with key global drivers of performance. The model accounts for 95% of global GDP, covering 250–500 time series per country.

Labor-force productivity growth typically alternates between high- and low-productivity regimes over time. To determine the current regime, we fit productivity data through a Markov model (Exhibit 1). The latest data show that US productivity growth has declined from –0.2% year-over-year in 3Q21 to –1.4% in 3Q22, signaling a "low-productivity" regime. The system had been in high-productivity equilibrium for four quarters following the Covid recession. (High-productivity regimes, indicated below in gray shading, average 3.8%, while low-productivity regimes average 1.1%.) A Hodrick-Prescott filter-based decomposition of year-over-year productivity growth into trend and cycle components also shows that the current trend of US productivity growth is 1.0%.

Over the next decade, the US has greater potential for higher, sustained growth than in the previous business cycle.

Exhibit 1. Productivity growth has decelerated



As of 06/30/22. Source: Voya Investment Management. Non-shaded areas in the chart denote low-productivity regimes.

As in the past, our CMA 2023 forecast is predicated on a "base" and an "alternative" scenario. The alternative scenario assumes that the US exhibits modest improvement in output per hour, largely the result of gains in total factor productivity as the labor share shifts away from brick-and-mortar to more productive firms. We generate our forecast based on a 60/40 weight to the base/alternative scenarios. Our forecast is for US GDP growth over the 10-year period to attain 1.9%. Exhibit 2 shows the 2032 values from this forecast, which are consistent with our estimates of longer-term, steady-state values for key US economic variables.

Exhibit 2. Our 2032 forecast for US economic and financial variables

	2032 Forecast
US GDP growth	**1.9%**
Inflation (CPI-U)	2.3%
CPI ex food and energy	2.4%
Federal funds rate	2.4%
10-year US Treasury yield	3.0%
Profit share	8.4%
Savings rate	9.4%

As of 11/21/22. Source: Voya Investment Management, S&P Global. Forecasts are subject to change.

Long-run assumptions

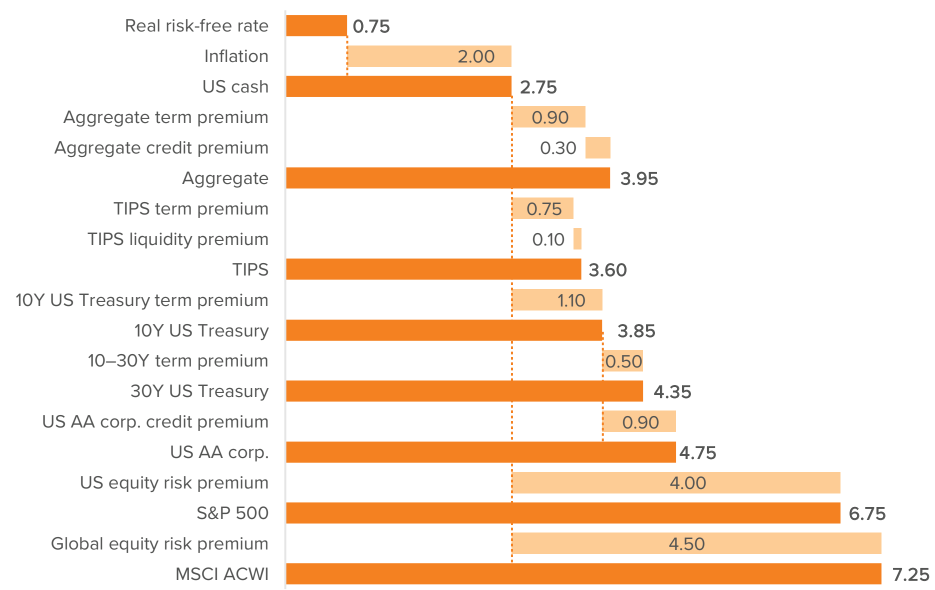
While 10-year forecasts guide our strategic asset allocations, our glidepath assumptions for target date strategies are based on long-run equilibrium return assumptions over much longer horizons, typically 40 years (Exhibit 3). At that point, we think of the economy as being in a steady state where GDP grows at its trend rate, inflation is at target, unemployment equals the non-accelerating inflation rate of unemployment, the real interest rate equals the "natural" rate of interest — neither contractionary nor inflation inducing — and all capital and goods markets are in equilibrium.[2]

These forecasts use a building block methodology. Starting with our expectations for real short-term yield and inflation, we generate a risk-free rate forecast and, from that, derive all equity and fixed income assets by adding the relevant risk premium:

- We derive the risk premium for US equities from the Gordon growth model, representing the sum of the dividend yield and the nominal earnings growth rate in excess of the risk-free rate. International equities add an international equity risk premium.
- Government bond return forecasts are the sum of the risk-free rate and an appropriate term premium. Corporate bond return forecasts add a credit-risk premium.

From a theoretical perspective, all risk premiums mean revert towards a long-run equilibrium, as the economy is in a steady state. The reason for mean reversion is that investment opportunities are time varying. Since the rate of arrival of new information is time varying, return volatility and covariance are time varying as well in the short run. Our econometric work (and that of academic researchers) confirms the stationarity of a number of risk premiums, which, in turn, justifies our assumption of constant average risk premiums, term premiums and credit spreads in the long-run equilibrium.

Exhibit 3. Long-run equilibrium return assumptions (%)



As of 11/21/22. Source: Voya Investment Management. Assumptions are subject to change.

[2] "Understanding Glide Path Design: Distribution of Labor Income among Participant Populations," Sinha, A. and Yuen, R., Voya Investment Management, 2Q18.

How we forecast returns

Our process for determining asset class risk and return estimates begins with a top-down forecast of economic growth, using a 60/40 blend of base-case and alternative scenarios. To develop these forecasts, we leverage S&P Global's economic modeling capabilities. These two scenarios capture the most important upside and downside risks facing the global economy and markets over the forecast horizon. Furthermore, in response to client demand and following guidance from organizations such as the Task Force on Climate-Related Financial Disclosures (TCFD), we have integrated climate scenarios into our economic forecasts this year, described on page 16 in Methodological considerations.

Our base-case scenario forecasts 2.6% US GDP growth through 2032, driven by strong consumer spending, below-trend productivity growth and subdued labor force growth. The alternative scenario incorporates slightly faster productivity growth, a higher dividend payout ratio, more inflation and an assumption that the Federal Reserve lets the economy run a little hotter than in the base case. Under these assumptions, returns for risk assets are modestly higher in the alternative scenario than in the base case.

For US stocks, we estimate earnings and dividends for the S&P 500 Index using our blended macroeconomic assumptions. Earnings growth is constrained by the neoclassical assumption that profits as a share of GDP cannot increase without limit but will converge to a long-run equilibrium. We then use a dividend discount model to determine fair value for the index each year during the forecast period. We construct returns for other US equity indexes, including REITs, using a single-index factor model in which beta sensitivities of each asset class, with respect to the market portfolio, are derived from our forward-looking covariance matrix estimation. Beta is by definition covariance over variance. (For additional detail, see "Covariance and correlation matrices methodology" on page 10.) Each equity asset class return is the sum of the risk-free interest rate and a specific risk premium determined from our estimate of beta sensitivity and market-risk premium forecasts.

For US bonds, we use the blended-scenario interest rate expectations to calculate expected returns for various durations. We model bond expected returns as the sum of current yield and a capital gain (or loss) based on duration and expected change in yields. For non-US bonds, the process is similar and includes an adjustment for expected currency movements. Return expectations for credit-related fixed income reflect yield spreads and expected default and recovery rates.

Exhibit 4. Ten-year return forecasts, 2023–2032

	Expected returns					
	Geometric mean return (%)	Arithmetic mean return (%)	Volatility (%)	Skewness	Kurtosis	Sharpe ratio
Stocks						
S&P 500	4.8	6.0	15.8	-0.53	1.2	0.23
S&P 500 Growth	4.1	5.6	18.0	-0.45	0.9	0.18
S&P 500 Value	5.4	6.4	15.3	-0.64	1.9	0.26
MSCI US Minimum Volatility	4.9	5.5	11.7	-0.66	1.4	0.26
Russell 3000	4.9	6.1	16.2	-0.58	1.4	0.23
Russell Midcap	4.8	6.3	17.8	-0.65	1.8	0.22
Russell 2000	4.2	6.7	22.2	-0.58	1.7	0.19
MSCI EAFE	3.6	5.3	18.7	-0.28	0.4	0.16
MSCI World	4.7	5.8	15.6	-0.61	1.3	0.22
MSCI EM	3.8	7.0	25.4	-0.34	0.8	0.18
MSCI ACWI	4.8	6.0	15.7	-0.63	1.3	0.22
Bonds						
Bloomberg US Aggregate	4.0	4.2	6.8	0.56	5.1	0.27
Bloomberg US Government Long	3.8	4.5	12.7	0.23	0.7	0.17
Bloomberg US TIPS	3.5	3.6	5.4	-0.89	4.4	0.23
Bloomberg US High Yield	6.9	7.3	11.2	-0.44	4.5	0.41
Credit Suisse Leveraged Loan	7.2	7.2	7.3	-1.67	22.9	0.26
Bloomberg Global Aggregate	3.3	3.6	7.7	0.14	1.0	0.16
Bloomberg Global Aggregate ex US	2.7	3.1	9.9	0.04	0.1	0.08
JPMorgan EMBI+	7.5	8.3	13.9	-1.09	7.9	0.37
US Treasury Bill 3M	2.3	2.3	1.0	1.02	1.4	0.00
Real assets						
Bloomberg Commodity	2.2	3.4	15.6	-0.47	1.8	0.07
FTSE EPRA Nareit Developed	3.4	5.5	20.6	-0.52	2.4	0.15

As of 11/21/22. Source: Voya Investment Management. Returns shown are in US dollar terms. Forecasts are subject to change.

Exhibit 5. Ten-year forecasted correlations matrix, 2023–2032

	S&P 500	Russell 1000 Growth	Russell 1000 Value	MSCI US Minimum Volatility	Russell 3000	Russell Midcap	Russell 2000	MSCI EAFE	MSCI World	MSCI EM	MSCI ACWI	Bloomberg Commodity	FTSE EPRA Nareit Developed	Bloomberg US Aggregate	Bloomberg US Government Long	Bloomberg US TIPS	Bloomberg US High Yield	Credit Suisse Leveraged Loan	Bloomberg Global Aggregate	Bloomberg Global Aggregate ex US	JPMorgan EMBI+	US Treasury Bill 3M
S&P 500	1.00																					
Russell 1000 Growth	0.96	1.00																				
Russell 1000 Value	0.95	0.83	1.00																			
MSCI US Minimum Volatility	0.90	0.83	0.89	1.00																		
Russell 3000	1.00	0.96	0.95	0.89	1.00																	
Russell Midcap	0.95	0.92	0.93	0.86	0.97	1.00																
Russell 2000	0.84	0.83	0.81	0.73	0.88	0.93	1.00															
MSCI EAFE	0.69	0.65	0.68	0.64	0.70	0.69	0.62	1.00														
MSCI World	0.96	0.93	0.92	0.87	0.97	0.94	0.84	0.86	1.00													
MSCI EM	0.53	0.51	0.50	0.47	0.54	0.55	0.52	0.56	0.58	1.00												
MSCI ACWI	0.95	0.91	0.91	0.85	0.95	0.93	0.84	0.86	0.99	0.70	1.00											
Bloomberg Commodity	0.29	0.26	0.31	0.24	0.30	0.34	0.32	0.35	0.34	0.35	0.36	1.00										
FTSE EPRA Nareit Developed	0.66	0.60	0.68	0.68	0.67	0.68	0.63	0.70	0.73	0.56	0.75	0.27	1.00									
Bloomberg US Aggregate	0.21	0.20	0.20	0.30	0.21	0.20	0.13	0.18	0.22	0.03	0.20	-0.04	0.25	1.00								
Bloomberg US Government Long	0.06	0.07	0.03	0.18	0.05	0.04	-0.02	0.02	0.05	-0.10	0.02	-0.16	0.12	0.88	1.00							
Bloomberg US TIPS	0.22	0.22	0.21	0.27	0.22	0.23	0.16	0.20	0.23	0.14	0.23	0.19	0.26	0.56	0.54	1.00						
Bloomberg US High Yield	0.58	0.56	0.57	0.54	0.59	0.61	0.59	0.51	0.60	0.47	0.62	0.27	0.55	0.21	0.06	0.29	1.00					
Credit Suisse Leveraged Loan	0.33	0.31	0.35	0.34	0.35	0.38	0.35	0.31	0.36	0.30	0.37	0.28	0.35	0.01	-0.18	0.18	0.57	1.00				
Bloomberg Global Aggregate	0.23	0.22	0.23	0.31	0.23	0.23	0.17	0.42	0.32	0.14	0.31	0.15	0.36	0.78	0.67	0.56	0.21	0.03	1.00			
Bloomberg Global Aggregate ex US	0.21	0.19	0.20	0.27	0.20	0.21	0.16	0.47	0.32	0.18	0.31	0.22	0.36	0.54	0.45	0.47	0.18	0.03	0.95	1.00		
JPMorgan EMBI+	0.44	0.42	0.43	0.47	0.44	0.45	0.39	0.38	0.45	0.57	0.50	0.19	0.50	0.38	0.27	0.33	0.43	0.21	0.35	0.28	1.00	
US Treasury Bill 3M	0.06	0.04	0.07	0.09	0.06	0.05	0.02	0.06	0.07	0.06	0.07	0.01	0.04	0.16	0.07	-0.03	0.05	0.05	0.12	0.08	0.09	1.00

As of 11/21/22. Source: Voya Investment Management. Projections are subject to change.

Appendix: Methodological considerations

Covariance and correlation matrices methodology

Asset class covariance and correlation matrices are crucial components of our capital market assumptions process, serving as the pillars of asset class standard deviation forecasts. This is a different process than forecasting returns, as correlations tend to wander over time. If we were to use a historical average or exponentially weighted methodology — which takes a long-run history and puts a heavier weight on recent observations — it could lead to risk forecasts that may represent the past but bear little resemblance to the future.

An example using stocks and bonds illustrates this point. Over the past 20 years, the correlation of returns between the S&P 500 Index and the Bloomberg US Aggregate Bond Index was –0.02; however, this offers little insight into the relationship between these two asset classes during unusual periods or when financial markets are in euphoric or pessimistic states. For example, over that same 20-year interval, the correlation of stocks and bonds was –0.10 during normal periods of returns, but 0.07 during unusual periods (Exhibit 6). Incorporating these periods of unusual correlation patterns can lead to a truer estimate of the durability of diversification between asset classes. We capture these unusual periods in our standard deviation and correlation forecasts using an academic framework called *turbulence*.

Our methodology incorporates periods of unusual correlation to develop truer estimates of the durability of diversification between asset classes.

Turbulence: An evolution from skull measurements to finance

The turbulence framework we use to estimate correlations and standard deviations of returns is derived from the academic work of the applied statistician Prasanta Chandra Mahalanobis. In the early 20th century, Mahalanobis analyzed human skull resemblances among castes and tribes in India. He created a formula to capture differences in skull size, which incorporated the standard deviation of measures of various skull parts. He then squared and summed the normalized differences, generating a single composite distance measure.[3]

This formula evolved into a statistical measure called the "Mahalanobis distance." The measure was groundbreaking in that it helped analyze data across standard deviations but also incorporated the correlations among data sets. More than 70 years later, the Mahalanobis distance was used by Kritzman and Li to formulate a concept called financial turbulence.[4] They postulated financial turbulence as a condition in which asset prices, given their historical patterns of returns, behave in an uncharacteristic way including extreme price moves. They further noted that financial turbulence often coincides with excessive risk aversion, illiquidity and price declines for risky assets. It is this turbulence framework (or unusualness of returns and correlations of returns) that we have used to forecast risk measures in our capital market assumptions.

Observing turbulence

Turbulence can be calculated for any given set of asset classes. Back to our example of US stocks and bonds, the two dimensions can be visualized as the equation of an ellipse using the returns of the S&P 500 Index and the Bloomberg US Aggregate Index (Exhibit 6). The center of the ellipse represents the average of the joint returns of the two assets. The boundary is a level of tolerance that separates normal from turbulent observations. This boundary takes the form of an ellipse rather than a circle because it accounts for the covariance of the asset classes.

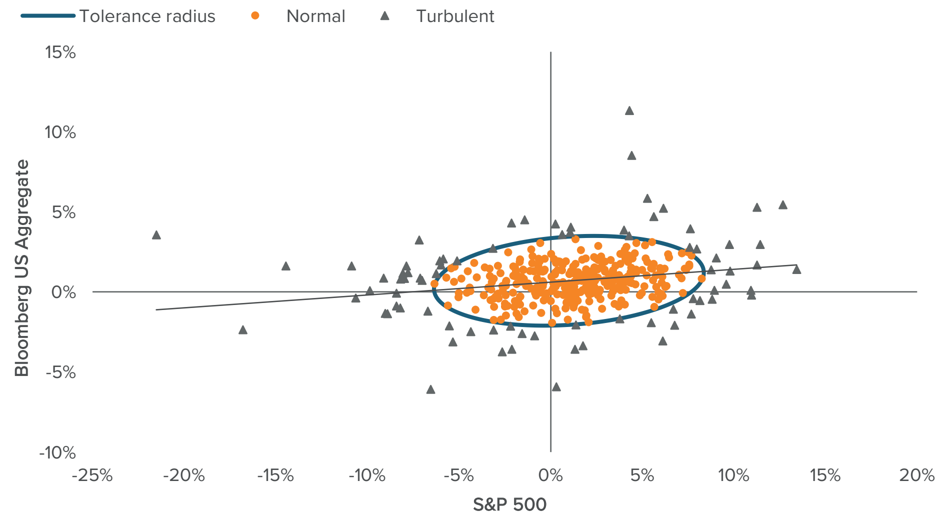
The idea captured by this measure is that certain periods are considered turbulent not only because returns are unusually high or low, but also because they moved in the opposite direction of what would have been expected based on the average correlation.

[3] Mahalanobis, P., "On the Generalized Distance in Statistics," *Proceedings of the National Institute of Sciences of India* vol. 2 no. 1 (1936): 49–55.

[4] Kritzman, M. and Y. Li, "Skulls, Financial Turbulence, and Risk Management," Financial Analysts Journal, vol. 66 no. 5 (2010): 30–41.

Exhibit 6. We account for non-normal observations by considering correlations

Normal and turbulent periods of stock and bond correlations, 20 years ended 09/30/22



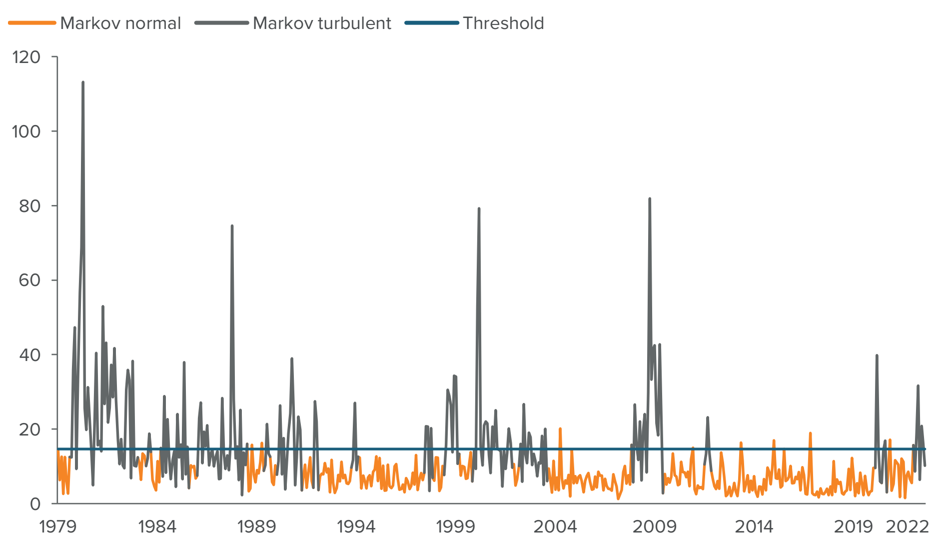
As of 09/30/22. Source: Voya Investment Management.

Using turbulence to create portfolios

The threshold for normalcy and turbulence shown in Exhibit 6 is not static; rather, it changes over time. Our process identifies turbulent market regimes by estimating a covariance matrix covering those periods of market stress alone, and is the outcome of a Markov model. The model classifies regimes rather than arbitrary thresholds, because thresholds would fail to capture the persistence of shifts in volatility. The Markov model output in Exhibit 7 illustrates turbulent and normal regimes.

Exhibit 7. Means and variances both matter when determining whether observations are turbulent

Markov normal and turbulent regimes over time



As of 08/31/22. Source: Voya Investment Management.

For turbulent market regimes, we make use of the concept of multivariate outliers in a return distribution. That is, we take into account not only the deviation of a particular asset class's return from the average, but also its volatility and correlation with other asset classes. We subsequently estimate a covariance matrix based on periods of normal and turbulent market performance. Finally, we blend these two covariance matrices using weights that allow us to express both views about the likelihood of each normal or turbulent regime and to capture the differential risk attitudes toward each. The weights we use to create our strategic asset allocation portfolios are 60% normal and 40% turbulent.

Although turbulent regimes have an observed frequency of only 30%, we overweight them at 40% to account for structural issues such as globalization, demographics and worldwide central bank intervention, which are prevalent today. Furthermore, overweighting turbulent periods increases the assumed risk, providing a more conservative matrix that emphasizes diversification during volatile periods. From this blended covariance matrix, we then extract the implied correlation matrix and standard deviations for each asset class. In our view, this process helps create a strategic asset allocation portfolio that can account for the empirical evidence that correlations will deviate through time.

Time dependency of asset returns and its impact on risk estimation

Recent research suggests that expected asset returns change over time in somewhat predictable ways, and that these changes tend to persist over long periods. Thus, changes among investment opportunities — all possible combinations of risk and return — are found to be persistent. This Appendix will set out the economic reasons for return predictability, its consequences for strategic asset allocation and the adjustments we have made to control for it in our estimation process.

Research suggests that expected asset returns change in somewhat predictable ways, which are persistent over time.

In our view, the common source of predictability in financial asset returns is the business cycle. The business cycle itself is persistent, and this makes real economic growth predictable, to some extent. The fundamental reason for the business cycle's persistence is that its components share the same quality. Consumers, for example, tend to smooth consumption since they dislike abrupt changes in their lifestyles. Research on permanent income and lifecycle consumption provides the theoretical basis for consumers' desire for a stable consumption path. When income is affected by transitory shocks, consumption should not change since consumers can use savings or borrowing to adjust consumption in well-functioning capital markets.

Robert Hall has formalized these ideas by showing that consumers will optimally choose to keep a stable path of consumption equal to a fraction of their present discounted value of human and financial wealth.[5] Investment, the second component of GDP, is sticky, as corporate investment in projects is usually long term in nature. Finally, government expenditures also have a low level of variability. Over a medium-term horizon, negative serial correlation sets in, as the growth phase of the cycle is followed by a contraction, and then that contraction is followed by renewed growth.[6]

How does this predictability of economic variables affect the predictability of asset returns? Consider stocks as an example.

Equity values are determined as the present discounted value of future cash flows, and they depend on four factors: expected cash flows, expected market risk premium, expected market risk exposure and the term structure of interest rates.

- Cash flows and corporate earnings tend to move with the business cycle.
- The market risk premium is high at business cycle troughs, when consumers are trying to smooth consumption and are less willing to take risks with their income, and it is low at business cycle peaks, when people are more willing to take risks. The market risk premium is a component of the discount rate in the present value calculation of the dividend discount model.

[5] Hall, R., "Stochastic Implications of the Life-Cycle-Permanent Income Hypothesis: Theory and Evidence," *Journal of Political Economy* 86 (1978): 971–988.

[6] Poterba, J. and Summers, L., "Mean Reversion in Stock Prices: Evidence and Implications," *Journal of Financial Economics* 22 (1988): 27–60.

- A firm's risk exposure (beta), another component of the discount rate, changes through time and is a function of its capital structure. Thus, a firm's risk increases with leverage, which is related to the business cycle.
- The last component of the discount rate is the risk-free rate, which is determined by the term structure of interest rates. The term structure reflects expectations of real interest rates, real economic activity and inflation, which are connected to the business cycle.

Thus, equity returns, and financial asset returns in general, are predictable to a certain extent. Expected returns of many assets tend to be high in bad macroeconomic times and low in good times.

This predictability of returns manifests itself statistically through *autocorrelation*. Autocorrelation in time series of returns describes the correlation between values of a return process at different points in time. Autocorrelation can be positive when high returns tend to be followed by high returns, implying momentum in the market. Conversely, negative autocorrelation occurs when high returns tend to be followed by low returns, implying mean reversion. In either case, autocorrelation induces dependence in returns over time.

Empirical persistence of the business cycle makes financial asset returns somewhat predictable.

Traditional mean-variance analysis focused on short-term expected return and risk assumes that returns do not exhibit time dependence and that prices follow a random walk. In a random walk, expected returns are constant, exhibiting zero autocorrelation; realized short-term returns are unpredictable. Volatilities and cross-correlations among assets are independent of the investment horizon. Thus, the annualized volatility estimated from monthly return data, scaled by the square root of 12, should be equal to the volatility estimated from quarterly return data, scaled by the square root of 4.

In the presence of autocorrelation, the scaling rule described above (using the square root of time) is invalid, since the sample standard deviation estimator is biased and the sign of autocorrelation matters for its impact on volatility and correlations. **Positive autocorrelation leads to an underestimation of true volatility.** A similar result holds for the cross-correlation matrix bias when returns exhibit autocorrelation. For long investment horizons, the risk/return tradeoff can be very different than for short investment horizons.

In a multi-asset portfolio, in which different asset classes display varying degrees of autocorrelation, failure to correct for the bias of volatilities and correlations will lead to suboptimal mean variance-optimized portfolios in which asset classes that appear to have low volatilities receive excessive allocations. Such asset classes include hedge funds, emerging market equities and non-public market assets such as private equity and private real estate, among others.

There are at least two ways to correct for autocorrelation:

- A direct method that adjusts the sample estimators of volatility, correlation and all higher moments
- An indirect method that cleans the data first, allowing us to subsequently estimate the moments of the distribution using standard estimators

Given that the direct methods become quite complex beyond the first two moments, our choice is to follow the second method and clean the return data of autocorrelation. Before we do that, we estimate and test the statistical significance of autocorrelation in our data series.

We estimate first-order autocorrelation as the regression slope of a first-order autoregressive process. We use monthly return data for the period 1979–2014. We subsequently test the statistical significance of the estimated parameter using the Ljung-Box Q-statistic.[7] The Q-statistic is a statistical test for serial correlation at any number of lags. It is distributed as a chi-square with k degrees of freedom, where k is the number of lags. Here we test for first-order serial correlation, thus $k = 1$. About 80% of our return series exhibit positive and statistically significant first-order serial correlation based on associated p-values at the 10% level of significance.[8]

Khandani and Lo provide empirical evidence that positive return autocorrelation is a measure of illiquidity exhibited among a broad set of financial assets including small-cap stocks, corporate bonds, mortgage-backed securities and emerging market investments.[9] The theoretical basis is that in a frictionless market, any predictability in asset returns can be immediately exploited, thus eliminating such predictability. While other measures of illiquidity exist, autocorrelation is the only measure that applies to both publicly and privately traded securities and requires only returns to compute.

Removing return autocorrelation prevents underestimation of volatility.

Since most of the return series we estimate exhibit autocorrelation, we apply the Geltner unsmoothing process to all series. This process corrects the return series for first-order serial correlation by subtracting the product of the autocorrelation coefficient ρ and the previous period's return from the current period's return and dividing by 1-ρ. This transformation has no impact on the arithmetic return, but the geometric mean is impacted since it depends on volatility. This correction is thus important to make for long-horizon asset allocation portfolios.

Accounting for climate change

The vast majority of research concludes climate change is a significant risk to our planet's ecosystem and, according to the IMF and many other well-respected institutions, is set to have major economic impacts on many countries.[10] While we believe global economic outcomes will continue to be dominated by the business cycle and event stresses, climate change is a material issue, and its importance could increase going forward. Therefore, we believe climate change risks – both physical and transition[11] – should be considered when making forecasts of the future. Physical risks, for the most part, are best incorporated at the security level, although there are certain countries and asset classes (e.g., real estate) for which it is easier to make a clear, broad connection.

There are a few channels through which climate change could theoretically influence capital market assumptions: macro, fundamentals and repricing.

Macro: Climate-related considerations impact consumer behavior, investment needs, financing, supply chain organization, cross-border trade and stranded assets. These are mostly transition-risk related, driven by government policy and market forces. Climate change's effect on these variables flows directly to GDP growth and inflation; the magnitude of the effect will be driven partly by the increase in productivity-enabling technologies.

Fundamentals: Top-line output establishes the base for what companies can earn. Profit margins form the other component of the equation. The transition is certain to affect industries to different degrees, but the consequences are difficult to forecast in aggregate, so we retain our tried-and-true approach of assuming profit margins in mean revert to equilibrium.

Repricing: Changes in valuation are the most difficult to gauge. Determinants of valuation at any one point and across time are highly uncertain, especially for broad asset classes (e.g., US large cap equities), which is the level at which we forecast CMAs. We acknowledge that certain sectors generally deserve higher valuations than others, and subscribe to the idea that capital will flow to more "sustainable" investments over time, but we argue that it is difficult to predict changes in relative pricing across sectors based on inherent "greenness," especially across countries. Instead of comparing asset class carbon footprints based on sector compositions, we think sustainability characteristics should be defined at or below the industry level. Therefore, premiums and discounts for those factors, including climate change, should

7 Ljung, G.M. and Box, G.E.P., "On a Measure of Lack of Fit in Time Series Models," *Biometrika*, 65, (1978): 297–303.

8 The p-value is the probability of rejecting the null hypothesis of no serial correlation when it is true (i.e., concluding that there is serial correlation in the data when in fact serial correlation does not exist). We set critical values at 10% and thus reject the null hypothesis of no serial correlation for p-values <10%.

9 Khandani, A.E. and Lo, A., "Illiquidity Premia in Asset Returns: An Empirical Analysis of Hedge Funds, Mutual Funds, and US Equity Portfolios," Quarterly Journal of Finance 1 (2011): 205–264.

10 International Monetary Fund, https://www.imf.org/en/Topics/climate-change/climate-and-the-economy#publications, accessed 10/31/22.

11 Climate change risks can be divided into two categories: 1) physical risks, which result from climatic events such as wildfires, storms and floods; and 2) transition risks, which result from policy actions taken to shift the economy away from fossil fuels.

be applied to individual companies within their respective groups. As a result, our efforts are centered on macro and (to a lesser degree) fundamental inputs.

To define and evaluate the impact of changes in climate-related macro and fundamental inputs, we leaned on our partners at S&P Global to develop plausible climate scenarios and expected economic outcomes. Although countless climate scenarios are plausible and investors would be well served to stress-test portfolios against some of those possibilities, only one will actually occur. Therefore, we took the most likely climate scenario, called “Inflections” in Exhibit 8A, and integrated those assumptions into the global economic model for the base case and alternative scenarios that form the backbone of our CMA.

The climate scenarios (Exhibits 8A and 8B) are developed within the context of achieving net-zero carbon emissions by 2050. This places them on a different time horizon than our economic scenarios used for our 10-year CMA, so they need to be rescaled; still, they enable us to capture important developments along various temperature pathways. Unfortunately, given the lack of legally binding climate commitments by countries, daunting technological gaps and recent geopolitical strains, the current trajectory appears to have us on a path for a 2.4° Celsius increase in global average temperatures by 2050 (Exhibit 9). In this base-case scenario, the energy transition delivers fundamental change at the global emissions level, but geopolitical relations are likely to force adaptation rather than facilitate international cooperation and technological disruption. In all cases, a critical variable influencing emission paths is the price of carbon (Exhibit 10) as well as government taxation, regulation and international coordination around it. To get to zero, emitting greenhouse gases must become expensive relative to alternative means of production.

The difference in economic outcomes between most climate scenarios tested was modest. Thus, the impact of climate change in our capital market assumptions is minor.

Like climate change itself, the impact on the economy is one that will be felt gradually. The difference in economic outcomes among most climate scenarios tested was modest. Thus, the impact of considering climate change in our capital market assumptions is minor. The exception, however, is the “Discord” scenario, in which countries become more inwardly focused, climate policies are inconsistent, and decarbonization efforts lose momentum, resulting in limited meaningful action. In this case, global growth takes a sizable hit. Over the 10-year forecast horizon, the economic damage would be mostly due to the series of crises that underly the geopolitical rancor preventing climate change mitigation as opposed to the negative effects of climate change itself. As the time horizon extends, however, so too does the risk of major and potentially irreversible physical costs.

What is clear from our analysis is that striving to address this negative externality will lead to an improved outlook for growth and most risk assets, relative to taking no action. Moreover, incorporating views on climate change into our forecasts provides us with a more comprehensive picture of the world, which will help us generate better estimates going forward.

Exhibit 8A. Summary of base, optimistic and pessimistic climate scenarios

	Green rules A revolutionary transformation toward a sustainable low-carbon economy	Inflections Base case view of the energy future	Discord A stagnant world with weak markets and policies
General themes	**Crisis backlash and strong government policy** Societal reactions to chronic crises drive strong government actions that result in revolutionary change in energy markets and emissions levels	**Market forces and national self-interest** A mix of social, market, and government forces drives fundamental change in energy use and emissions pathways.	**Weak markets and policies** Political instability, combined with isolationist trends, inhibits governments, causes market uncertainty and slows the energy transition.
International cooperation	**Strong** International cooperation strengthens in response to strong public demands to address security concerns — which are increasingly linked to climate change.	**Mixed** The global balance of power is more broadly distributed than it has been in almost a century. National interests are central.	**Weak** International relations suffer from chronic domestic political division and weakness, sowing mistrust and isolationism.
Economic environment	**Mixed** Initial policy disorder, combined with the costs of forced energy transition, causes economic disruptions and hardships over the short term, but eventually establishes conditions that encourage private investment. Average growth: 2.5%	**Moderate** Recovery from the Covid crisis is uneven; an eventual return to pre-2020 average growth rates masks underlying long-term structural shifts in the global economy. Average growth: 2.6%	**Weak** The world emerges from the Covid crisis battered by uncertainty and facing ongoing political and economic fallout, which weakens governments and market confidence. Average growth: 2.1%
Climate policy	**Very strong** Political pressure and national security interests eventually drive nations to cooperate on global standards and protocols for GHG emissions across the world and promote clean energy technologies, business models, and lifestyles. **Some G20 countries move much closer to net-zero goals but do not meet them.**	**Strong** Climate policy moves forward strongly but remains driven more by national interests than global goals, hindering the effectiveness of international coordination on standards and conventions and the consistency of net-zero programs and efforts. **G20 countries do not meet net-zero goals.**	**Weak to moderate** Climate policy is fragmented as many countries become more inwardly focused and decarbonization efforts lose political momentum in the face of chronic economic uncertainty and weakness. **Many countries abandon net-zero goals.**

As of 09/30/22. Source: S&P Global. Forecasts are subject to change.

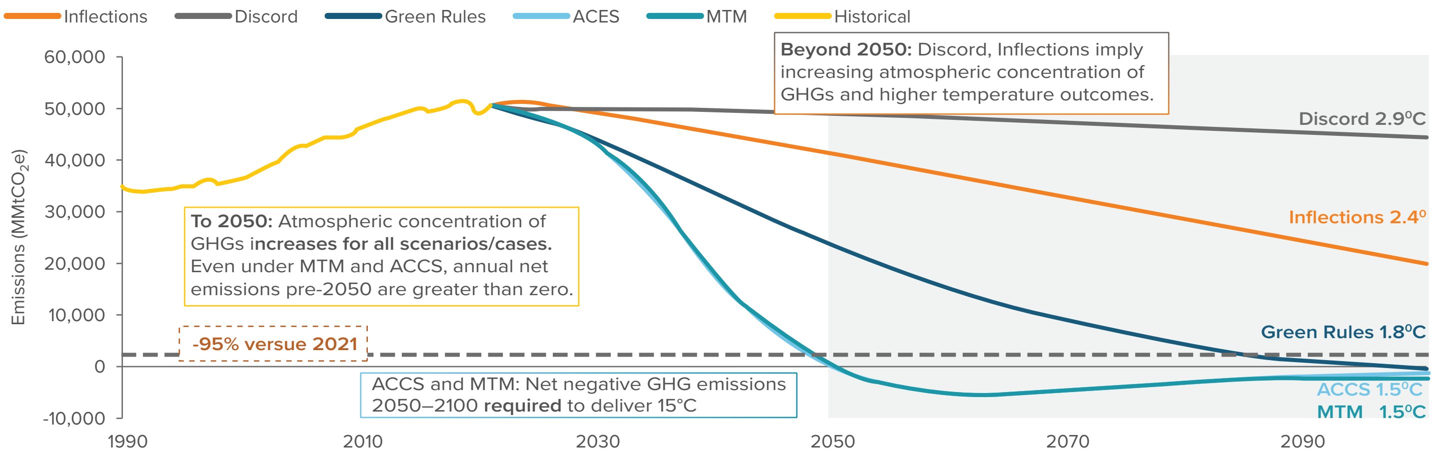
Exhibit 8B. Summary of net-zero climate scenarios

	Accelerated carbon capture systems (CCS) Net zero 2050 with high carbon capture	Multi-tech mitigation (MTM) Net zero 2050 with low carbon capture
General themes	**Broad global use of CCS in the energy and non-energy sectors**	**Supply diversification, electrification, and renewables dominate as key drivers, as well as a moral imperative to move away from hydrocarbons**
International cooperation	**Strong** Recognition that CCS can help accomplish decarbonization goals, use existing infrastructure and save jobs.	**Strong** Intense policy and societal intent to minimize fossil fuel use across all sectors. Incentives widely used to foster green hydrogen.
Economic environment	**Moderate** Costs of rapid acceleration of expensive carbon capture keep economic growth slightly below that of the “green rules” scenario. *Average growth: 2.5%*	**Moderate** Costs of a rapid shift away from hydrocarbons and abandonment of existing facilities keep economic growth below that of the “green rules” scenario for some period. *Average growth: 2.5%*
Climate policy	**Very strong** Very strong and coordinated climate policies globally. High carbon prices to incentivize use of carbon capture, with global carbon markets reaching $200 per metric ton of CO_2 (real 2020 US$) by 2040.	**Very strong** Very strong and coordinated climate policies globally. Moderately high carbon prices, reaching $150 per metric ton of CO_2 (real 2020 US$) by 2040, supplemented by incentives and mandates to reduce fossil fuels.

As of 09/30/22. Source: S&P Global. Forecasts are subject to change.

Exhibit 9. The path to 2050 and beyond: Emission trends and implied temperatures

Only the back-cast cases achieve the net-zero target of the Paris Agreement

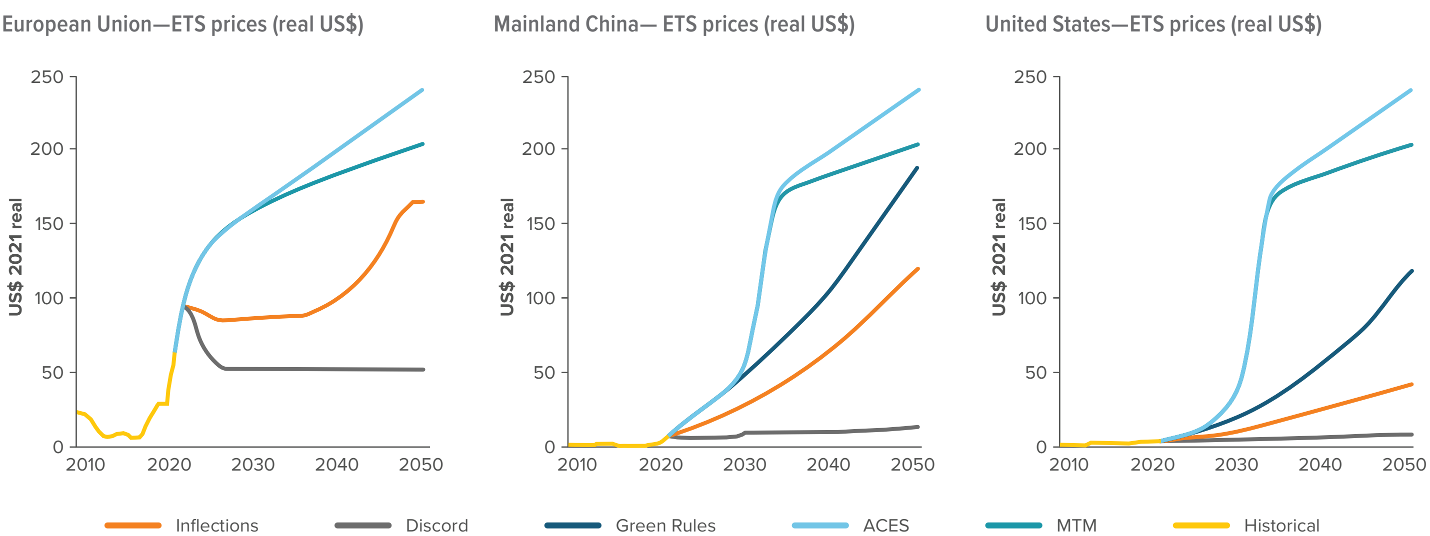


Note: *MtCO2e = million metric tons of CO2 equivalent.*

As of 09/30/22. Source: S&P Global. Forecasts are subject to change.

Exhibit 10. Lower-carbon outlooks see emissions trading systems expand and prices rise

Net-zero cases assume global convergence of carbon pricing by 2050



As of 09/30/22. Source: S&P Global. Forecasts are subject to change.

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