Moody's Analytics

Real World and Risk Neutral ESG Validation
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Today’s Presenters

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Agenda

1. What is an Economic Scenario Generator?
2. Risk Neutral ESG
    1. Model Choice
    2. Calibration
    3. Validation
3. Real World ESG
    1. Model Choice
    2. Calibration
    3. Validation

1

What is an Economic Scenario Generator?

What is the Economic Scenario Generator?

» Generates scenario for economic variables and asset returns

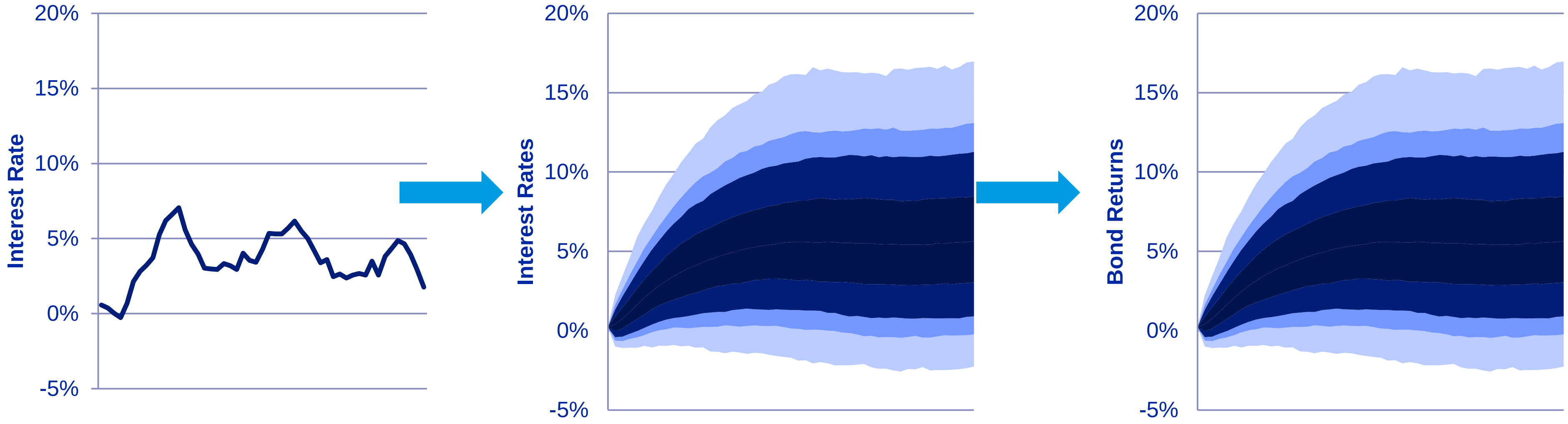
Risk Factors, for example:

- Real and nominal interest rates
- Credit spreads
- Equity volatility
- Exchange rates

Asset returns, for example:

- Nominal, Index linked bonds
- Corporate Bond returns
- Equities
- Foreign assets

» Uses stochastic models to generate many paths for each risk factor and asset



Stochastic Modelling Applications

Valuation & Reporting
Market Consistent: MCEV, SII, IFRS 17
US Stat & GAAP: C3PII, AG43, VM20, FAS133

Pricing
In-force pricing, Product development

Hedging & Risk Management
Greeks, Hedge effectiveness, CPPI

Real World Projection & ALM
SAA, Cashflow testing, Duration Analysis, PFE

Balance Sheet & Capital Projection
CCAR, 1-Yr VaR, ORSA, Forecasting

Types of ESG Calibration

Market-Consistent

For the **valuation** of complex liabilities

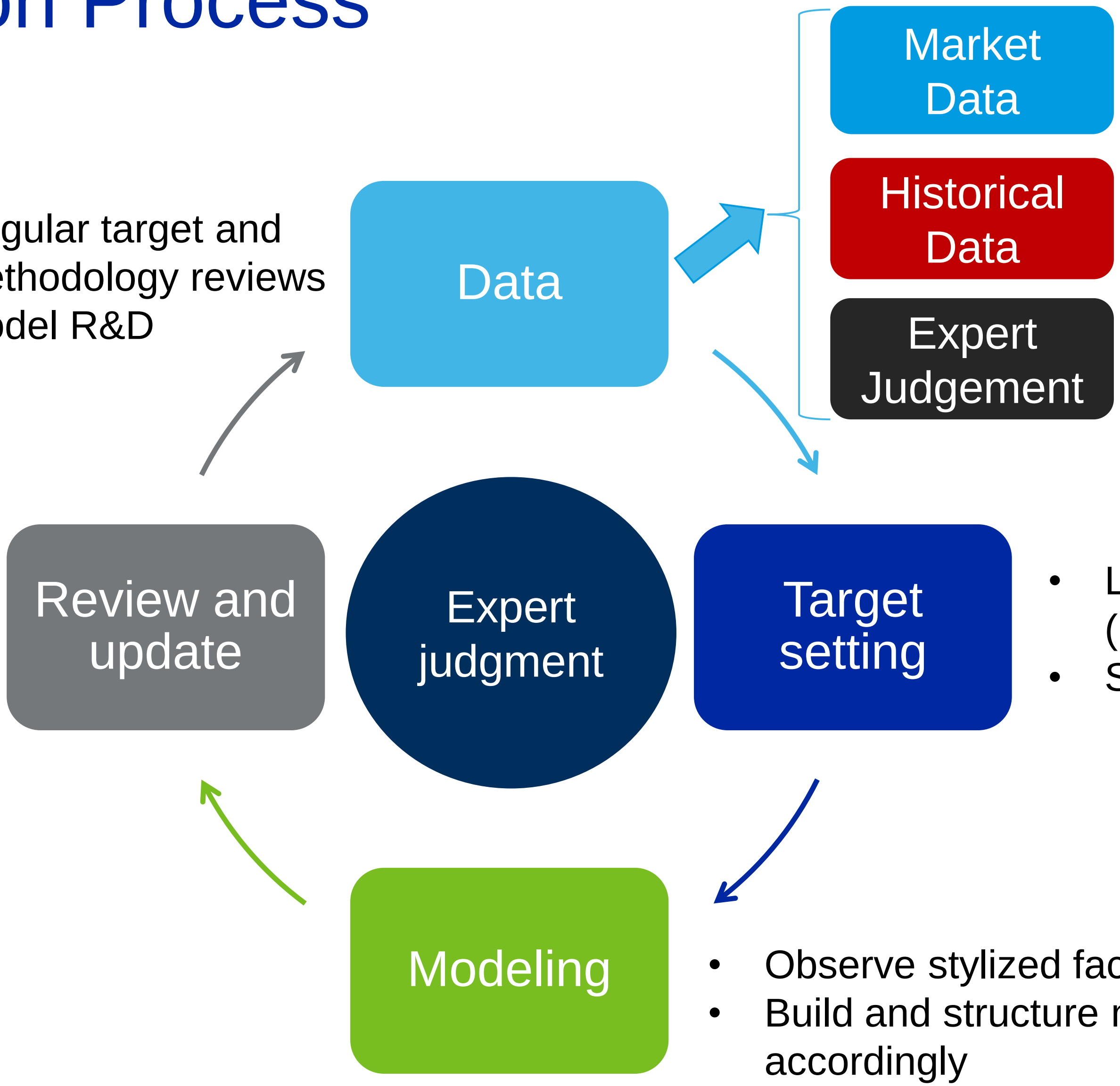
- All assets earn ***risk-free rate on average -*** *same definition as* ***Risk-Neutral***
- Monte-Carlo simulation ***replicates market-price –*** *average of simulated discounted future cashflows*
- Distributions are typically market-implied – *calibration to market prices/implied volatilities*

Real-World

Realistic **projection** of asset and/or liability cashflows

- Risky assets on average earn ***risk-free rate*** PLUS ***risk-premium***
- Distribution and statistics are realistic. Should reflect a plausible set of future outcomes.
- One can set own assumptions about volatility and distributions of outputs – *adjust model calibration to match these views.*

Calibration Process



Initial Yield Curve
Swaption Implied Volatilities

Historic Standard Deviation
Historic Average Returns
Historic Correlations

Long Term Assumptions
Speed of Convergence

- Regular target and methodology reviews
- Model R&D

- Long term (unconditional) targets
- Short term targets

- Observe stylized facts
- Build and structure models accordingly

2 Risk Neutral ESG

Risk Neutral Calibration Objectives

» Do all assets earn ***risk-free rate*** on average?

- Check that the *average* risk-free discounted future price equals to the current price
- This check is called a ***Martingale Test***

» Do Monte-Carlo option prices equal to Market option prices?

- At different maturities?
- At different strike prices?
- With sophisticated models Monte-Carlo prices converge to Market option prices if Market Price exists

» Does the model behave “well” beyond after the period of market data availability?

- What level are expected risk-free rates at?
- Is volatility sensible over longer time horizons?

Model Choice – RN Nominal Rate Example

Key Considerations

- Initial Yield Curve
  - Does the model allow the full yield curve as an input or is a parametric fit needed?
- Correlations
  - Does the model produce sensible correlation across the term-structure?
  - Is this important for the product(s) being valued?
- Fit to Market Data
  - Does the model have the ability/flexibility to fit to a range of swaption volatilities varying across different dimensions of the cube?
- Long-term behaviour
  - Can a view of long-term model volatility be incorporated?
- Recalibration
  - Is recalibration of the model easy? Stresses for EC, KRD etc.

Model Choice - Nominal Rate Model Example LMM+

1. Initial forward **yield curve** is a direct input to the model and is **fit exactly**.

2. Model of **displaced** forward rates where the magnitude of displacement can **control** the distribution of rates.

3. **Stochastic volatility** process allows for an **excellent fit** to market data both **ATM and OTM.**

EXHIBIT 1.2.2

ESG Output Yield Curve Validation

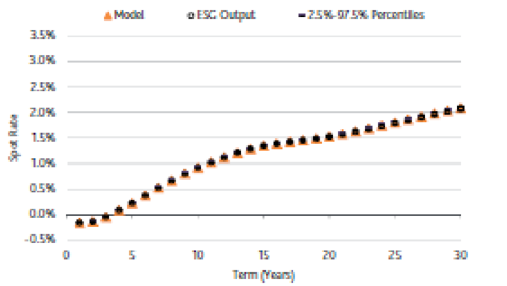
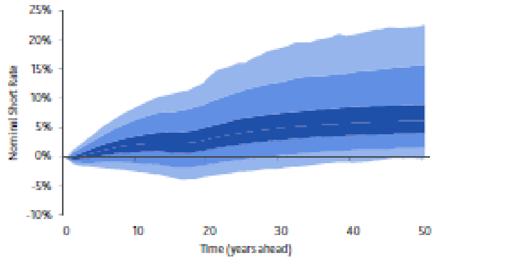


EXHIBIT 1.2.3

Short Rate Distribution



Away-From-the-Money Validation - Volatility

EXHIBIT 1.2.9a

Fit to 5Y Maturity, 10Y Tenor Swaption Implied Volatilities

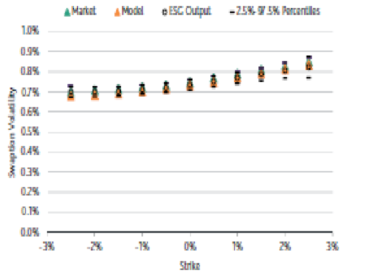


EXHIBIT 1.2.9b

Quality of Fit

Strike	Market (%)	Model (%)	ESG Output (Percentiles)	
-0.025	0.70	0.68	0.70	(0.67, 0.73)
-0.02	0.71	0.69	0.70	(0.67, 0.73)
-0.015	0.72	0.69	0.70	(0.68, 0.73)
-0.01	0.72	0.70	0.71	(0.68, 0.74)
-0.005	0.73	0.72	0.72	(0.69, 0.75)
0	0.75	0.73	0.74	(0.71, 0.77)
0.005	0.77	0.75	0.75	(0.72, 0.78)
0.01	0.79	0.77	0.77	(0.74, 0.8)
0.015	0.81	0.79	0.79	(0.75, 0.83)
0.02	0.83	0.81	0.81	(0.76, 0.85)
0.025	0.85	0.84	0.83	(0.77, 0.88)

EXHIBIT 1.2.6a

Fit to 10Y Swaption Implied Volatilities

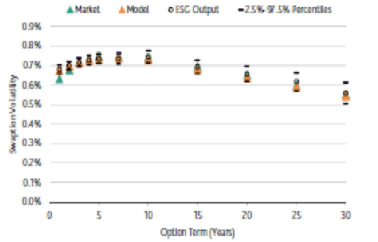


EXHIBIT 1.2.6b

Quality of Fit

Term	Market (%)	Model (%)	ESG Output (Percentiles)	
1	0.63	0.68	0.68	(0.66, 0.71)
2	0.68	0.70	0.70	(0.67, 0.73)
3	0.72	0.71	0.72	(0.69, 0.74)
4	0.74	0.72	0.73	(0.7, 0.76)
5	0.75	0.73	0.74	(0.71, 0.77)
7	0.75	0.74	0.74	(0.7, 0.77)
10	0.74	0.73	0.75	(0.71, 0.78)
15	0.69	0.68	0.69	(0.65, 0.73)
20	0.65	0.64	0.66	(0.61, 0.7)
25	0.60	0.59	0.62	(0.57, 0.67)
30	0.55	0.54	0.56	(0.5, 0.62)

EXHIBIT 1.2.7a

Fit to 20Y Swaption Implied Volatilities

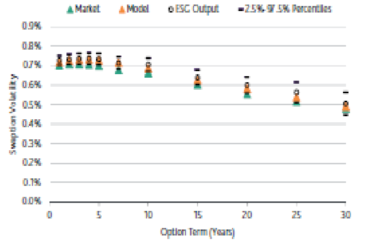
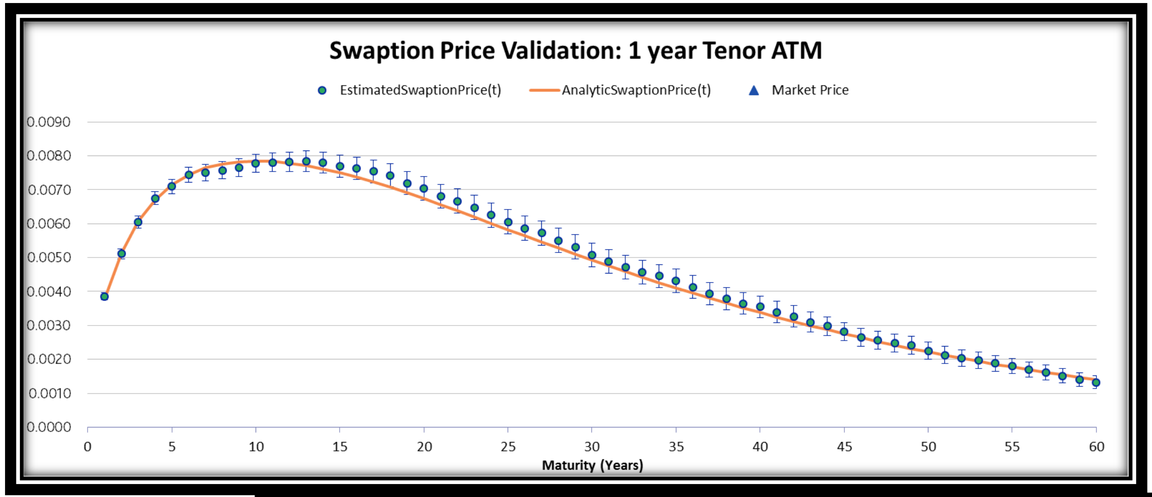


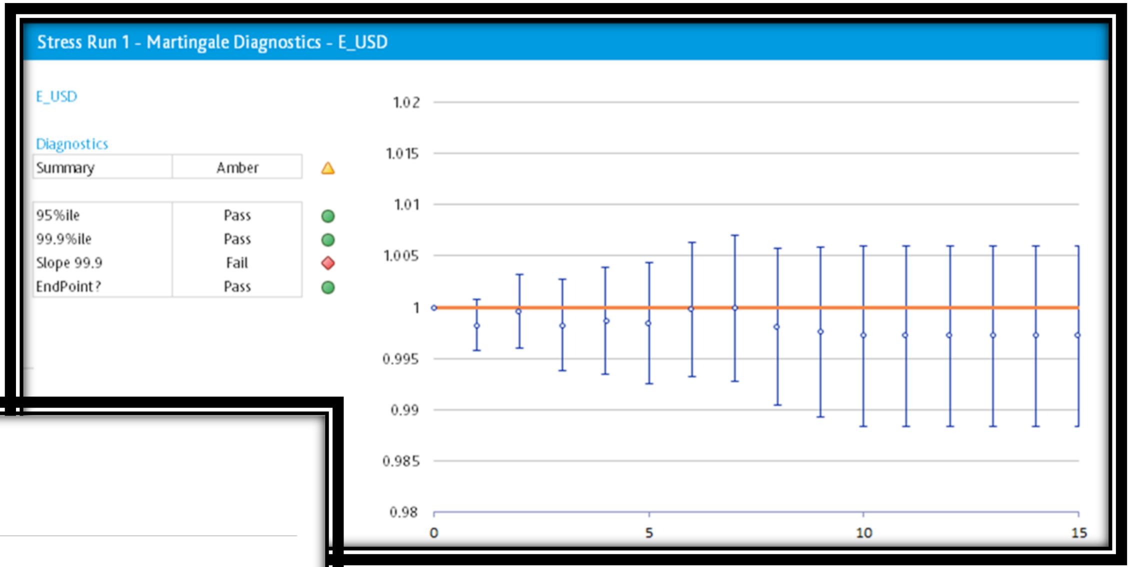
EXHIBIT 1.2.7b

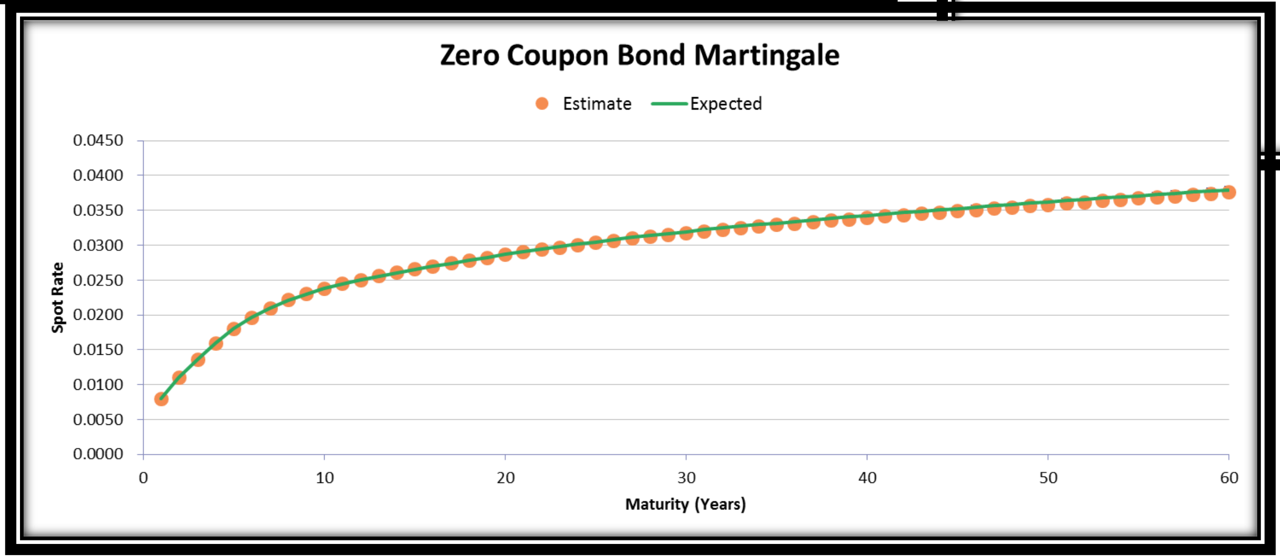
Quality of Fit

Term	Market (%)	Model (%)	ESG Output (Percentiles)	
1	0.70	0.72	0.73	(0.7, 0.76)
2	0.71	0.73	0.73	(0.7, 0.76)
3	0.71	0.73	0.74	(0.7, 0.77)
4	0.71	0.73	0.74	(0.7, 0.77)
5	0.70	0.73	0.73	(0.7, 0.77)
7	0.68	0.72	0.71	(0.68, 0.75)
10	0.66	0.69	0.71	(0.67, 0.74)
15	0.60	0.63	0.64	(0.6, 0.68)
20	0.56	0.58	0.60	(0.55, 0.65)
25	0.52	0.54	0.56	(0.51, 0.62)
30	0.48	0.49	0.51	(0.44, 0.57)

Risk Neutral Validation

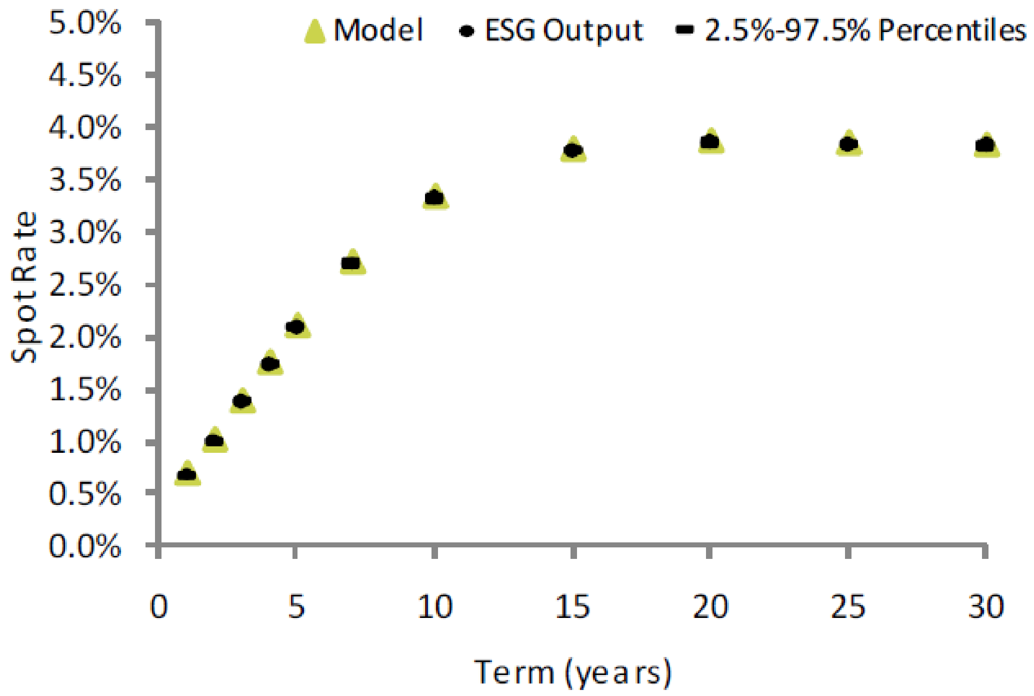






ZCB Martingale Test

This is used to test the validity of the simulated cash behaviour. To do this, the zero coupon bond prices implied by the cash output, are compared to the prices implied by the initial yield curve.



Asset Martingale Test

Inputs

- Stochastic model for evolution of
  - Asset Total Return Index $\{S_T\}$
  - Cash Total Return Index $\{C_T\}$

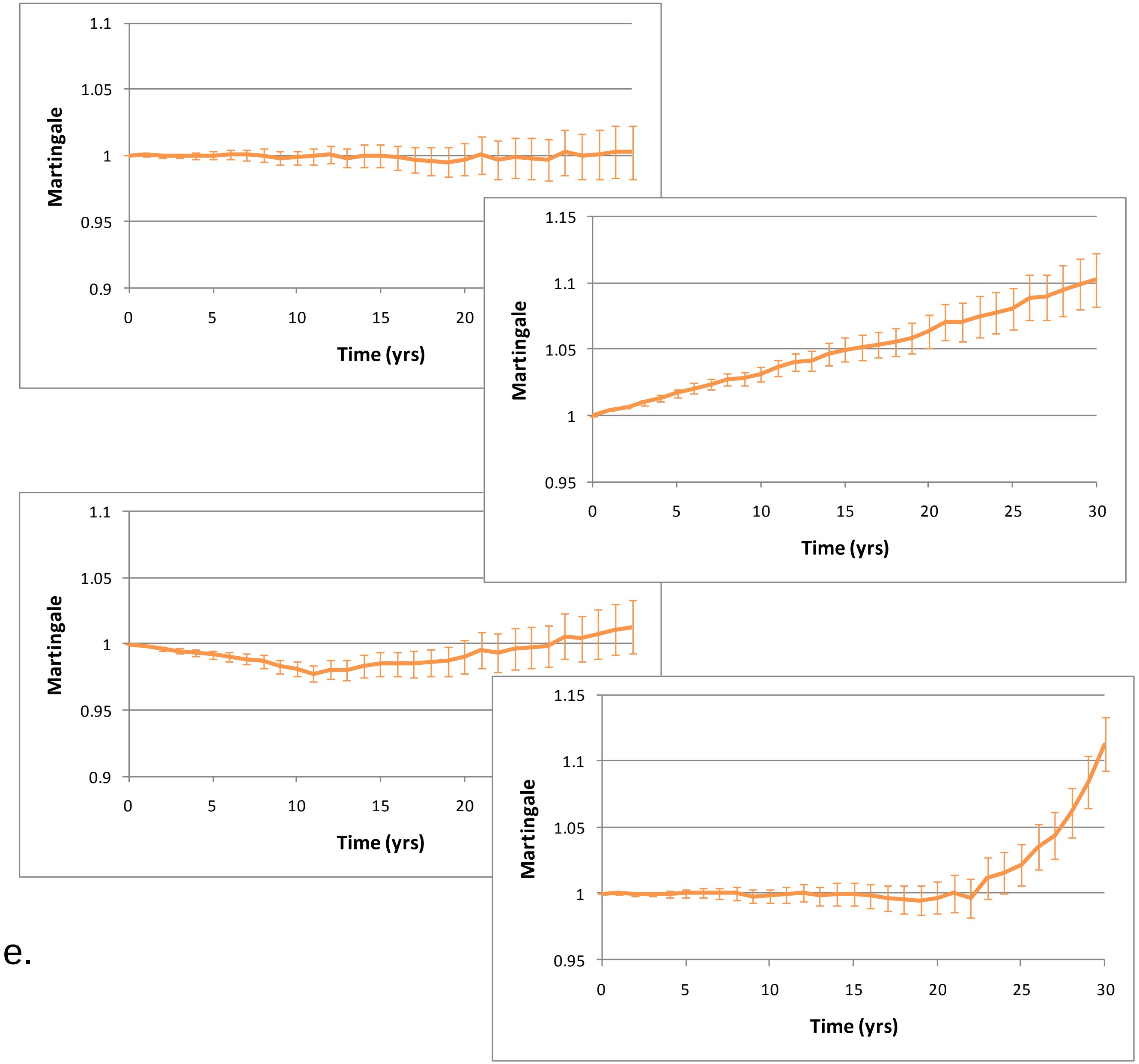
Calculation

- Obtain *N* simulations of S_T and C_T
- Compute the (risk-neutral) expectation: $E_Q[S_T/C_T]$
- Compute standard error:

$$\frac{1}{\sqrt{N}}\mathrm{stdev}\left(\frac{S_T}{C_T}\right)$$

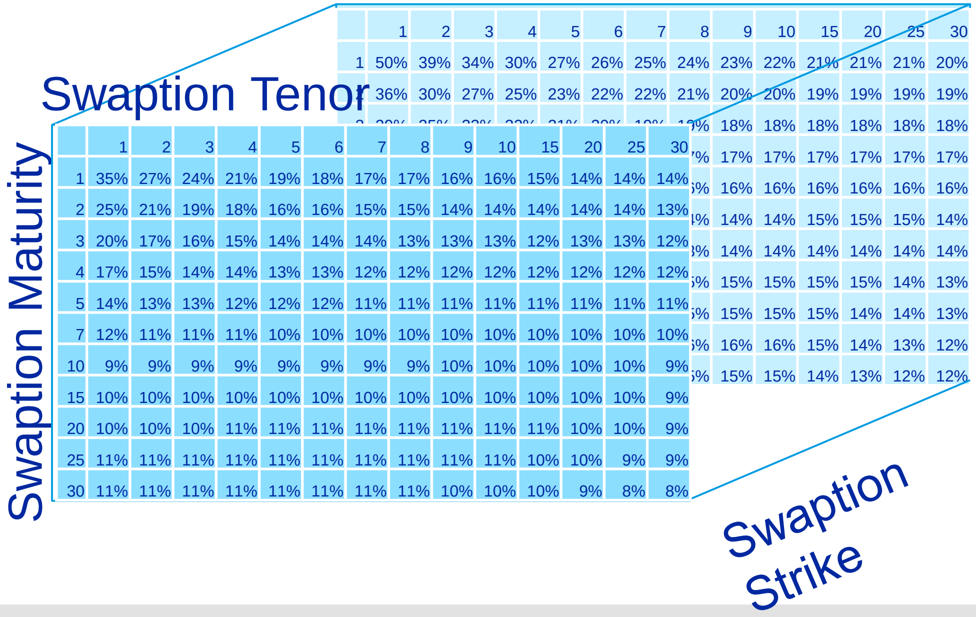
Test

- Start at $S_0 = 1$
- For each $T > 0$ check that $E_Q[S_T/C_T] = 1$ within 1.96 s.e.



Swaption Implied Volatility Tests

- Swaption Cube
  - *Maturity*
  - *Tenor*
  - *Strike*



	1	2	3	4	5	6	7	8	9	10	15	20	25	30
1	35%	27%	24%	21%	19%	18%	17%	17%	16%	16%	15%	14%	14%	14%
2	25%	21%	19%	18%	16%	16%	15%	15%	14%	14%	14%	14%	14%	13%
3	20%	17%	16%	15%	14%	14%	14%	13%	13%	13%	12%	13%	13%	12%
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	1	2	3	4	5	6	7	8	9	10	15	20	25	30
1	50%	39%	34%	30%	27%	26%	25%	24%	23%	22%	21%	21%	21%	20%
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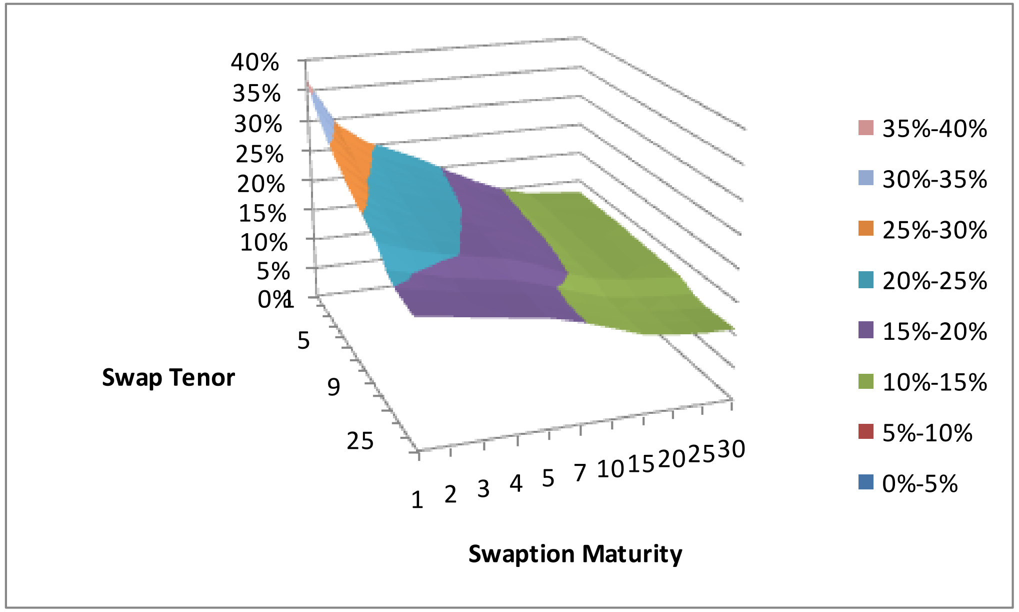
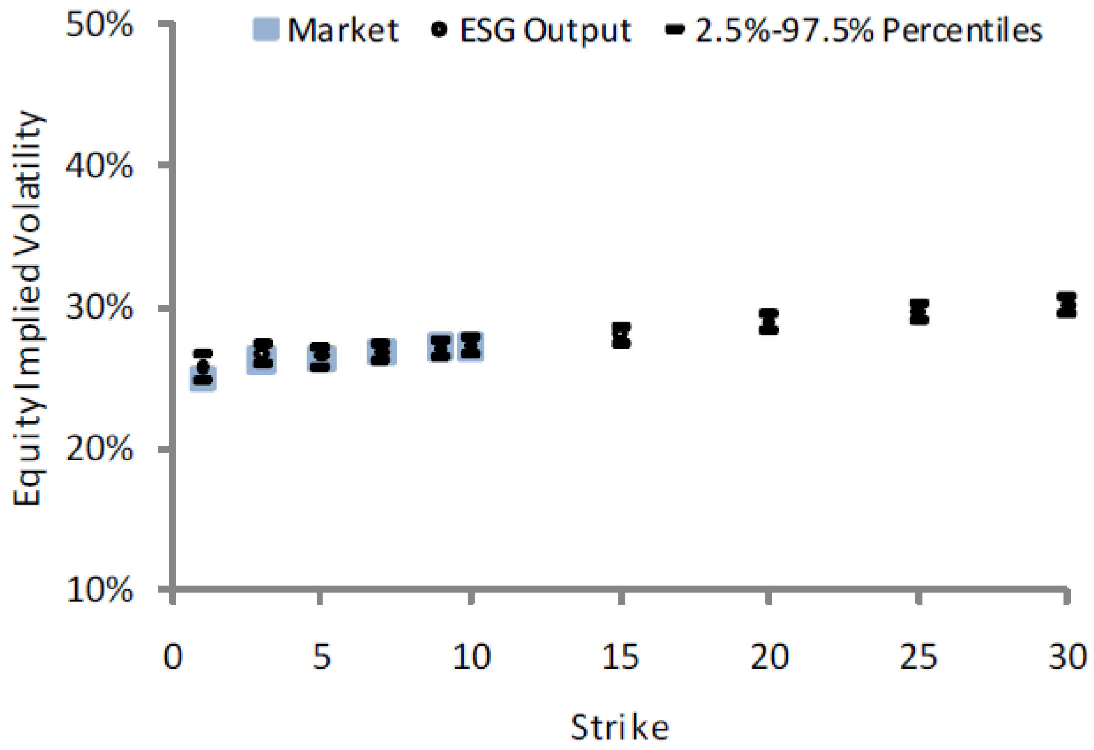


Equity Option Implied Volatility Test

This test calculates equity option prices/IVs implied by the ESG input. These can then be compared with market prices.



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Real World ESG

Real World Calibration Objectives

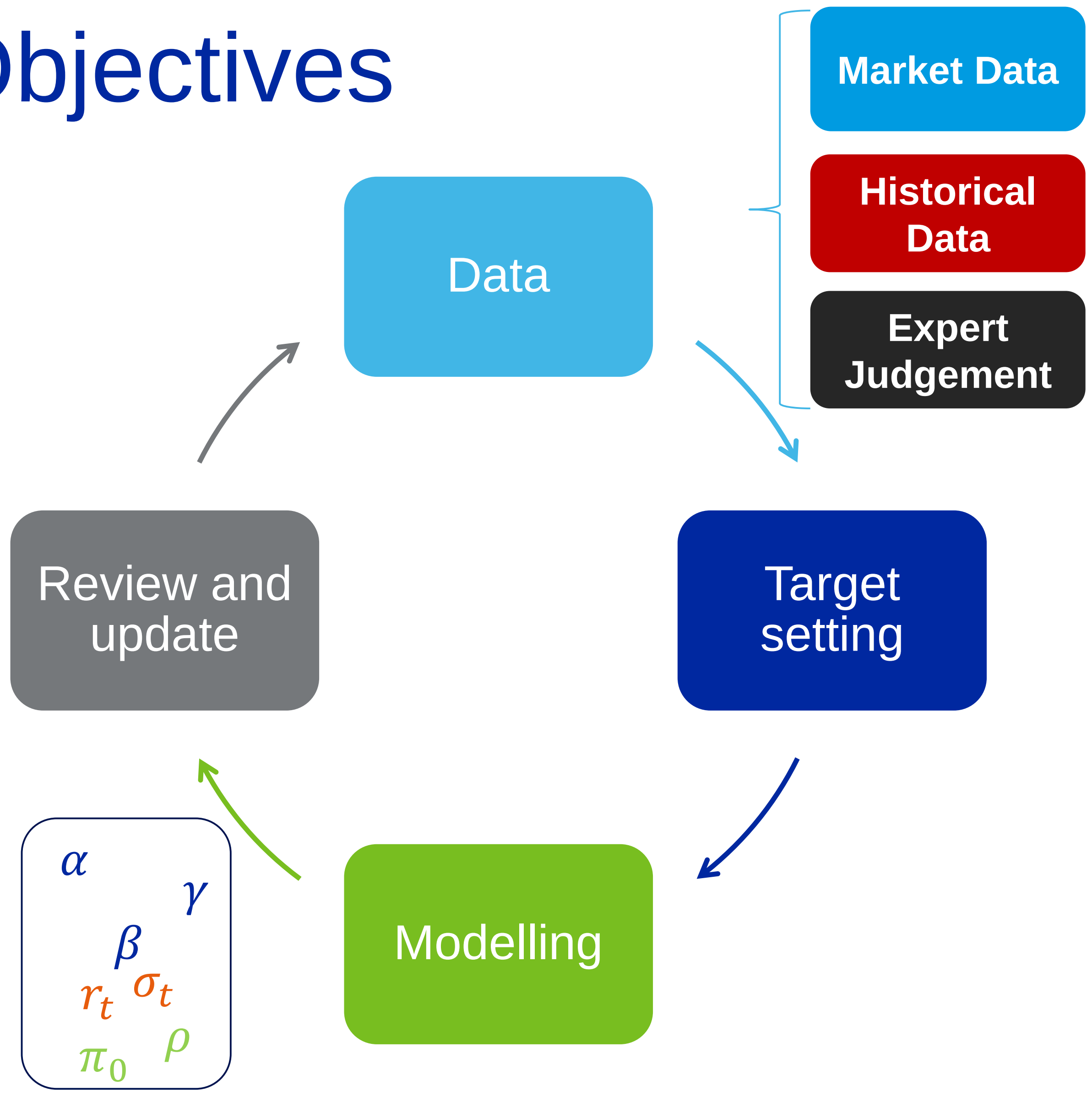
Calibrating ESGs in a Real World process can often present challenges particularly when setting views on the long-term dynamics of risk drivers

Requires a target setting process which leverages historical data and economic consensus

For example, may look to focus on some of these distributional characteristics:

- Expected Levels - Mean or Median
- Dispersions (Std. Deviation of Levels) and/or Volatility (Std. Deviation of Changes)
- Skew and Kurtosis
- Correlations between changes or levels of multiple risk drivers/outputs

Models should also initialized at today's market level – Yield Curves, Spreads etc.



Model Choice – RW Nominal Rate Example

Key Considerations

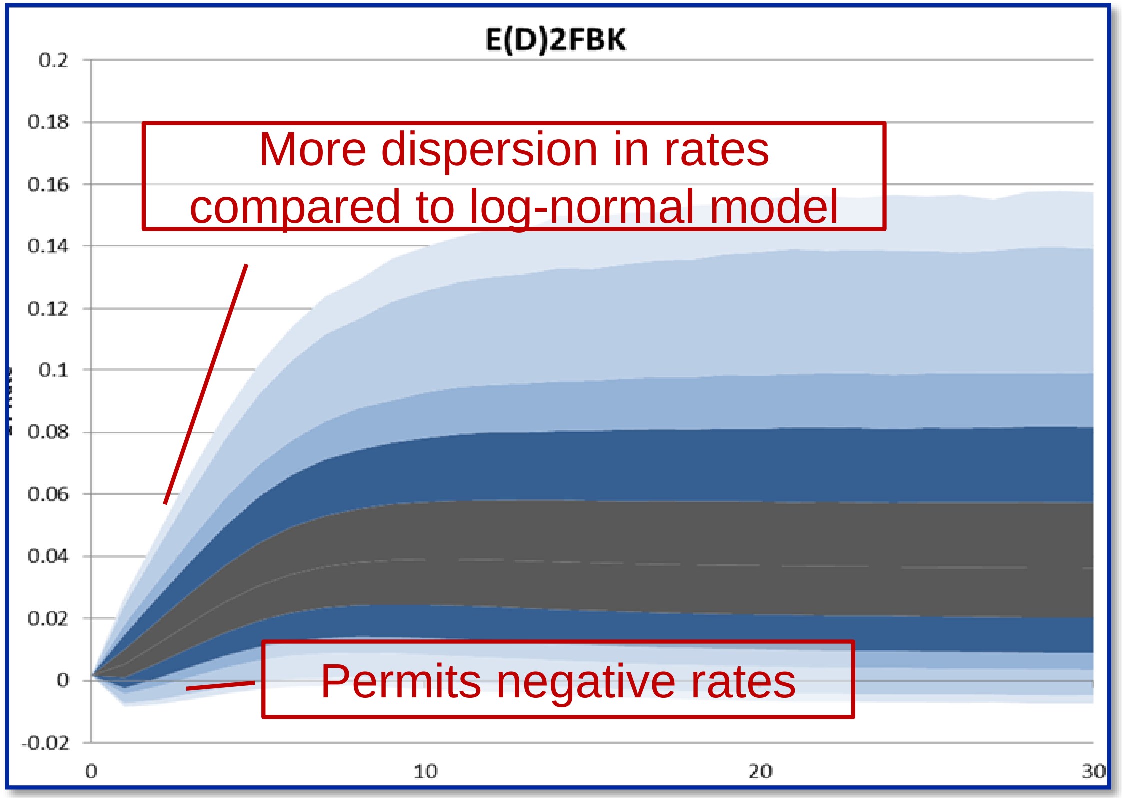
- Initial Yield Curve
  - Does the model allow the full yield curve as an input or is a parametric fit needed?
- Distribution of Rates
  - Expectations – does the model allow calibration to an expected path for rates or a single point? A single maturity or multiple maturities?
  - Dispersion/Volatility – does the model suitably capture uncertainty of future interest rates? Is volatility proportional to rate levels or absolute?
  - Correlations – does the model produce sensible correlation across the term-structure?
  - Higher Moments/Percentiles – does the model produce suitable scenarios in the tail of the distribution?
- Recalibration
  - Does the model allow for easy recalibration? Running stress cases, sensitivities, own views etc.
- Ease of understanding
  - Do model parameters have some level of intuition?

Model Choice - Nominal Rate Example - ED2FBK

Extended 2-Factor Black-Karasinski

Key Features:

- » **Extended: input initial curve**
- » Displacement: absolute volatility gives more realistic distributions
- » 2-Factors: **de-correlated rates**, realistic dynamics
- » Easy to calibrate (good analytics) – mean, median, volatility, percentiles etc.
- » Easy to understand (moderate complexity)



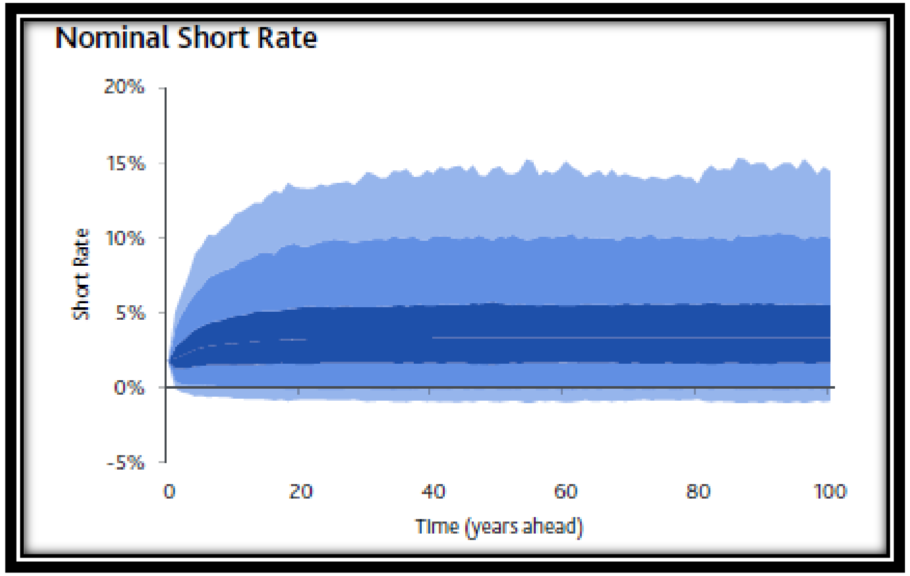
Other ESG model options:

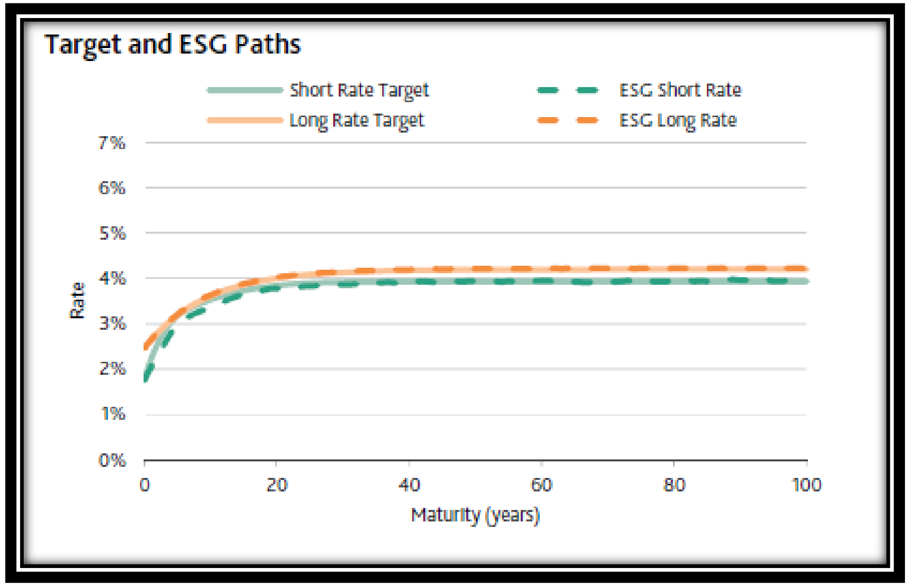
LMM+, LMM, 3-Factor Cox-Ingersol-Ross, 2-Factor Hull-White, 2-Factor Vasicek.

Real World Validation

How can we think about validating RW scenarios?

- » Time 0 characteristics - Initial Interest Rate, Initial Spread fits
  - – Does the market fit well?
- » Time 0 characteristics - Market instrument tests
  - – Is my own portfolio being priced accurately? Bond holdings etc.
- » Forward Looking Marginal Distributions – Mean, Standard Deviation, Skew, Kurtosis
  - – Is my model distribution close to my targets used in the calibration process?
  - – What is the model and calibration telling me about my distribution outside of these targets?
  - – What is my main horizon of concern?
  - – Which variables/metrics am I most sensitive to?
- » Joint Distributions
  - – Are my output correlations close to my target values?
  - – What do other correlations look like?





Back-testing/Historical Calibrations

Back-testing and Historical Calibrations can provide some useful intuition but there are some important considerations

- Historical Calibrations
  - How does the distribution of the model change when initialized at historical periods? E.g. pre-financial crisis
  - May seek some conditionality in the distributions over the shorter term but stability over the longer term.
  - This can be of particular relevance when considering variables with proportional volatility properties – e.g. interest rates.
  - Can help with understanding the dynamics of the model

- Back-testing
  - May be a natural extension of the historical calibrations – looking at historical realizations and where they fall in the distribution.
  - Needs to be done with caution:
    - May be difficult to quantify where in the distribution a particular realization may fall – i.e. is this observation a 1 in 2, 1 in 10, 1 in 100 year event?
    - This can be more complicated when considering joint probabilities of multiple variables.
    - Has there be a fundamental change in economy policy that may reduce probability of these scenarios? E.g. Inflation in the 1980s and more formal central bank targeting.

Back-testing

A comparison of models – constant vs. stochastic equity volatility