

Findur Advanced Curve Analytics Update

Safe Harbor



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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.

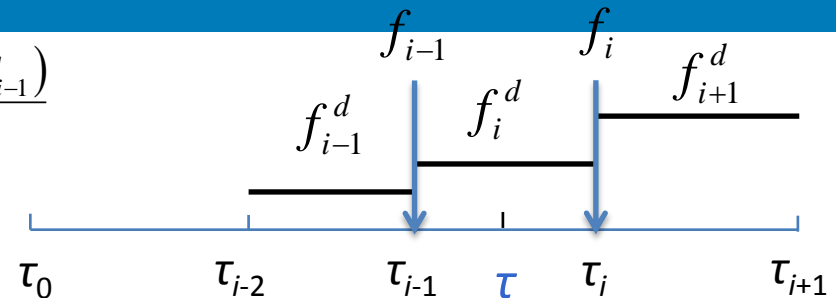
Yield curve type	Forwards positive?	Forward smoothness	Method local?	Forwards stable?	Bump hedges local?
Linear on discount	no	not continuous	excellent	excellent	very good
Linear on rates	no	not continuous	excellent	excellent	very good
Raw (linear on log of discount)	yes	not continuous	excellent	excellent	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 $f_i^d = -\frac{\ln(DF_i) - \ln(DF_{i-1})}{\tau_i - \tau_{i-1}}$

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

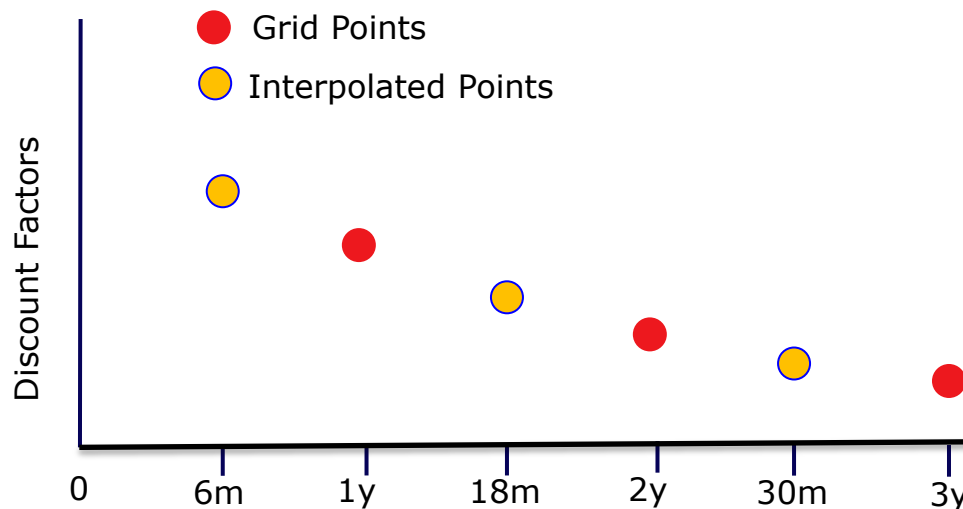


Find an interpolatory function f that satisfies the following conditions

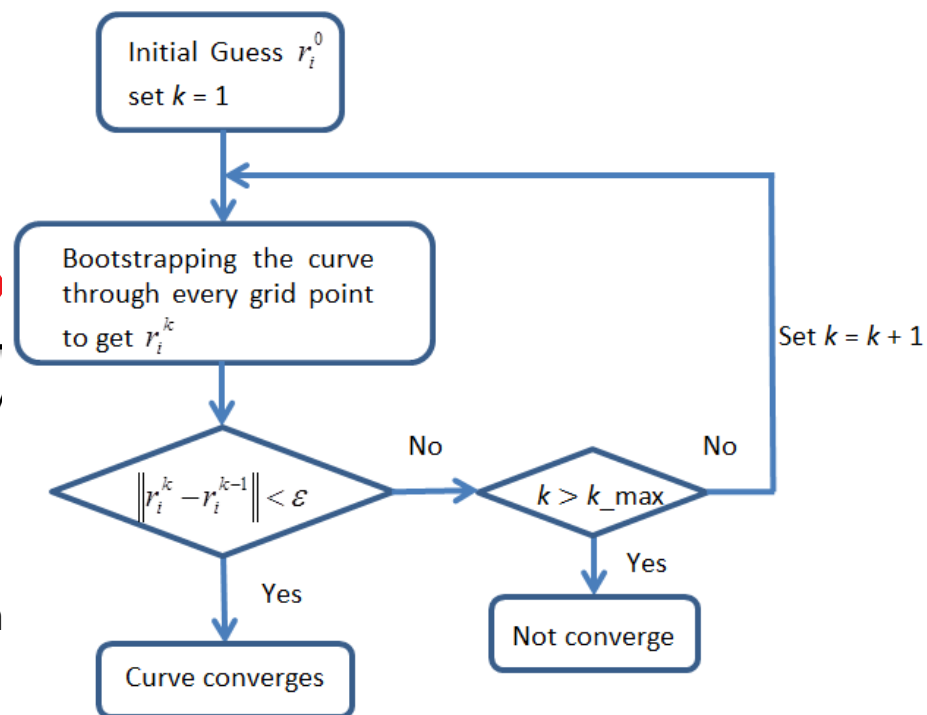
- $f(\tau_{i-1}) = f_{i-1}$ and $f(\tau_i) = f_i$ (boundary condition)
- $\frac{1}{\tau_i - \tau_{i-1}} \int_{\tau_{i-1}}^{\tau_i} f(t) dt = f_i^d$ so the discrete forward is recovered by the curve
- f is positive
- f is continuous
- if $f_{i-1}^d < f_i^d < f_{i+1}^d$ then $f(\tau)$ is increasing on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



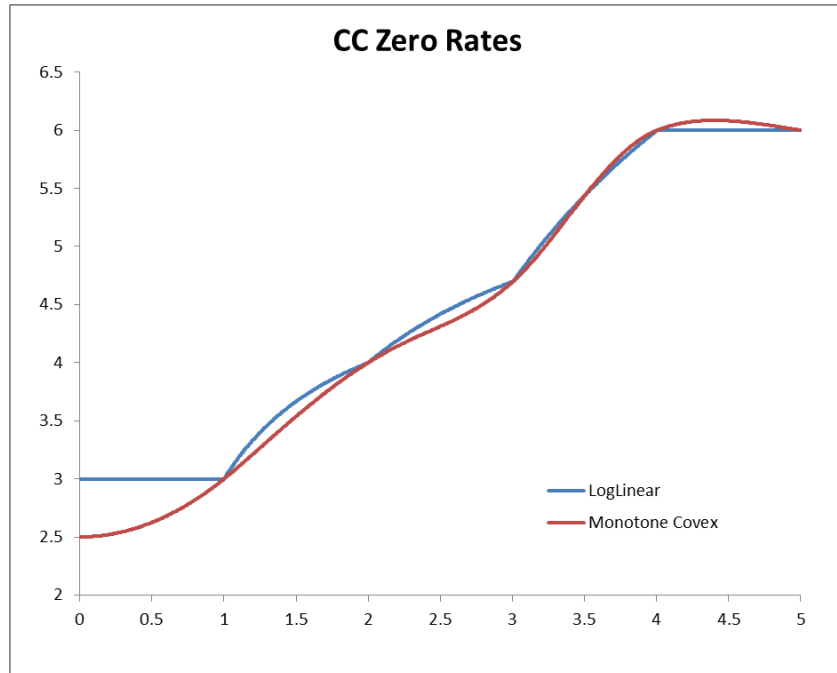
- Guess initial cc zero rates or discount factors for unknown grid points,
- perform interpolation to determine any missing discount factors,
- find the optimal value for each grid point.
- Then iterate the above steps using the previous values as the initial guess until convergence



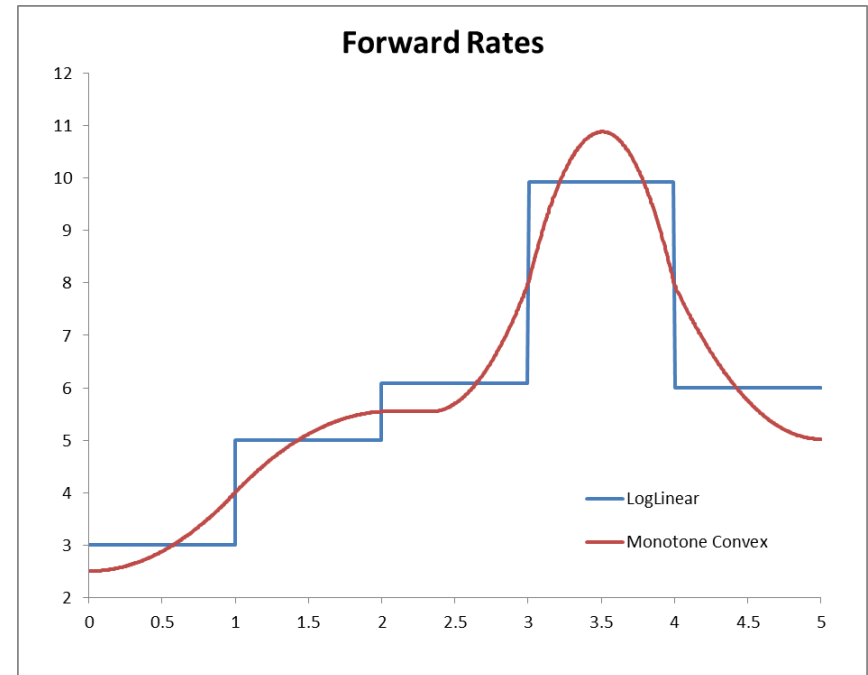
Implement MC Interpolation Method

- 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.

Swap Input - 53 Plain Vanilla and Limits - Ins #30317 - Deal #30061 - Tran #30061

File View Configure Screen Layout Misc Credit Risk Script Help

Primary Input Secondary Input Transaction Profile Reset CFLOW Option

Action: None [Process]

Template: Ref MC_Interpolator Ins Type IRS

Our Unit: FIFTH THIRD BANK - CM Our Pfolio: 001 Our Pfolio Agreement Fees: Trader: administrator Ctp Unit: None Ctp Legal: None Ctp Pfolio: None Contact: None

Trade Date: 10/02/2013 Settle Date: 10/04/2013 Pricing Model: Discounting

Side Type: Receive Fixed Pay Float

Early Termination: Pay / Rec Receive Pay Fix / Float Fixed Float Proj Index: LIBOR_MCInterp.L Payment Currency: USD USD Notional Currency: USD USD Unit: Currency Currency Notnl: 100,000,000.00 100,000,000.00 Spot Px: Discounting Index: LIBOR_MCInterp.L LIBOR_MCInterp.L Start Date: 10/04/2013 Fr 10/04/2013 Fr End Date: 10/04/2018 Th 10/04/2018 Th Fixed Rate/1st Reset: 1.545000 0.000000 Min Rate: Max Rate: Yield Basis: 30/360 Act/360 Index Tenor: 3m Float Spd (bps): 0.000000 Reset Period: 3m Payment Period: 6m

Swap Pricer - Ins #30317 - Deal #30061 - Tran #30061

Pricer Misc Help

Run [Icons]

Net PV: USD 0.04

Receive Fixed Pay Float

Projection Index: LIBOR_MCInterp.USD.m Discount Index: LIBOR_MCInterp.USD.m Volatility:

Local PV: USD 7,517,755.22 USD -7,517,755.18 Coupon/Rate: 1.545000 Floating Offset: 0.000000 Notional: Upfront Payment: Backend Payment:

Standard Official Index LIBOR_MCInterp.USD (ID 1020297 Version ID 1020311)

File View Input Input Style Options Configure Misc Data Warehouse Help

Data Set: Universal Current: 10/02/2013 MDD Auto Refre 10

12/04/2013 02:46pm administra Settle: 10/04/2013

Calc - F1

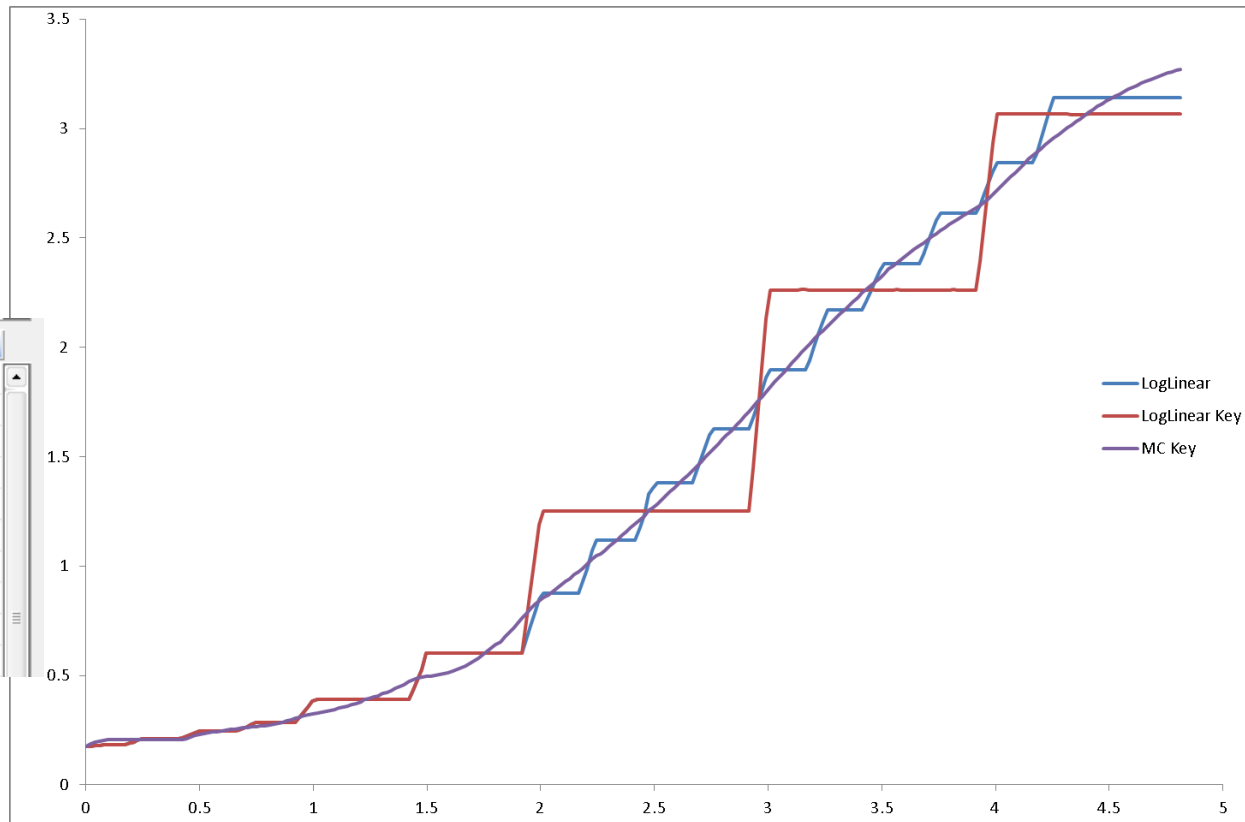
Variable	1W Parameters	Futures	Price	effective	change	close	adj
Alpha	0.02755537	12/18/2013	99.7200	0.28	99.72	0.00	0.05
Sigma	0.01030410	03/19/2014	99.6750	0.32	99.68	0.00	0.18
		06/18/2014	99.6300	0.37	99.63	0.00	0.36
Over Night	Rate	09/17/2014	99.5700	0.42	99.57	0.00	0.61
O/N	0.10510	12/17/2014	99.4950	0.50	99.50	0.00	0.93
T/N	0.10510	03/18/2015	99.3950	0.59	99.40	0.00	1.30
1w	0.13660	06/17/2015	99.2550	0.73	99.26	0.00	1.73
2w	0.14965	09/16/2015	99.0700	0.91	99.07	0.00	2.22
1m	0.17575	12/16/2015	98.8250	1.15	98.83	0.00	2.77
2m	0.21450	03/16/2016	98.5600	1.41	98.56	0.00	3.37
3m	0.24435	06/15/2016	98.2900	1.67	98.29	0.00	4.05
Bootstrap	Rate	09/21/2016	98.0150	1.94	98.02	0.00	4.80
5y	1.54500	12/21/2016	97.7450	2.20	97.75	0.00	5.53
6y	1.88800	03/15/2017	97.5050	2.43	97.51	0.00	6.34
7y	2.17700	06/21/2017	97.2650	2.66	97.27	0.00	7.24
8y	2.41500	09/20/2017	97.0450	2.87	97.05	0.00	8.16
9y	2.61500						
111m	2.65700						
114m	2.69900						
117m	2.74100						
10y	2.78300						
126m	2.85525						
11y	2.92750						
138m	2.98875						
12y	3.05000						
15y	3.30300						
20y	3.51700						
25y	3.62200						
30y	3.67800						
40y	3.69700						
50y	3.67400						

Examples 3: 1M Forward Rates With 3 methods

Method 1: Only quoted basis swaps using Log Linear (labelled LogLinear Key, big steps)

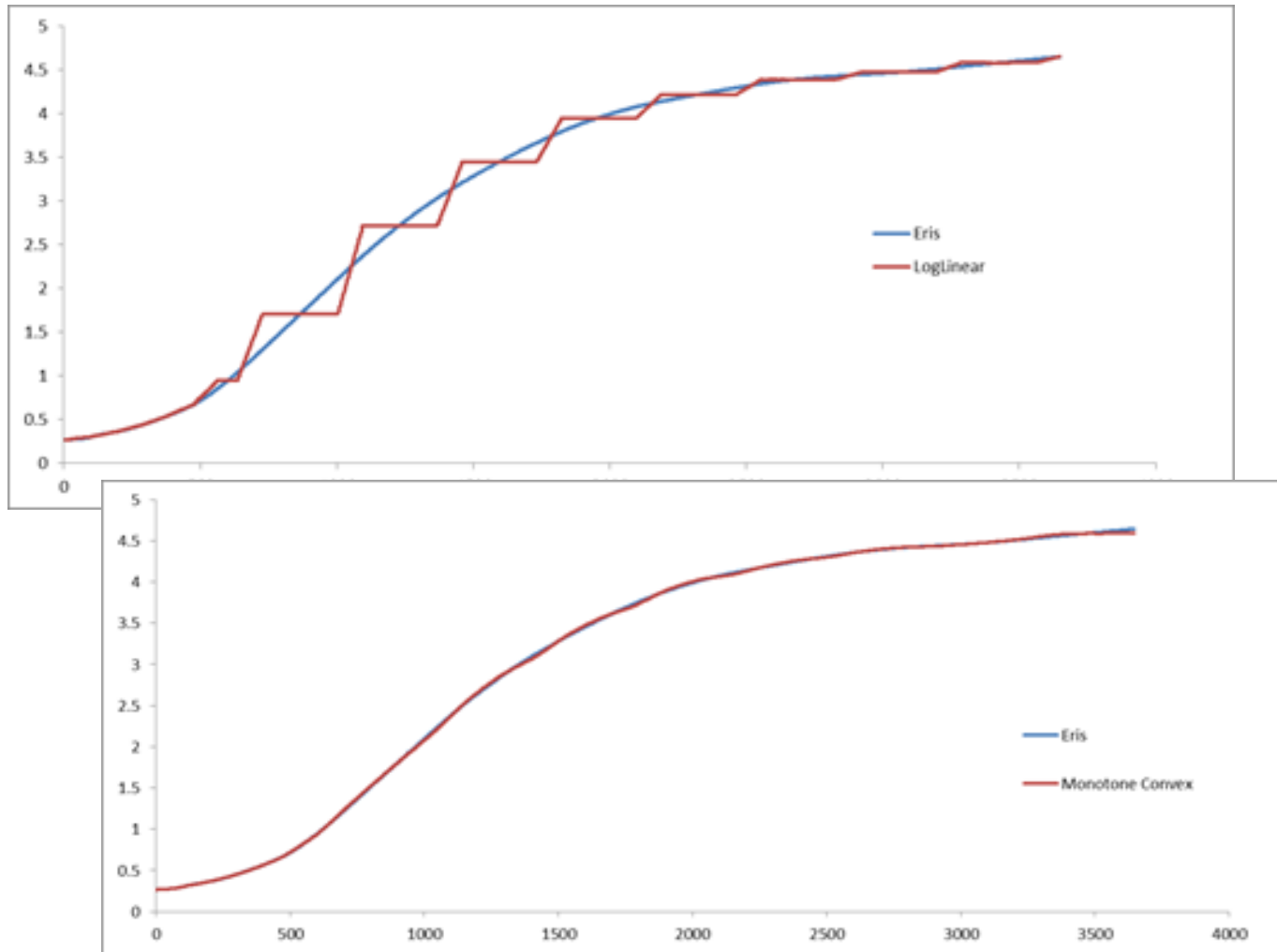
Method 2: Additional grid points interpolated between quoted swaps using Log Linear (labelled LogLinear, smaller steps)

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
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

Grid Point ID 70 of Standard Official Index OIS.USD (ID 1022668 Version ID 10228...

File Help

	Value
Grid Point ID	70
Grid Point Label	4y
Ins Category	Bond / Swap
Priority Level	Eight (lowest)
Start Date	settle
End Date	4y
Effective Form	Rate
Input Format	Percent
Input Label	Rate
Input Min	-100.000000
Input Max	100.000000
Delta Shift	0.000100
Input Display	Show When Active
Epsilon	1.000000000000
Shared Ins #	0
MNO ID	None

Input Formula
 adj=grid_pt("4y", FED_FUNDS.USD");
 input=grid_pt("4y", "LIBOR3M.USD");

	Receive	Pay
Fixed/Float	Fixed	Float
Projection Idx		Current Index
Discounting Idx	Current Index	Current Index
Fix Rate/Flt Spd	input	adj
Std. Notnl	1,000,000.00	1,000,000.00
Index Tenor	n/a	1d
Yield Basis	30/360	Act/360
Reset Period		1d
Payment Period	6m	3m
Avg Period	n/a	3m
Comp Period	n/a	n/a
Averaging Type	Unweighted	Unweighted
Roll Convention	Normal - EOM	Normal - EOM

Input Field Label	Input Field Format	Input F
input	Percent	Yes
effective	Percent	No
change	Percent	No
close	Percent	No
spread	Percent	No
adj	Percent	No
bo_spd	Percent	Yes
beta	Percent	Yes
def_load	Percent	No
exp_load	Percent	No
lan	Percent	No

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

Grid Point ID 19 of Standard Official Index OIS_Test.USD (ID 1020303 Version ID 10203...)

File Help

Grid Point Id: 19

☒ Input Formula ☐ Alternate Formulas

(((pow(1 + (pow((1 + (((pow((1 + grid_pt("10y", parent, current_bmo)*360/365/2), 0.5) - 1)*4) - input)/4), 4) - 1)/360, 90) - 1)*4);

	Receive	Pay
Fixed/Float	Fixed	
Projection Idx	Current Index	
Discounting Idx	Current Index	
Fix Rate/Fit Spd	input	
Std. Notnl	1,000,000.00	
Amortize Period		
Index Tenor	n/a	
Unit		
Yield Basis	Act/360	

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

Grid Point ID 39 of Standard Official Index LIBOR_OIS.USD (ID 1020309 Version ID 102...

File Help

Grid Point Id: 39

Input Formula ☒ Alternate Formulas ☐

input;

	Receive	Pay
Fixed/Float	Fixed	Float
Projection Idx	Current Index	Current Index
Discounting Idx	OIS_Test.USD	OIS_Test.USD
Fix Rate/Flt Spd	input	0
Std. Notnl	1,000,000.00	1,000,000.00
Amortize Period		
Index Tenor	n/a	3m
Unit		
Yield Basis	Act/360	Act/360
Reset Period	n/a	3m
Payment Period	1y	3m
Avg Period	n/a	n/a
Comp Period	n/a	3m
Averaging Type	Unweighted	Unweighted
Roll Convention	Normal - EOM	Normal - EOM
Profile Per End Date Adj		

Grid Point Label: 1y

Ins Category: Bond / Swap

Priority Level: Seven

Start Date: settle

End Date: 1y

Start Time:

End Time:

Effective Form: Rate

Input Format: Percent

Input Label: Rate

Input Min: Unlimited Min

Input Max: Unlimited Max

Delta Shift: 0.010000

Input Display: Show When Active

Epsilon: 0.000010000000

Shared Ins #: 0

MDO ID: /BXSU/US\$W1

Trading Ins:

Sensitivity: Effective

	Format	Use
input	Percent	Yes
effective	Percent	No
change	Percent	No
close	Percent	No
spread	Percent	No
adj	Percent	No
bo_spd	Percent	Yes
beta	Decima	Yes
def_load	Decima	No
exp_load	Decima	No

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

Grid Point ID 2 of Standard Official Index 1Mv3M_LIBOR_OIS.USD (ID 1020311 Version 1...

File Help

Grid Point Id: 2

☒ Input Formula ☐ Alternate Formulas

input;

	Receive	Pay
Fixed/Float	Float	Float
Projection Idx	LIBOR_OIS.U	Current Index
Discounting Idx	OIS_Test.USD	OIS_Test.USD
Fix Rate/Flt Spd	0	input
Std. Notnl	1,000,000.00	1,000,000.00
Amortize Period		
Index Tenor	3m	1m
Unit		
Yield Basis	Act/360	Act/360
Reset Period	3m	1m
Payment Period	3m	1m
Avg Period	n/a	n/a
Comp Period	3m	1m
Averaging Type	Unweighted	Unweighted
Roll Convention	Normal - EOM	Normal - EOM
Profile Per End Date Adj		

	Format	Use
input	BPS	Yes
effective	Percen	No
change	Percen	No
close	Percen	No
spread	Percen	No
adj	Percen	No
bo_spd	BPS	Yes
beta	BPS	Yes
def_load	Decima	No
exp_load	Decima	No

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

Grid Point ID 8 of Standard Official Index SWAP_CURVE.CAD (ID 1023046 Version ID 103...

File Help

	Value
Grid Point ID	8
Grid Point Label	4y
Ins Category	Bond / Swap
Priority Level	Eight (lowest)
Start Date	settle
End Date	4y
Effective Form	Rate
Input Format	Percent
Input Label	Rate
Input Min	-100.000000
Input Max	100.000000
Delta Shift	0.010000
Input Display	Show When Active
Epsilon	1.000000000000
Shared Ins #	0
MDO ID	None
Sensitivity	Effective

Input Formula
input;

	Receive	Pay
Fixed/Float	Float	Float
Projection Idx	IR_SWAP.CAD	IR_SWAP.USD
Discounting Idx	Current Index	SWAP_CURVE.USD
Fix Rate/Flt Spd	input	0
Std. Notnl	1,000,000.00	1,000,000.00
Index Tenor	3m	3m
Yield Basis	Act/365 Fixed	Act/360
Reset Period	3m	3m
Payment Period	3m	3m
Avg Period	n/a	n/a
Comp Period	3m	3m
Averaging Type	Unweighted	Unweighted
Roll Convention	Normal - EOM	Normal - EOM
Reset Generator	Serial Shift	Serial Shift

Input Field Label	Input Field Format	Input Field Is
input	Percent	Yes
effective	Percent	Yes
change	Percent	No
close	Percent	No
spread	Percent	No
adj	Percent	No
bo_spd	Percent	Yes
beta	Percent	Yes
def_load	Decimal	No
exp_load	Decimal	No
lag	Decimal	No

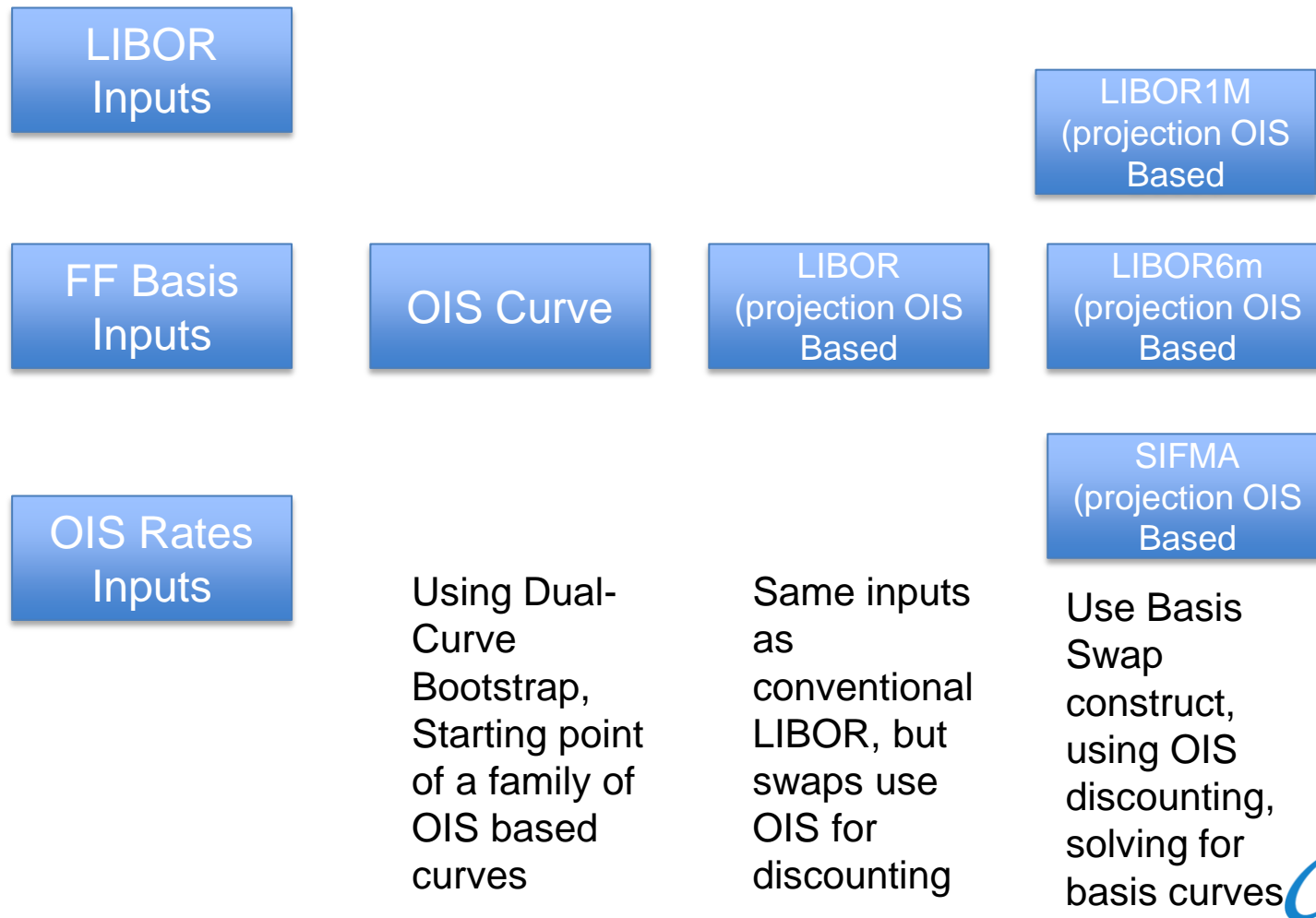
Multi-Curve Valuation Models

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

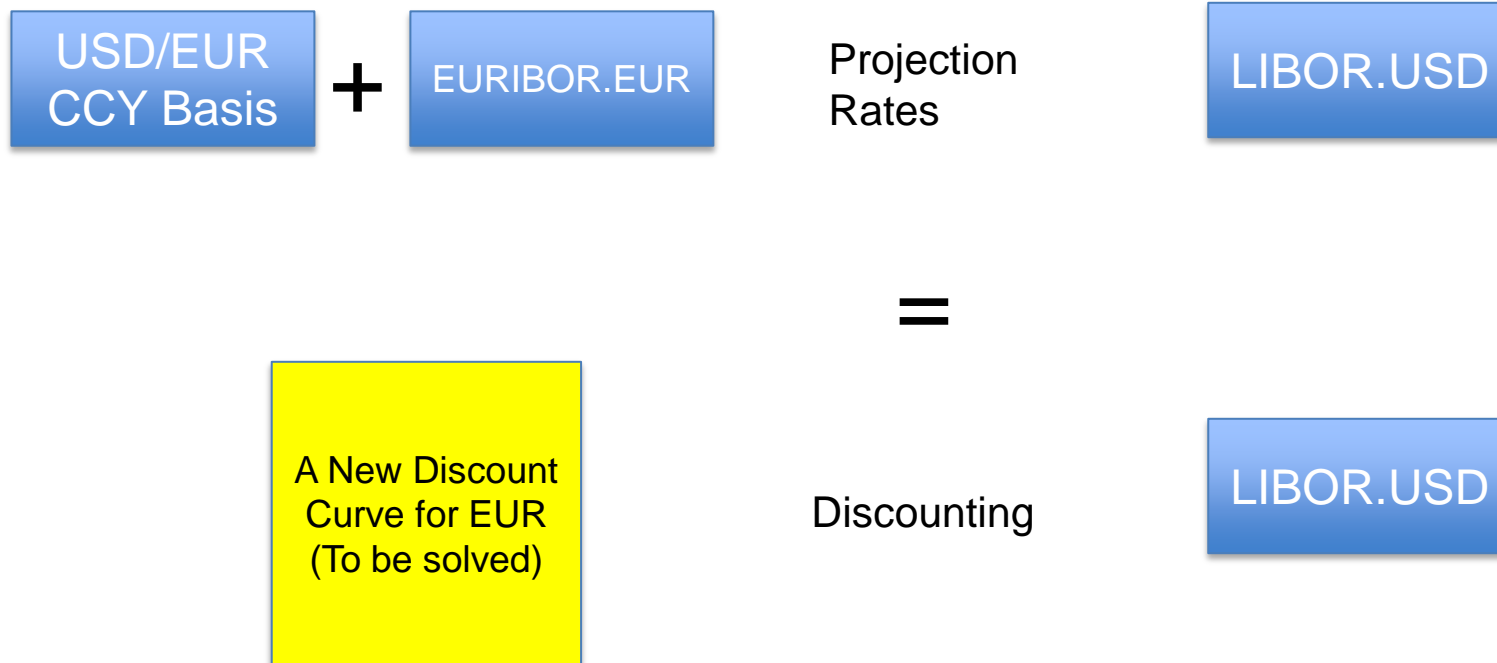
Conclusions and Discussions

- 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

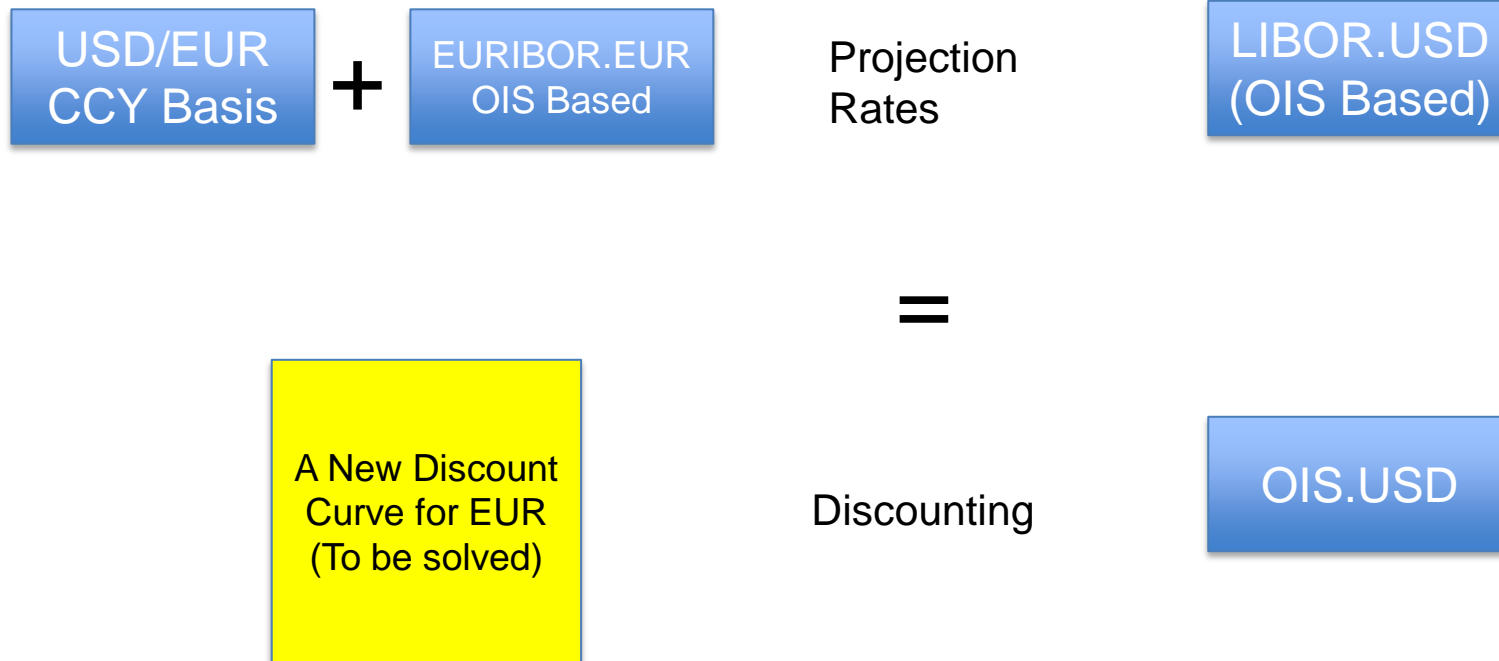
OIS Curve Structure for In-Currency Valuations



Cross Currency Curve Structure (Conventional)



Cross Currency Curve Structure (OIS Based)





Thank you