Economic Scenarios
Modelling Approaches and Challenges

Agenda

1 Economic Scenarios Use-cases

2 Economic Scenarios Modeling Approaches

3 Model Choice Overview and Considerations

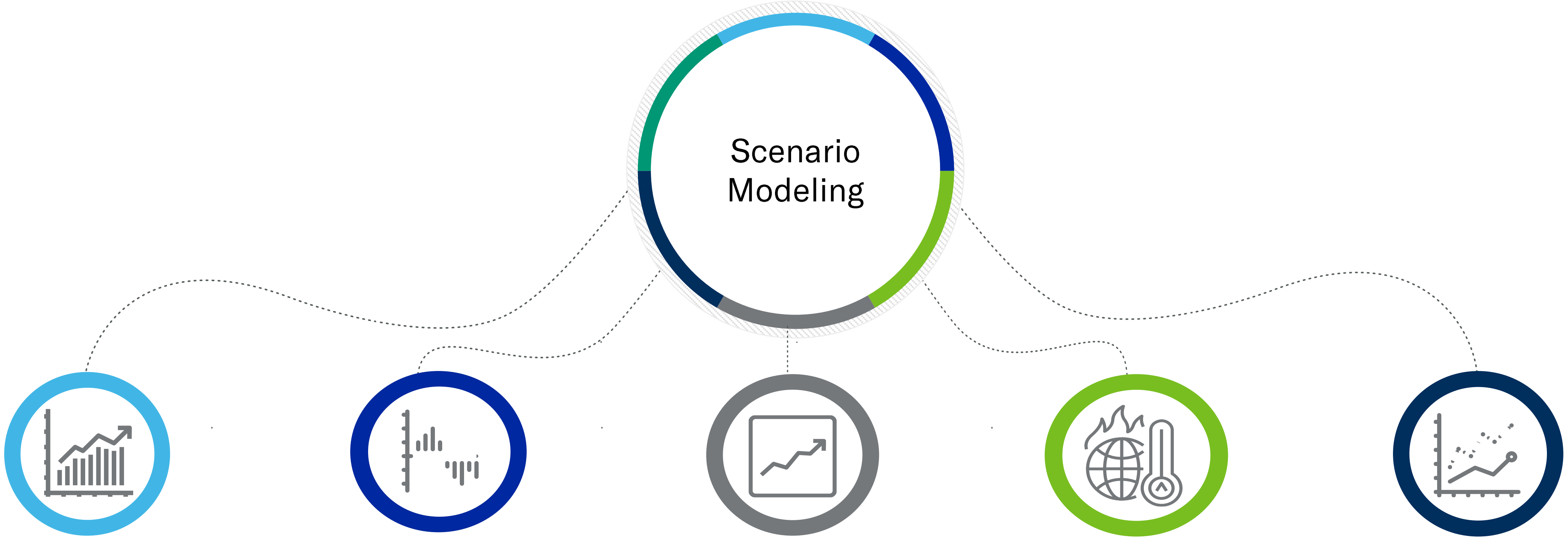
4 Example Challenge: Backtesting

5 Q&A

MOODY'S

Economic Scenarios Use-cases

Economic Scenarios Applications



Investment Strategy

Setting investment strategy involves assessing potential future returns on investments

Risk & Capital Management

Assess risk of business decisions and current exposures

Narrative Scenarios

Economic forecasting of macro-variables, e.g., GDP, inflation or short/long rates

Climate Scenarios

Assess risks and opportunities from climate change and associated policies

Stress Testing

Used by regulators for assessing the business resilience

Key Requirements of Different Economic Scenarios Use-Cases

Accurate Valuation of Assets and Liabilities

Sensible distributions over short, medium and long-term.

Realistic Distributions of asset returns and risk factors

Forward Looking Multi-timestep modeling

Consistency across various time-horizons and use-cases

Comprehensive account of the market dynamics and risk factors

Realistic joint behavior across returns and risk factors

No-arbitrage

Realistic Dynamics allowing for path dependency

Speed of Calibration

Ability to recalibrate to own views

Simplicity and parsimony

Economic Scenarios Modeling Approaches

What is a Model?

Model Definition

- The Federal Reserve Board defines a model as:
  - "model refers to a quantitative method, system, or approach that applies statistical, economic, financial, or mathematical theories, techniques, and assumptions to process input data into quantitative estimates." - *Board of Governors of the Federal Reserve System and Off ice of the Comptroller of the Currency, "Guidance on Model Risk Management," SR 11-7, April 4, 2011, https://www.federalreserve.gov/bankinforeg/srletters/sr1107.htm.*

- From the above definition we can see that models touch upon a number of different areas that a financial services company may be involved in and may utilize a number of different techniques to achieve.

- For the purposes of this seminar we will primarily focus on providing an introduction to the modeling of the future behaviour of market and economic risks with some specific examples of:
  - Interest Rates
  - Equity Markets

- We will discuss deterministic and stochastic modeling giving some consideration to why a particular approach may be appropriate.

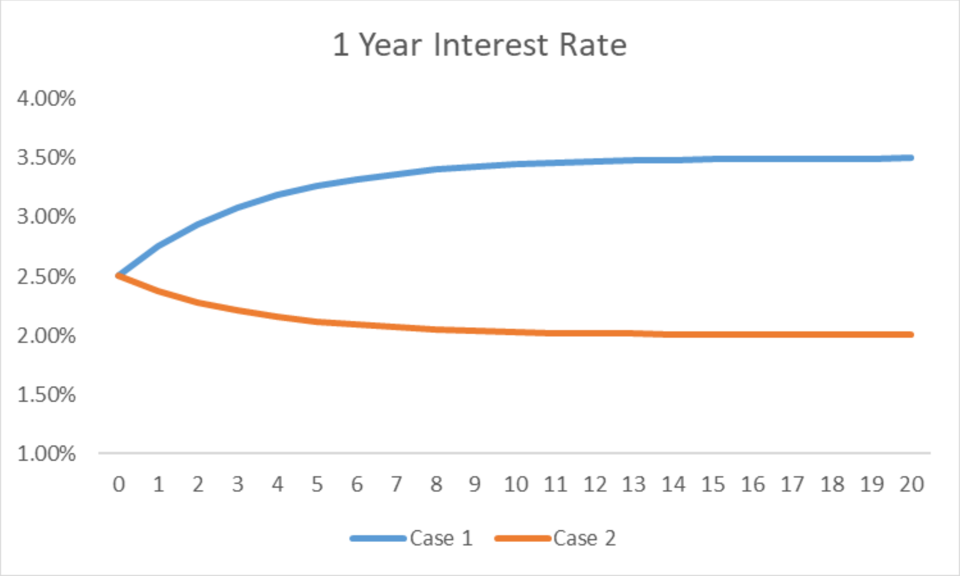
Deterministic Models

Deterministic Models

- In a deterministic model the future value or path of the modelled variable is fully determined. i.e. given an initial value, set of parameters, model structure etc. we know exactly what the value of the variables will be in the future.
- This, however, isn't to say that we are certain about a particular outcome happening in the future. We can change the parameters, model structure etc. to generate a new deterministic scenario under different conditions.
  - For example, we could run an econometric model to generate a scenario reflecting steady growth in an economy and run it again to reflect a recessionary environment.
- Example – a simple deterministic model for the 1-year interest rates:

$$r_t = r_{t-1} + \alpha(\mu - r_{t-1})\Delta t$$

Case 1
$r_0 = 0.025, \alpha = 0.25, \mu = 0.035$
Case 2
$r_0 = 0.025, \alpha = 0.25, \mu = 0.02$

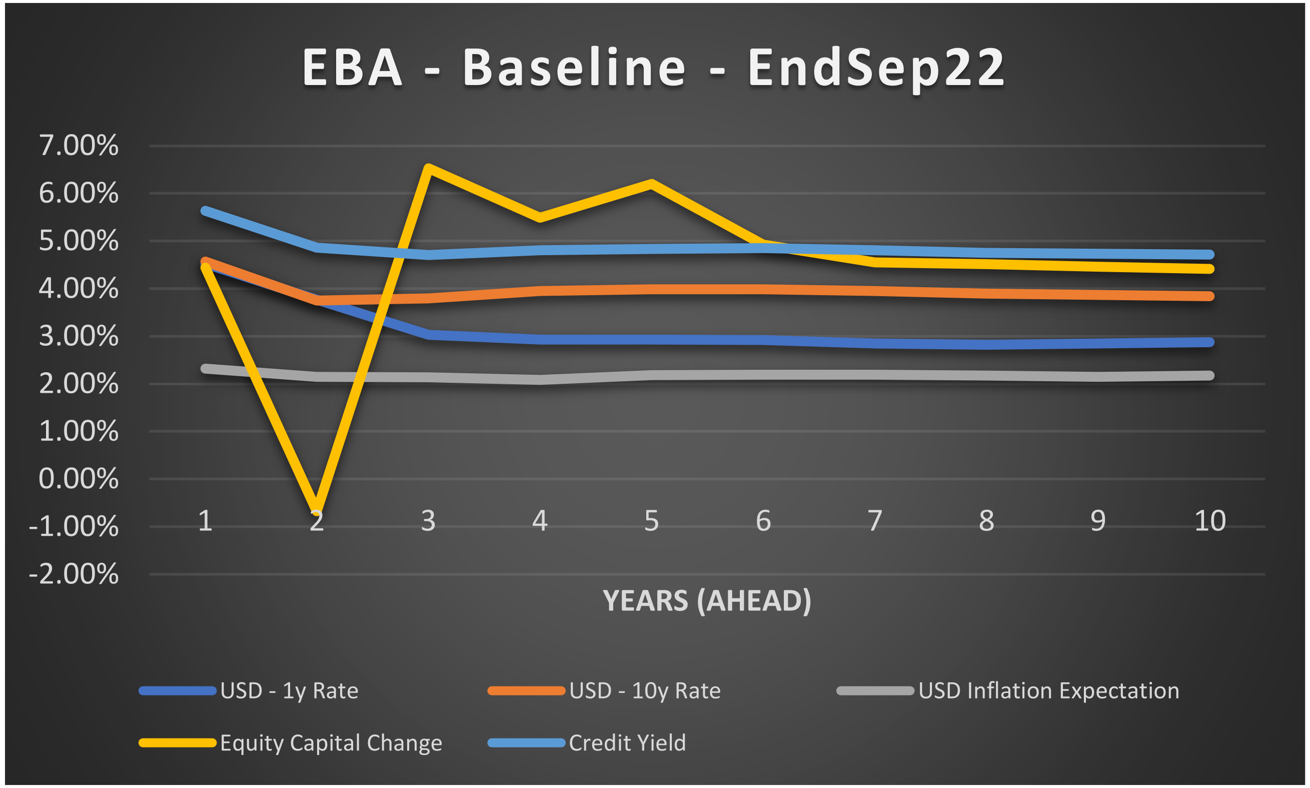


Deterministic Models - Macroeconomic Paths

- BL Baseline (most likely)
- CF Consensus Forecast
- S0 Upside – 4th Percentile
- S1 Upside – 10th Percentile
- S2 Downside – 75th Percentile
- S3 Downside – 90th Percentile
- S4 Downside – 96th Percentile
- S5 Slower-Trend Growth
- S6 Stagflation
- S7 Next-Cycle Recession
- S8 Low Oil Price

More…

- US Fed CCAR
- UK PRA
- TW Trade War
- BX Brexit



Source: EBA Forecasts on Moodys.com

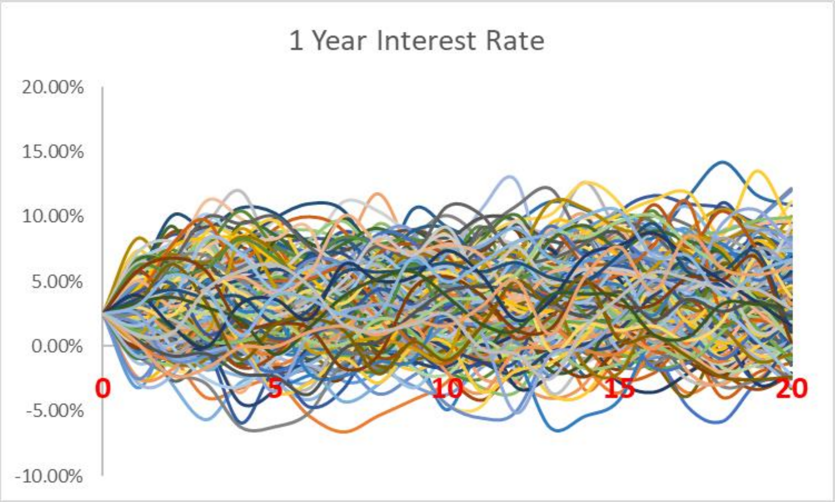
Stochastic Models

Stochastic Models

- In a stochastic model the future value or path of the modelled variables is uncertain. We are seeking to capture the random evolution of the modelled variable
- The model would be run many hundreds or thousands of times to generate a distribution of possible results. This is typically achieved by generating hundreds or thousands of “shocks”/random numbers that will apply to the model to determine each path.
- The model may also have a deterministic or structural component as well as a stochastic component.
- Example – a simple stochastic model for the 1 year interest rates:

$$dr_t = \alpha(\mu - r_{t-1})dt + \sigma dW_t \qquad r_t = r_{t-1} + \alpha(\mu - r_{t-1})\Delta t + \sigma\sqrt{\Delta t}N(0,1)$$

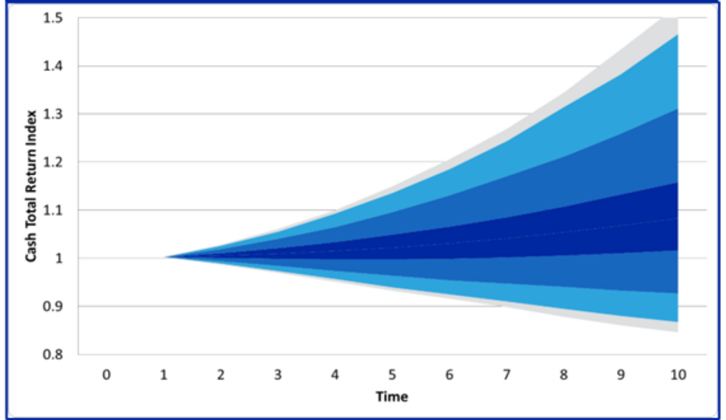
Case 1
$r_0 = 0.025, \alpha = 0.25, \mu = 0.035, \sigma = 0.02$



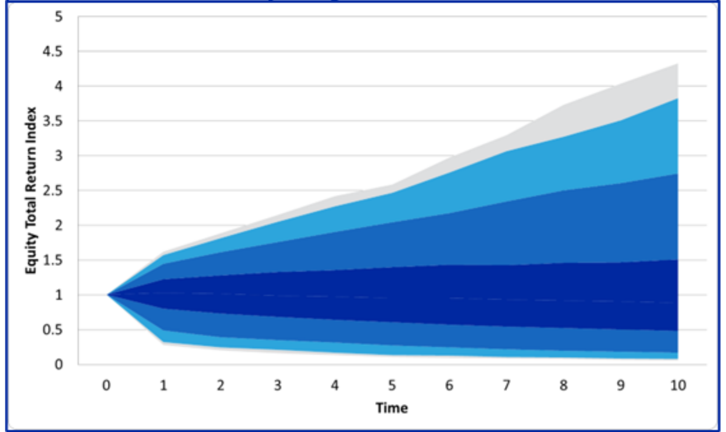
Stochastic Models - Valuation Example

Simulate (1)

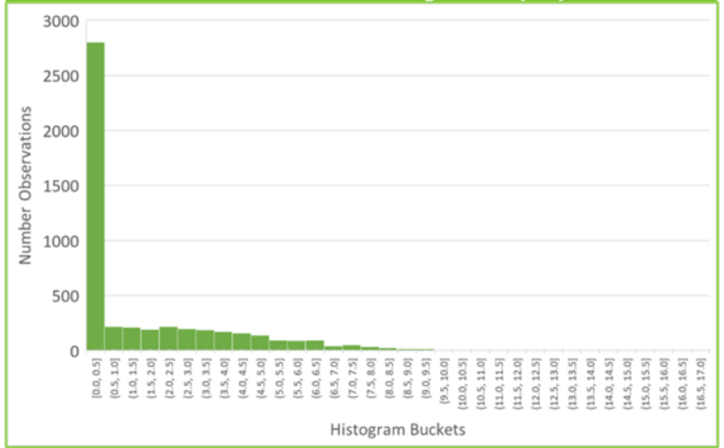
Cash Rollup (Numeraire)



Equity Return



Calculate Payoff (2)

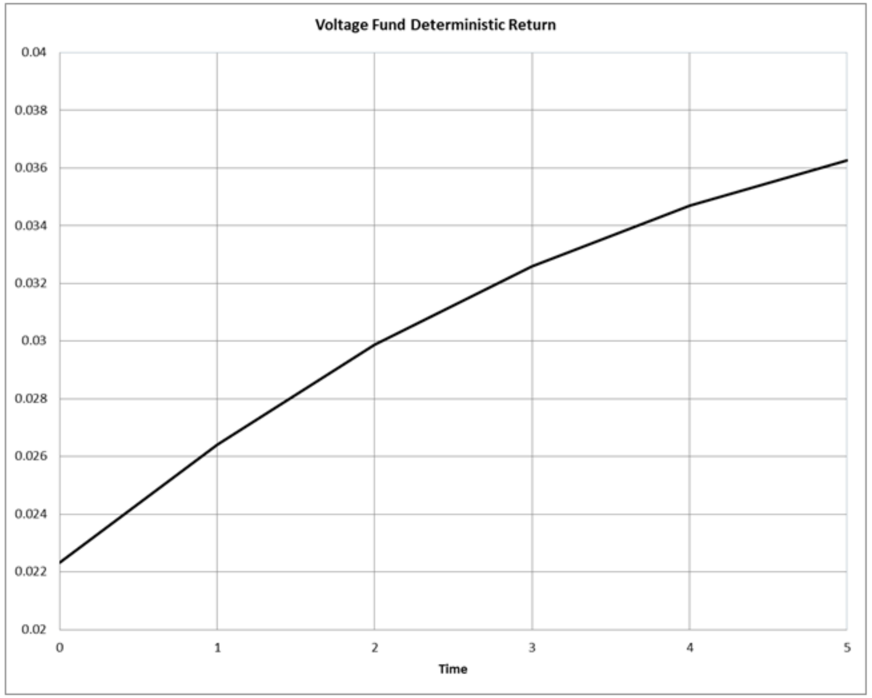


Discount to PV and Average (3)

$$V_0 = \mathbb{E}^{\mathbb{Q}}\left[\frac{MAX(S(5)-K,0)}{C(5)}\right]$$

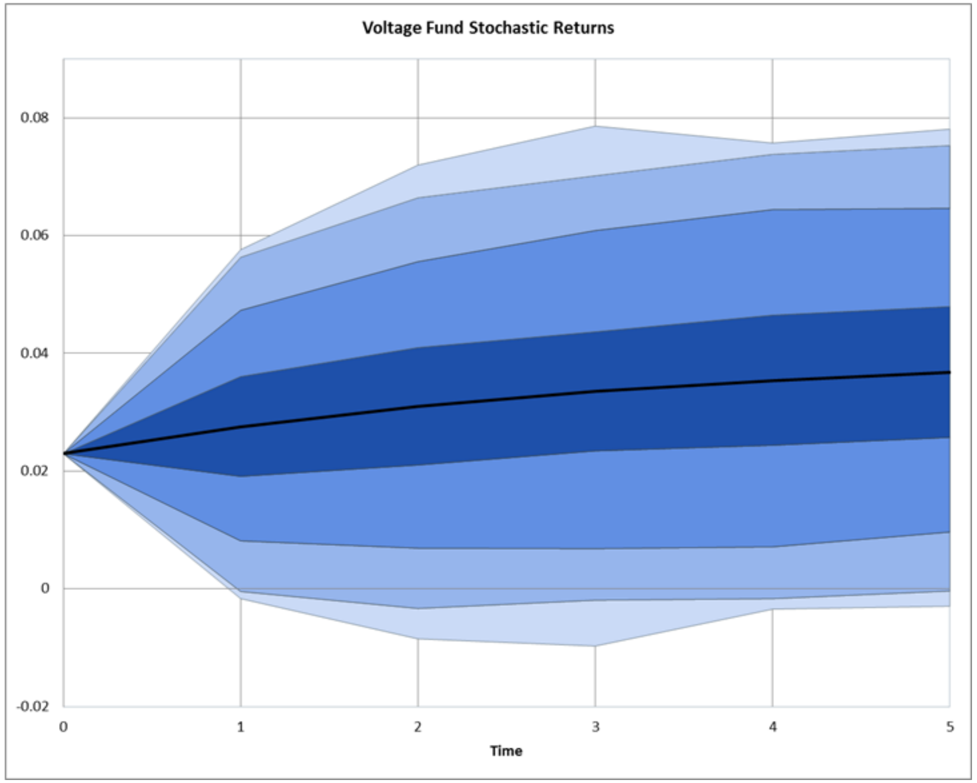
$$\widehat{V_0} = \frac{1}{N}\sum_{i=1}^{N}\left[\frac{MAX(S(5)-K,0)}{C(5)}\right]$$

Deterministic or Stochastic?



With a **deterministic** model we could tell customers “Based on our calculations the Voltage fund will make a return of 2.5% in the coming year”

- Single outcome or “Trial”



With a **stochastic** model we could say something like “On average the Voltage fund should return 2.5% in the next year but there is a 10% chance that it will return more than 5%”

- Many thousands of outcomes or “Trials”

When do we need stochastic models?

Deterministic vs. Stochastic Models

- A deterministic model can provide some useful insights for the company. For example, a deterministic model may be used to create an in-house best estimate scenario or range of possible future scenarios.
  - If using something like an econometric model it can be possible to attribute a narrative to each of the scenarios – e.g. baseline view, recessionary view etc.
- These could then be used to assess the impact on both sides of the balance sheet in the future and gain some insight into how the business may develop.

- For certain applications, however, we are likely concerned not only with the assets and/or liabilities under a few scenarios but looking at the distribution of possible future scenarios. They may be concerned with:
  - Average values
  - Standard Deviations
  - Tail percentiles
  - Conditional Tail Expectations
- Typically, we don't have closed-form solutions for the distribution of future asset and liability cashflows/values:
  - The distribution of risk drivers affecting the assets and liabilities may be complex.
  - Assets and Liabilities may be sensitive to a number of risk drivers so the joint behaviour of these is important.
  - As a result, we need to generate a set of correlated stochastic scenarios for each of these risk drivers and assess the assets and/or liabilities to generate a distribution of future values.

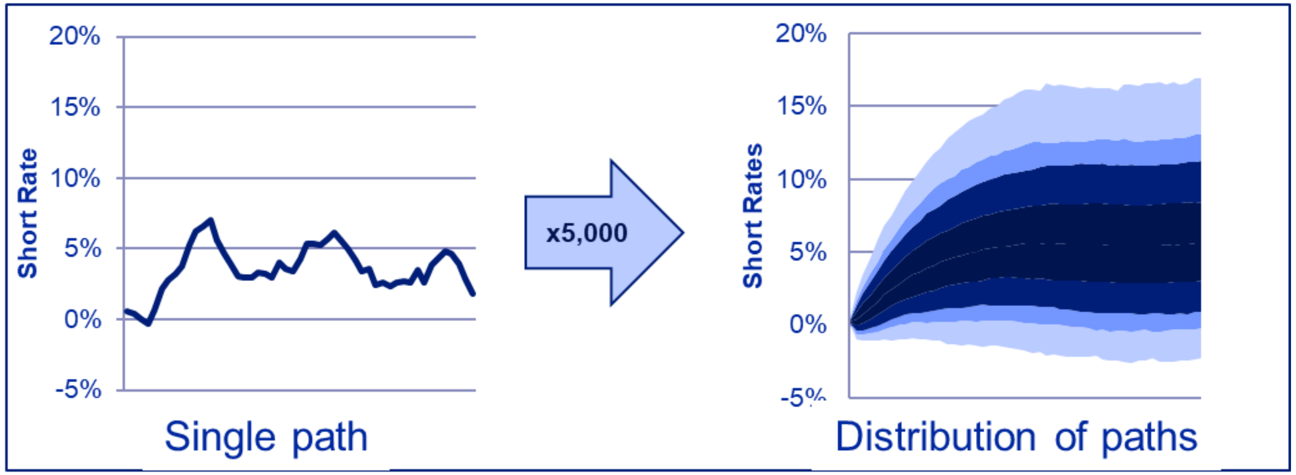
Model-Choice Overview and Considerations

Scenario Generator

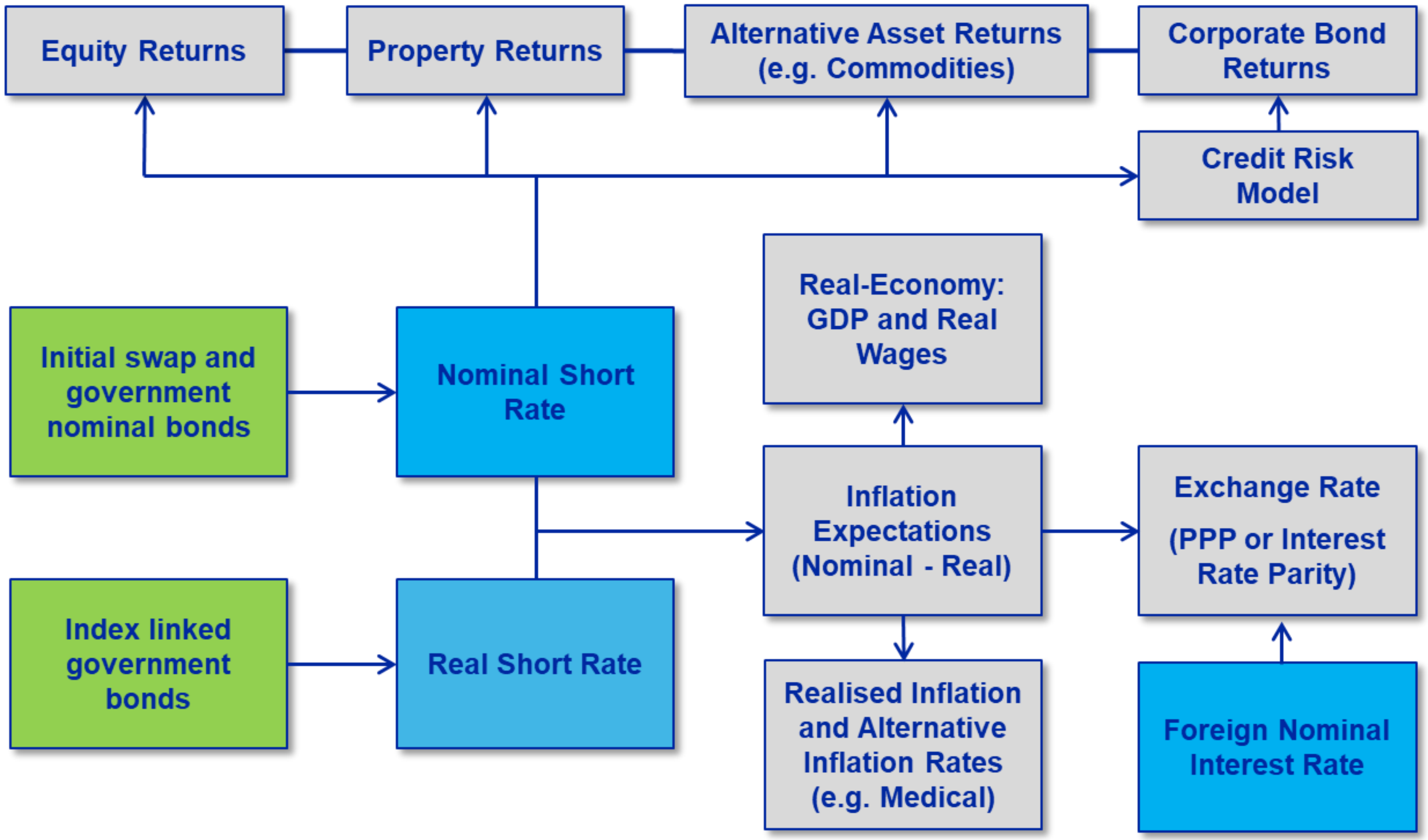
Monte Carlo engine used to simulate possible future paths of market variables.

Generates realistic multi-timestep forward-looking scenarios with sophisticated risk metrics.

Allows for a broad range of outputs and validations feeding into downstream processes.



Economy Model Structure



Structural relationships and correlations ensure plausible dependencies between asset classes

Equity Model Choices

Constant Volatility

- Classical Model for equity returns where equity markets are modelled as geometric Brownian Motion (aka Black-Scholes Model).

$$dS_t = S_t(\sigma dW_t + \mu dt)$$

Time Varying Deterministic Volatility

- Extension of the Constant Volatility Model accounting for the fact that the volatility in equity markets is non-constant and can vary through time.

$$dS_t = S_t(\sigma_t dW_t + \mu dt)$$

Stochastic Volatility Jump Diffusion

- Model combining Heston Stochastic Model and Merton's Jump Diffusion Model to allow for the robust volatility and returns dynamics (clustering, mean reversion, rare events, distributional skew).

$$S^{XS}(t) = S^{SV}(t)\ S^{JD}(t)$$

$$d\ln S^{JD}(t) = -\lambda\ \bar{\mu}\, dt + \ln J\, dN(t)$$

$$d\ln S^{SV}(t) = \left(\mu - \frac{v(t)}{2}\right) dt + \sqrt{v(t)}\, dW_1$$

Time Dependent Stochastic Volatility Jump Diffusion

- Extensions of the above models making deterministic parameters of SVJD stochastic.

$$d\ln S^{SV}(t) = \left(\mu_t - \frac{v(t)}{2}\right) dt + \sqrt{v(t)}\, dW_1$$

Equity Model Use-Case Considerations

Requirements	Constant	TVDV	SVJD	TD-SVJD
Models of Excess Returns	✓	✓	✓	✓
Fat tailed distributions	✗	✗	✓	✓
Term Dependent Volatility	✗	✓	✓	✓
Stochastic Volatility	✗	✗	✓	✓
Strong Positive Correlation	✓	✓	✓	✓
Stronger Tail Dependence	✗	✗	✓	✓
Easy to understand:	✓	✓	✓	✗
Reasonable run-times	✓	✓	✓	✓
Robust and stable calibration	✓	✓	✓	✗
Arbitrage free	✓	✓	✓	✓
Additional Requirements				
Ability to model large IV surfaces	✗	✗	✗	✓
Ability to model complex volatility structures	✗	✗	✗	✓

Example Challenges
Model Backtesting

Challenges and Considerations

- Stochastic volatility modeling across asset classes and economies
- Tail risk modeling across asset classes and economies
- Parsimonious yield curve modeling
- Modeling stochastic credit rating transition probabilities
- Uncertainty of long-term Capital Market Assumptions
- Recalibrating an ESG to alternative assumptions
- **<u>Back-testing to help calibrate and evaluate an ESG</u>**
- Modeling illiquid and private assets
- Creating deterministic what-if and stress scenarios
- ...

...

Backtesting: Definition and Considerations

Definition: Compare SG output from a specific historic model calibration to realized market outcomes.

Considerations:

- Average projected path of a variable represents the expected future outcome at the model calibration date.
  - Dependent on: (i) model, (ii) its calibration (utilizing historic and current market data).
  - What happens in the market is not always what was historically expected.
  - Some pandemic-induced market changes should sit in the tail of modelled distributions.
- Where in the distribution should the recent 'tail events' sit?
  - Impossible to determine this with limited historic data. Every crisis will impact markets differently.
  - Very difficult to justify tail/percentile targets .
  - Modelled tails may be an artifact of model and its calibration to targets we are confident in (e.g. Mean/Std.Dev)
- When should a backtesting analysis start? What metrics should be analyzed (absolute/proportional changes)?

Backtesting analysis: a qualitative (not quantitative) way of assessing modelling success

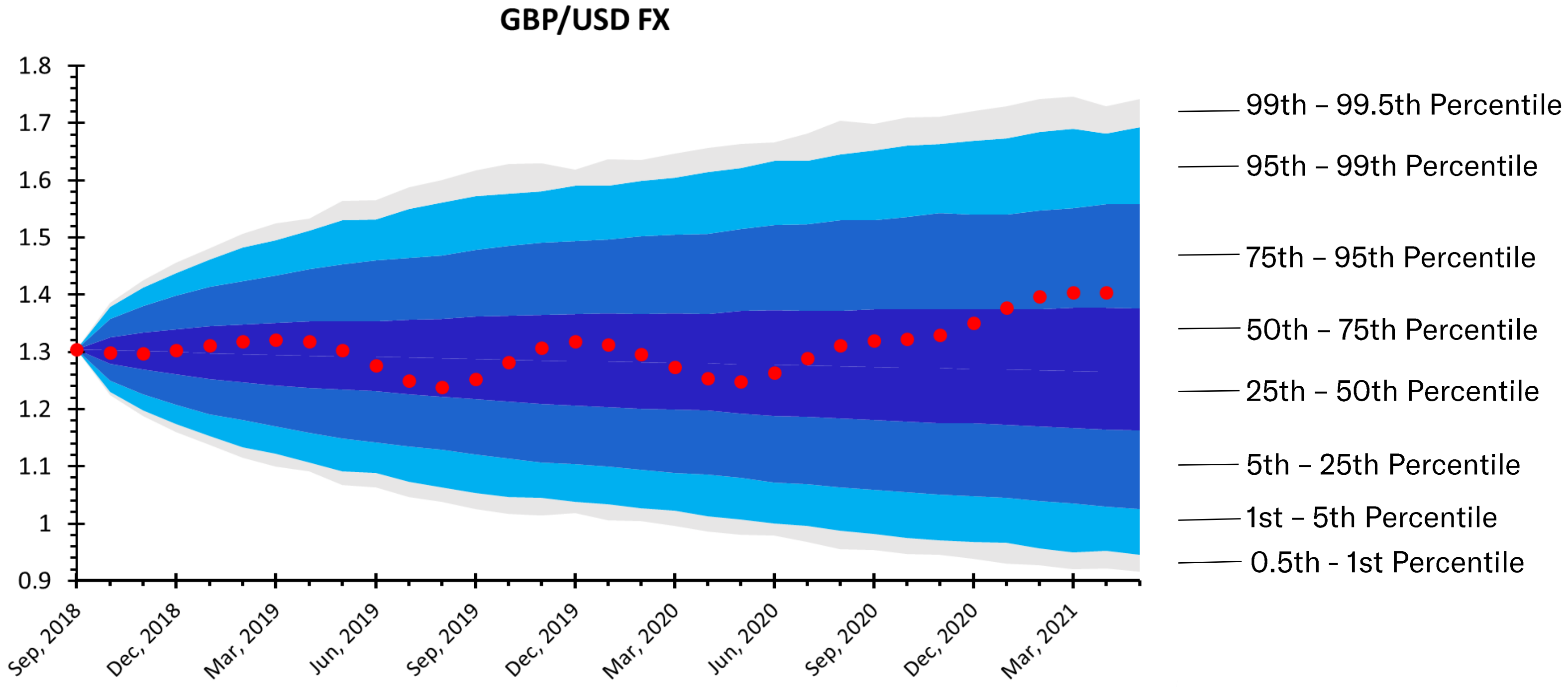
Results should be reviewed with caution.

Backtesting: Two Case Studies

1. Pre-pandemic: simulation from end-September 2018 → 2021

2. Post-pandemic recovery: simulation from end-March 2020 → 2021

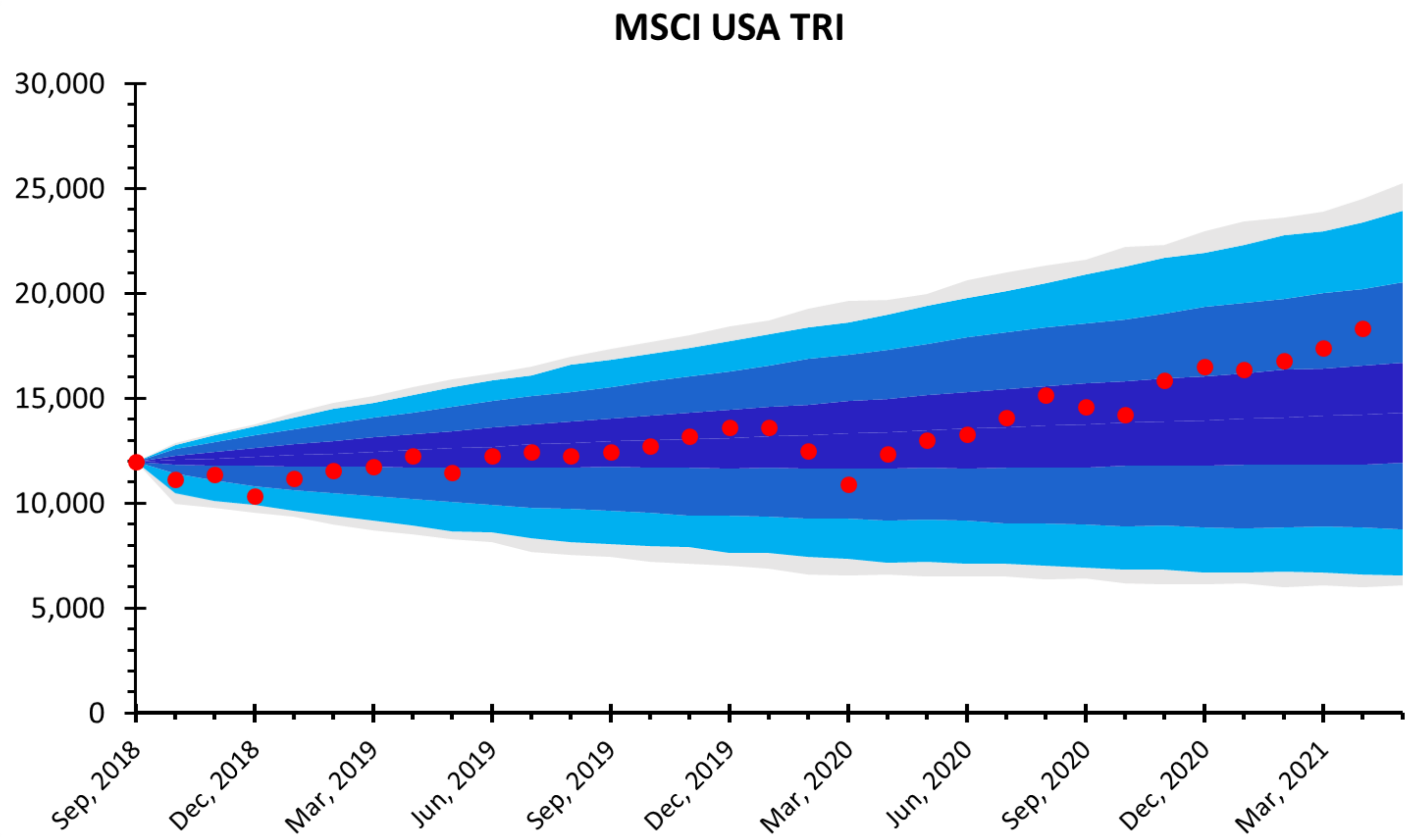
Example:



Market data: Moody's Analytics

» Market data frequency is monthly.

Backtesting End-Sept 2018 (USD): Equity Total Return Index

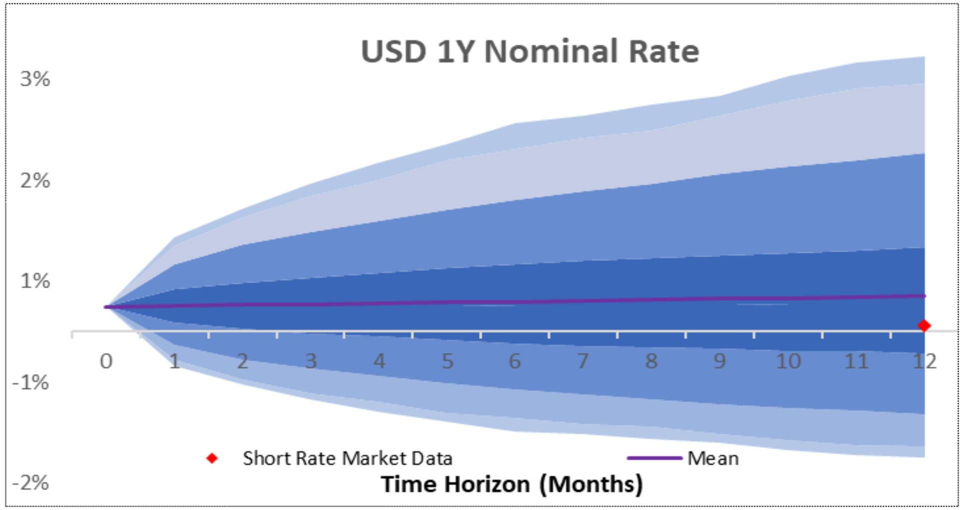


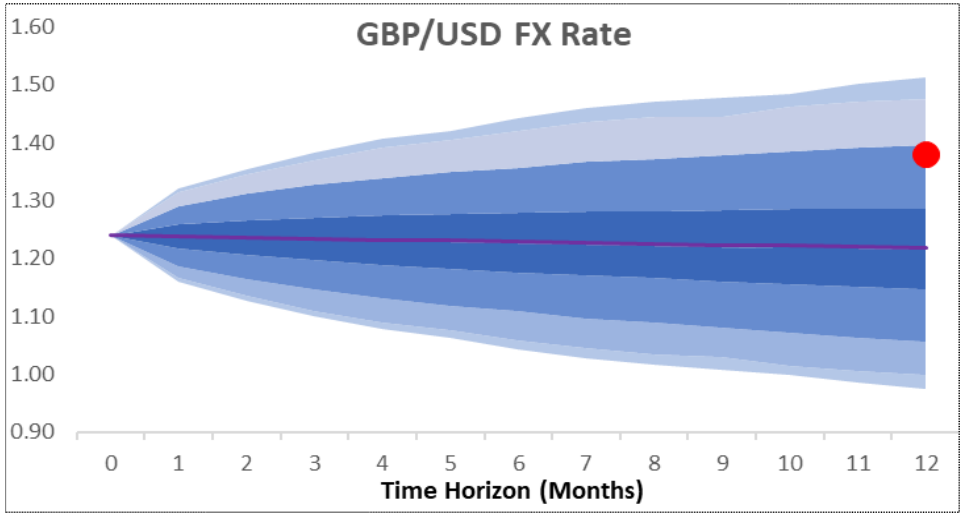
End March 2020 drop:

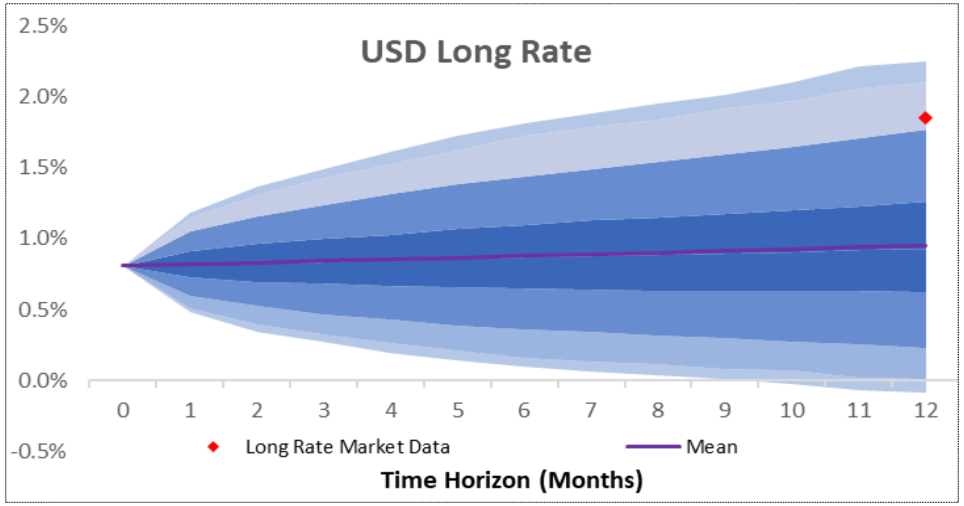
- » A rare event.
- » 45/581 historic observations have a proportional drop over 1.5 year period greater than that at mid-March 2021. (approximately 1/13 chance of drop this size or bigger)
- » Historic observations of this size occurred during three crisis periods: 2008/09, 2000 and 1974.
- » ‘Correctly’ sitting in 5th – 25th %ile range?

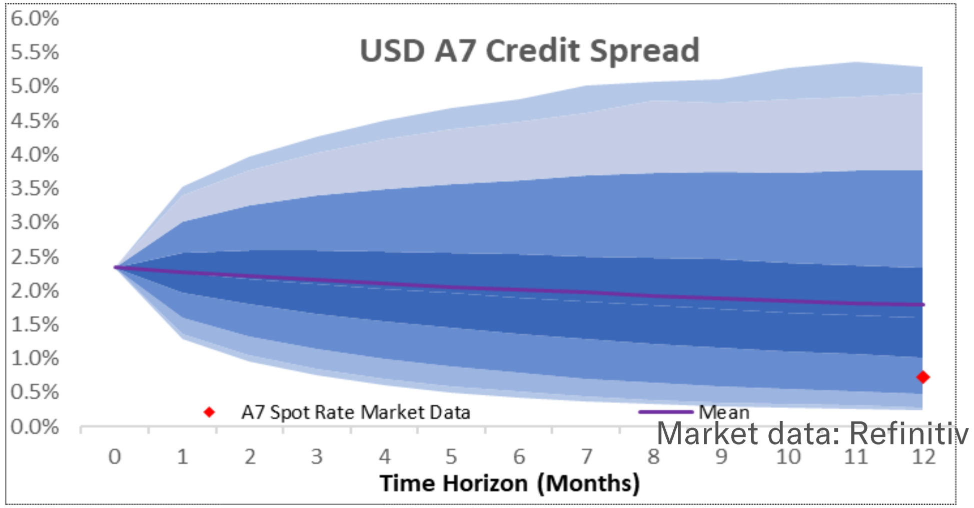
Market data: MSCI USA (Refinitiv)

Backtesting the Market's Recovery: 12-month projection from end-March 2020



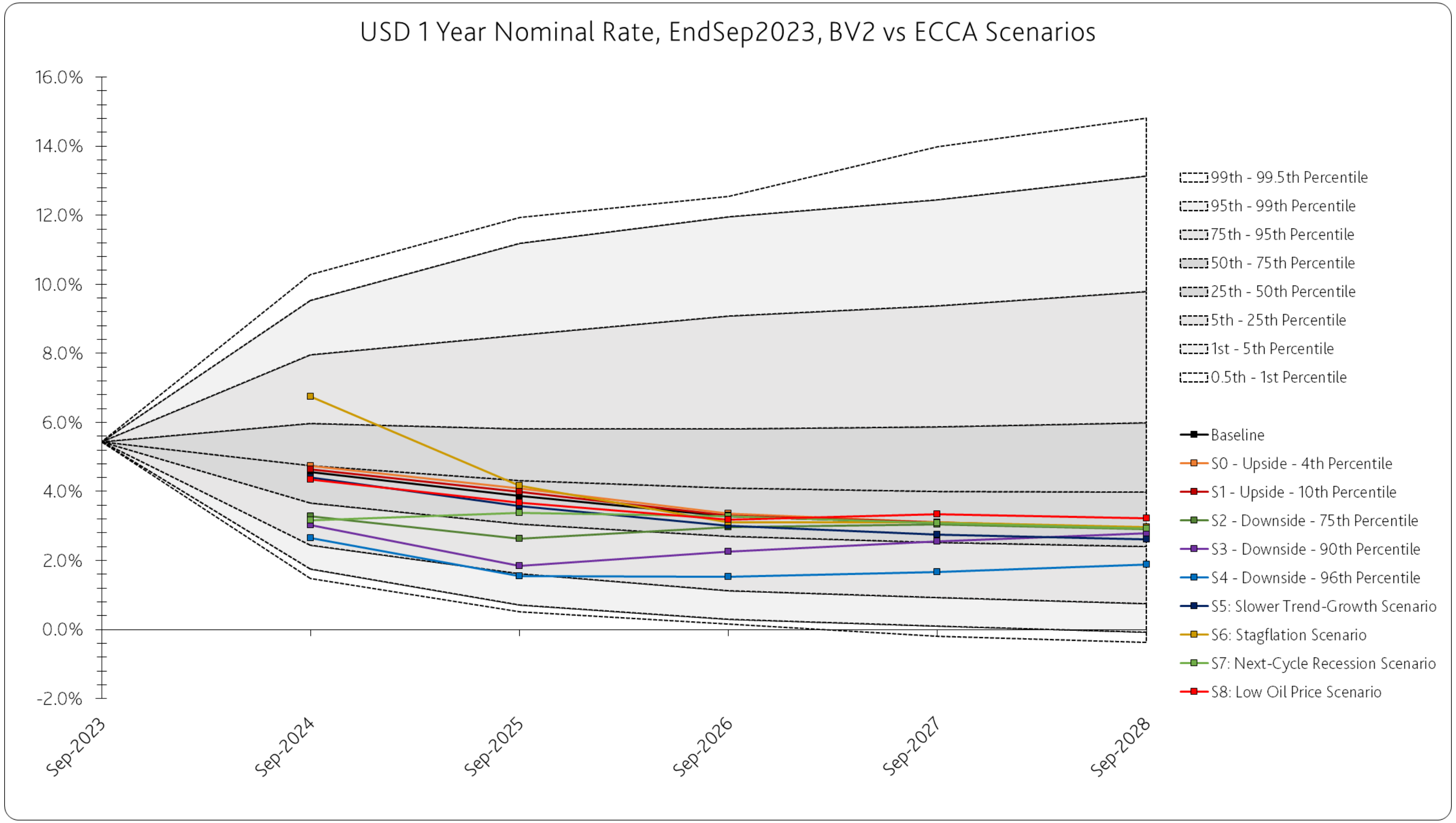






Market data: Refinitiv

Forward Looking Model Validation: Using Narrative Scenarios



- Modelled distributions can be sense-checked against economists' narrative forecasts.
- Routinely performed (also with survey-based forecasts) across many economies/model as part of our Best Views governance process.

Key Takeaways

- Scenario Modeling is an important source of insights across variety of use-cases.
- Different use-cases lend itself to different modeling approaches and models.
- Model back-testing gives an example of an important consideration for suitability of economic scenarios.

Questions

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Thank you

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