Findur Advanced Curve Analytics Update

Safe Harbor

This material is intended to outline our general product offering and direction. It is intended for information purposes only, and it is not a commitment to deliver any material, code, or functionality. This content should not be relied upon in making purchasing decisions. The development, release, and timing of any features or functionality described for OpenLink's products remain at the sole discretion of OpenLink. All materials provided are the confidential and proprietary materials of OpenLink.

OPENLINK

Agenda

- Monotone Convex Interpolation
  - Introduction and Methodology
  - Implementing through the Curve API extension
  - Results and Examples

- Multi-Curve Valuations
  - OIS curve setup and Configuration
  - OIS related LIBOR (Benchmark) curve
  - OIS related LIBOR Basis Curves
  - Currency Basis Curve
  - Multi-Curve Valuation Models

Background

- Three interpolation methods available in the past for interest rate curves:
    - Linear
    - Log Linear
    - Cubic Spline (done through Curve API, supplied at client's request)
- They all have various limitations
- As OIS discounting and daily margining become important, valuation accuracy is becoming critically important

Picking A Good Interpolation Method

Table 1: A synopsis of the comparison between methods.

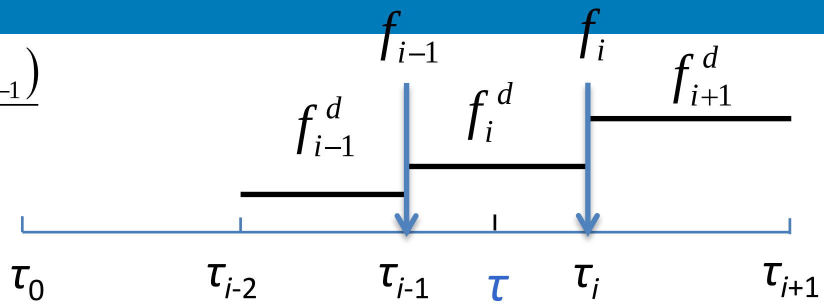
Yield curve type	Forwards positive?	Forward smoothness	Method local?	Forwards stable?	Bump hedges local?
Linear on discount	no	not continuous	excellent	excellent	very good
Linear on rates	no	not continuous	excellent	excellent	very good
Raw (linear on log of discount)	yes	not continuous	excellent	excellent	very good
Linear on the log of rates	no	not continuous	excellent	excellent	very good
Piecewise linear forward	no	continuous	poor	very poor	very poor
Quadratic	no	continuous	poor	very poor	very poor
Natural cubic	no	smooth	poor	good	poor
Hermite/Bessel	no	smooth	very good	good	poor
Financial	no	smooth	poor	good	poor
Quadratic natural	no	smooth	poor	good	poor
Hermite/Bessel on rt function	no	smooth	very good	good	poor
Monotone piecewise cubic	no	continuous	very good	good	good
Quartic	no	smooth	poor	very poor	very poor
Monotone convex (unameliorated)	yes	continuous	very good	good	good
Monotone convex (ameliorated)	yes	continuous	good	good	good
Minimal	no	continuous	poor	good	very poor

From Hagan, P. and G. West, Methods for constructing a yield curve, WILMOTT magazine, 2008

Monotone Convex Method

Discrete forward rates $f_i^{\,d} = -\dfrac{\ln(DF_i) - \ln(DF_{i-1})}{\tau_i - \tau_{i-1}}$

Define $f_i = \dfrac{\tau_i - \tau_{i-1}}{\tau_{i+1} - \tau_{i-1}} f_{i+1}^{\,d} + \dfrac{\tau_{i+1} - \tau_i}{\tau_{i+1} - \tau_{i-1}} f_{i+1}^{\,d}$

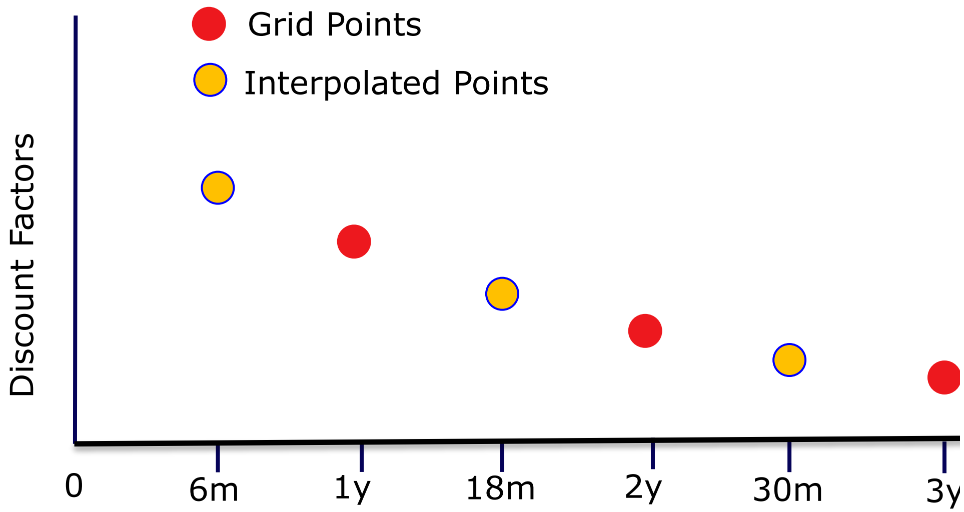


Find an interpolatory function *f* that satisfies the following conditions

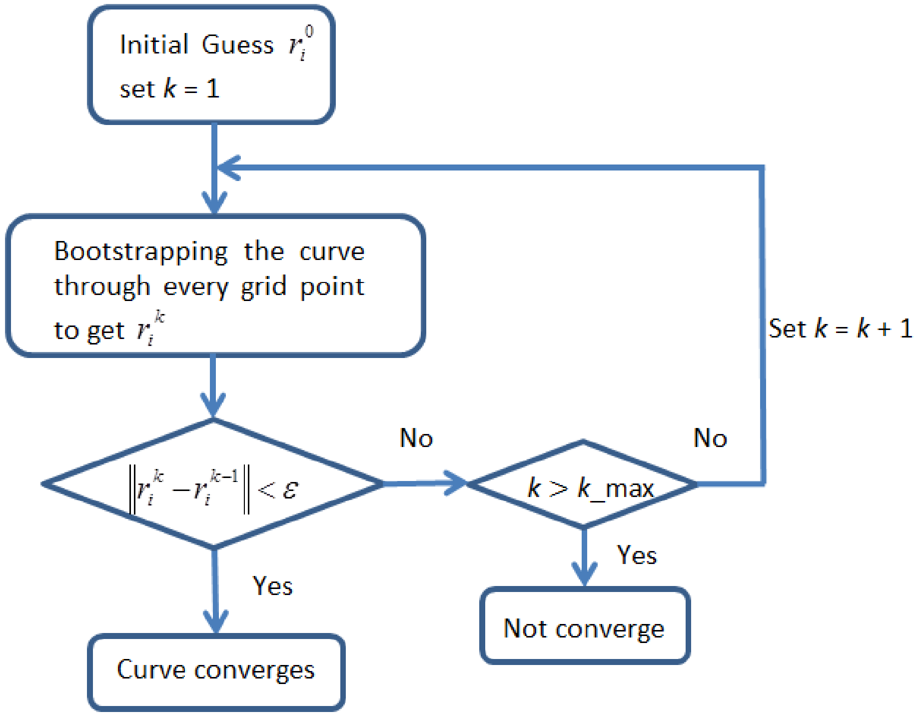
- $f(\tau_{i-1}) = f_{i-1}$ and $f(\tau_i) = f_i$ (boundary condition)
- $\dfrac{1}{\tau_i - \tau_{i-1}} \displaystyle\int_{\tau_{i-1}}^{\tau_i} f(t)\,dt = f_i^{\,d}$ so the discrete forward is recovered by the curve
- *f* is positive
- *f* is continuous
- if $f_{i-1}^{\,d} < f_i^{\,d} < f_{i+1}^{\,d}$ then $f(\tau)$ is increasing on $[\tau_{i-1}, \tau_i]$, and if $f_{i-1}^{\,d} > f_i^{\,d} > f_{i+1}^{\,d}$ then $f(\tau)$ is decreasing on $[\tau_{i-1}, \tau_i]$,

Observation: Interpolation and Curve Bootstrapping (Construction) are intertwined. We need to have a new bootstrapping that uses the interpolation at the same time

Curve Constructor: an iterative method for convergence



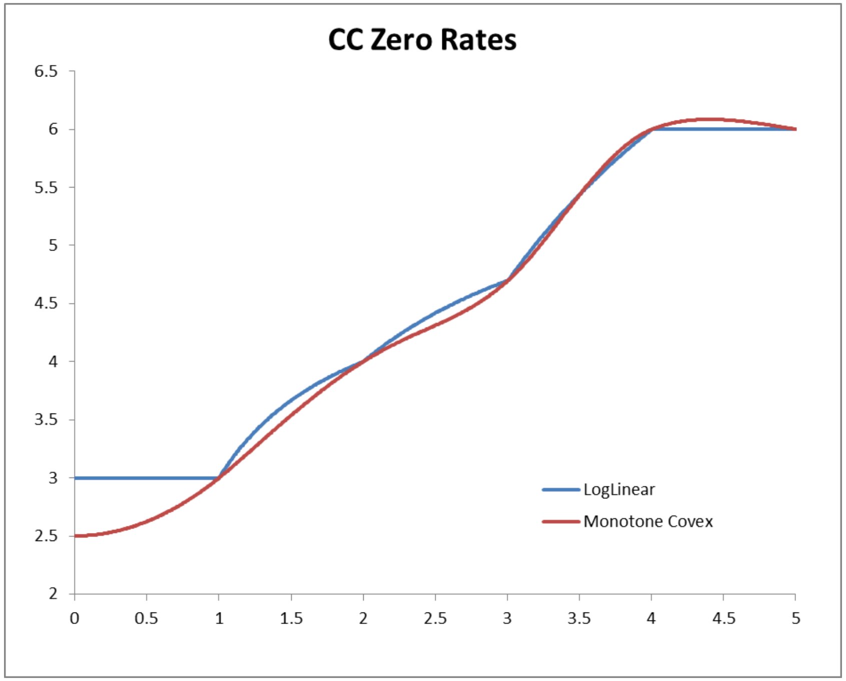
- Guess initial cc zero rates or discount factors for unknown grid points,
- perform interpolation to determine any missin discount factors,
- find the optimal value for each grid point.
- Then iterate the above steps using the previous values as the initial guess until convergence



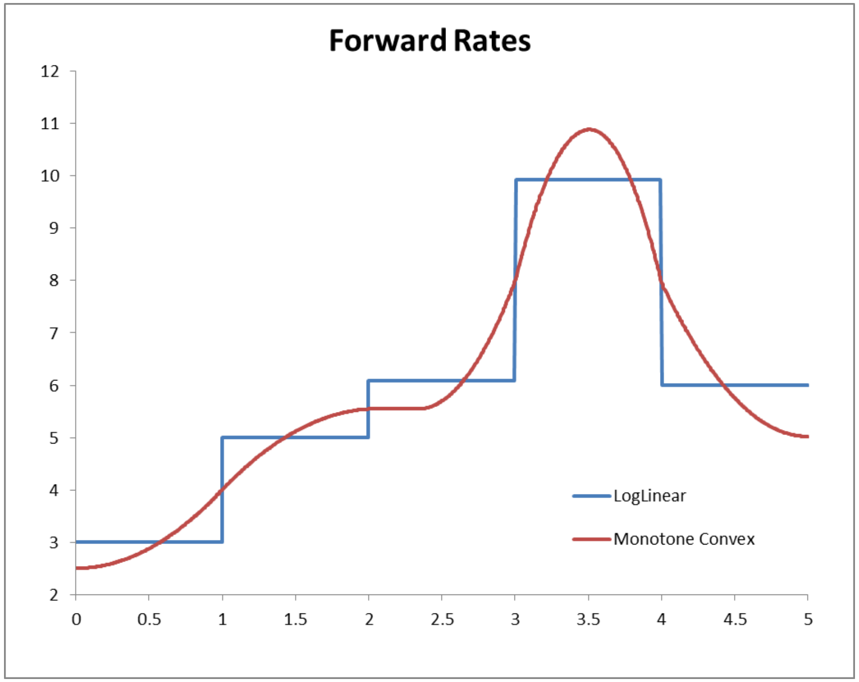
Implement MC Interpolation Method

- Through the Findur Curve API extension and OpenComponents
- Curves built with this interpolator behave and can be used just like internal Findur Curves for pricing and simulation purposes
- Calculated curve outputs can be viewed in the standard Findur curve output window
- Curve inputs and outputs can also be viewed through simulation results like Index Rates and Index Output
- Available as an extension from V10

Example 1: Simple Bootstrapping from CC Zero Rates

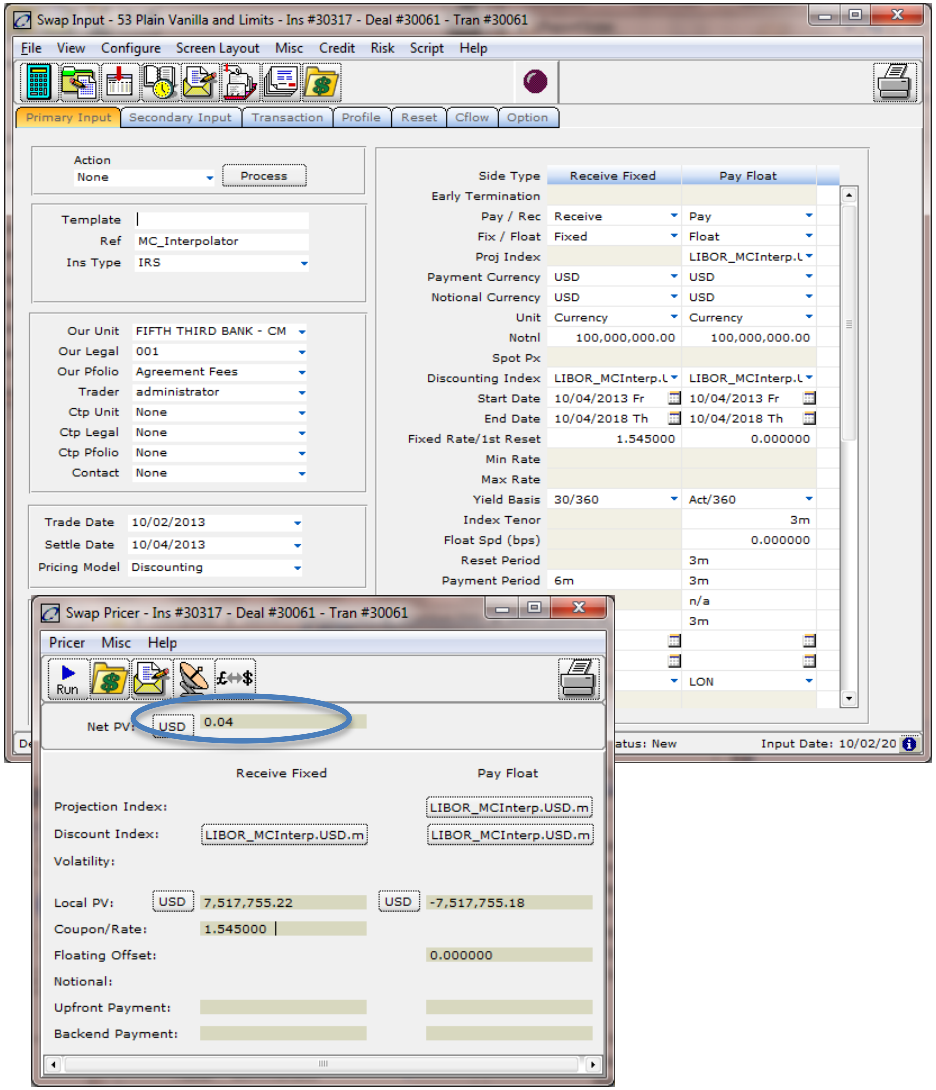


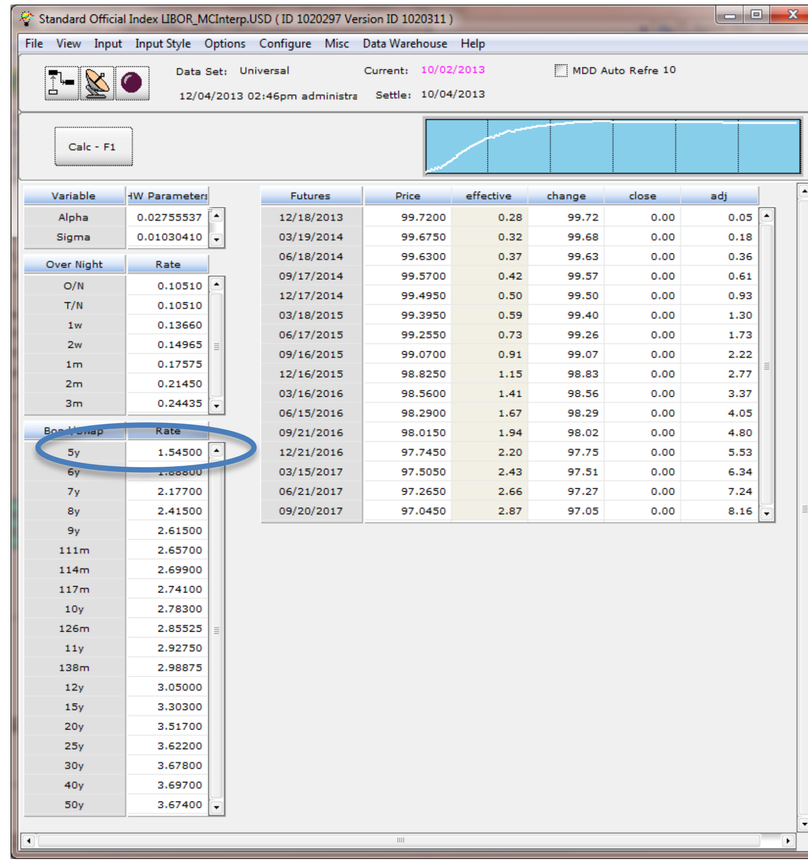
Year	CC Zero Rate
1	3.00%
2	4.00%
3	4.70%
4	6.00%
5	6.00%



Example 2

All input instruments to the bootstrap are exactly reproduced.

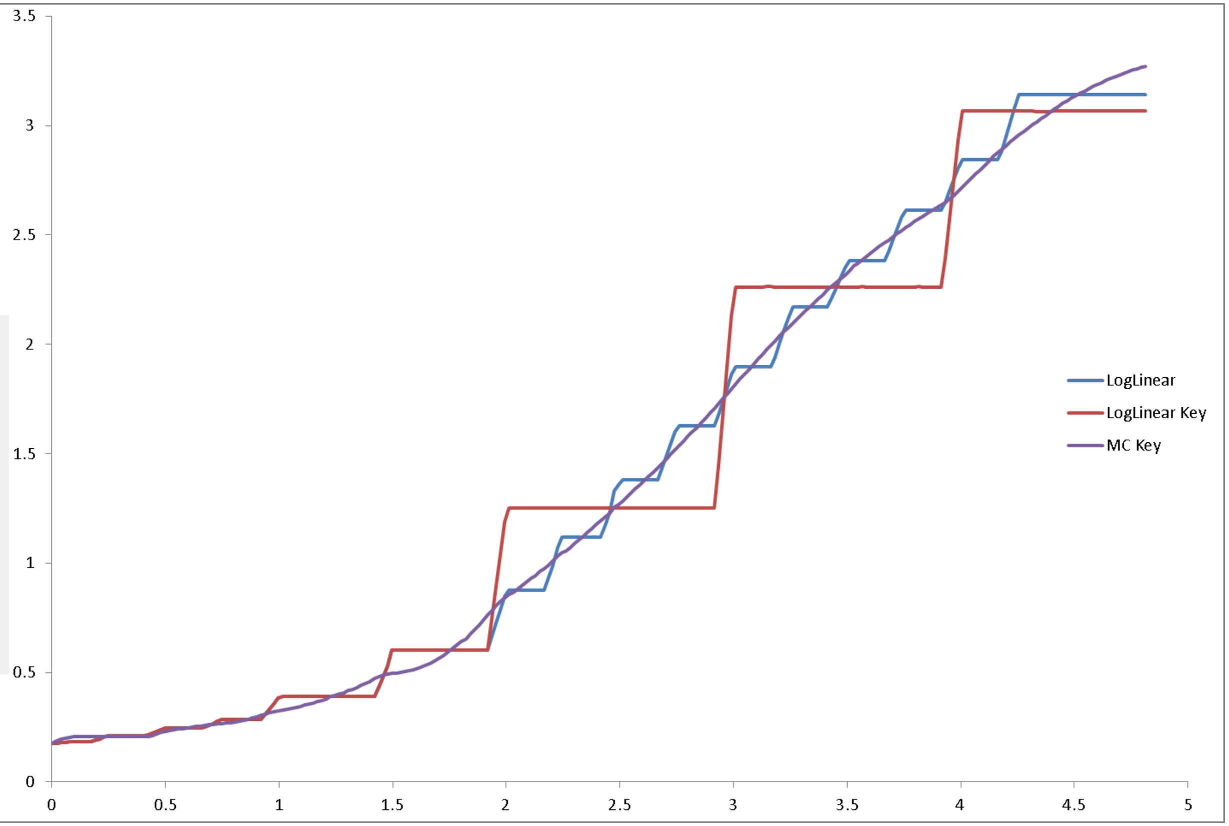




Examples 3: 1M Forward Rates With 3 methods

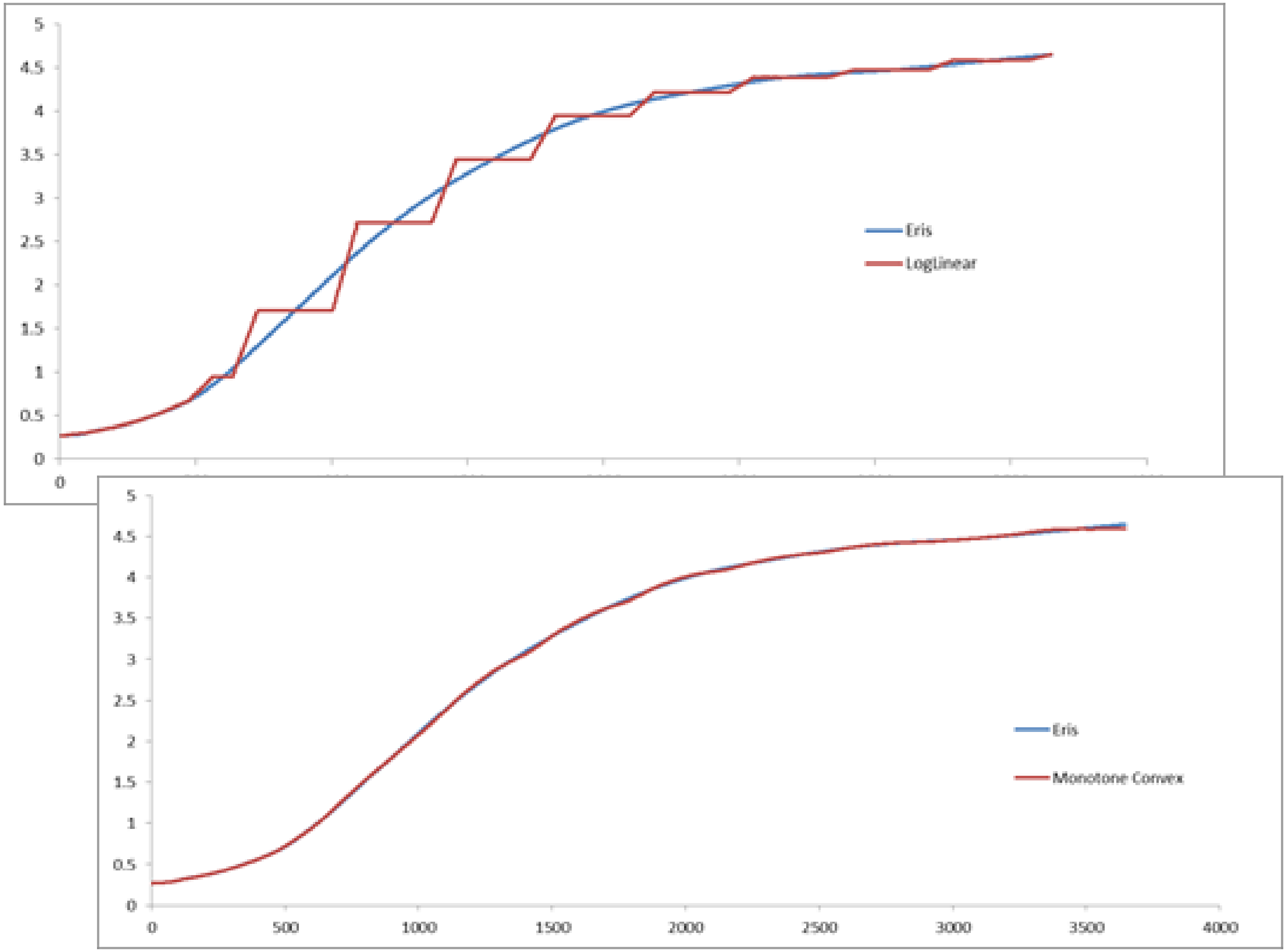
Method 1: Only quoted basis swaps using Log Linear (labelled LogLinear Key, big steps)
Method 2: Additional grid points interpolated between quoted swaps using Log Linear (labelled LogLinear, smaller steps)
Method 3: Only quoted basis swaps with Monotone Convex (labelled MC Key, smoothest)

Bond/Swap	Spread
3m	6.0000
6m	6.7500
9m	7.3750
12m	7.8750
18m	8.1250
2y	8.3750
36m	8.2500
48m	8.1250
5y	8.1250
7y	7.3750



Bond/Swap	Spread
3m	6.0000
6m	6.7500
9m	7.3750
12m	7.8750
18m	8.1250
2y	8.3750
27m	8.3438
30m	8.3125
33m	8.2813
36m	8.2500
39m	8.2188
42m	8.1875
45m	8.1563
48m	8.1250
51m	8.1250
54m	8.1250
57m	8.1250
5y	8.1250
7y	7.3750

Example 4: Comparison to Published Curves



Summary:

- Smooth forwards for benchmark and basis indexes and much improved valuations.
- Available from V10+ using Curve API Extension
- Applicable to all interest rate curves: benchmark, in-currency basis, cross currency basis
- Robust and fast performance (e.g. much better than Cubic Spline)

Multi-Curve Valuation

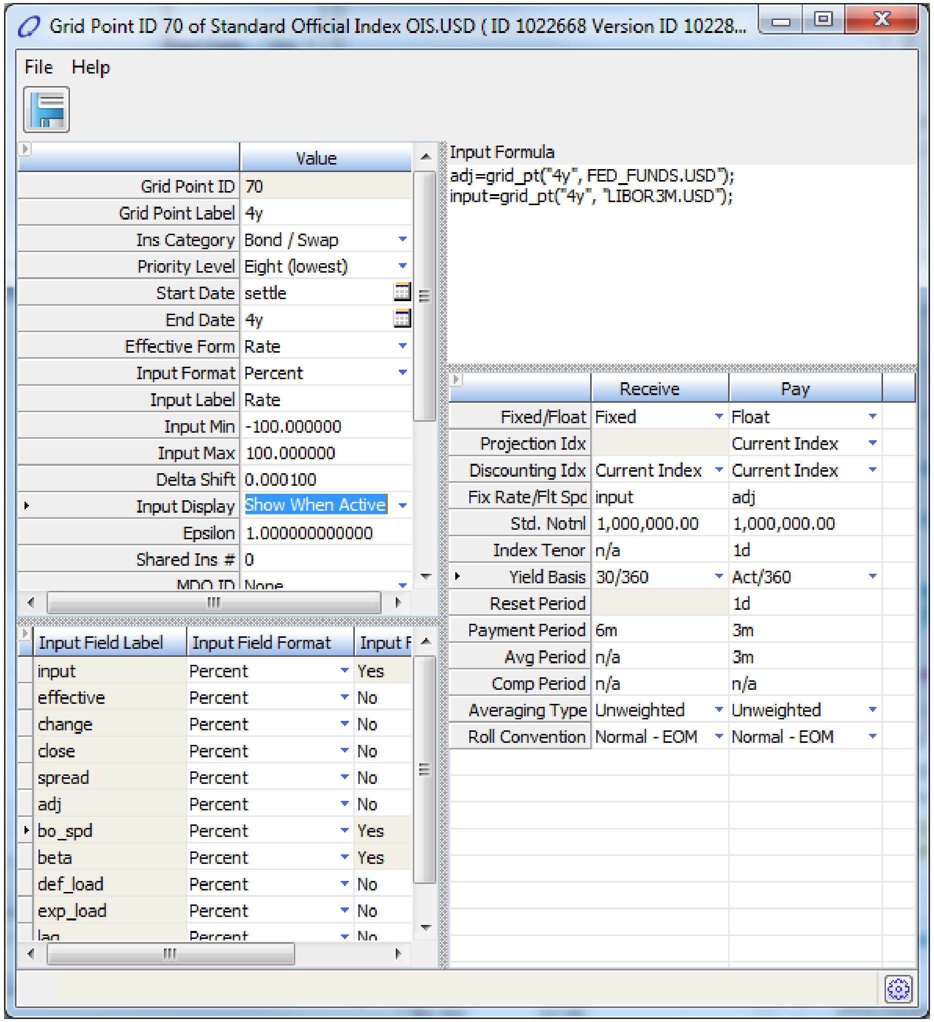
Background

- With emphasis on credit risk and push by regulations, OIS discounting has become the norm in the industry
- OIS methodologies and available market data have also become more standard
- OpenLink has a set of best practice recommendations and configurations that have been adopted by our clients
- Multi-Curve valuation models for available for a wide set of instruments

OIS Discounting Curve: Dual Curve Bootstrap (Our previous recommendation)

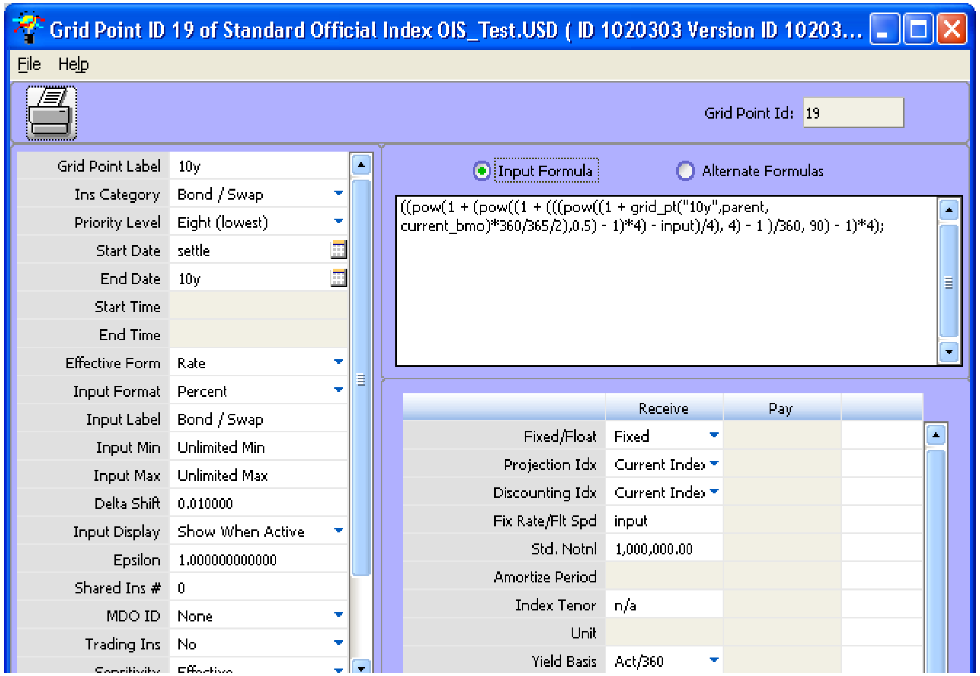
- Building Blocks (USD example)
  - OIS Cash and quoted Swaps: Overnight to 5y
  - FF/LIBOR Basis Swaps: 7y – 20y
  - Extrapolated LIBOR/FF basis: 25y -40y

- Special Considerations
  - FedFund LIBOR Basis Swaps: Synthesize an (FF+Spd)/Fixed Swap from LIBOR Swap and LIBOR/FF basis.
  - Extrapolated LIBOR/FF: Assuming constant LIBOR/FF basis beyond last quoted (20y) basis swap



OIS Discounting Curve: Using Bloomberg Approximation (Updated alternative recommendation)

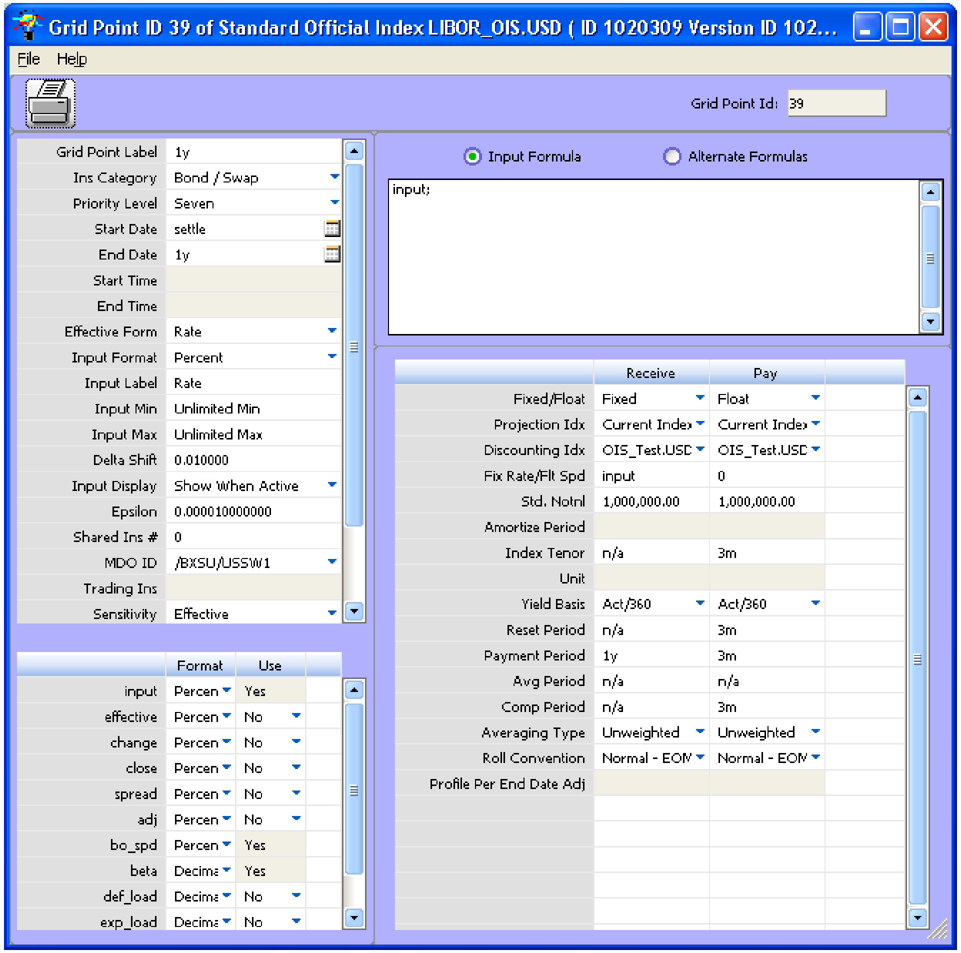
- Building Blocks (USD example)
  - OIS Cash and quoted swaps: overnight to 1y.
  - FF/LIBOR Basis Swaps: 7y – 30y
  - Extrapolated LIBOR/FF basis: 30y+ – 50y
- Special Considerations
  - FF LIBOR Basis Swaps: use a BBG curve formula to approximate OIS swap rate from LIBOR swap rates and LIBOR/FF basis
  - Extrapolated LIBOR/FF: Assuming constant LIBOR/FF basis beyond last quoted (20y) basis swap



Benchmark (LIBOR3M) Projection Curve with OIS Discounting

- Conventional LIBOR Index:
  - Used in both projection and Discounting together
  - For use in valuation of uncollateralized trades
- OIS based LIBOR Index
  - Used only for projection paired with OIS discounting
  - For use in valuation of collateralized trades

- Building Blocks for OIS based LIBOR:
  - same as conventional LIBOR, cash/future/swaps
- Special Considerations
  - Cash/futures: same as conventional
  - Swaps: OIS curve to be used as parent in discounting

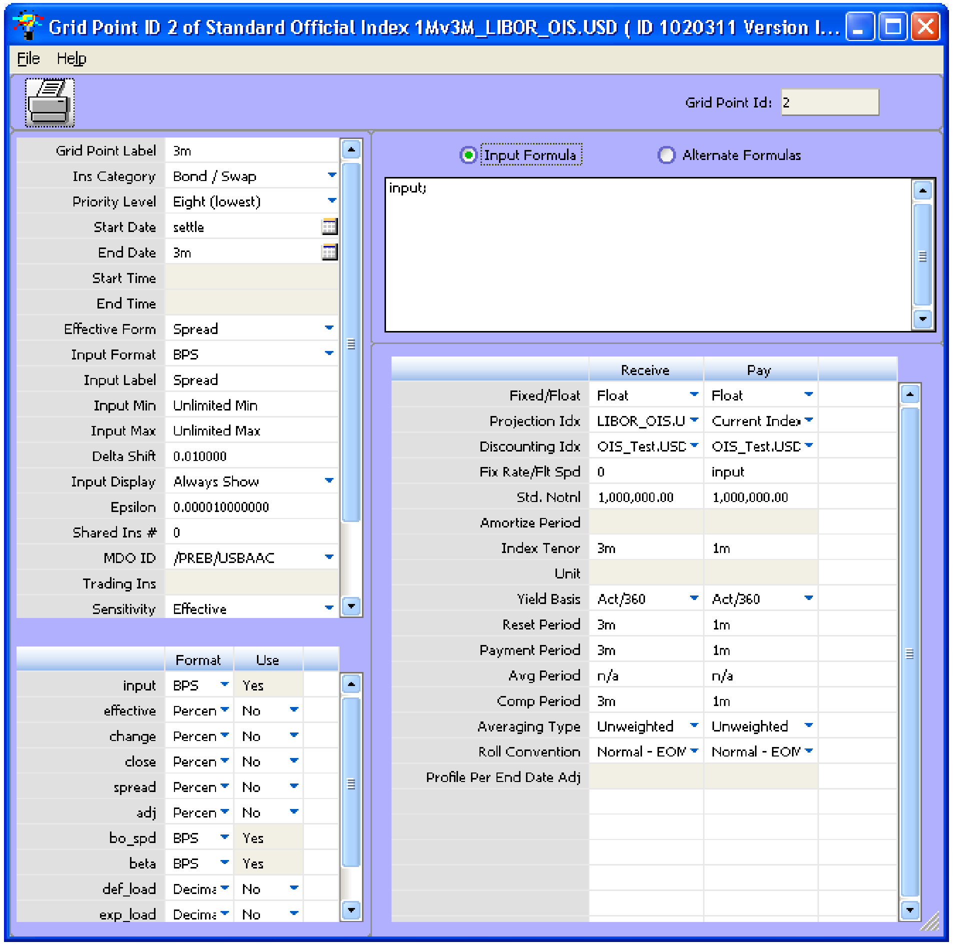


Basis Projection Curves with OIS Discounting

- Distinction from Conventional basis curves
  - Used only for projection paired with OIS discounting
  - For use in valuation of collateralized trades

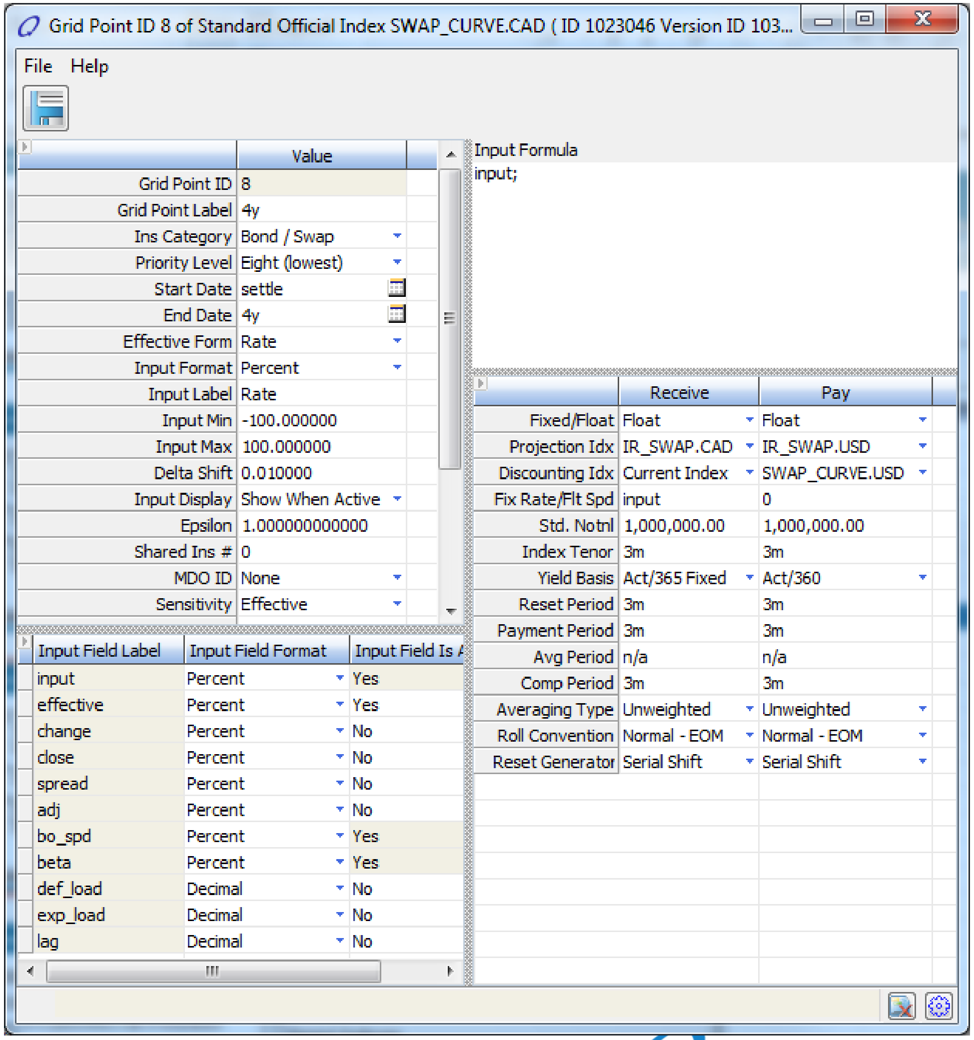
- Building Blocks:
  - same as conventional basis curves: basis swaps

- Special Considerations
  - Basis Swaps: OIS Based LIBOR curve as projection
  - Basis Swaps: OIS curve to be used as parent in discounting



Cross-Currency Swap Curves

- Constructed using Currency Basis Swap (Float/Float)
- Full controls of projection and discounting curves on both sides
- Standard Setup:
    - Proj Curves: Benchmark IR curves for both currencies
    - Disc Curve on USD side: OIS or LIBOR USD Curve
    - Disc Curve on Currency side : To be solved in bootstrap
- Internal consistency with standard and quoted deals



Multi-Curve Valuation Models

Multi-Curve Enabled Models	Sample Instruments
Discounting	Swap, Bond, Basis Swap
Black	Cap/Floor, CMS,
Black Swaption	European Swaption, Cancelable Swap
HW 1 Factor, HW 2 Factor	Bermudan and American Swaption, Bond Option, Currency Swaption,
Gaussian 1 Factor and 2 Factor	Similar as above

OPENLINK

Conclusions and Discussions

- Various similar or equivalent approaches can be chosen based on data availability and user preferences
- Can be combined with Monotone Convex method to further improve curve and valuation accuracy
- Need to aim for operational efficiency to deal with the expanded set of curves
- Deals can still be booked with conventional curves, but mapped to OIS related curves in a Reval Sim as needed.
- For options, 2-curve models are required for OIS discounted options
- Detailed whitepaper available on OpenLink OIS approaches

OIS Curve Structure for In-Currency Valuations

LIBOR Inputs

FF Basis Inputs

OIS Rates Inputs

OIS Curve

LIBOR (projection OIS Based

LIBOR1M (projection OIS Based

LIBOR6m (projection OIS Based

SIFMA (projection OIS Based

Using Dual-Curve Bootstrap, Starting point of a family of OIS based curves

Same inputs as conventional LIBOR, but swaps use OIS for discounting

Use Basis Swap construct, using OIS discounting, solving for basis curves

Cross Currency Curve Structure (Conventional)

USD/EUR CCY Basis + EURIBOR.EUR

Projection Rates

LIBOR.USD

=

A New Discount Curve for EUR (To be solved)

Discounting

LIBOR.USD

Cross Currency Curve Structure (OIS Based)

USD/EUR CCY Basis + EURIBOR.EUR OIS Based

Projection Rates

LIBOR.USD (OIS Based)

=

A New Discount Curve for EUR (To be solved)

Discounting

OIS.USD

Questions/Discussions

Thank you