



# Low Latency Interest Rate Markets Theory, Pricing & Practice



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## PART ONE: Theory

### IR Markets, Products & Models

- Introduction to IR Markets
- Interest Rate Swaps
- IR Products & CDS
- Yield Curves
- IR Risk
- Credit Models

### Quant Research Papers

<https://ssrn.com/author=1728976>

### Support Materials: Quant Research, C++ and Excel Examples

<https://github.com/nburgessx/SwapsBook>

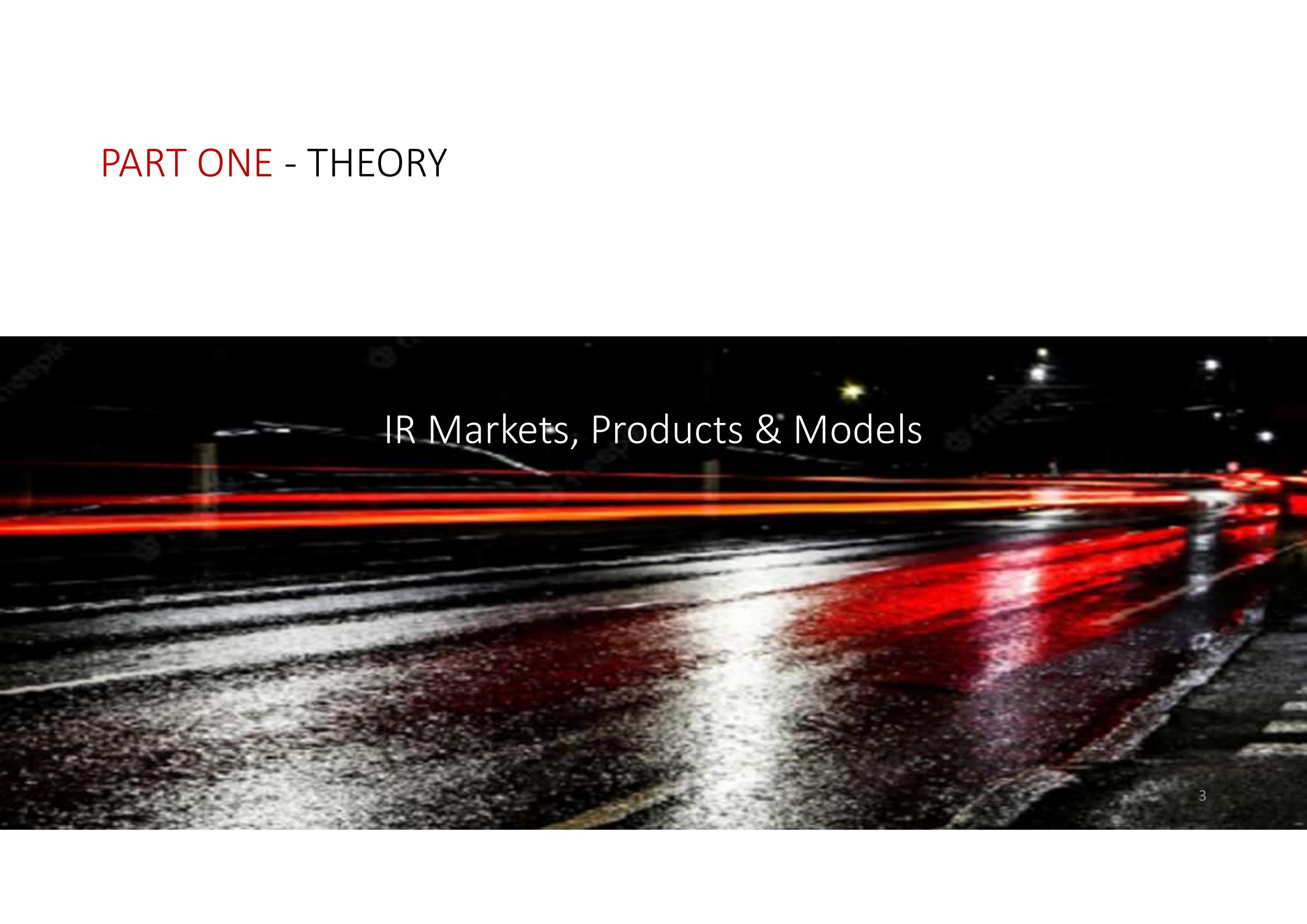
## PART TWO: Pricing & Practice

### Case Studies

- IRS Pricing Formulae
- IRS Pricing Case Study
- Asset Swap Structuring
- Asset Swap Pricing Case Study
- Pricing Tricks & Rules of Thumb



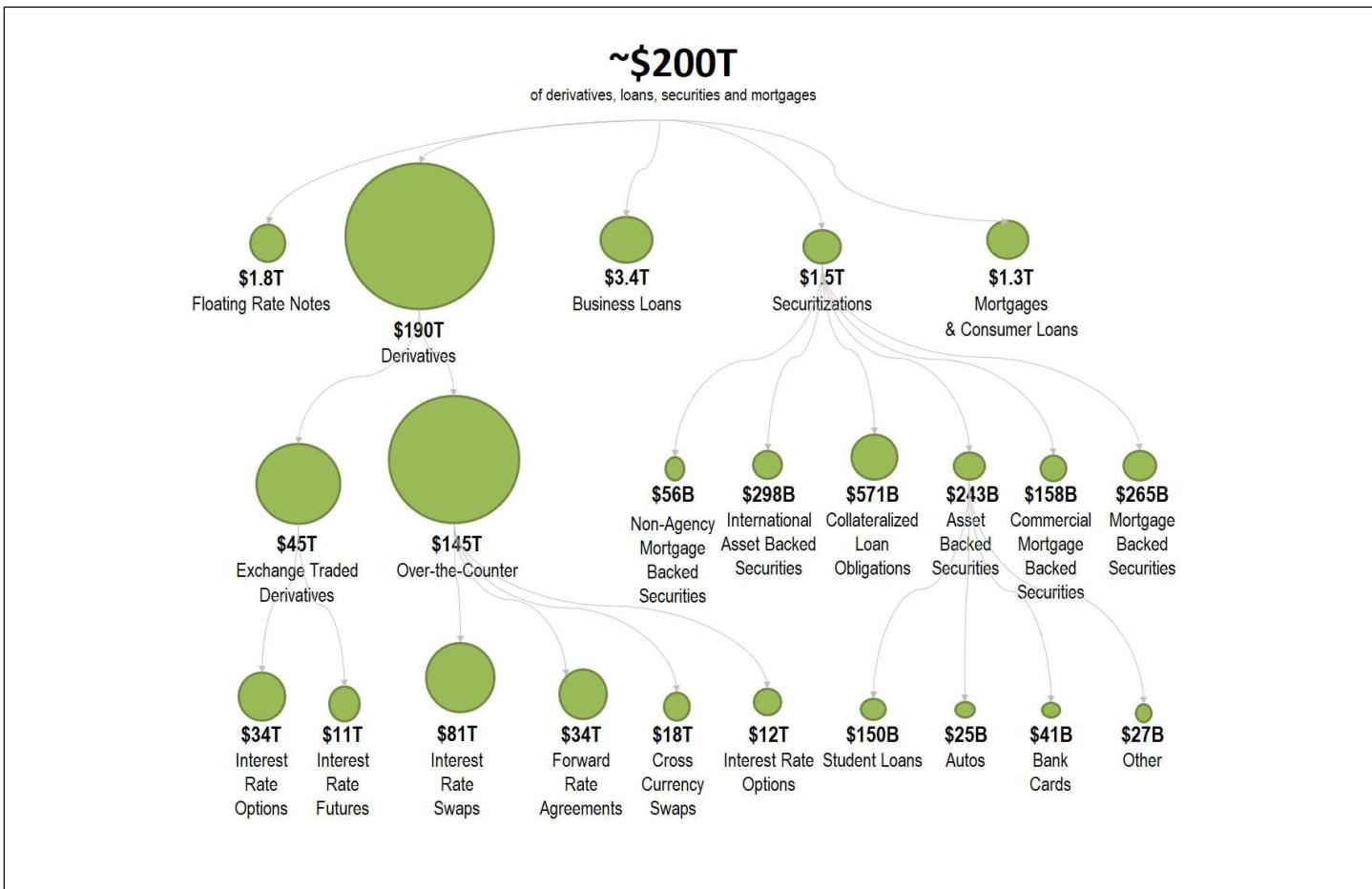
## PART ONE - THEORY

A blurred night photograph of a city street. The image shows streaks of red and orange light from moving vehicles, creating a sense of motion blur. The background is dark, and some distant lights are visible.

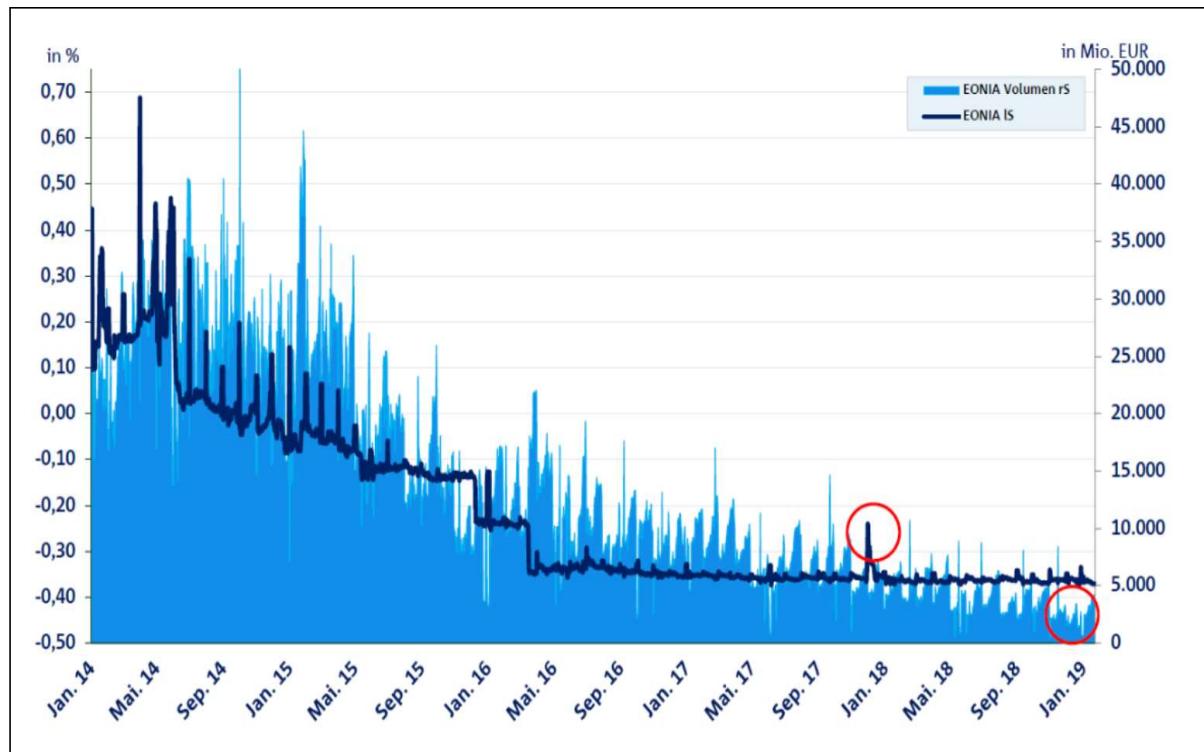
IR Markets, Products & Models

# Chapter 1 – Introduction to Interest Rate Markets

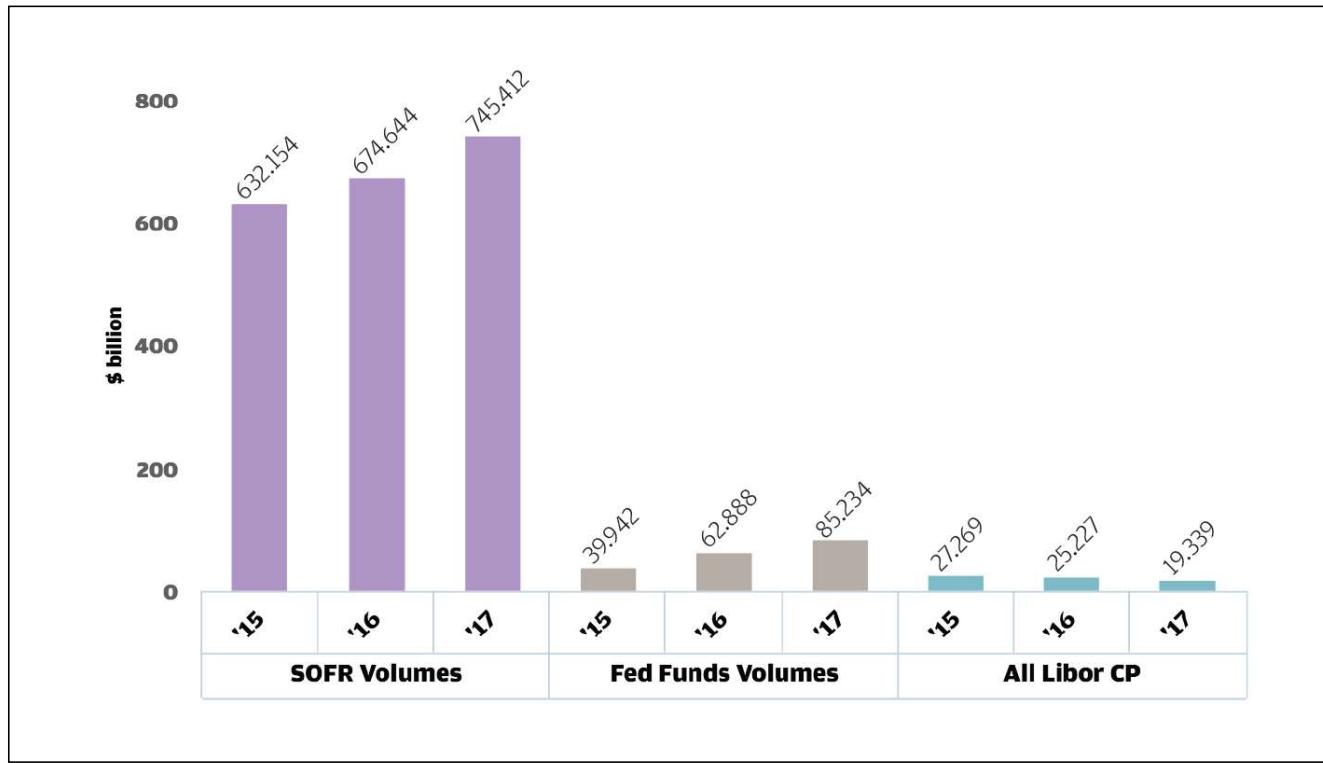
## USD Interest Rate Market



## EUR EONIA Interest Rate Market Volume



## US FED Fund, LIBOR & SOFR Volumes



## Alternative Risk-Free Rate Benchmarks

Overview of identified alternative RFRs in selected currency areas

	<b>United States</b>	<b>United Kingdom</b>	<b>Euro area</b>	<b>Japan</b>
Alternative rate	<b>SOFR</b> (secured overnight financing rate)	<b>SONIA</b> (sterling overnight index average)	<b>ESTER</b> (euro short-term rate)	<b>TONA</b> (Tokyo overnight average rate)
Administrator	Federal Reserve Bank of New York	Bank of England	ECB	Bank of Japan
Data source	Triparty repo, FICC GCF, FICC bilateral	Form SMMD (BoE data collection)	MMSR	Money market brokers
<b>Wholesale non-bank counterparties</b>	<b>Yes</b>	<b>Yes</b>	<b>Yes</b>	<b>Yes</b>
<b>Secured</b>	<b>Yes</b>	<b>No</b>	<b>No</b>	<b>No</b>
<b>Overnight rate</b>	<b>Yes</b>	<b>Yes</b>	<b>Yes</b>	<b>Yes</b>
Available now?	Yes	Yes	Oct 2019	Yes

FICC = Fixed Income Clearing Corporation; GCF = general collateral financing; MMSR = money market statistical reporting; SMMD = sterling money market data collection reporting.

Sources: ECB; Bank of Japan; Bank of England; Federal Reserve Bank of New York; Financial Stability Board; Bank of America Merrill Lynch; International Swaps and Derivatives Association.

## USD LIBOR vs SOFR Benchmark Rates

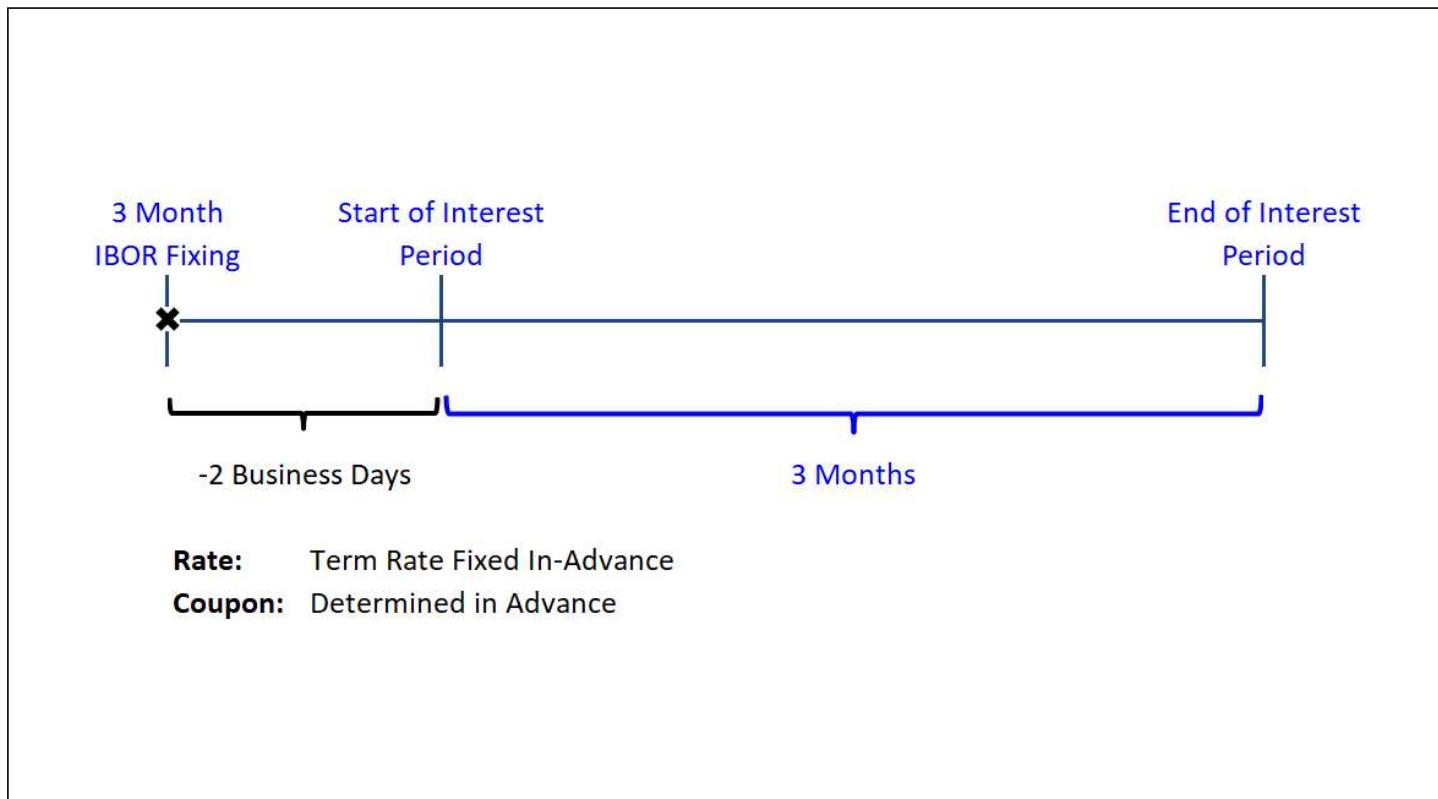
### LIBOR

1. Unsecured rate
2. Various maturities
3. Built-in credit component
4. Partially transaction based
5. \$500 million underlying transactions

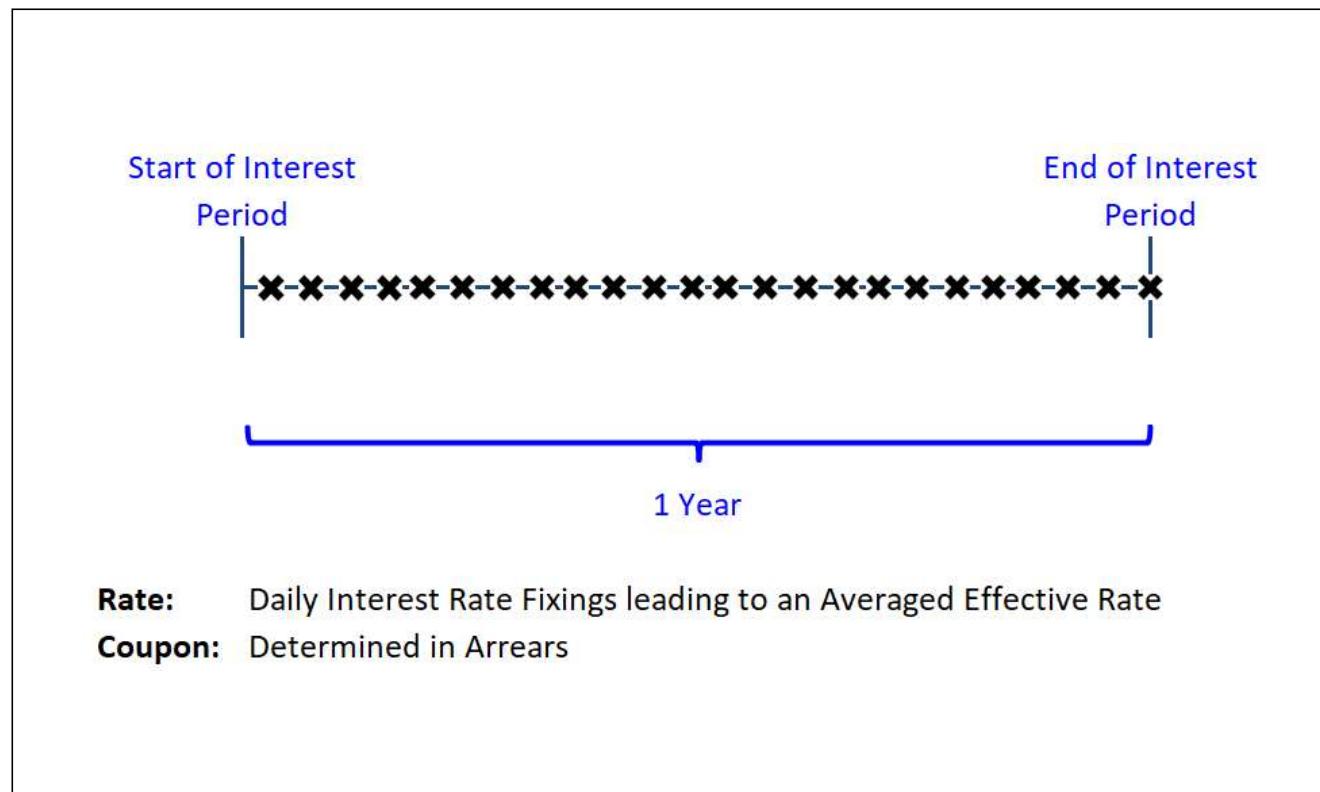
### SOFR

1. Secured rate
2. Overnight
3. Minimal credit risk
4. Wholly transaction-based
5. \$750 billion underlying transactions

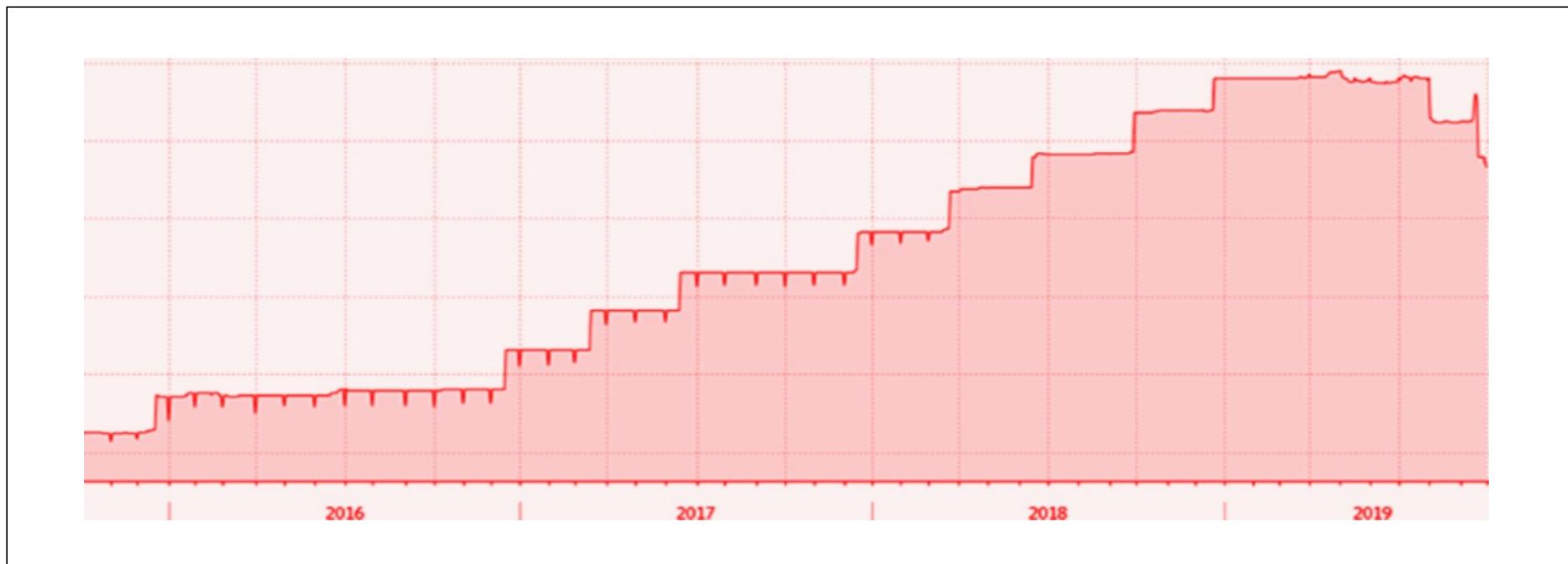
## LIBOR Fixing In-Advance



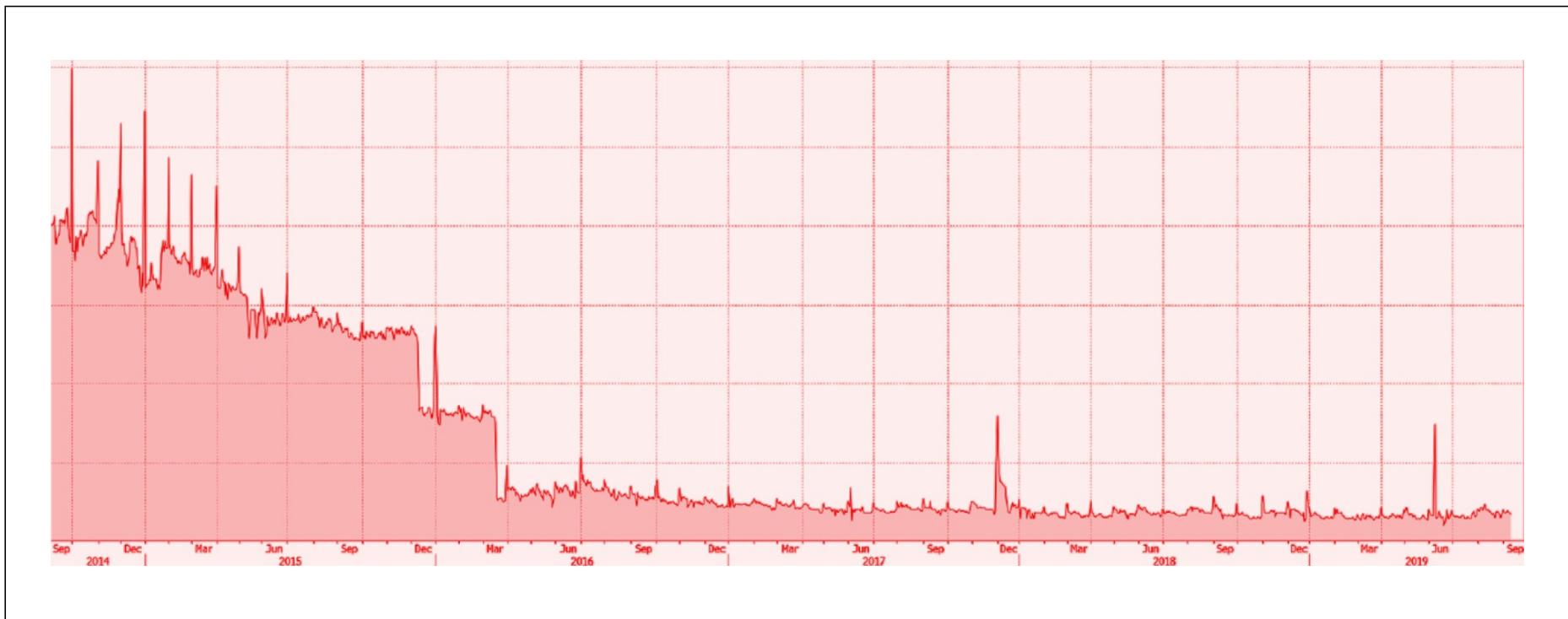
## Risk-Free Benchmarks – Daily IR Fixings



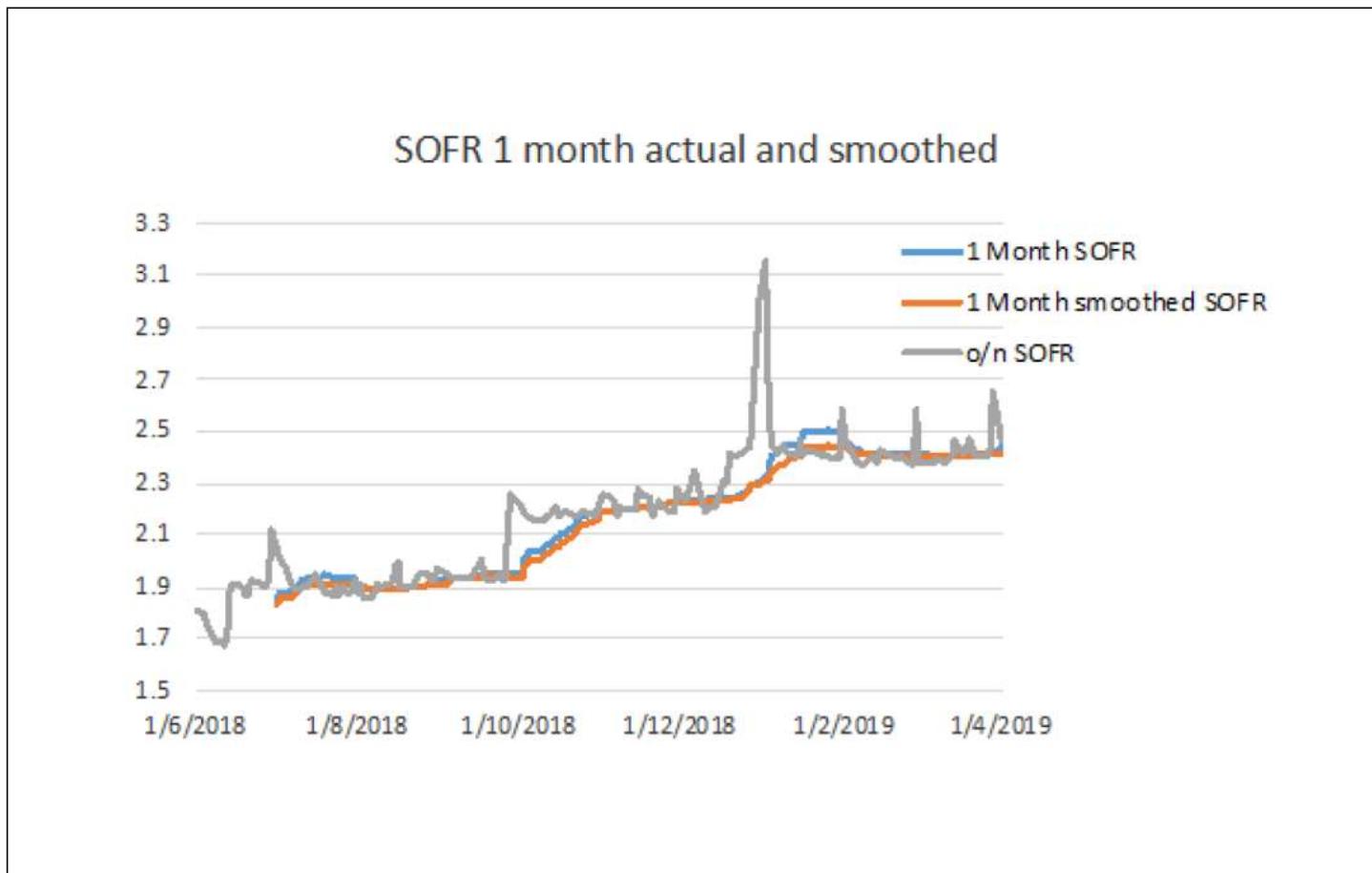
## US FED Funds Overnight Index (2015-2019)



## EUR EONIA Overnight Rate (2014-2019)

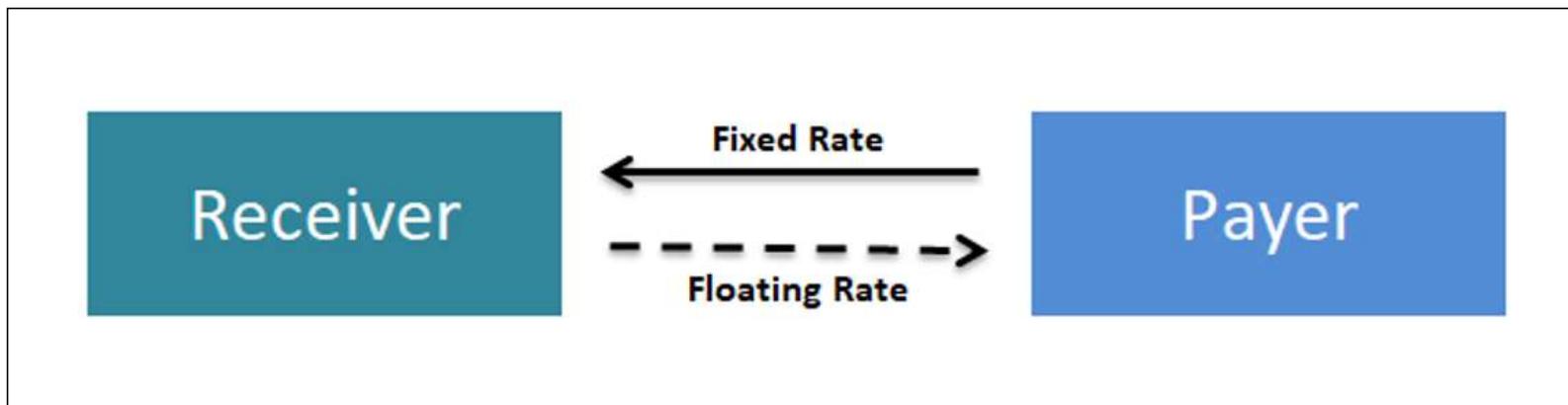


## USD SOFR Overnight and Term Rates (2018-2019)



## Chapter 2 – Introduction to Interest Rate Swaps

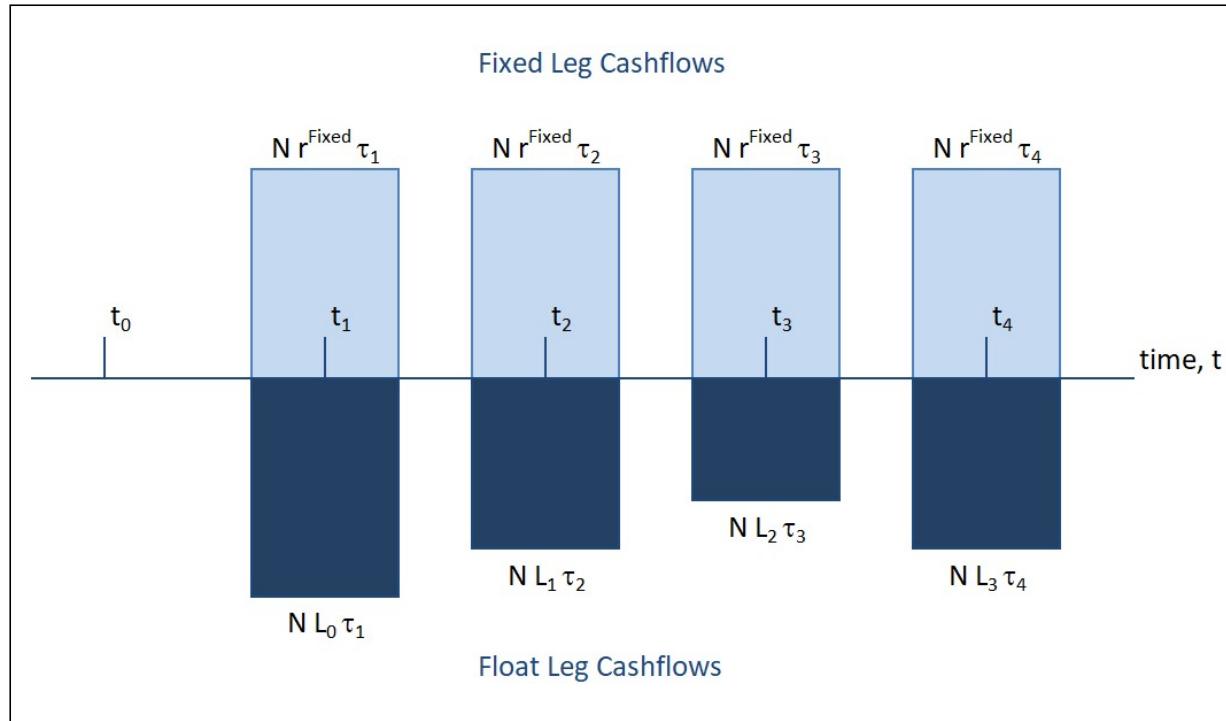
## Interest Rate Swap (IRS) – Exchange Fixed for Floating Interest



$$\text{Swap PV} = PV(\text{Fixed Leg}) - PV(\text{Float Leg})$$

$$\text{Swap PV} = \underbrace{\sum_{i=1}^n N r \tau_i P(t_0, t_i)}_{\text{Fixed Leg}} - \underbrace{\sum_{j=1}^m N(l_{j-1} + s) \tau_j P(t_0, t_j)}_{\text{Float leg}}$$

## IRS Fixed and Floating Cash Flows



$$\text{Swap PV} = \underbrace{\sum_{i=1}^n N r \tau_i P(t_0, t_i)}_{\text{Fixed Leg}} - \underbrace{\sum_{j=1}^m N(l_{j-1} + s) \tau_j P(t_0, t_j)}_{\text{Float leg}}$$

## IRS Pricing Formulae

$$\text{Swap PV} = \text{PV(Fixed Leg)} - \text{PV(Float Leg)}$$

$$\text{Swap PV} = \underbrace{\sum_{i=1}^n N r \tau_i P(t_0, t_i)}_{\text{Fixed Leg}} - \underbrace{\sum_{j=1}^m N(l_{j-1} + s) \tau_j P(t_0, t_j)}_{\text{Float leg}}$$

$$\text{Par Rate, } p = \frac{\sum_{j=1}^m N(l_{j-1} + s) \tau_j P(t_0, t_j)}{\sum_{i=1}^n N \tau_i P(t_0, t_i)} = \frac{\text{PV(Float Leg)}}{\text{Annuity(Fixed Leg)}}$$

## USD IRS – Quote Par Rate as a Spread to US Treasury Bond Yields

Spreads vs Treasuries				
Tenor	Bid	/	Ask	Change
1Y	14.627	/	15.614	-0.794
2Y	9.991	/	10.374	+0.068
3Y	8.082	/	8.432	-0.262
4Y	5.250	/	5.535	-0.385
5Y	5.053	/	5.446	-0.360
6Y	2.500	/	2.875	-0.253
7Y	0.356	/	0.671	-0.308
8Y	0.503	/	0.809	-0.877
9Y	-0.125	/	0.500	-0.377
10Y	0.072	/	0.441	-0.471
12Y	6.113	/	6.424	-1.038
15Y	1.123	/	1.375	-0.563
20Y	-4.875	/	-4.500	-0.565
25Y	-13.500	/	-13.000	-1.125
30Y	-24.171	/	-23.786	-0.715

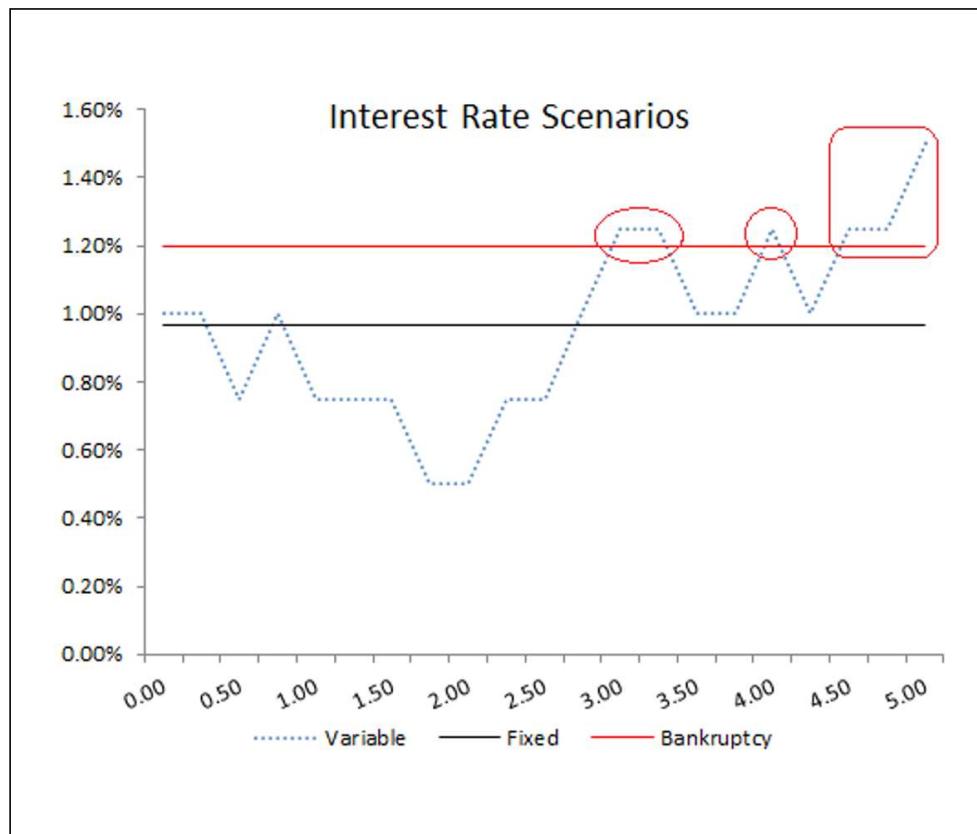
Swap Rate % = US Treasury Yield % + Spread

## EUR IRS – Quote as Par Rate

EUR 6M EURIBOR			
Tenor	Bid	Ask	Change
1Y	0.041	/	0.046 -0.002
18M	0.052	/	0.058 -0.002
2Y	0.075	/	0.080 -0.001
3Y	0.146	/	0.151 -0.001
4Y	0.241	/	0.246 -0.004
5Y	0.351	/	0.356 -0.004
6Y	0.470	/	0.475 -0.007
7Y	0.592	/	0.597 -0.009
8Y	0.711	/	0.716 -0.011
9Y	0.820	/	0.825 -0.014
10Y	0.917	/	0.922 -0.015
15Y	1.243	/	1.251 -0.024
20Y	1.377	/	1.385 -0.030
25Y	1.407	/	1.416 -0.035
30Y	1.413	/	1.423 -0.038

## Chapter 3 – Interest Rate Products & Pricing

## Interest Rate Scenarios & Bankruptcy



## New Interest Rate Swaps Trade at Par i.e. Zero PV

Swap PV \$0		Float Leg \$75,000					Fixed Leg \$75,000				
time, t	Notional, N	Float Rate, $I_i$	Accrual Period, $\tau_i$	Discount Factor, P	PV	time, t	Notional, N	Fixed Rate, R	Accrual Period, $\tau_i$	Discount Factor, P	PV
1	\$1,000,000	1.00%	1.00	1.0000	\$10,000	1	\$1,000,000	1.50%	1.00	1.0000	\$15,000
2	\$1,000,000	1.25%	1.00	1.0000	\$12,500	2	\$1,000,000	1.50%	1.00	1.0000	\$15,000
3	\$1,000,000	1.50%	1.00	1.0000	\$15,000	3	\$1,000,000	1.50%	1.00	1.0000	\$15,000
4	\$1,000,000	1.75%	1.00	1.0000	\$17,500	4	\$1,000,000	1.50%	1.00	1.0000	\$15,000
5	\$1,000,000	2.00%	1.00	1.0000	\$20,000	5	\$1,000,000	1.50%	1.00	1.0000	\$15,000



$$\text{Par Rate, } p = \frac{\sum_{j=1}^m N(I_{j-1} + s) \tau_j P(t_0, t_j)}{\sum_{i=1}^n N \tau_i P(t_0, t_i)} = \frac{PV(\text{Float Leg})}{\text{Annuity(Fixed Leg)}}$$

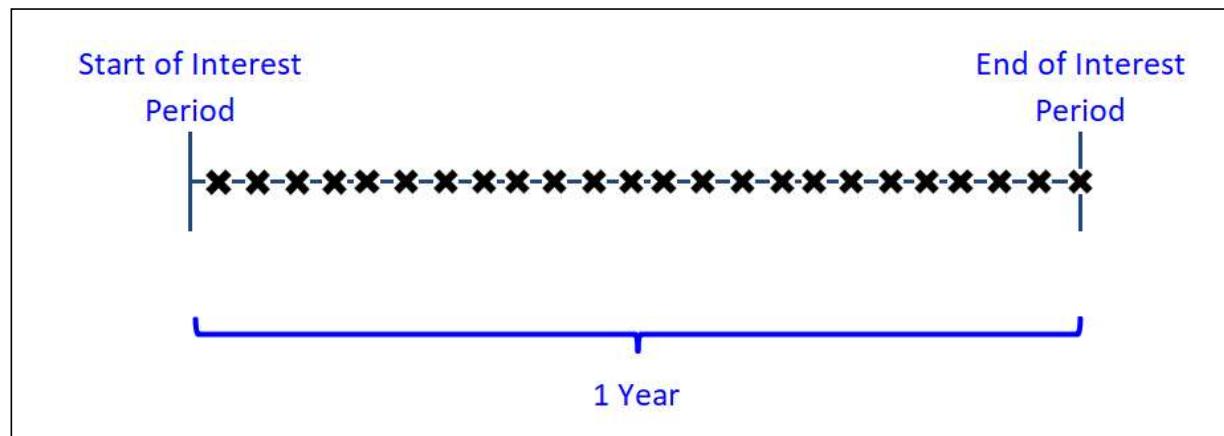
## Existing Interest Rate Swaps – Quote as a Present Value (PV)

Swap PV \$25,000			Float Leg \$100,000			Fixed Leg \$75,000					
time, t	Notional, N	Float Rate, $l_j$	Accrual Period, $\tau_j$	Discount Factor, P	PV	time, t	Notional, N	Fixed Rate, R	Accrual Period, $\tau_j$	Discount Factor, P	PV
1	\$1,000,000	1.50%	1.00	1.0000	\$15,000	1	\$1,000,000	1.50%	1.00	1.0000	\$15,000
2	\$1,000,000	1.75%	1.00	1.0000	\$17,500	2	\$1,000,000	1.50%	1.00	1.0000	\$15,000
3	\$1,000,000	2.00%	1.00	1.0000	\$20,000	3	\$1,000,000	1.50%	1.00	1.0000	\$15,000
4	\$1,000,000	2.25%	1.00	1.0000	\$22,500	4	\$1,000,000	1.50%	1.00	1.0000	\$15,000
5	\$1,000,000	2.50%	1.00	1.0000	\$25,000	5	\$1,000,000	1.50%	1.00	1.0000	\$15,000



$$Swap\ PV = \underbrace{\sum_{i=1}^n N r \tau_i P(t_0, t_i)}_{Fixed\ Cash\ Flows} - \underbrace{\sum_{j=1}^m N(l_{j-1} + s) \tau_j P(t_0, t_j)}_{Variable\ Floating\ Cash\ Flows}$$

## Overnight / RFR Indexed Swaps – Annual Coupons Comprising of Daily IR Fixings



## Swap Compounding Conventions – Arithmetic vs Geometric

		No. Coupon Term Days	Cpn YearFrac, $\tau_c$	Total GF	Total DF	
		30	0.0822	1.002192	0.997813	
Start	End	nDays	DailyRate, $r_i$	DailyYearFrac, $\tau_i$	GrowthFactor, GF	DiscountFactor, DF
Wed, 9-Dec-20	Thu, 10-Dec-20	1	4.89%	0.0027	1.000134	0.999866
Thu, 10-Dec-20	Fri, 11-Dec-20	1	4.18%	0.0027	1.000249	0.999751
Fri, 11-Dec-20	Mon, 14-Dec-20	3	1.81%	0.0082	1.000398	0.999603
Mon, 14-Dec-20	Tue, 15-Dec-20	1	3.11%	0.0027	1.000483	0.999517
Tue, 15-Dec-20	Wed, 16-Dec-20	1	1.46%	0.0027	1.000523	0.999477
Wed, 16-Dec-20	Thu, 17-Dec-20	1	0.85%	0.0027	1.000546	0.999454
Thu, 17-Dec-20	Fri, 18-Dec-20	1	1.48%	0.0027	1.000587	0.999414
Fri, 18-Dec-20	Mon, 21-Dec-20	3	0.41%	0.0082	1.000620	0.999380
Mon, 21-Dec-20	Tue, 22-Dec-20	1	4.51%	0.0027	1.000744	0.999257
Tue, 22-Dec-20	Wed, 23-Dec-20	1	1.25%	0.0027	1.000778	0.999222
Wed, 23-Dec-20	Thu, 24-Dec-20	1	4.30%	0.0027	1.000896	0.999105
Thu, 24-Dec-20	Fri, 25-Dec-20	1	2.57%	0.0027	1.000966	0.999034
Fri, 25-Dec-20	Mon, 28-Dec-20	3	3.70%	0.0082	1.001271	0.998730
Mon, 28-Dec-20	Tue, 29-Dec-20	1	2.09%	0.0027	1.001329	0.998673
Tue, 29-Dec-20	Wed, 30-Dec-20	1	3.10%	0.0027	1.001413	0.998589
Wed, 30-Dec-20	Thu, 31-Dec-20	1	4.24%	0.0027	1.001530	0.998473
Thu, 31-Dec-20	Fri, 1-Jan-21	1	2.62%	0.0027	1.001602	0.998401
Fri, 1-Jan-21	Mon, 4-Jan-21	3	4.73%	0.0082	1.001991	0.998013
Mon, 4-Jan-21	Tue, 5-Jan-21	1	3.99%	0.0027	1.002101	0.997903
Tue, 5-Jan-21	Wed, 6-Jan-21	1	0.82%	0.0027	1.002124	0.997881
Wed, 6-Jan-21	Thu, 7-Jan-21	1	1.35%	0.0027	1.002161	0.997844
Thu, 7-Jan-21	Fri, 8-Jan-21	1	1.16%	0.0027	1.002192	0.997813

<b>Arithmetic Rate</b>	<b>Geometric Rate</b>	<b>Fast Geometric Rate</b>
<b>2.6646%</b>	<b>2.6673%</b>	<b>2.6673%</b>

$$r_A = \left( \sum_{i=1}^n r_i \tau_i \right) / \tau_c$$

$$r_G = \left( \prod_{i=1}^n (1 + r_i \tau_i) - 1 \right) / \tau_c$$

$$r_{FG} = \left( \left( \frac{1}{DF_n} \right) - 1 \right) / \tau_c$$


## Swap Booking Template

Swap Generator Template		USD_SWAP_3M	
Dynamic Trade Info	LEG TYPE PAY / RECEIVE	LEG1:FIXED PAY	LEG2:FLOAT RECEIVE
	NOTIONAL 1,000,000	1,000,000	1,000,000
	FIXED RATE (%) 1.00%	1.00%	-
	FLOAT SPREAD (BPS) 0.00	-	0.00
	EFFECTIVE DATE / LAG 2D	2D	2D
	MATURITY DATE / TENOR 2Y	2Y	2Y
	LEG CURRENCY USD	USD	USD
	NOTIONAL EXCHANGE NONE	NONE	NONE
	LEVERAGE 1.00	1.00	1.00
	FRONT STUB INDEX -	-	NATURAL
Static Data + Schedule Info	BACK STUB INDEX -	-	NATURAL
	VALUATION CURRENCY USD	USD	USD
	FORECAST INDEX -	-	USD3M
	DISCOUNT INDEX USDOIS	USDOIS	USDOIS
	INDEX COMPOUND METHOD -	-	NONE
	SPREAD COMPOUND METHOD -	-	NONE
	ROLL DAY END	END	END
	STUB TYPE SHORT START	SHORT START	SHORT START
	FIXING BUS DAY ADJUSTMENT -	-	MODIFIED_FOLLOWING
	FIXING CALENDAR -	-	NY+LDN
	FIXING LAG -	-	2D
	FIXING IN-ADVANCE / IN-ARREARS SEMI-ANNUAL	SEMI-ANNUAL	IN-ADVANCE
	ACCRUAL FREQUENCY MODIFIED_FOLLOWING	MODIFIED_FOLLOWING	QUARTERLY
	ACCRUAL BUS DAY ADJUSTMENT NY	NY	MODIFIED_FOLLOWING
	ACCRUAL CALENDAR 30/360	30/360	NY
	ACCRUAL DAYCOUNT SEMI-ANNUAL	SEMI-ANNUAL	ACT/360
	PAYMENT FREQUENCY MODIFIED_FOLLOWING	MODIFIED_FOLLOWING	QUARTERLY
	PAYMENT BUS DAY ADJUSTMENT NY	NY	MODIFIED_FOLLOWING
	PAYMENT CALENDAR 2D	2D	NY
	PAYMENT LAG 2D	2D	2D

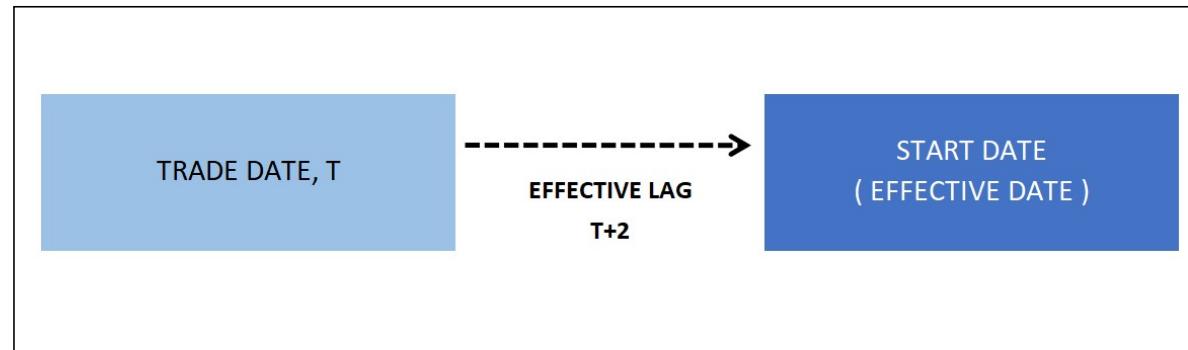


## Swap Booking Convention using Swap Generator Template Shorthand

Swap Generator	Pay/Rec	Notional	Fixed (%)	Spread (bps)	Maturity	Trade Handle
	Fixed					
USD_SWAP_3M	PAY	1,000,000	1.00%	0.00	1Y	USD_SB3_1Y:0
USD_SWAP_3M	PAY	1,000,000	1.00%	0.00	2Y	USD_SB3_2Y:0
USD_SWAP_3M	PAY	1,000,000	1.00%	0.00	3Y	USD_SB3_3Y:0
USD_SWAP_3M	PAY	1,000,000	1.00%	0.00	4Y	USD_SB3_4Y:0
USD_SWAP_3M	PAY	1,000,000	1.00%	0.00	5Y	USD_SB3_5Y:0
USD_SWAP_3M	PAY	1,000,000	1.00%	0.00	6Y	USD_SB3_6Y:0
USD_SWAP_3M	PAY	1,000,000	1.00%	0.00	7Y	USD_SB3_7Y:0
USD_SWAP_3M	PAY	1,000,000	1.00%	0.00	8Y	USD_SB3_8Y:0
USD_SWAP_3M	PAY	1,000,000	1.00%	0.00	9Y	USD_SB3_9Y:0
USD_SWAP_3M	PAY	1,000,000	1.00%	0.00	10Y	USD_SB3_10Y:0
USD_SWAP_3M	PAY	1,000,000	1.00%	0.00	11Y	USD_SB3_11Y:0
USD_SWAP_3M	PAY	1,000,000	1.00%	0.00	12Y	USD_SB3_12Y:0
USD_SWAP_3M	PAY	1,000,000	1.00%	0.00	13Y	USD_SB3_13Y:0
USD_SWAP_3M	PAY	1,000,000	1.00%	0.00	14Y	USD_SB3_14Y:0
USD_SWAP_3M	PAY	1,000,000	1.00%	0.00	15Y	USD_SB3_15Y:0
USD_SWAP_3M	PAY	1,000,000	1.00%	0.00	20Y	USD_SB3_20Y:0
USD_SWAP_3M	PAY	1,000,000	1.00%	0.00	25Y	USD_SB3_25Y:0
USD_SWAP_3M	PAY	1,000,000	1.00%	0.00	30Y	USD_SB3_30Y:0



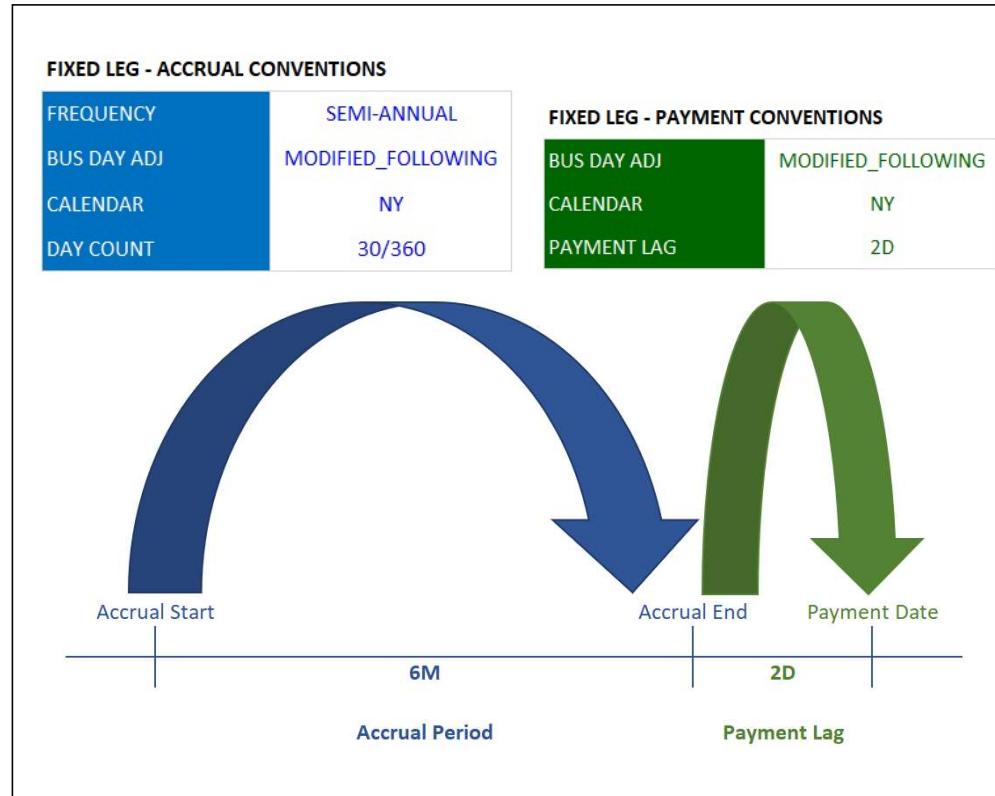
## Effective Lag: Trade Date vs Start Date (Effective Date)



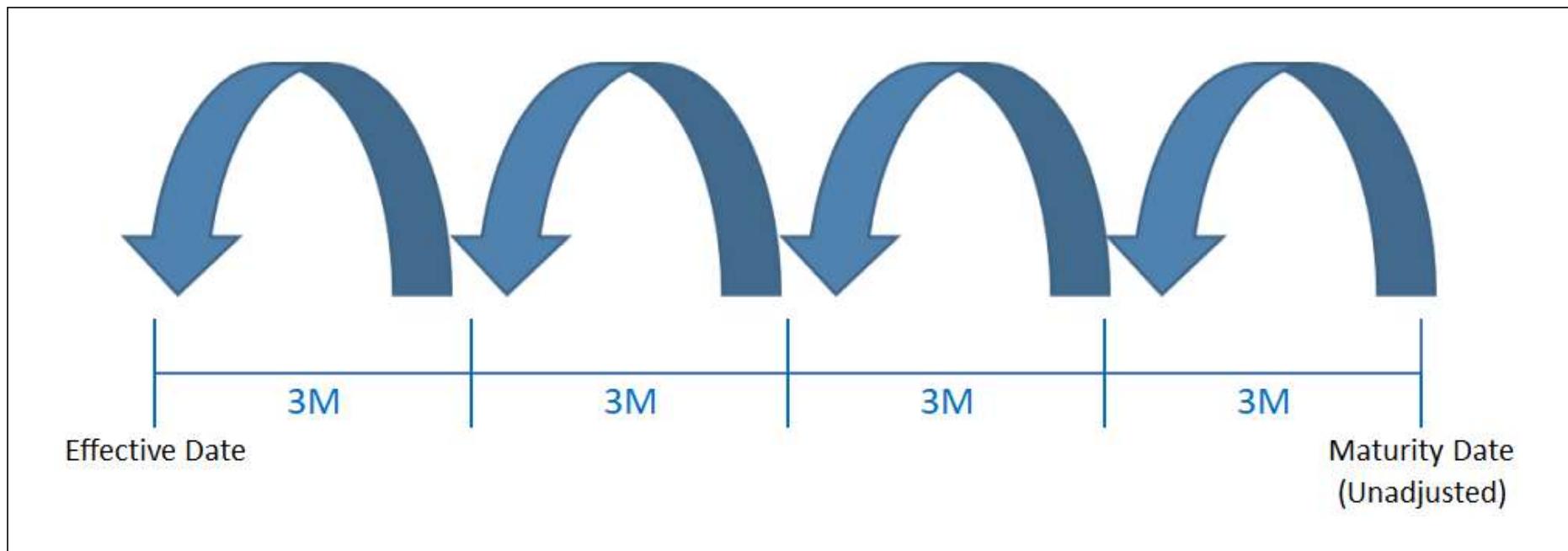
## Swap Conventions: IR Fixings, Accrual and Payment Dates

FLOAT LEG - FIXED CONVENTIONS	
BUS DAY ADJ	MODIFIED_FOLLOWING
CALENDAR	NY+LDN
FIXING LAG	2D
FLOAT LEG - ACCRUAL CONVENTIONS	
FREQUENCY	QUARTERLY
BUS DAY ADJ	MODIFIED_FOLLOWING
CALENDAR	NY
DAY COUNT	ACT/360
FIXED LEG - ACCRUAL CONVENTIONS	
FREQUENCY	SEMI-ANNUAL
BUS DAY ADJ	MODIFIED_FOLLOWING
CALENDAR	NY
DAY COUNT	30/360
FLOAT LEG - PAYMENT CONVENTIONS	
BUS DAY ADJ	MODIFIED_FOLLOWING
CALENDAR	NY
PAYMENT LAG	2D
FIXED LEG - PAYMENT CONVENTIONS	
BUS DAY ADJ	MODIFIED_FOLLOWING
CALENDAR	NY
PAYMENT LAG	2D

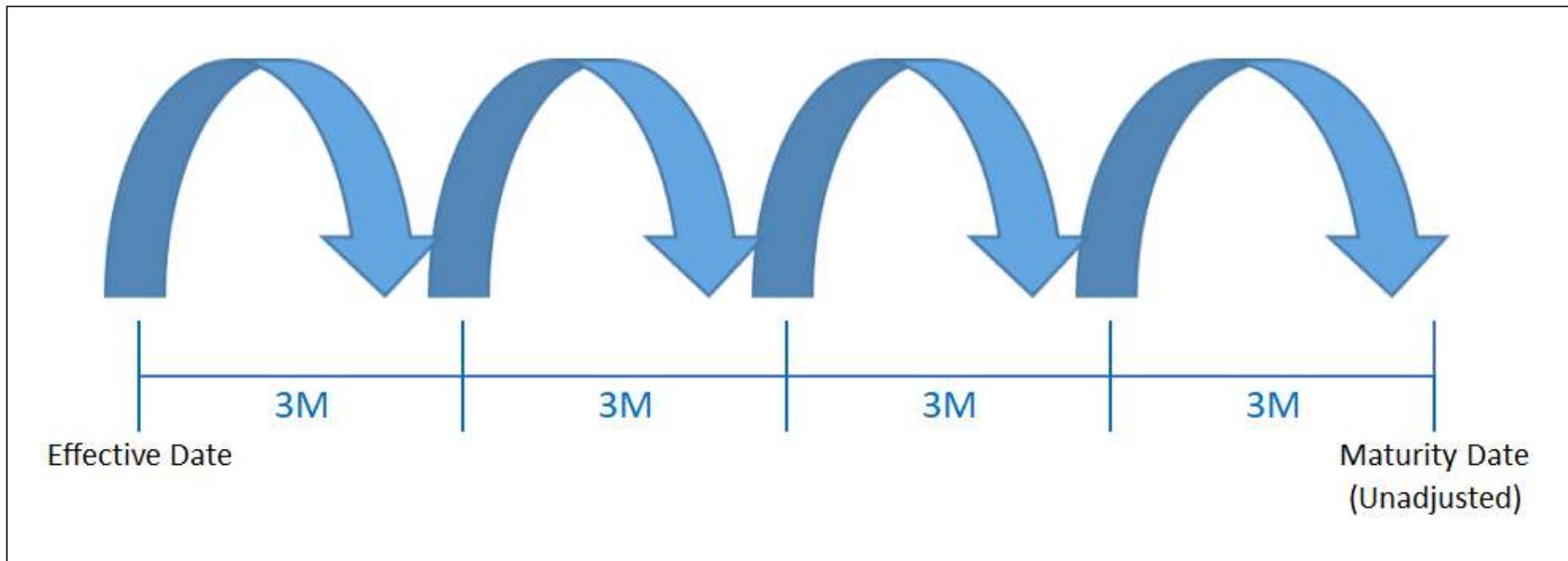
## Fixed Leg – Accrual Date Conventions



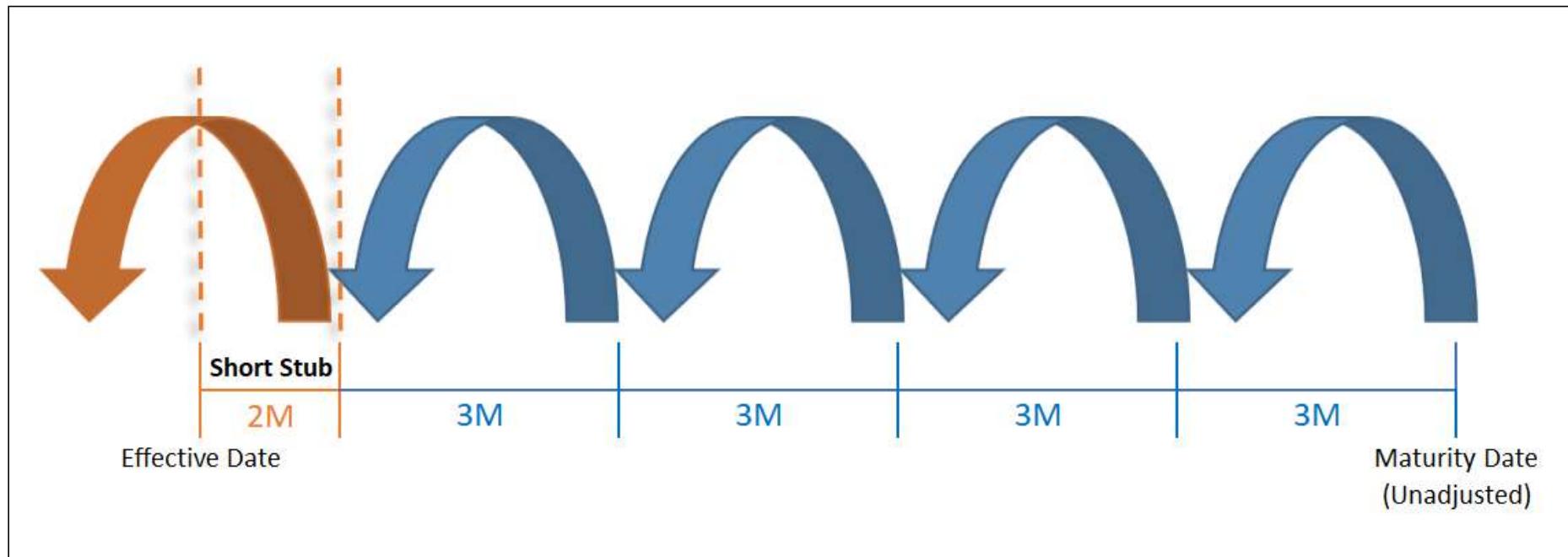
Swap Accrual Date Conventions (Market Default = SHORT START i.e. Roll Backwards)



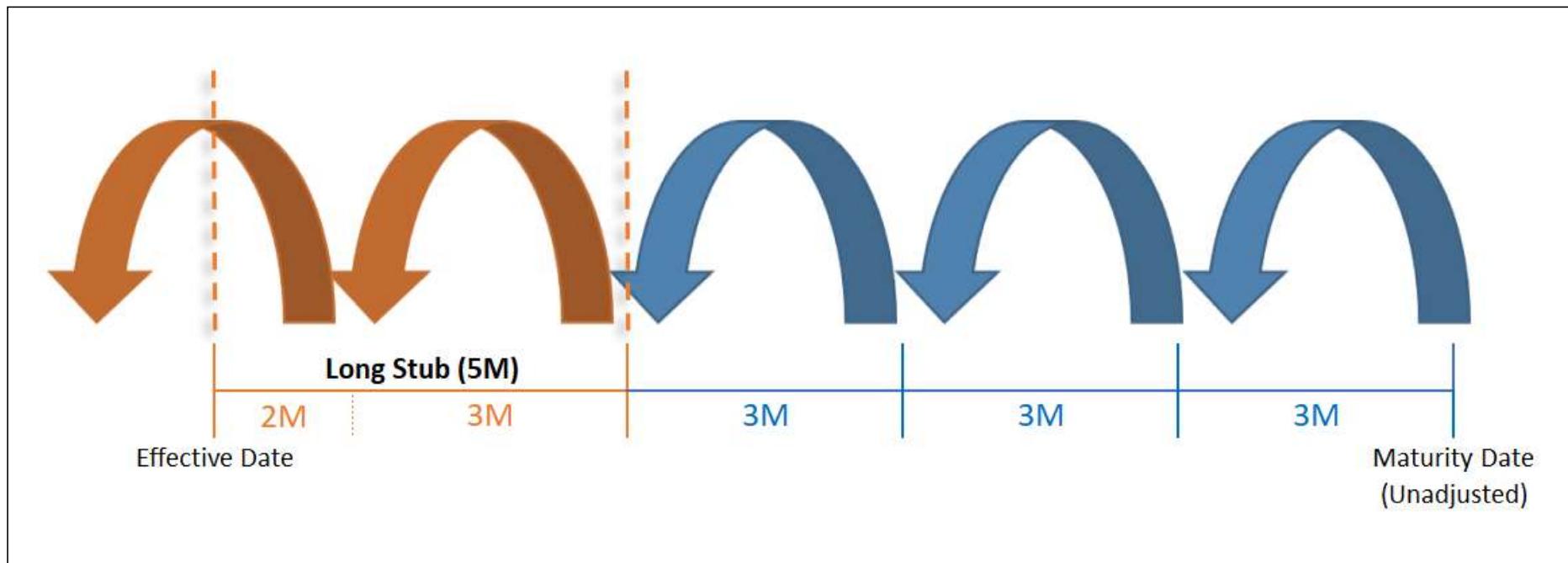
Accrual Dates when using SHORT END i.e. Roll Forwards



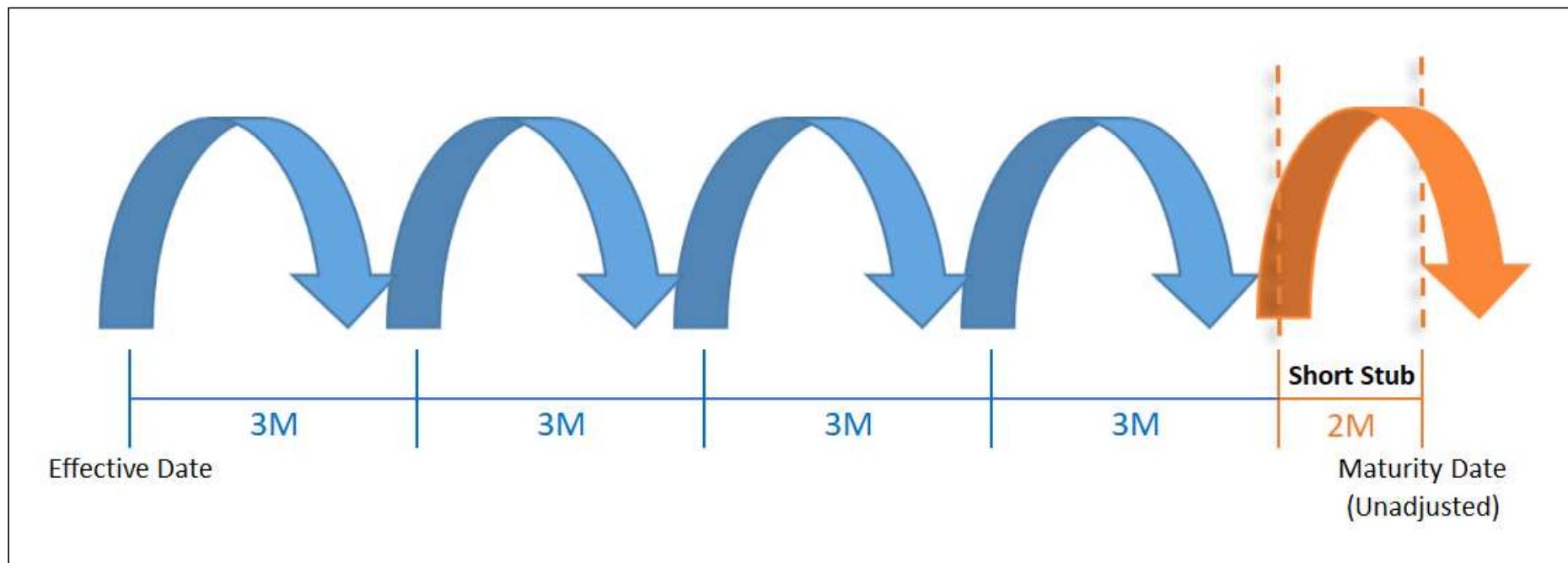
## Stub Coupons: SHORT START



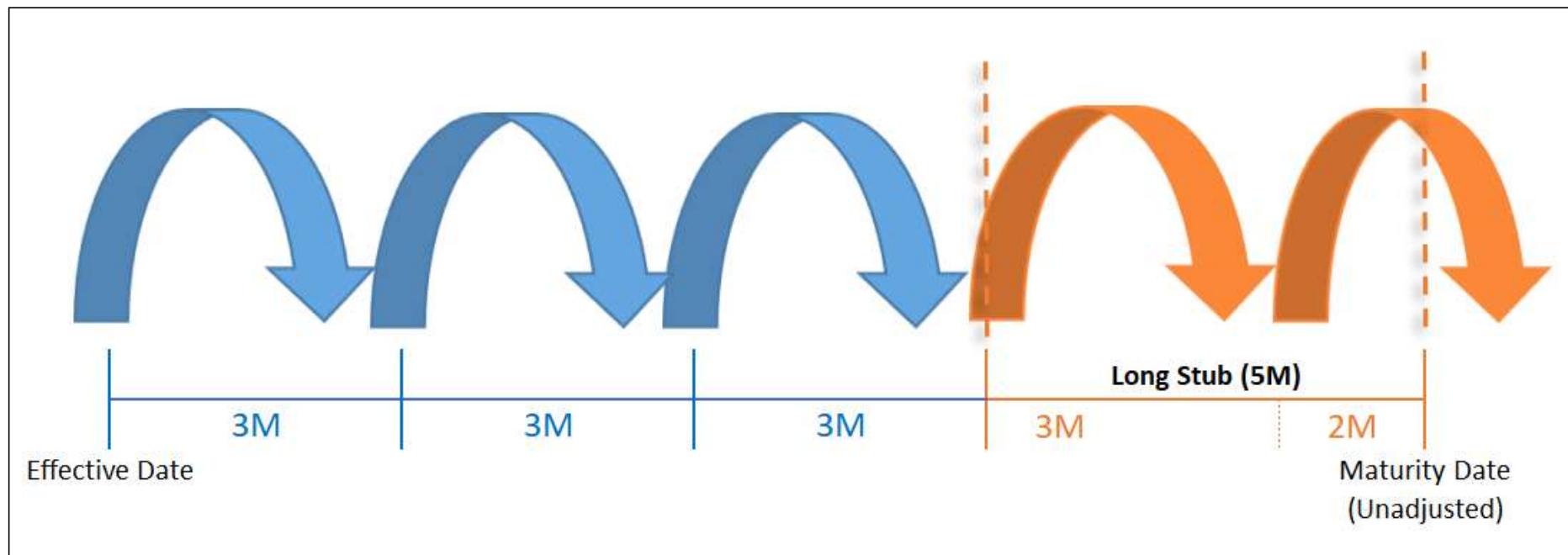
## Stub Coupons: LONG START



## Stub Coupons: SHORT END



Stub Coupons: LONG END



## Fixed Leg: Accrual Year Fractions & Payment Discount Factors

Year Fraction		Discount Factor	
Accrual Start	Accrual End	Pay Date	
21-May-22	19-Nov-22	19-Nov-22	
19-Nov-22	21-May-23	21-May-23	
21-May-23	19-Nov-23	19-Nov-23	
19-Nov-23	20-May-24	20-May-24	

Fixed Leg				
N	r <sup>Fixed</sup>	τ <sub>i</sub>	P( t <sub>0</sub> , t <sub>i</sub> )	NPV <sup>Fixed</sup>
1,000,000	1.0000%	0.50	0.997824	4,989
1,000,000	1.0000%	0.50	0.994549	4,973
1,000,000	1.0000%	0.50	0.991815	4,959
1,000,000	1.0000%	0.50	0.987801	4,939

$$PV^{Fixed\ Leg} = r \sum_{i=1}^n N_i \tau_i P(t_0, t_i)$$




## Float Leg: IR Fixings, Accrual Year Fractions & Payment Discount Factors

Forward Rate		Year Fraction		Discount Factor	
Fixing Date		Accrual Start	Accrual End	Pay Date	
19-May-22		21-May-22	20-Aug-22	20-Aug-22	
18-Aug-22		20-Aug-22	19-Nov-22	19-Nov-22	
17-Nov-22		19-Nov-22	18-Feb-23	18-Feb-23	
16-Feb-23		18-Feb-23	21-May-23	21-May-23	
19-May-23		21-May-23	20-Aug-23	20-Aug-23	
18-Aug-23		20-Aug-23	19-Nov-23	19-Nov-23	
17-Nov-23		19-Nov-23	19-Feb-24	19-Feb-24	
17-Feb-24		19-Feb-24	20-May-24	20-May-24	

**Float Leg**

N	$l_{j-1}$	s	$\tau_j$	$P(t_0, t_j)$	$NPV^{\text{float}}$
1,000,000	0.2800%	0.00	0.25	0.999302	700
1,000,000	0.2995%	0.00	0.25	0.997824	747
1,000,000	0.3385%	0.00	0.25	0.996240	843
1,000,000	0.3775%	0.00	0.25	0.994549	939
1,000,000	0.4165%	0.00	0.25	0.992752	1,034
1,000,000	0.4555%	0.00	0.25	0.991815	1,129
1,000,000	0.4750%	0.00	0.25	0.989860	1,175
1,000,000	0.5140%	0.00	0.25	0.987801	1,269

$$PV^{\text{float Leg}} = \sum_{j=1}^m N_j (l_{j-1} + s) \tau_j P(t_0, t_j)$$

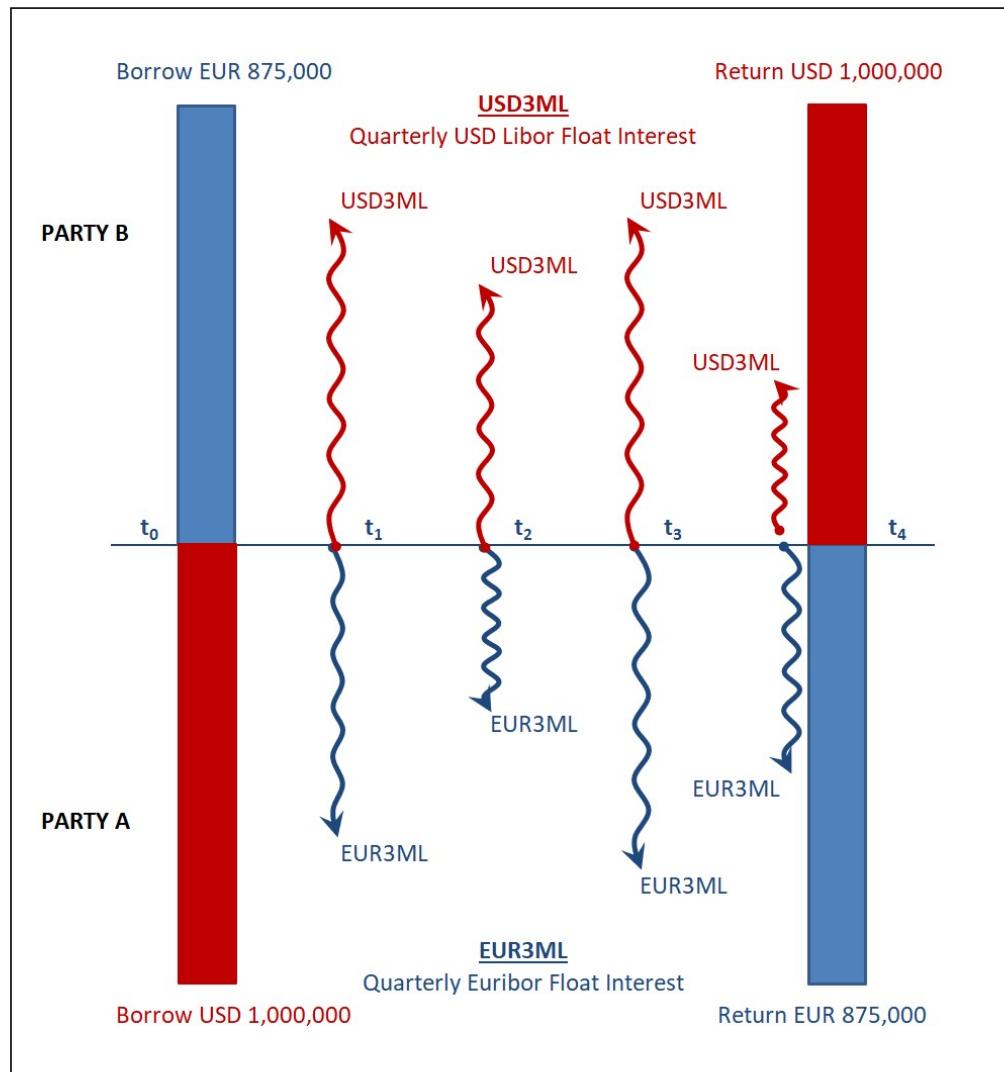

## LIBOR Conventions: Coupon Frequency & Daycount

SWAP LEG	CONVENTION	EUR	USD	GBP	JPY
FLOAT LEG	FREQUENCY DAYCOUNT	SEMI-ANNUAL ACT/360	QUARTERLY ACT/360	SEMI-ANNUAL ACT/365	SEMI-ANNUAL ACT/360
FIXED LEG	FREQUENCY DAYCOUNT	ANNUAL 30E/360	SEMI-ANNUAL 30/360	SEMI-ANNUAL ACT/365	SEMI-ANNUAL ACT/365F

## RFR Conventions: Coupon Frequency & Daycount

SWAP LEG	CONVENTION	EUR	USD	GBP	JPY
FLOAT LEG	FREQUENCY DAYCOUNT	SEMI-ANNUAL ACT/360	QUARTERLY ACT/360	SEMI-ANNUAL ACT/365	SEMI-ANNUAL ACT/360
FIXED LEG	FREQUENCY DAYCOUNT	ANNUAL 30E/360	SEMI-ANNUAL 30/360	SEMI-ANNUAL ACT/365	SEMI-ANNUAL ACT/365F

## XCCY Swap Cash Flow Illustration



## XCCY Swap Trade Booking

	TRADE PARAMETERS	LEG1	LEG2
TRADE ECONOMICS	LegType	FLOAT	FLOAT
	Currency	EUR	USD
	Notional	8,769,622	10,000,000
	NotionalExchange	ALL	ALL
	PayReceive	PAY	RECEIVE
	EffectiveDate	Fri, 26-Oct-18	Fri, 26-Oct-18
	MaturityDateOrTenor	1Y	1Y
	FixedRate (%)	-	-
	FloatSpread (Bps)	0.00	0.00
	IndexCompoundMethod	NONE	NONE
	SpreadCompoundMethod	NONE	NONE
	Leverage	1.00	1.00
	ForecastCurve	EUR3M	USD3M
	DiscountCurve	EURDF_USDCSA	USDDF
MTM SWAPS	isMTMResetLeg	FALSE	TRUE
	ResetBaseFX	1.00000	1.14030
	ValuationCurrency	USD	USD
COUPON & STUB CONVENTIONS	CouponRollDay	NATURAL	NATURAL
	isEndOfMonth	TRUE	TRUE
	StubType	SHORT_START	SHORT_START
	FrontStubCurveIndex	NATURAL	NATURAL
	BackStubCurveIndex	NATURAL	NATURAL
	FrontStubDate	-	-
SCHEDULE INFORMATION	BackStubDate	-	-
	AccrualFrequency	QUARTERLY	QUARTERLY
	AccrualCalendar	TGT+NY+LON	TGT+NY+LON
	AccrualBusDayConv	MOD_FOLLOWING	MOD_FOLLOWING
	AccrualDaycount	ACT/360	ACT/360
	IRFixingBusDayConv	MOD_FOLLOWING	MOD_FOLLOWING
	IRFixingCalendar	TGT+NY+LON	TGT+NY+LON
	IRFixingLag	2D	2D
	IRFirstFixingLag	-	-
	PaymentFrequency	QUARTERLY	QUARTERLY
NON-DELIVERABLES	PaymentBusDayConv	MOD_FOLLOWING	MOD_FOLLOWING
	PaymentCalendar	TGT+NY+LON	TGT+NY+LON
	PaymentLag	2D	2D
	IsNonDeliverable	FALSE	FALSE
NON-DELIVERABLES	SettlementCurrency	-	-
	FFixingLag	-	-
	FFixingBusDayConv	-	-
	FFixingCalendar	-	-

## Non-Deliverable Currencies: Require FX Fixing Conventions

	Currency	Leg1	Leg2
NON- DELIVERABLES	IsNonDeliverable	TRUE	-
	SettlementCurrency	USD	-
	FXFixingLag	2D	-
	FXFixingBusDayConv	MOD_FOLLOWING	-
	FXFixingCalendar	SAO+NY	-

## USD/EUR XCCY Swap Transaction

TradeDate	Fri, 26-Oct-18	-
Maturity (Years)	Sat, 26-Oct-19	1Y
Trade Notional	1,000,000	-
Trade Currency	USD	-
MtM	YES	-
NotionalExchanges	YES	-
Reset Currency	USD	USD
CSA Currency	USD	-
Valuation Currency	USD	-
SpotFX	1.14030	USD/EUR
LegCurrency	EUR	USD
LegNotional	876,962	1,000,000
PayOrReceive	PAY	RECEIVE
LegType	FLOATING	FLOATING
RateOrSpread (%)	0.00000%	0.00000%
FloatIndex	EUR EURIBOR 3M	USD LIBOR 3M
Frequency	QUARTERLY	QUARTERLY
LegResetsRequired	NO	YES
LegSpotFX	0.87696	1.14030
ValuationFXAdj	1.14030	1.00000
DaycountBasis	ACT/360	ACT/360
UseMarketSchedule	NO	NO

## USD/EUR XCCY Swap Cash Flows

### LEG 1 - EUR CASH FLOWS

Notional	FXFixingDate	FwdFX	NotionalExch	FloatRate	Coupon	DiscFactor	CouponPV	SpotFX	ValuationPV
			876,962		876,962	1.000000	876,962	1.14030	1,000,000
-876,962	Fri, 26-Oct-18	0.87696	0	-0.31695%	703	1.002365	704	1.14030	803
-876,962	Fri, 25-Jan-19	0.86980	0	-0.31644%	701	1.004182	704	1.14030	803
-876,962	Fri, 26-Apr-19	0.86287	0	-0.28931%	641	1.005926	645	1.14030	736
-876,962	Fri, 26-Jul-19	0.85560	-876,962	-0.22709%	-876,459	1.007807	-883,301	1.14030	-1,007,229

### LEG 2 - USD CASH FLOWS

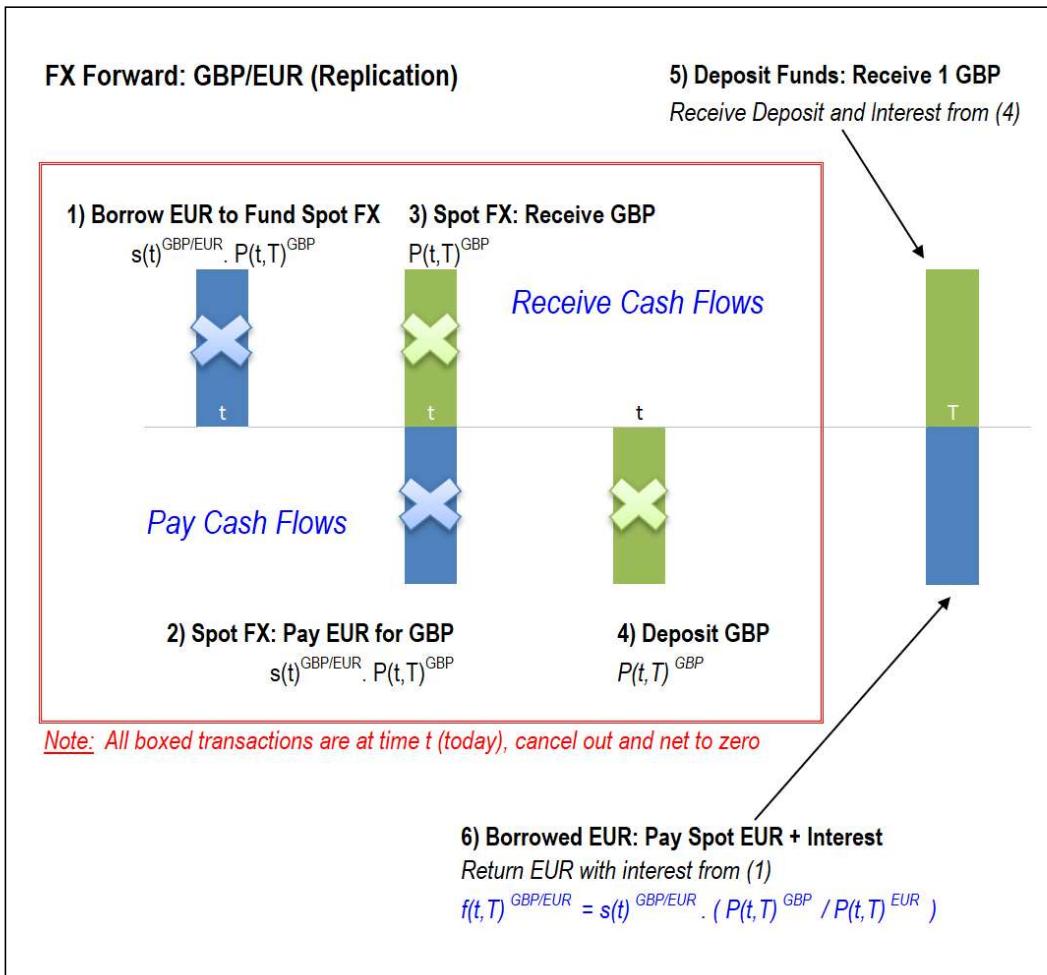
Notional	FXFixingDate	FwdFX	NotionalExch	FloatRate	Coupon	DiscFactor	CouponPV	SpotFX	ValuationPV
			-1,000,000		-1,000,000	1.000000	-1,000,000	1.00000	-1,000,000
1,000,000	Fri, 26-Oct-18	1.14030	-8,233	2.47475%	-1,977	0.994180	-1,966	1.00000	-1,966
1,008,233	Fri, 25-Jan-19	1.14969	-8,104	2.79581%	-979	0.988041	-967	1.00000	-967
1,016,337	Fri, 26-Apr-19	1.15893	-8,635	2.93764%	-1,088	0.981419	-1,067	1.00000	-1,067
1,024,972	Fri, 26-Jul-19	1.16878	1,024,972	3.05383%	1,032,884	0.974803	1,006,858	1.00000	1,006,858



## USD/EUR Marked-to-Market XCCY Swap (MTM)

Trade Template		USDEUR MTMXCCY USD3ML EUR3ML 1Y	
Swap	LEG1:FLOAT		LEG2:FLOAT
	RECEIVE		PAY
	1,000,000		884,799.15
	USD		EUR
	2D	Tue, 26-Mar-2019	2D
	1Y	Thu, 26-Mar-2020	Thu, 26-Mar-2020
	3M	USD3ML	EUR3ML
	0.000		-12.625
	QUARTERLY		QUARTERLY
	QUARTERLY		QUARTERLY
Day Count		ACT/360	ACT/360
Market			
Curve Date	Fri, 22-Mar-2019		Fri, 22-Mar-2019
Leg NPV	1,002,566.12		-1,002,566.12
Forecast Curve	USD3ML		EUR3ML
Discount Curve	USDOIS		EUROIS_USDCSA
Valuation Results			
Valuation Date	Fri, 22-Mar-2019		
Valuation Ccy	USD		
Par Spread (bps)	-12.625		
NPV	0.00		
BR01	-102.10		
DV01	0.00		

## FX Forward Replication



$$f(t,T)^{GBP/EUR} = s(t) \left( \frac{1 + r^{EUR}(T-t)}{1 + r^{GBP}(T-t)} \right)$$

## EUR/USD FX Forward Calculation (USD CSA)

FXFixingDate	$s^{\text{EUR/USD}}$	$P(t_0, t_i)^{\text{EUR\_USDCSA}}$	$P(t_0, t_i)^{\text{USD\_USDCSA}}$	$f(t_i)^{\text{USD/EUR}}$
Fri, 26-Oct-18	1.14030	1.000000	1.000000	1.14030
Fri, 25-Jan-19	1.14030	1.002365	0.994180	1.14969
Fri, 26-Apr-19	1.14030	1.004182	0.988041	1.15893
Fri, 26-Jul-19	1.14030	1.005926	0.981419	1.16878

x

$$f(t, T)^{\text{FOR/DOM}} = s(t)^{\text{FOR/DOM}} \left( \frac{P(t, T)^{\text{DOM\_CCYCSA}}}{P(t, T)^{\text{FOR\_CCYCSA}}} \right)$$

## EUR/USD XCCY MTM – Notional Resets on USD Leg

Notional <sup>EUR</sup>	FFixingDate	ForwardFX	Notional <sup>USD</sup>	NotionalReset <sup>USD</sup>
876,962	Fri, 26-Oct-18	1.14030	1,000,000	-8,233
876,962	Fri, 25-Jan-19	1.14969	1,008,233	-8,104
876,962	Fri, 26-Apr-19	1.15893	1,016,337	-8,635
876,962	Fri, 26-Jul-19	1.16878	1,024,972	1,024,972



$$N_{t_i}^{DOM} = N_{t_0}^{DOM} \left( \frac{f(t_0, t_i)^{DOM/FOR}}{s(t_0)^{DOM/FOR}} \right)$$

## EUR/USD XCCY Notionals for EUR and USD Trade Legs

### Notional Scaling Factor, $\psi(t, \text{EUR})$

Notional	$s^{\text{USD} / \text{EUR}}$	$f(t)^{\text{USD} / \text{EUR}}$	$\alpha(t, \text{EUR})$	$\beta(t, \text{EUR})$	$\psi(t, \text{EUR})$	NotionalAdj
876,962						
876,962	1.1403	1.1403	1.1403	1.0000	1.1403	1,000,000
876,962	1.1403	1.1403	1.1403	1.0000	1.1403	1,000,000
876,962	1.1403	1.1403	1.1403	1.0000	1.1403	1,000,000
876,962	1.1403	1.1403	1.1403	1.0000	1.1403	1,000,000

### Notional Scaling Factor, $\psi(t, \text{USD})$

Notional	$s^{\text{USD} / \text{EUR}}$	$f(t)^{\text{USD} / \text{EUR}}$	$\alpha(t, \text{USD})$	$\beta(t, \text{USD})$	$\psi(t, \text{USD})$	NotionalAdj
1,000,000						
1,000,000	1.1403	1.1403	1.0000	1.0000	1.0000	1,000,000
1,000,000	1.1403	1.1497	1.0000	1.0082	1.0082	1,008,233
1,000,000	1.1403	1.1589	1.0000	1.0163	1.0163	1,016,337
1,000,000	1.1403	1.1688	1.0000	1.0250	1.0250	1,024,972



## EUR/USD XCCY MTM – EUR and USD Cash Flows

### Leg1 - EUR Cashflows

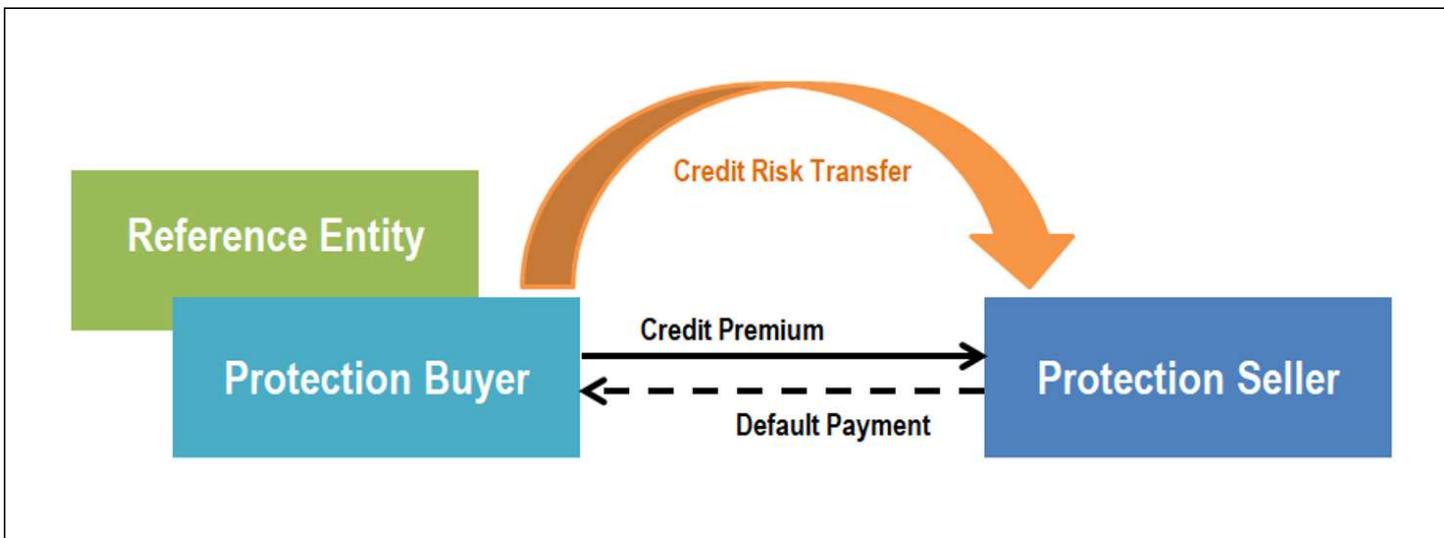
									USD	-4,887
Notional	FX Fixing Date	Fwd FX	Notional Exch	Spread	Float Rate	Coupon	Disc Factor	Coupon PV	Spot FX	Valuation PV
			876,962			876,962	1.0000	876,962	1.1403	1,000,000
-876,962	Fri, 26-Oct-18	0.8770	0	0.00%	-0.31695%	703	1.0024	704	1.1403	803
-876,962	Fri, 25-Jan-19	0.8698	0	0.00%	-0.31644%	701	1.0042	704	1.1403	803
-876,962	Fri, 26-Apr-19	0.8629	0	0.00%	-0.28931%	641	1.0059	645	1.1403	736
-876,962	Fri, 26-Jul-19	0.8556	-876,962	0.00%	-0.22709%	-876,459	1.0078	-883,301	1.1403	-1,007,229

### Leg2 - USD Cashflows

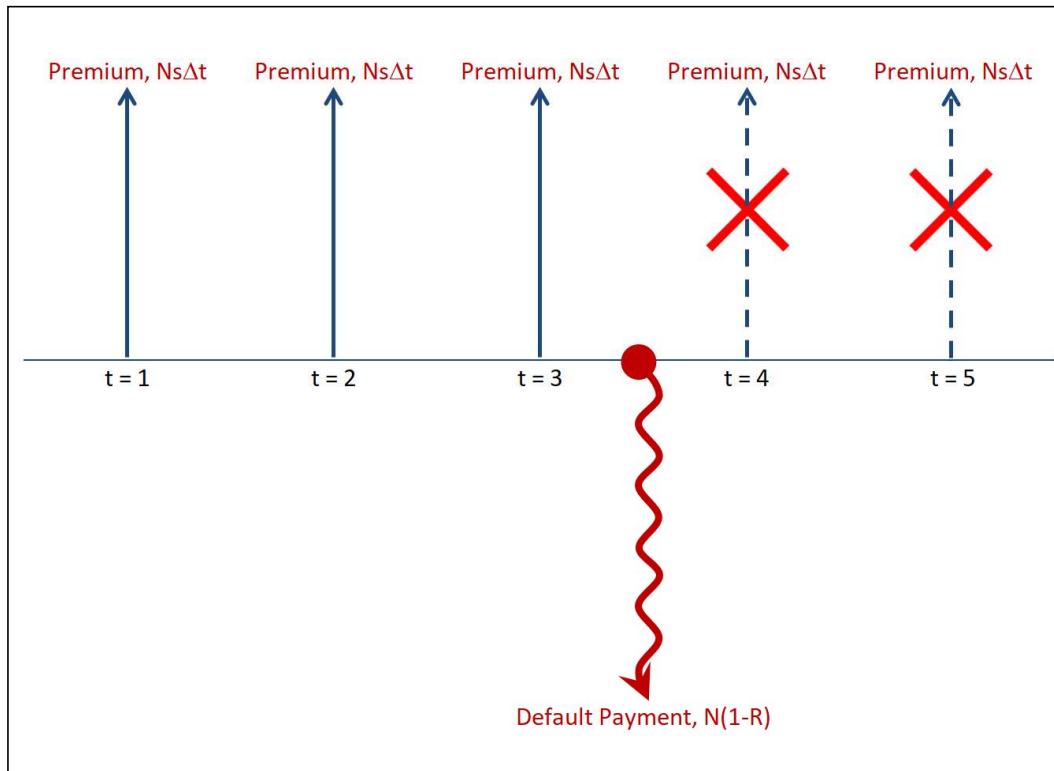
									USD	2,858
Notional	FX Fixing Date	Fwd FX	Notional Exch	Spread	Float Rate	Coupon	Disc Factor	Coupon PV	Spot FX	Valuation PV
			-1,000,000			-1,000,000	1.0000	-1,000,000	1.0000	-1,000,000
1,000,000	Fri, 26-Oct-18	1.1403	-8,233	0.00%	2.47475%	-1,977	0.9942	-1,966	1.0000	-1,966
1,008,233	Fri, 25-Jan-19	1.1497	-8,104	0.00%	2.79581%	-979	0.9880	-967	1.0000	-967
1,016,337	Fri, 26-Apr-19	1.1589	-8,635	0.00%	2.93764%	-1,088	0.9814	-1,067	1.0000	-1,067
1,024,972	Fri, 26-Jul-19	1.1688	1,024,972	0.00%	3.05383%	1,032,884	0.9748	1,006,858	1.0000	1,006,858



## Credit Default Swaps (CDS)



## Credit Default Swap Cash Flows



## CDS – Premium Leg Cash Flows

Premium Leg							Total PV	-4,943.10
Time, T	Notional, N	Credit Spread, s	Year Fraction, $\delta_t$	Coupon	P(Survive), Q(T)	Disc Fact, P(t,T)	PV	
0.25	-1,000,000	0.5000%	0.2500	-1,250	0.997919	0.997503	-1,244.28	
0.50	-1,000,000	0.5000%	0.2500	-1,250	0.995842	0.995012	-1,238.59	
0.75	-1,000,000	0.5000%	0.2500	-1,250	0.993770	0.992528	-1,232.93	
1.00	-1,000,000	0.5000%	0.2500	-1,250	0.991702	0.990050	-1,227.29	



$$PV(\text{Premium Leg}) = \sum_{i=1}^n \underbrace{N s \Delta(t_{i-1}, t_i)}_{\text{Coupon}} \underbrace{\frac{Q(t_i)}{P(\text{Survive})}}_{\text{Discount Factor}} \underbrace{P(t_0, t_i)}_{\text{Discount Factor}}$$

## CDS – Premium Leg Cash Flows for Accrued Interest on Default

Accrued Interest							Total PV	-5.15
Time, T	Notional, N	Credit Spread, s	Year Fraction, $\delta t$	Coupon	P(Survive), Q(T)	Disc Fact, P(t,T)	PV	
0.25	-1,000,000	0.5000%	0.1250	-625	0.002081	0.997503	-1.30	
0.50	-1,000,000	0.5000%	0.1250	-625	0.002077	0.995012	-1.29	
0.75	-1,000,000	0.5000%	0.1250	-625	0.002072	0.992528	-1.29	
1.00	-1,000,000	0.5000%	0.1250	-625	0.002068	0.990050	-1.28	



$$PV(CDS \text{ Accrued Interest}) = \sum_{i=1}^n \underbrace{N s \left( \frac{\Delta(t_{i-1}, t_i)}{2} \right)}_{\text{Half a Coupon}} \underbrace{[Q(t_{i-1}) - Q(t_i)]}_{\text{Default within Premium Period}} \underbrace{P(t_0, t_i)}_{\text{Discount Factor}}$$

## CDS – Protection Leg Cash Flows

Protection Leg					Total PV	4,947.86
Time, T	Notional, N	Loss Given Default, LGD	P(Default), Q(t)λ(t)	Disc Fact, P(t,T)	PV	
0.25	1,000,000	600,000	0.002081	0.997503	1,245.48	
0.50	1,000,000	600,000	0.002077	0.995012	1,239.79	
0.75	1,000,000	600,000	0.002072	0.992528	1,234.12	
1.00	1,000,000	600,000	0.002068	0.990050	1,228.47	

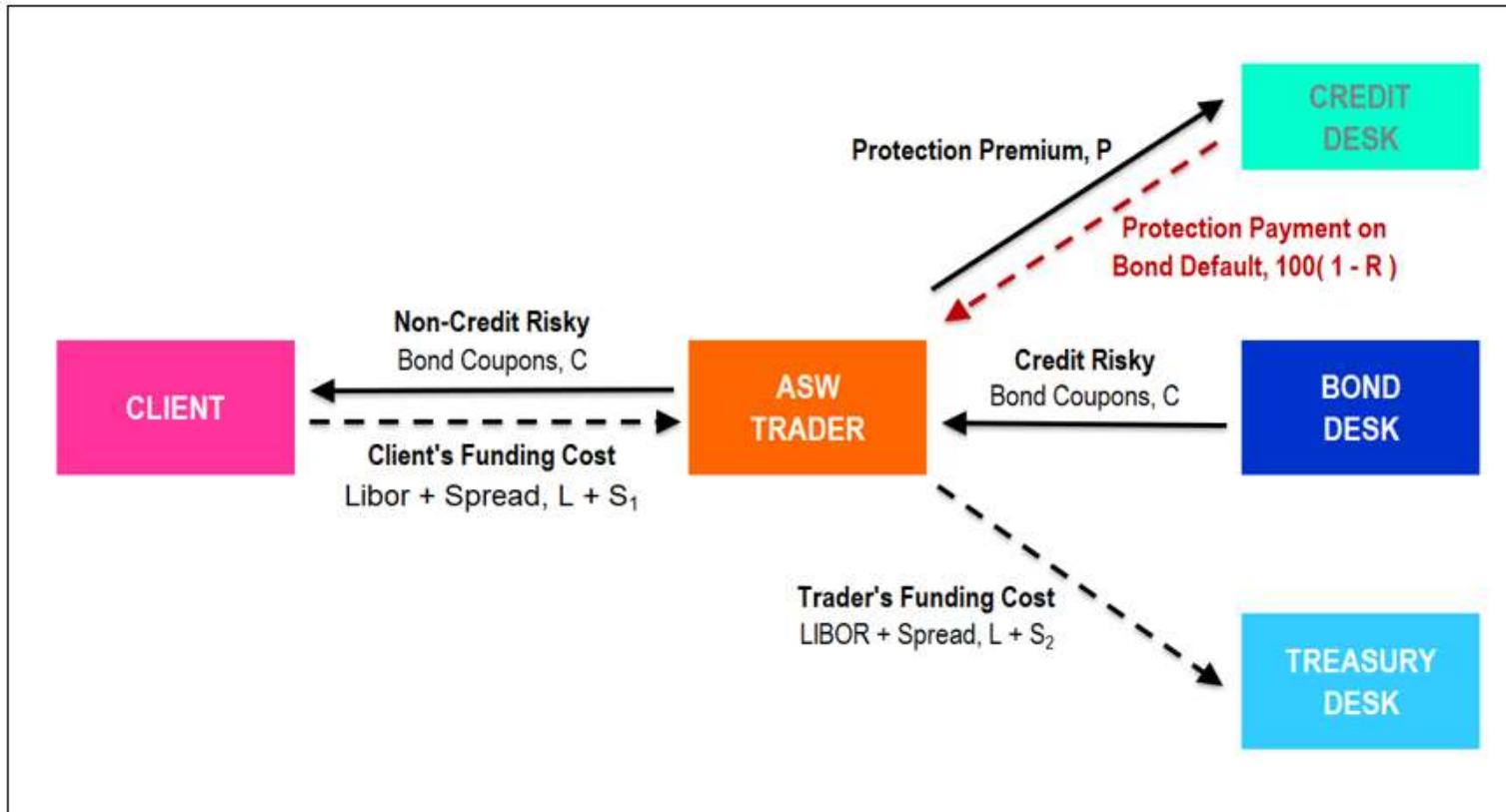


$$PV(\text{Protection Leg}) = \sum_{i=1}^n \underbrace{N(1 - R)}_{\text{Loss Given Default}} \underbrace{[Q(t_{i-1}) - Q(t_i)]}_{\text{Default within Premium Period}} \underbrace{P(t_0, t_i)}_{\text{Discount Factor}}$$

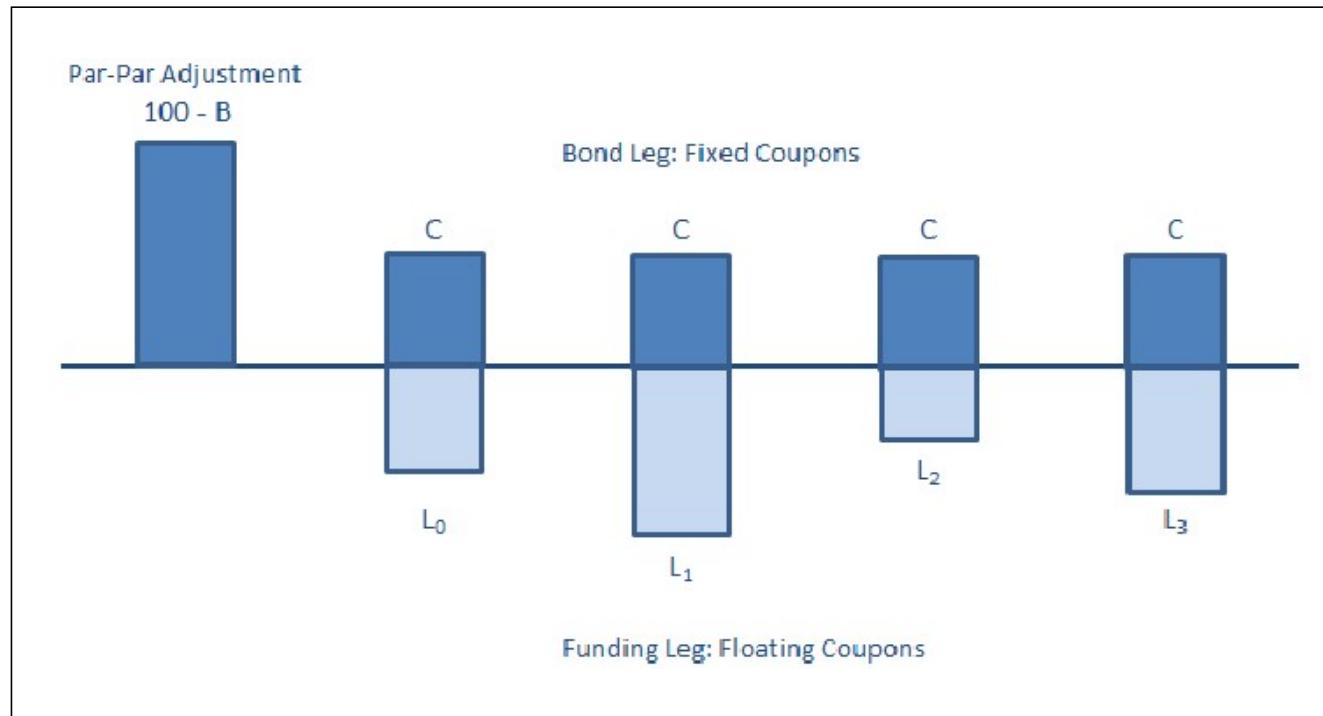
## CDS Trade Booking

Trade Template		USD CDS 5% FORD MOTOR 5Y	
<b>Swap</b>		<b>LEG1:PREMIUM</b>	<b>LEG2:PROTECTION</b>
Pay / Receive		PAY	RECEIVE
Notional	10,000,000		10,000,000
Currency	USD		USD
Reference Entity	US35370BX76	Ford Motor Company	
Accrual Start	IMM Wed, 16-Mar-2016		
Effective Date	5D Mon, 23-May-2016	5D Mon, 23-May-2016	
Maturity Date	5Y Tue, 16-Mar-2021	5Y Tue, 16-Mar-2021	
Fixed Rate (bps)	500.000		
Recovery Rate (%)		40.000%	
Pay Frequency	QUARTERLY		
Day Count	ACT/360		
<b>Market</b>			
Curve Date	Mon, 16-May-2016	Mon, 16-May-2016	
Credit Curve		USD_FORD_MOTOR_CO	
Discount Curve	USDOIS	USDOIS	
<b>Valuation Results</b>			
Valuation Date	Mon, 16-May-2016		
Par Spread (bps)	139.173800		
Clean PV	-1,669,036		
Accrued	-87,500		
Dirty PV	-1,786,536		
DV01	4,357.30		
CS01	4,951.24		

## Asset Swap Structuring (ASW)



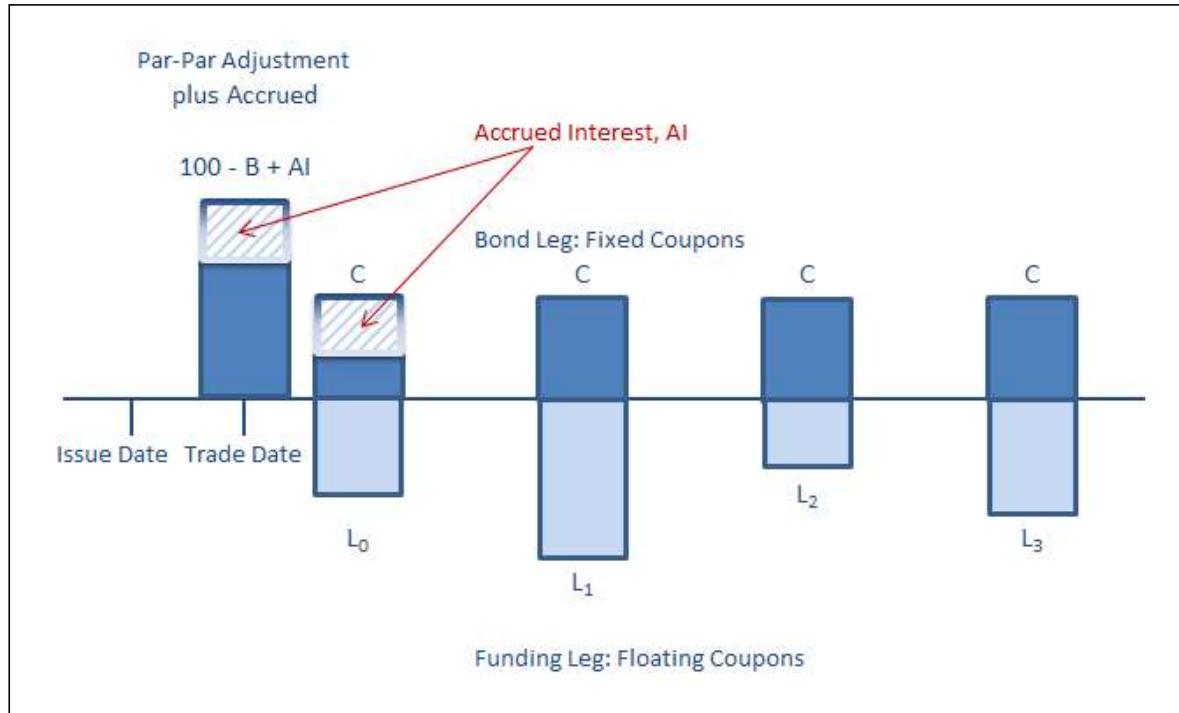
## Asset Swap Cash Flows (Par-Par Method)



$$\begin{aligned}
 PV(\text{Asset Swap}) = & \underbrace{\sum_{i=1}^n N_i r^{\text{Fixed}} \tau_i P(t_0, t_i)}_{\text{Fixed Bond Leg}} - \underbrace{\sum_{j=1}^m N_j (l_{j-1} + s) \tau_j P(t_0, t_j)}_{\text{Float Funding Leg}} \\
 & + N \left( \frac{100 - B}{100} \right)
 \end{aligned}$$

*Bond Price Adjustment*

## ASW Cash Flow Pricing using Dirty/Clean Bond Prices, B



## ASW Pricing Illustration

Clean Price	106.680
Dirty Price	106.919
Accrued (175 Days)	2,391.87
Ticker	DE0001102390 Govt
Security Name	DBR 0 1/2 02/15/2026
Issue Date	Fri, 15-Jan-16
First Coupon Date	Wed, 15-Feb-17
Maturity Date	Sun, 15-Feb-26
Coupon	0.50%
Price	106.680
Is Clean Price	TRUE
Day Count	ACT/ACT
Frequency	Annual

## Asset Swap Par-Par Spread Calculation

### Swap Leg Breakdown

Fixed PV	51,219
Accrued Interest	2,392
Fixed PV Less Accrued	48,828
Float PV	22,805

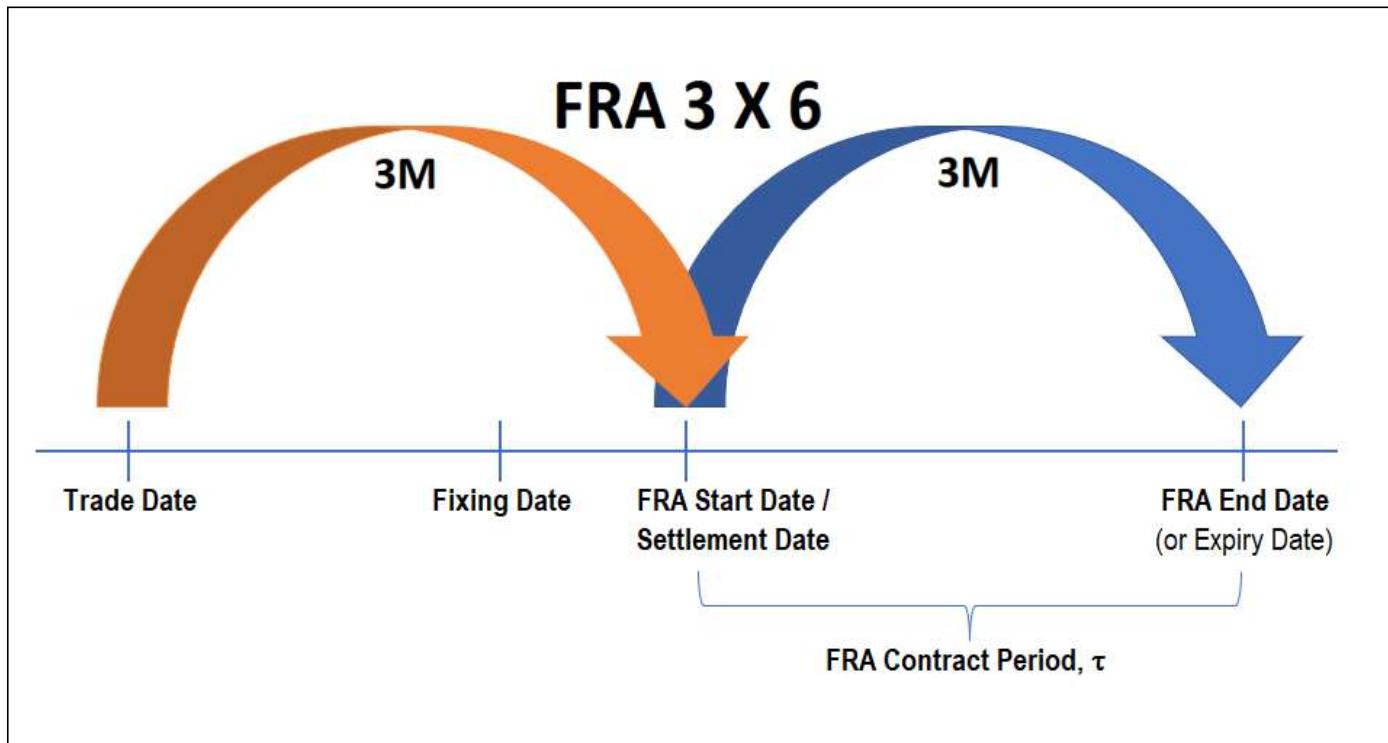
### Asset Swap Calculation

Swap PV	26,022
Par Adjustment	-66,800
Discounting Difference	6
Float Annuity	9,907,204
ASW Spread	-41.166

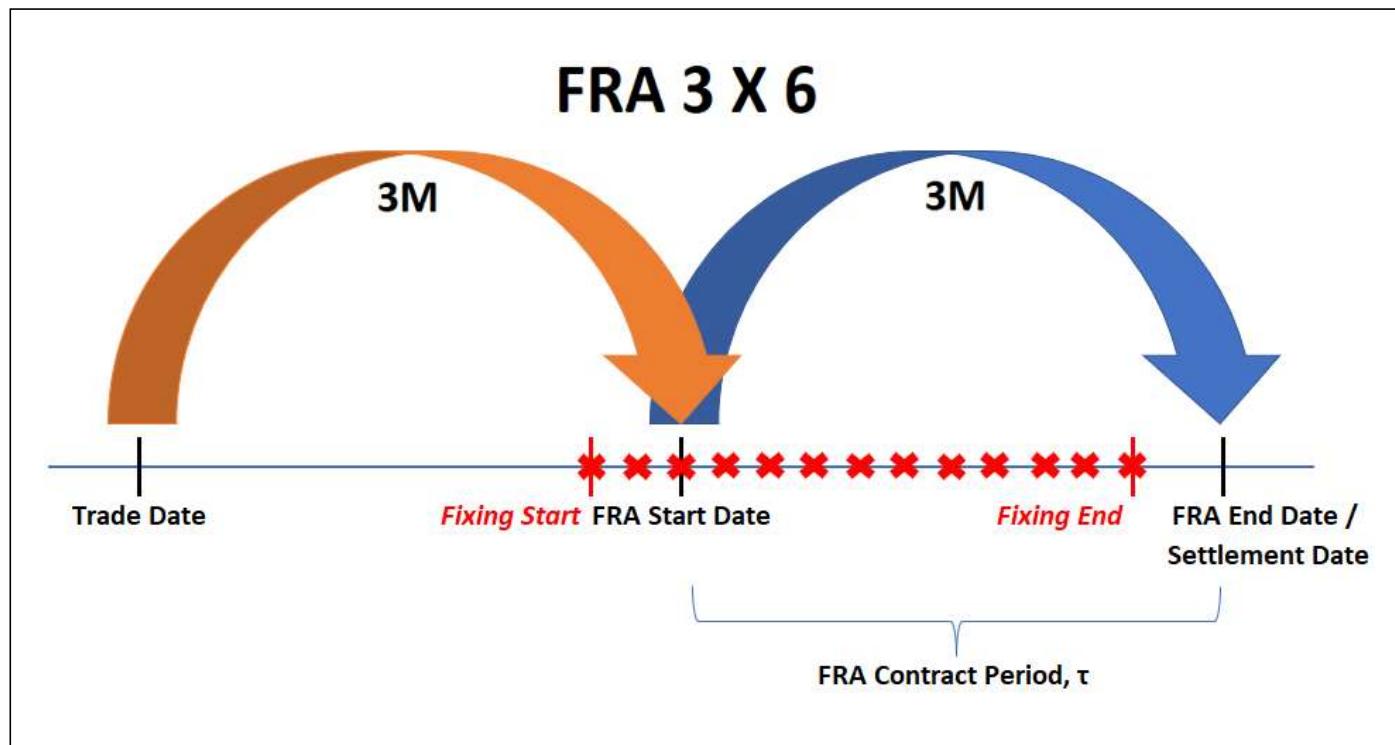
$$PV(\text{Asset Swap}) = \underbrace{\sum_{i=1}^n N_i r^{\text{Fixed}} \tau_i P(t_0, t_i)}_{\text{Fixed Bond Leg}} - \underbrace{\sum_{j=1}^m N_j (l_{j-1} + s) \tau_j P(t_0, t_j)}_{\text{Float Funding Leg}} + \underbrace{N \left( \frac{100 - B}{100} \right)}_{\text{Bond Price Adjustment}}$$

$$s = \left( \frac{(r^{\text{Fixed}} - p) A_N^{\text{Fixed}} + N \left( \frac{100 - B}{100} \right)}{A_N^{\text{Float}}} \right)$$

## FRA Contracts (LIBOR)



## FRA Contracts (RFR)

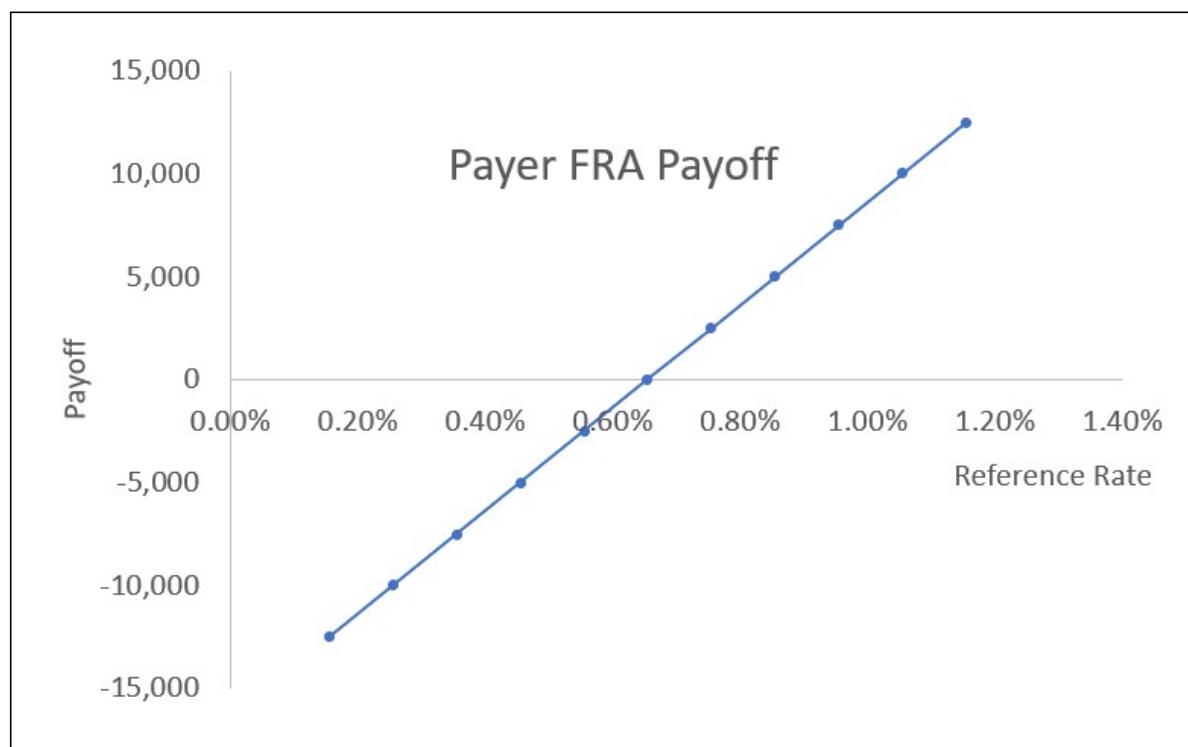


## FRA Quotes

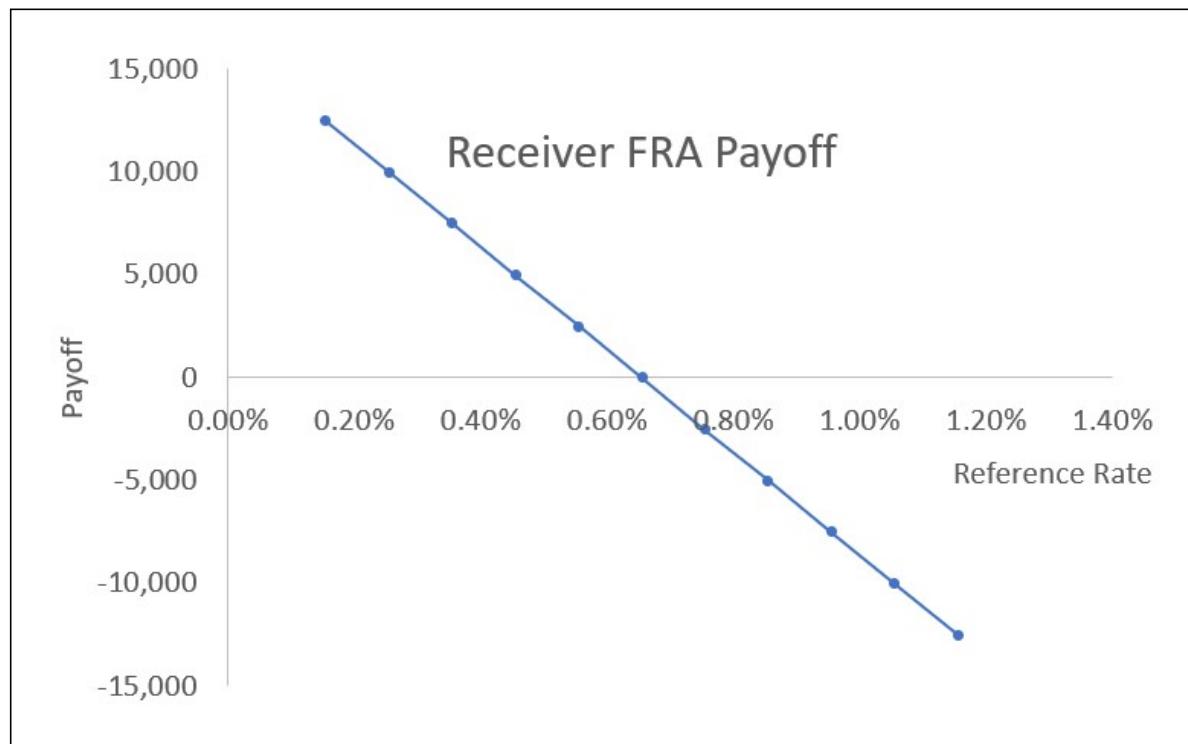
Contract	Bid	Offer	Spot Rate
USD 3M LIBOR	-	0.292%	0.292%
3 X 6	0.405%	0.420%	0.357%
4 X 7	0.425%	0.442%	0.371%
5 X 8	0.445%	0.463%	0.386%
6 X 9	0.465%	0.485%	0.400%
7 X 10	0.495%	0.513%	0.415%
8 X 11	0.525%	0.542%	0.430%
9 X 12	0.555%	0.570%	0.445%
10 X 13	0.584%	0.598%	0.460%
11 x 14	0.613%	0.627%	0.475%
12 X 15	0.642%	0.655%	0.490%

3 X 6       $\underbrace{0.405\%}_{\substack{\text{Bid} \\ \text{Deposit} \\ \text{Receive} \\ \text{Short}}}$  –  $\underbrace{0.420\%}_{\substack{\text{Offer} \\ \text{Borrow} \\ \text{Pay} \\ \text{Long}}}$

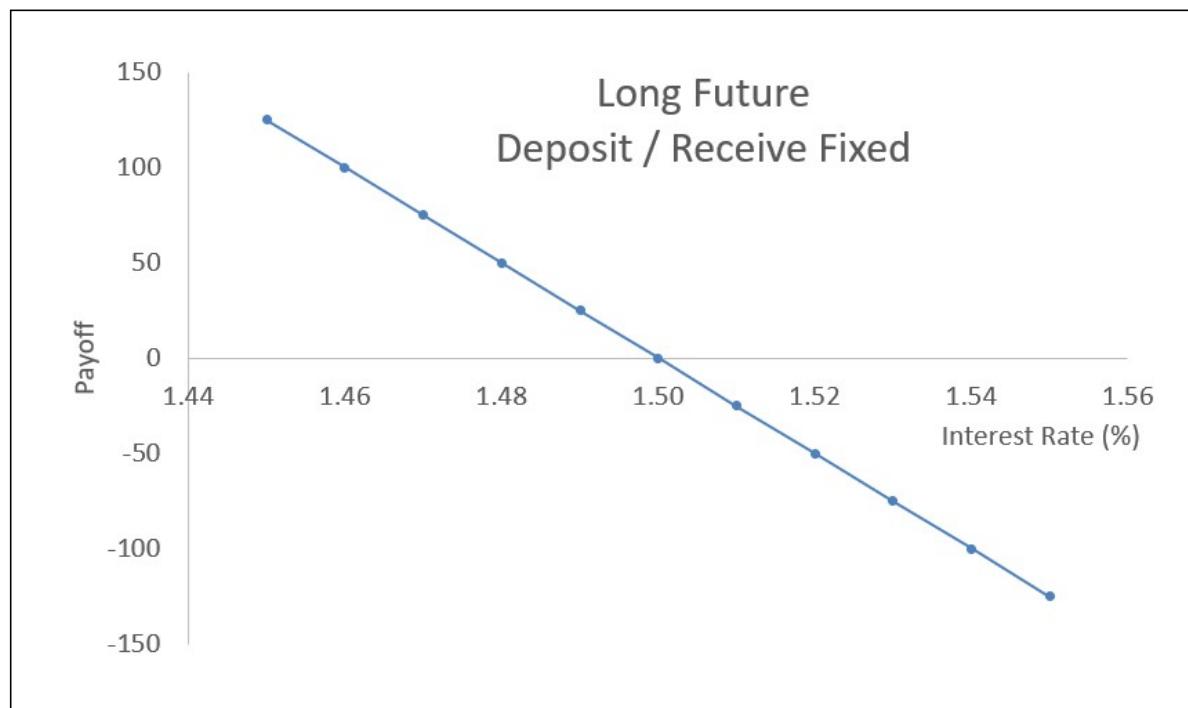
### FRA Payoff (Pay Fixed)



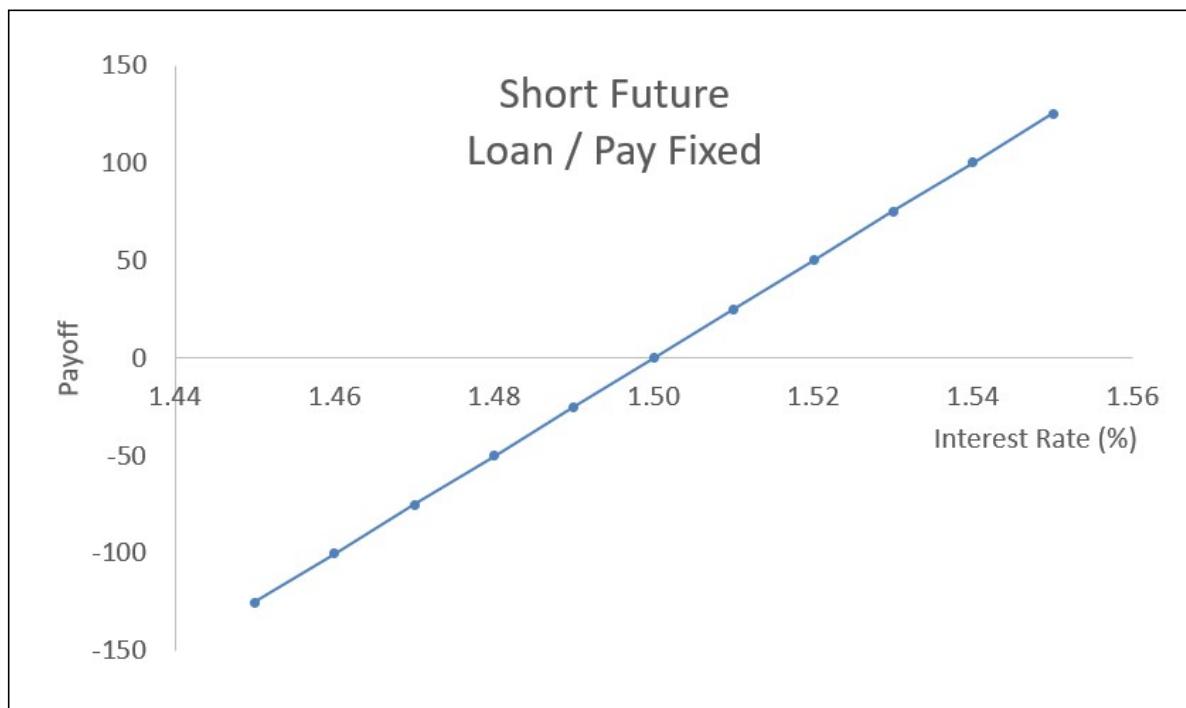
### FRA Payoff (Receive Fixed)



## Long Futures Payoff



## Short Futures Payoff



## Futures Month Ticker Symbols

Month	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Symbol	F	G	H	J	K	M	N	Q	U	V	X	Z

## Futures Colour Codes

YEAR	COLOUR
1st	White
2nd	Red
3rd	Green
4th	Blue
5th	Gold
6th	Purple
7th	Orange
8th	Pink
9th	Silver
10th	Copper

## CME Futures Quotes (1 of 2)

TICKER	MONTH	LAST PRICE	CHANGE	PRIOR PRICE	OPEN	HIGH	LOW	VOLUME
SR3M2	JUN-22	98.1175	-0.005 (-0.01%)	98.1225	98.1225	98.1475	98.11	45,593
SR3U2	SEP-22	97.06	+0.015 (+0.02%)	97.045	97.035	97.18	97.03	236,774
SR3Z2	DEC-22	96.71	+0.04 (+0.04%)	96.67	96.63	96.87	96.605	339,455
SR3H3	MAR-23	96.735	+0.105 (+0.11%)	96.63	96.58	96.88	96.54	305,759
SR3M3	JUN-23	96.97	+0.145 (+0.15%)	96.825	96.77	97.1	96.735	255,183
SR3U3	SEP-23	97.195	+0.18 (+0.19%)	97.015	96.965	97.315	96.935	199,337
SR3Z3	DEC-23	97.365	+0.20 (+0.21%)	97.165	97.13	97.475	97.095	185,140
SR3H4	MAR-24	97.49	+0.21 (+0.22%)	97.28	97.24	97.595	97.22	152,166
SR3M4	JUN-24	97.595	+0.225 (+0.23%)	97.37	97.34	97.68	97.315	112,246
SR3U4	SEP-24	97.625	+0.21 (+0.22%)	97.415	97.375	97.715	97.37	72,282
SR3Z4	DEC-24	97.62	+0.195 (+0.20%)	97.425	97.39	97.71	97.38	68,370
SR3H5	MAR-25	97.615	+0.175 (+0.18%)	97.44	97.405	97.705	97.395	52,353
SR3M5	JUN-25	97.58	+0.155 (+0.16%)	97.425	97.39	97.675	97.38	49,777
SR3U5	SEP-25	97.535	+0.14 (+0.14%)	97.395	97.355	97.62	97.345	19,103
SR3Z5	DEC-25	97.47	+0.12 (+0.12%)	97.35	97.31	97.56	97.305	15,861
SR3H6	MAR-26	97.41	+0.10 (+0.10%)	97.31	97.265	97.505	97.26	12,703
SR3M6	JUN-26	97.355	+0.085 (+0.09%)	97.27	97.225	97.455	97.22	10,425
SR3U6	SEP-26	97.32	+0.08 (+0.08%)	97.24	97.19	97.42	97.185	2,435
SR3Z6	DEC-26	97.27	+0.07 (+0.07%)	97.2	97.15	97.37	97.15	3,040
SR3H7	MAR-27	97.225	+0.06 (+0.06%)	97.165	97.115	97.33	97.11	1,867

## CME Futures Quotes (2 of 2)

TICKER	MONTH	LAST PRICE	CHANGE	PRIOR PRICE	OPEN	HIGH	LOW	VOLUME
SR3M7	JUN-27	97.18	+0.05 (+0.05%)	97.13	97.09	97.29	97.075	1,810
SR3U7	SEP-27	97.135	+0.04 (+0.04%)	97.095	97.05	97.18	97.05	158
SR3Z7	DEC-27	97.135	+0.08 (+0.08%)	97.055	97.19	97.19	97.135	34
SR3H8	MAR-28	-	-	97.03	-	-	-	0
SR3M8	JUN-28	-	-	96.995	-	-	-	0
SR3U8	SEP-28	-	-	96.96	-	-	-	0
SR3Z8	DEC-28	-	-	96.92	-	-	-	19
SR3H9	MAR-29	-	-	96.89	-	-	-	0
SR3M9	JUN-29	-	-	96.85	-	-	-	0
SR3U9	SEP-29	-	-	96.82	-	-	-	0
SR3Z9	DEC-29	-	-	96.79	-	-	-	0
SR3H0	MAR-30	-	-	96.765	-	-	-	0
SR3M0	JUN-30	-	-	96.725	-	-	-	0
SR3U0	SEP-30	-	-	96.685	-	-	-	0
SR3Z0	DEC-30	-	-	96.67	-	-	-	0
SR3H1	MAR-31	-	-	96.645	-	-	-	0
SR3M1	JUN-31	-	-	96.62	-	-	-	0
SR3U1	SEP-31	-	-	96.6	-	-	-	0
SR3Z1	DEC-31	-	-	96.59	-	-	-	0

## Futures Margin & P&L (1 of 2)

Date	Position	Profit / Loss	Cash Flow	Margin Account Balance								
Day One	Buy 10 Futures @ 9910	Initial Margin: 10 x 2,500 = (25,000) Pay		25,000 CR								
	Settlement Price @ 9942	( 9942 - 9910 ) x 25 x 10 = 8,000 Profit		33,000 CR								
		Variation Margin: 8,000 Receive		25,000 CR								
Day Two	Settlement Price @ 9932	( 9932 - 9942 ) x 25 x 10 = (2,500) Loss	Variation Margin: (2,500) Pay	22,500 CR 25,000 CR								
Day Three	Sell 6 Futures @ 9927	( 9927 - 9932 ) x 25 x 6 = (750) Loss		24,250 CR								
	Settlement Price @ 9925	( 9925 - 9932 ) x 25 x 4 = (700) Loss	Variation Margin: = -750 - 700 = (1,450) Pay	23,550 CR 25,000 CR								
		Initial Margin: 6 x 2,500 = 15,000 Receive		10,000 CR								
Day Four	Sell 4 Futures @ 9938	( 9938 - 9925 ) x 25 x 4 = 1,300 Profit	Closing of Position Return of Margin Balance 11,300 Receive	11,300 CR 0								
<table border="1"> <thead> <tr> <th>Net Position</th> <th>Net P&amp;L</th> <th>Net Cash Flows</th> <th>Margin Account Balance</th> </tr> </thead> <tbody> <tr> <td>0 Futures</td> <td>5,350</td> <td>5,350</td> <td>0</td> </tr> </tbody> </table>					Net Position	Net P&L	Net Cash Flows	Margin Account Balance	0 Futures	5,350	5,350	0
Net Position	Net P&L	Net Cash Flows	Margin Account Balance									
0 Futures	5,350	5,350	0									

## Futures Margin & P&L (2 of 2)

Date	Profit / Loss	Cash Flow	Cash Flow Description	Margin Account
Day One		(25,000)	Open Position Pay Initial Margin	25,000
	8,000			33,000
		8,000	Profit Receive Margin	25,000
Day Two		(2,500)		22,500
		(2,500)	Loss Margin Call	25,000
Day Three	(750)			24,250
	(700)			23,550
		(1,450)	Loss Margin Call	25,000
		15,000	Partial Close Position Receive Initial Margin	10,000
Day Four	1,300			11,300
		11,300	Fully Close Position Receive Margin Balance	0
Net P&L		Net Cash Flows	Margin Balance	
5,350		5,350	0	

## Yield Curve Calibration with Contiguous Futures

**Cash Rates**

Term	Bid	Ask
3M	2.42300%	2.42300%

**Contiguous Futures**

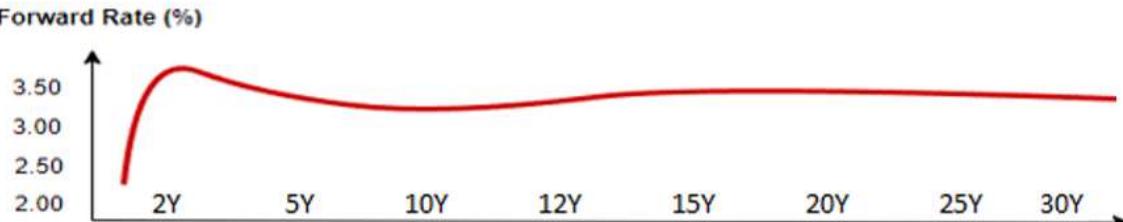
1	6
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**Futures**

	Contract	Price	Cvx Adj	Rate
1	SEP-22 + 3	96.6750	-0.00110	3.32390%
2	DEC-22 + 3	96.1450	-0.00326	3.85174%
3	MAR-23 + 3	96.1850	-0.00659	3.80841%
4	JUN-23 + 3	96.3550	-0.01087	3.63413%
5	SEP-23 + 3	96.5650	-0.01600	3.41900%
6	DEC-23 + 3	96.7600	-0.02203	3.21797%
7	MAR-24 + 3	96.8950	-0.02893	3.07607%
8	JUN-24 + 3	96.9950	-0.03670	2.96830%

**Curve Template**

USD3ML



The graph plots Forward Rate (%) on the Y-axis (ranging from 2.00 to 3.50) against Time in Years on the X-axis (labeled 2Y, 5Y, 10Y, 12Y, 15Y, 20Y, 25Y, 30Y). The curve starts at approximately 2.2% at 2 years, rises sharply to about 3.5% at 5 years, then gradually declines to around 3.4% at 10 years, and remains relatively flat until 30 years.

## Chapter 4 – Yield Curves, Forecasting & Discounting Cash Flows

## Yield Curve Calibration with Serial Futures

**Cash Rates**

Term	Bid	Ask
3M	2.42300%	2.42300%

**Serial Futures**

1	6
---	---

**Futures**

	Contract	Price	Cvx Adj	Rate
1	JUL-22 + 3	97.4475	-0.00009	2.55241%
2	AUG-22 + 3	97.1100	-0.00045	2.88955%
3	SEP-22 + 3	96.6750	-0.00103	3.32397%
4	OCT-22 + 3	96.4950	-0.00159	3.50341%
5	NOV-22 + 3	96.3250	-0.00224	3.67276%
6	DEC-22 + 3	96.1450	-0.00305	3.85195%
7	JAN-23 + 3	96.1850	-0.00616	3.80884%
8	FEB-23 + 3	96.3550	-0.01016	3.63484%

**Forward Rate (%)**

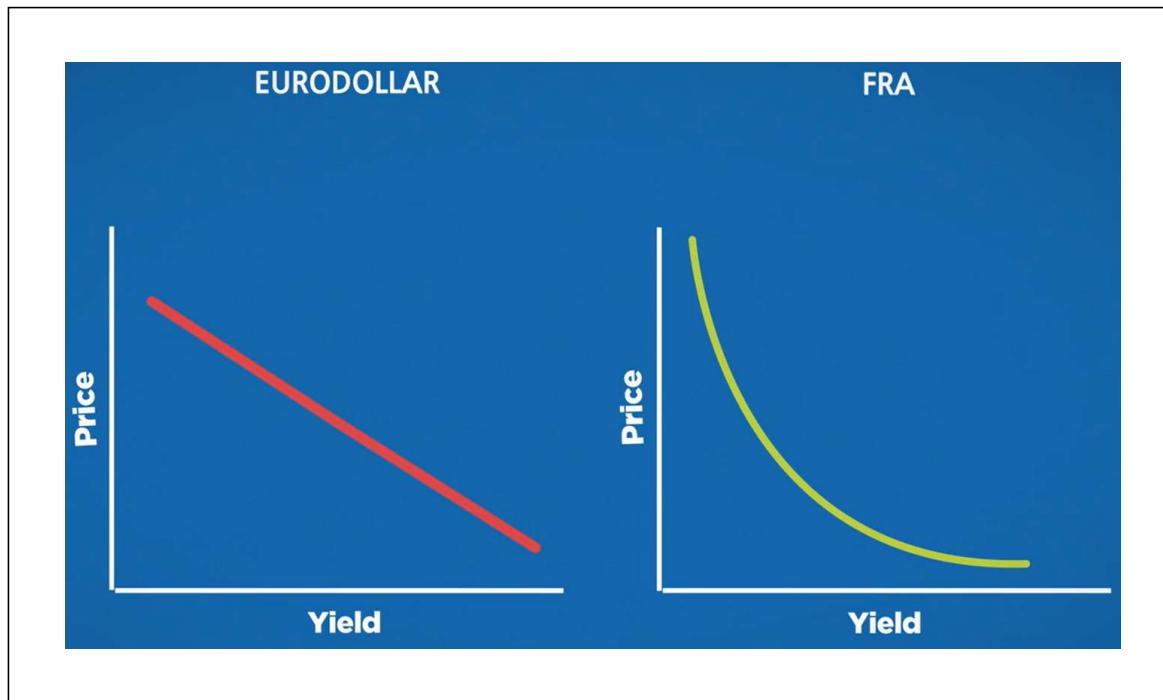
**Curve Template**

🔍

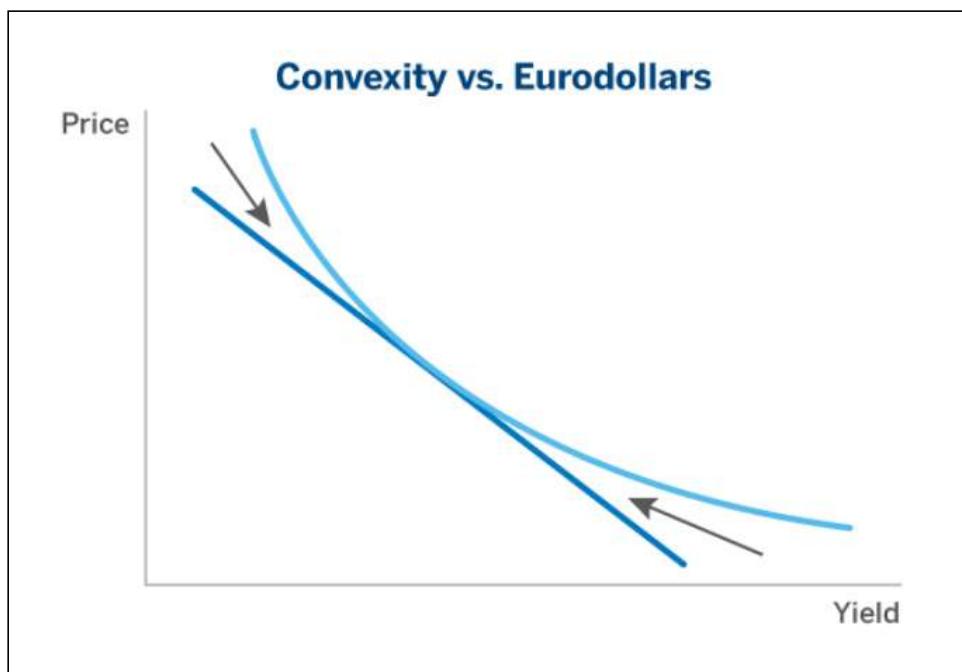
**Swaps**

Term	Bid	Ask
1Y	3.41532%	3.42668%
2Y	3.38246%	3.39164%
3Y	3.23062%	3.24638%
4Y	3.17325%	3.18184%
5Y	3.15423%	3.16357%
6Y	3.14866%	3.15714%
7Y	3.14521%	3.15179%
8Y	3.14509%	3.15131%

## Price Behaviour: Futures vs FRAs



## Futures Convexity Adjustments

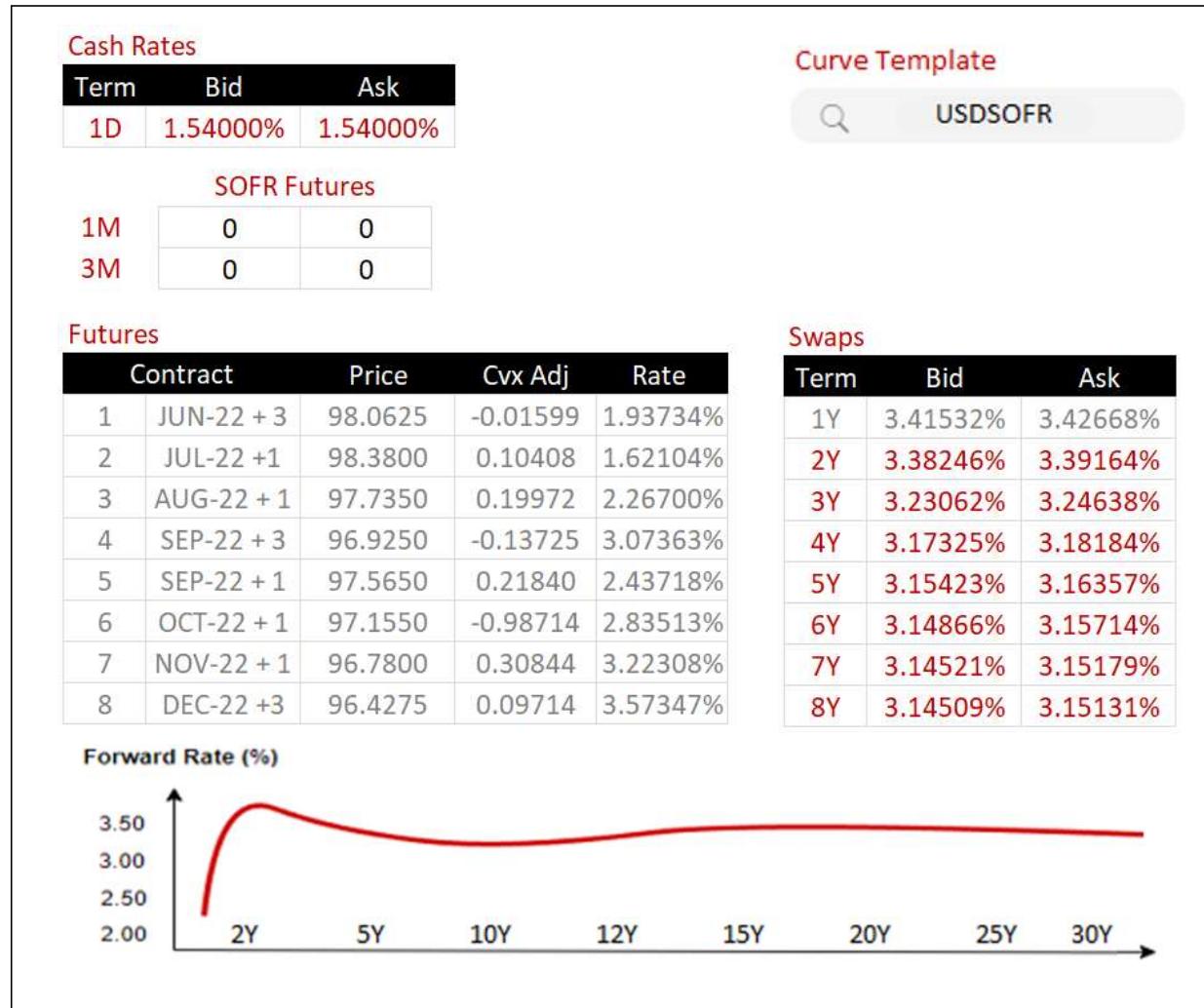


*Convexity Adjustment = Futures Price – FRA Price*

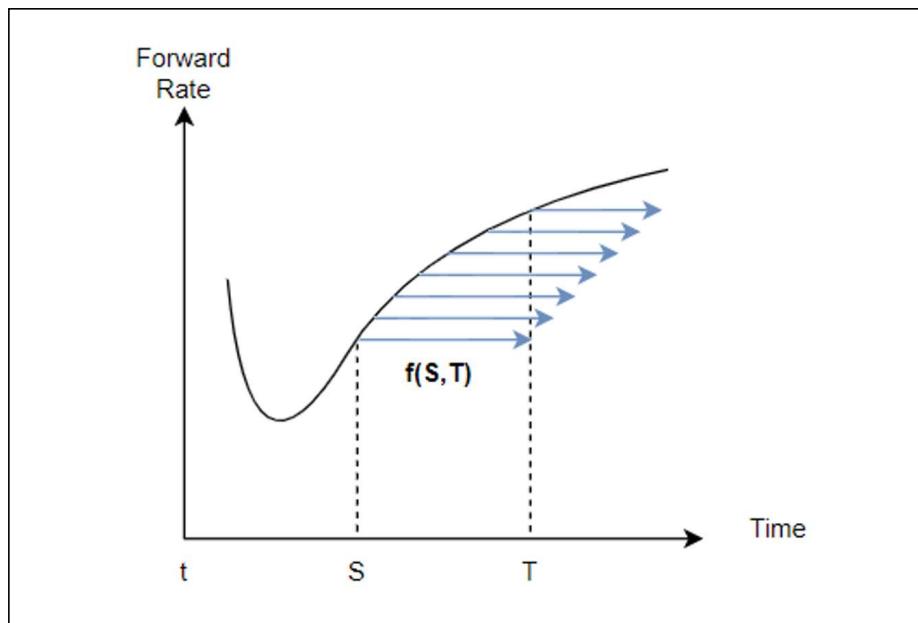
$$CA(HW1F) = \left( \frac{B(T_1, T_2)}{T_2 - T_1} \right) [ B(T_1, T_2)(1 - e^{-2aT_1}) + 2a B(0, T_1)^2 ] \left( \frac{\sigma^2}{4a} \right)$$

$$B(T_1, T_2) = \left( \frac{1 - e^{-a(T-t)}}{a} \right)$$

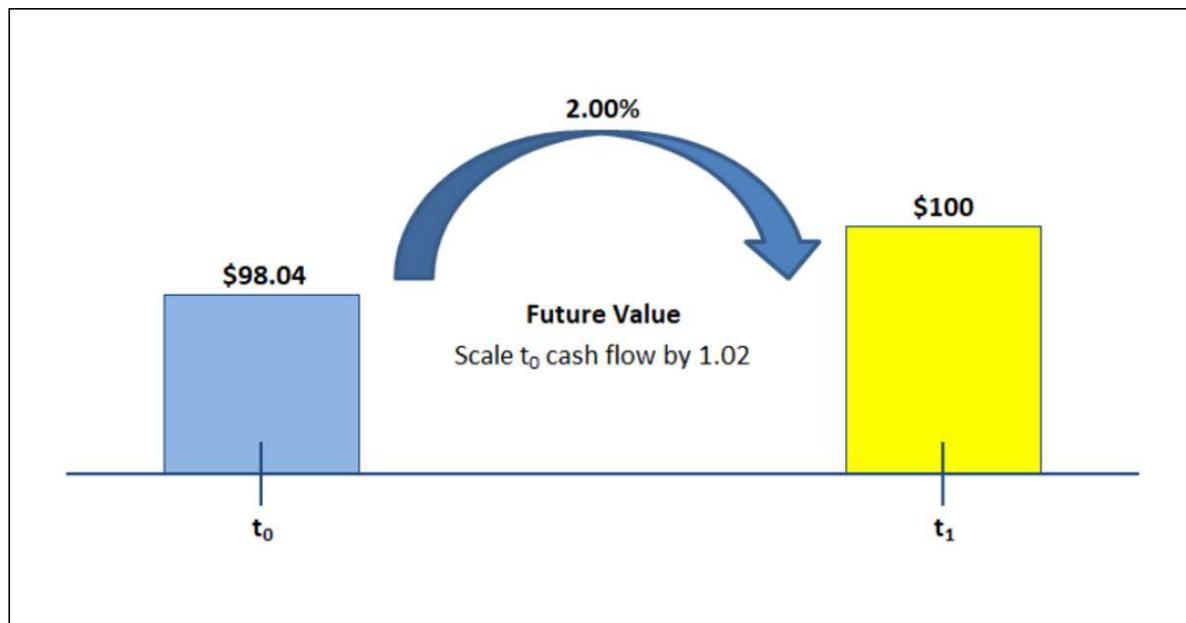
## USD SOFR Curve Calibration



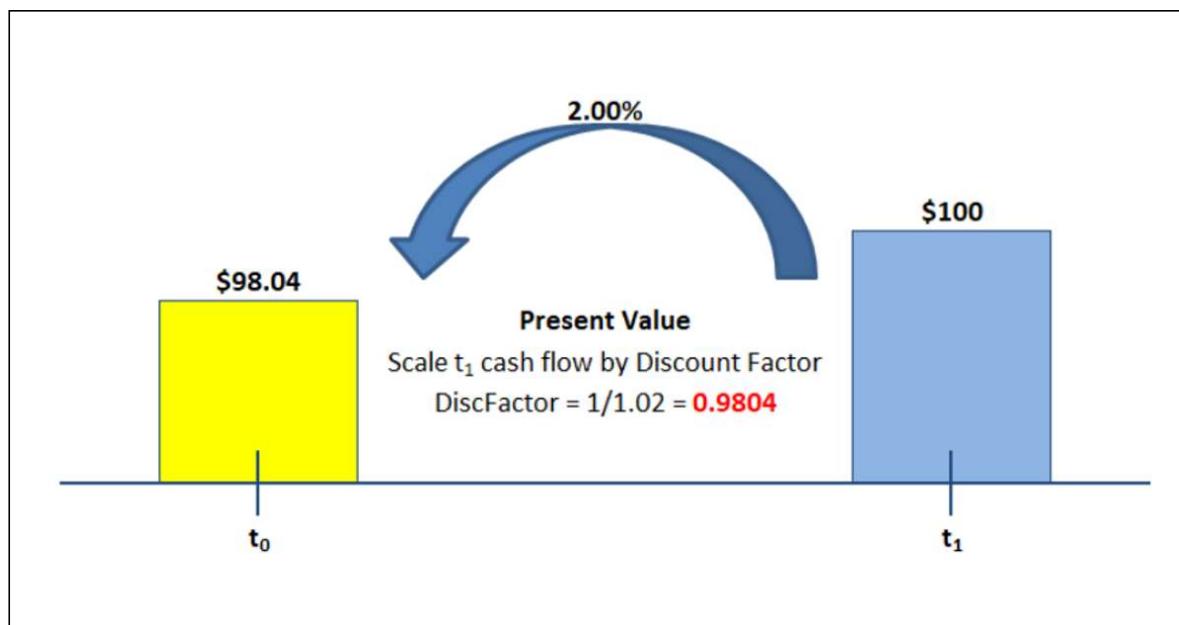
## Forward Curve Illustration



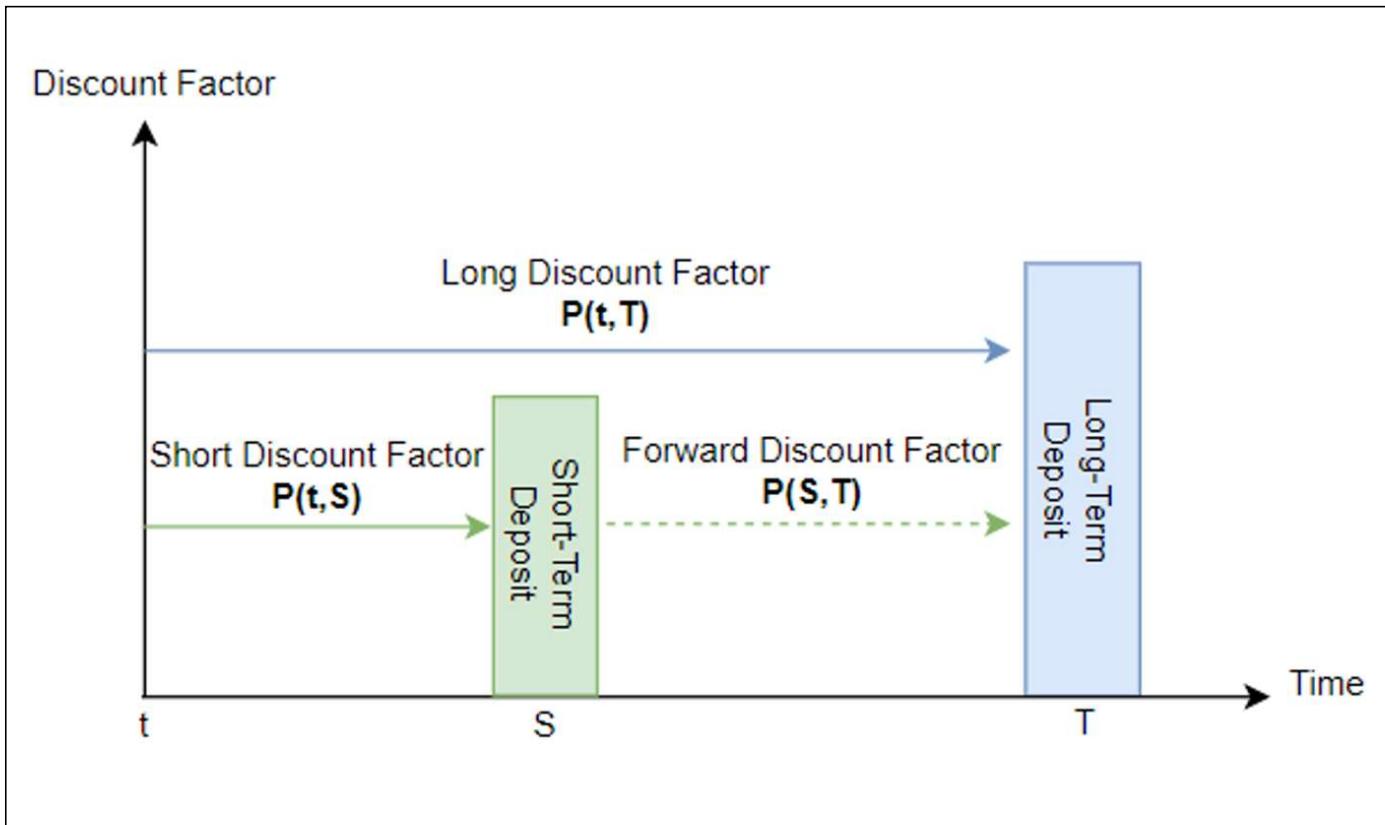
## Growth Factors for Future Value Calculations



## Discount Factors for Present Value Calculations

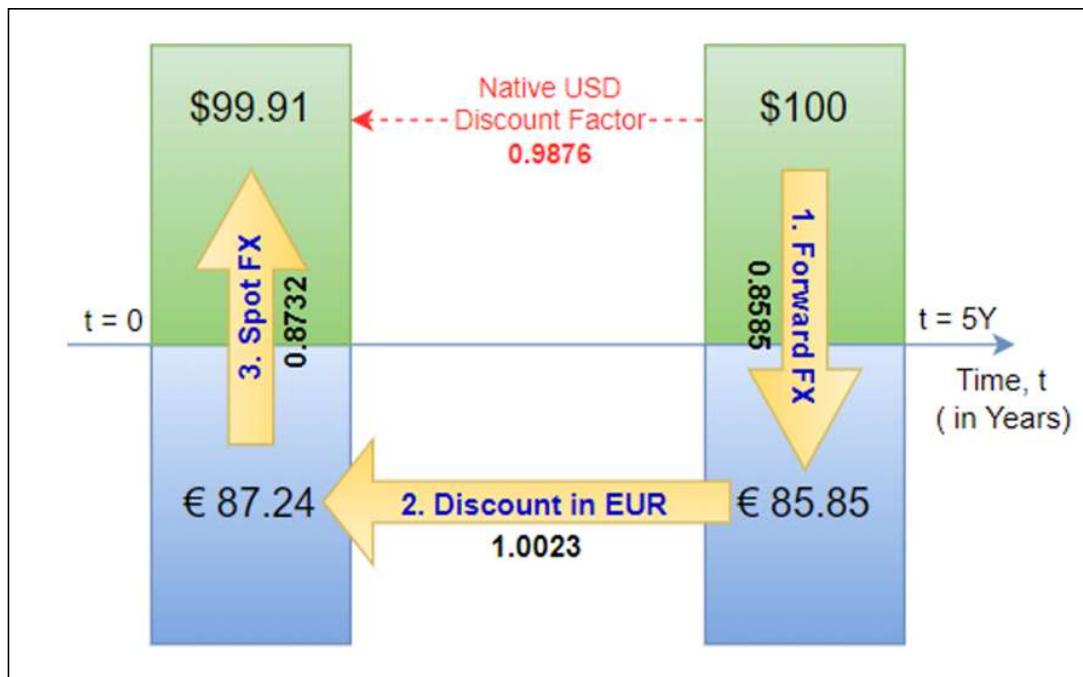


## Forward Rate Replication



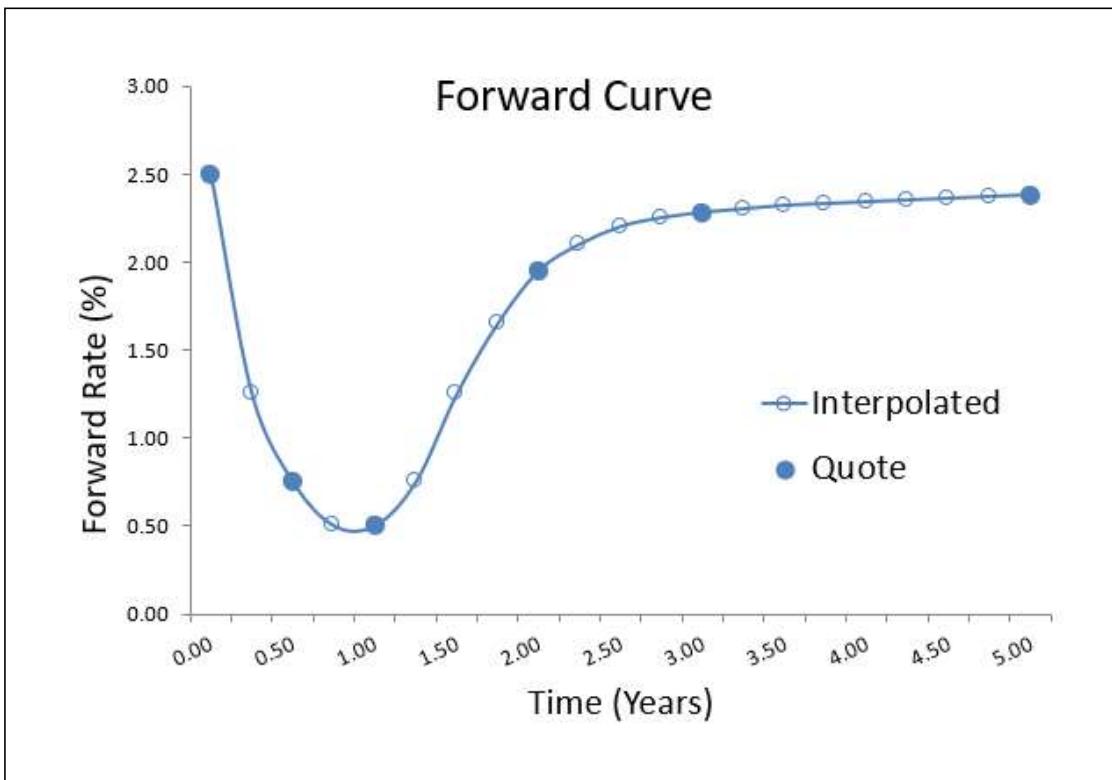
$$P(t, S) \cdot P(S, T) = P(t, T) \quad f(S, T) = \frac{\ln \left( \frac{P(t, S)}{P(t, T)} \right)}{T - S}$$

## Illustration USD Discount Factor with EUR CSA Collateral

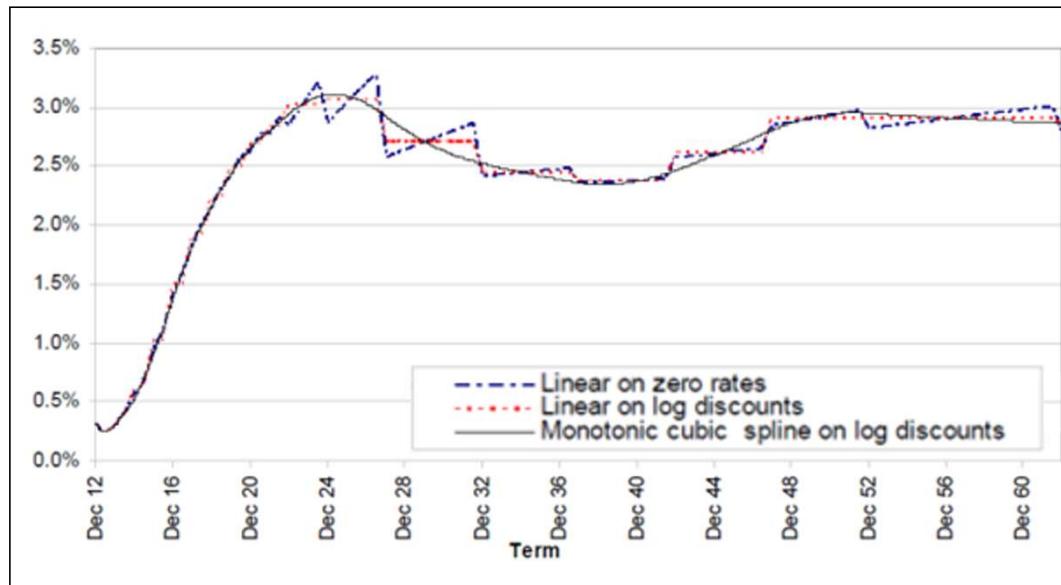


$$P(t, T)^{USD\_EURCSA} = P(t, T)^{EUR} \left( \frac{f(t, T)^{EUR/USD}}{s(t)^{EUR/USD}} \right)$$

## Forward Curve Interpolation



## Forward Curve Interpolation Methods



## OIS Curve Calibration Instruments

OIS Curve (1D)			
Instrument	Tenor	Quote	Interpolation Style
Cash Deposit	1D	2.02480	Linear
OIS Swap	6M	7.73450	Spline
OIS Swap	1Y	1.59890	Spline
OIS Swap	18M	1.52050	Spline
OIS Swap	2Y	1.46050	Spline
OIS Swap	5Y	1.36900	Spline
LIBOR-OIS Basis Swap	7Y	0.26563	Spline
LIBOR-OIS Basis Swap	10Y	0.26063	Spline
LIBOR-OIS Basis Swap	15Y	0.25500	Spline
LIBOR-OIS Basis Swap	20Y	0.25375	Spline
LIBOR-OIS Basis Swap	30Y	0.25375	Spline
LIBOR-OIS Basis Swap	40Y	0.25375	Spline
LIBOR-OIS Basis Swap	50Y	0.25375	Spline

## Swap Curve Calibration Instruments

Swap Curve (USD3ML)			
Instrument	Tenor	Quote	Interpolation Style
Cash Deposit	3M	2.13940	Linear
Future1	SEP-19	97.85500	Linear
Future2	DEC-19	97.97500	Linear
Future3	MAR-20	98.23500	Linear
Future4	JUN-20	98.33500	Linear
Future5	SEP-20	98.39500	Linear
Future6	DEC-20	98.38000	Linear
LIBOR Swap	3Y	1.69450	Spline
LIBOR Swap	5Y	1.65880	Spline
LIBOR Swap	7Y	1.67880	Spline
LIBOR Swap	10Y	1.74720	Spline
LIBOR Swap	15Y	1.84090	Spline
LIBOR Swap	20Y	1.89680	Spline
LIBOR Swap	30Y	1.92460	Spline
LIBOR Swap	40Y	1.92460	Spline
LIBOR Swap	50Y	1.92460	Spline

## Tenor Basis Curve Calibration Instruments

Tenor-Basis Curve (USD6ML)			
Instrument	Term (Years)	Quote	Interpolation Style
Cash Deposit	6M	2.70300	Linear
LIBOR Basis Swap (3X6)	1Y	0.01750	Spline
LIBOR Basis Swap (3X6)	2Y	0.04125	Spline
LIBOR Basis Swap (3X6)	3Y	0.05125	Spline
LIBOR Basis Swap (3X6)	4Y	0.05625	Spline
LIBOR Basis Swap (3X6)	5Y	0.06125	Spline
LIBOR Basis Swap (3X6)	7Y	0.07375	Spline
LIBOR Basis Swap (3X6)	10Y	0.08500	Spline
LIBOR Basis Swap (3X6)	15Y	0.09625	Spline
LIBOR Basis Swap (3X6)	20Y	0.10375	Spline
LIBOR Basis Swap (3X6)	30Y	0.11000	Spline
LIBOR Basis Swap (3X6)	40Y	0.11000	Spline
LIBOR Basis Swap (3X6)	50Y	0.11000	Spline

## USD LIBOR Curve Calibration

**Cash Rates**

Term	Bid	Ask
3M	2.42300%	2.42300%

**Contiguous Futures**

1	6
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**Futures**

	Contract	Price	Cvx Adj	Rate
1	SEP-22 + 3	96.6750	-0.00110	3.32390%
2	DEC-22 + 3	96.1450	-0.00326	3.85174%
3	MAR-23 + 3	96.1850	-0.00659	3.80841%
4	JUN-23 + 3	96.3550	-0.01087	3.63413%
5	SEP-23 + 3	96.5650	-0.01600	3.41900%
6	DEC-23 + 3	96.7600	-0.02203	3.21797%
7	MAR-24 + 3	96.8950	-0.02893	3.07607%
8	JUN-24 + 3	96.9950	-0.03670	2.96830%

**Curve Template**

🔍

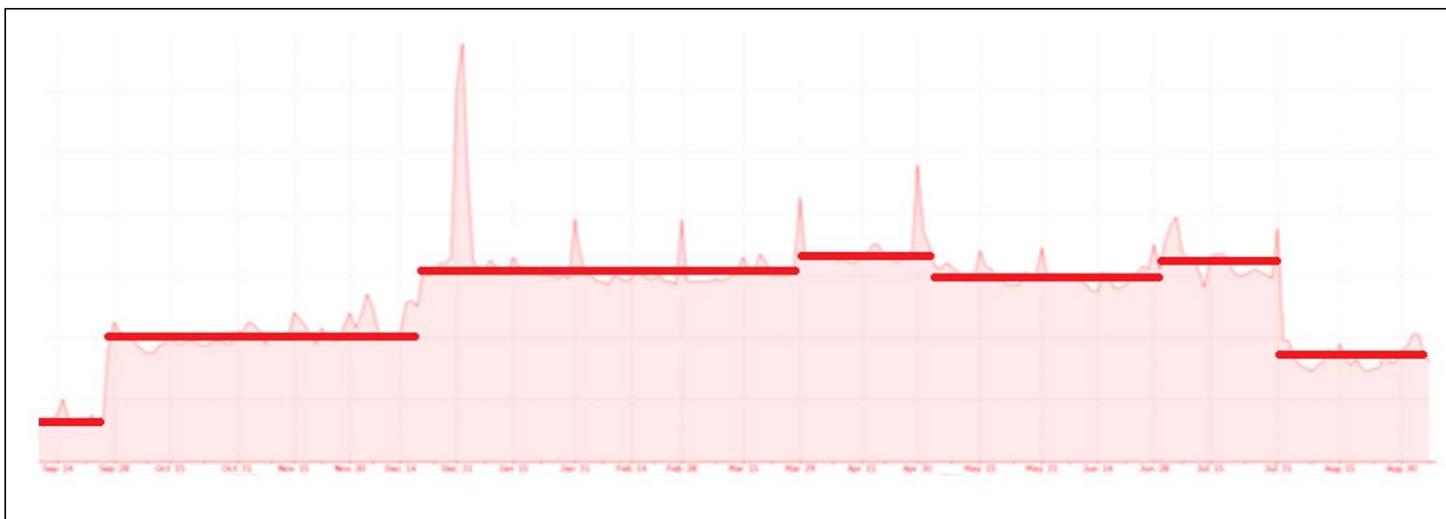
**Swaps**

Term	Bid	Ask
1Y	3.41532%	3.42668%
2Y	3.38246%	3.39164%
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4Y	3.17325%	3.18184%
5Y	3.15423%	3.16357%
6Y	3.14866%	3.15714%
7Y	3.14521%	3.15179%
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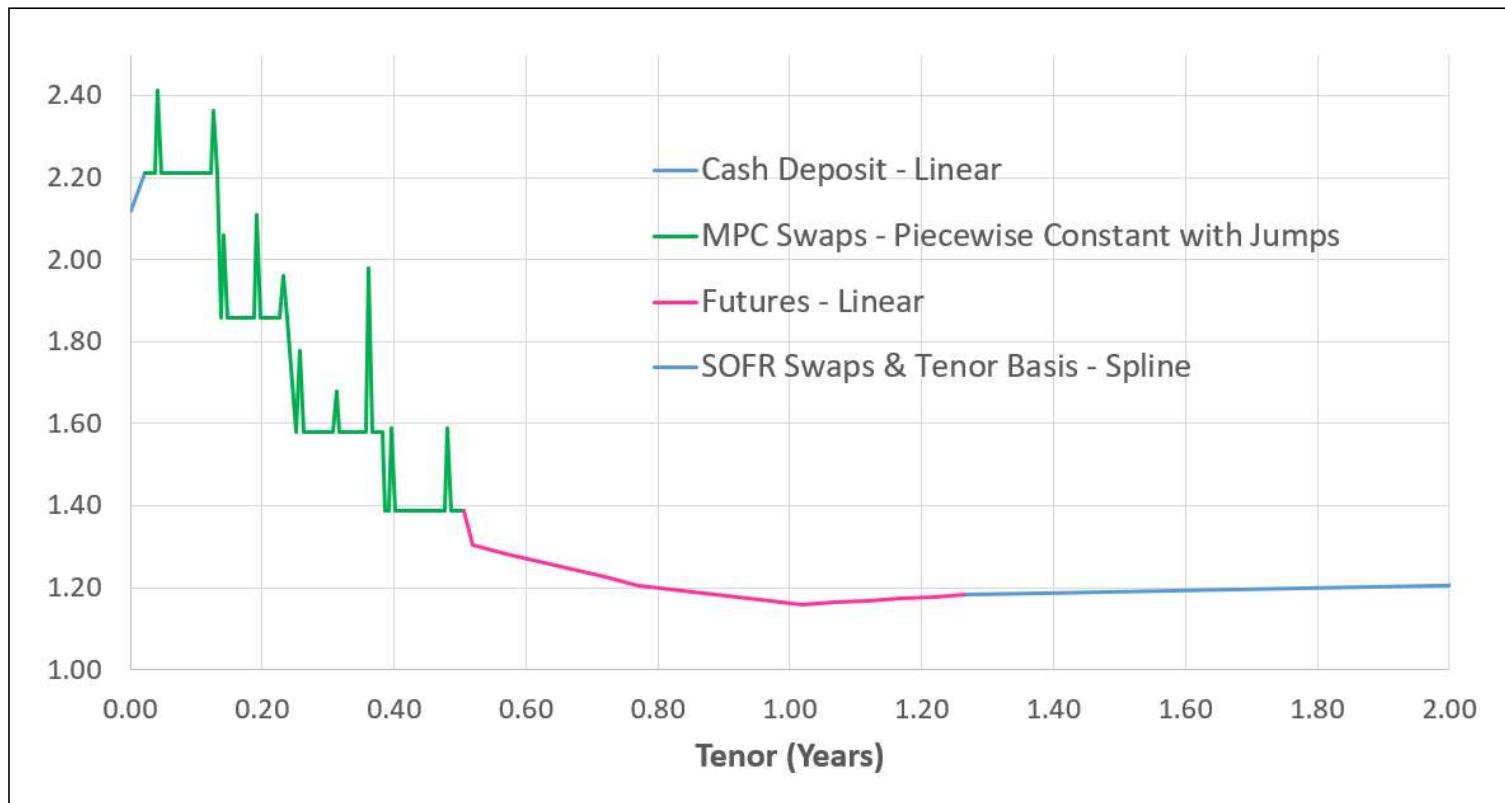
**Forward Rate (%)**

The graph illustrates the forward rate curve, which shows the expected future interest rates based on current market conditions. The curve is relatively flat for longer maturities, indicating low volatility in the long-term rates.

## USD SOFR Forward Curve Shape



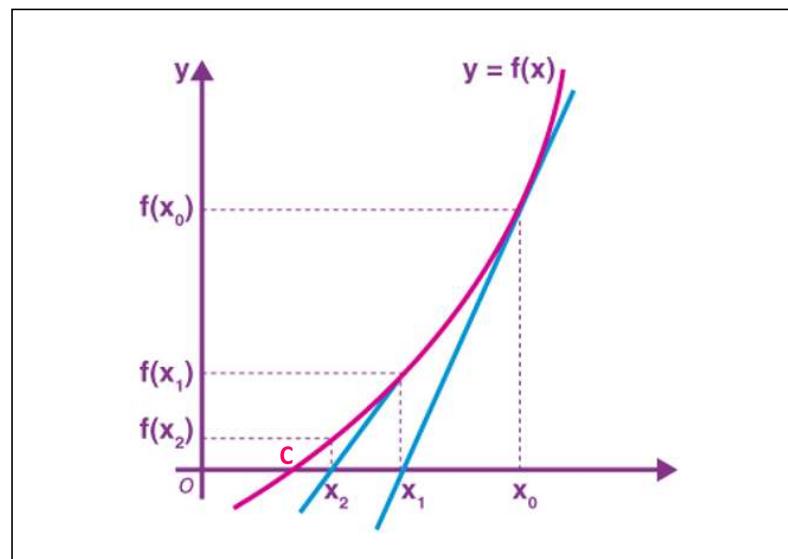
## USD SOFR Curve – Calibration Instrument Behaviour



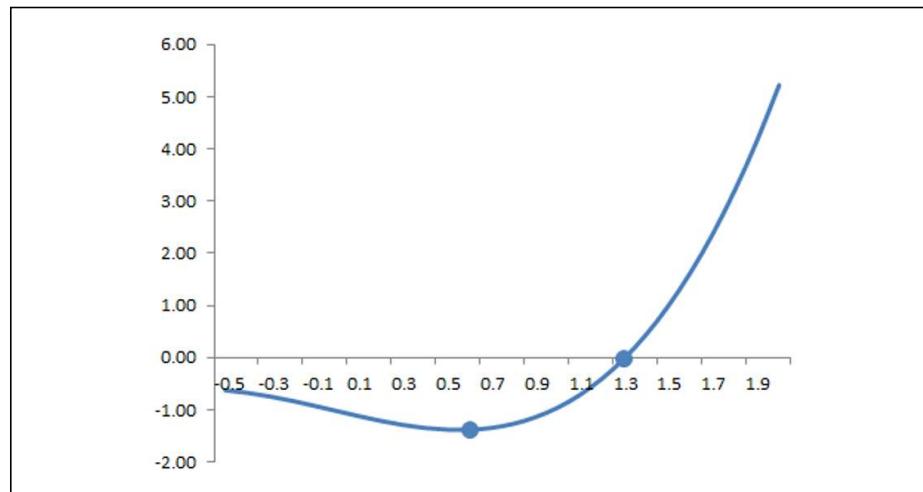
## Newton-Raphson Solving & Minimizing Technique

$$x_{n+1} = x_n - \frac{f(x)}{f'(x_n)}$$

$$x_{n+1} = x_n - \frac{f'(x_n)}{f''(x_n)}$$



## Newton-Raphson Solving & Minimizing Technique



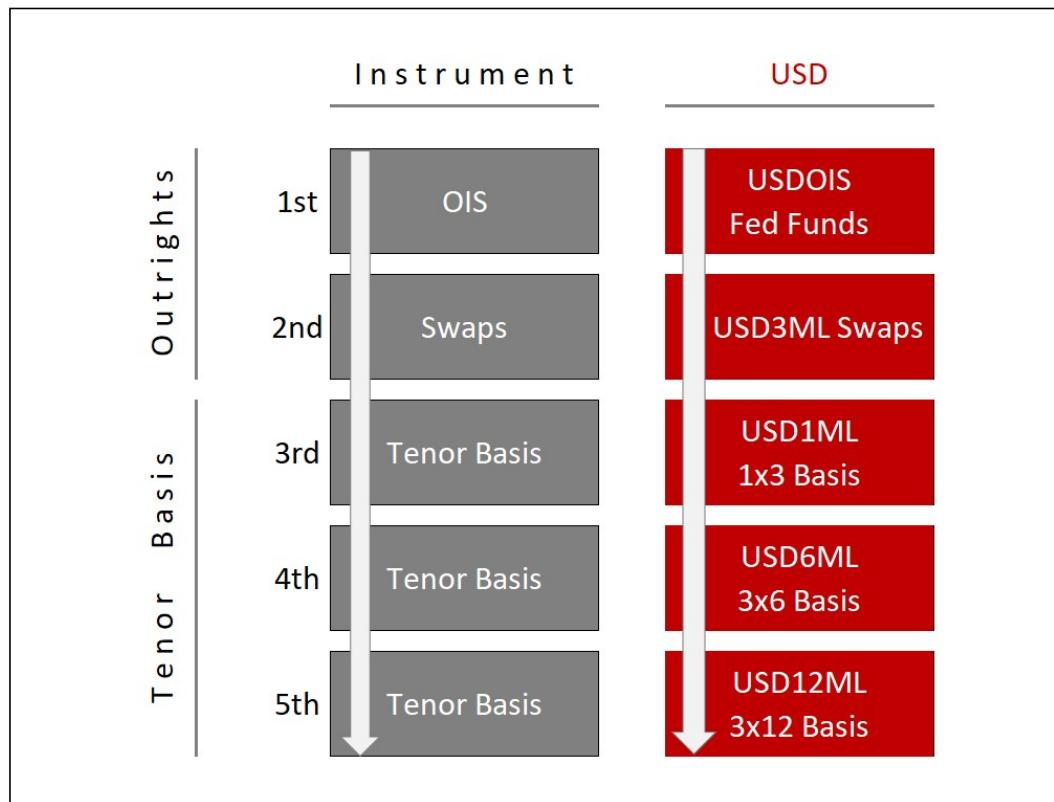
### Example 1: Newton-Raphson Solving Technique

n	$x_{n+1}$	$x_n$	$f(x_n)$	$f'(x_n)$	$\epsilon$
1	3.39	5.00	119.00	74.00	1.608
2	2.36	3.39	34.63	33.51	1.033
3	1.74	2.36	9.76	15.69	0.622
4	1.43	1.74	2.50	8.04	0.311
5	1.33	1.43	0.47	5.10	0.093
6	1.32	1.33	0.04	4.33	0.008

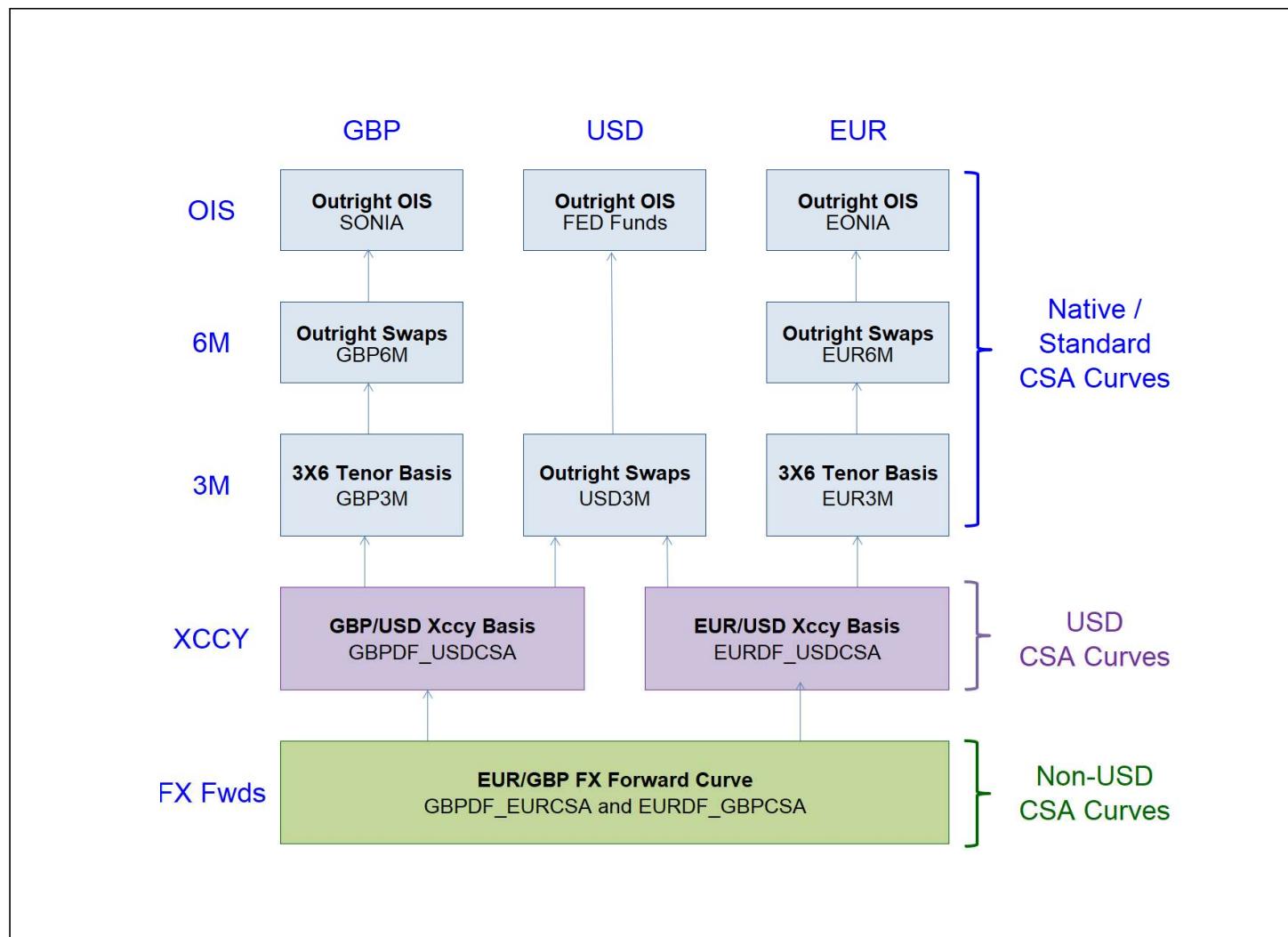
### Example 2: Newton-Raphson Solving Technique

n	$x_{n+1}$	$x_n$	$f(x_n)$	$f'(x_n)$	$\epsilon$
1	2.53	5.00	74.00	30.00	2.467
2	1.33	2.53	18.25	15.20	1.201
3	0.79	1.33	4.33	7.99	0.541
4	0.61	0.79	0.88	4.75	0.185
5	0.58	0.61	0.10	3.64	0.028
6	0.58	0.58	0.00	3.47	0.001

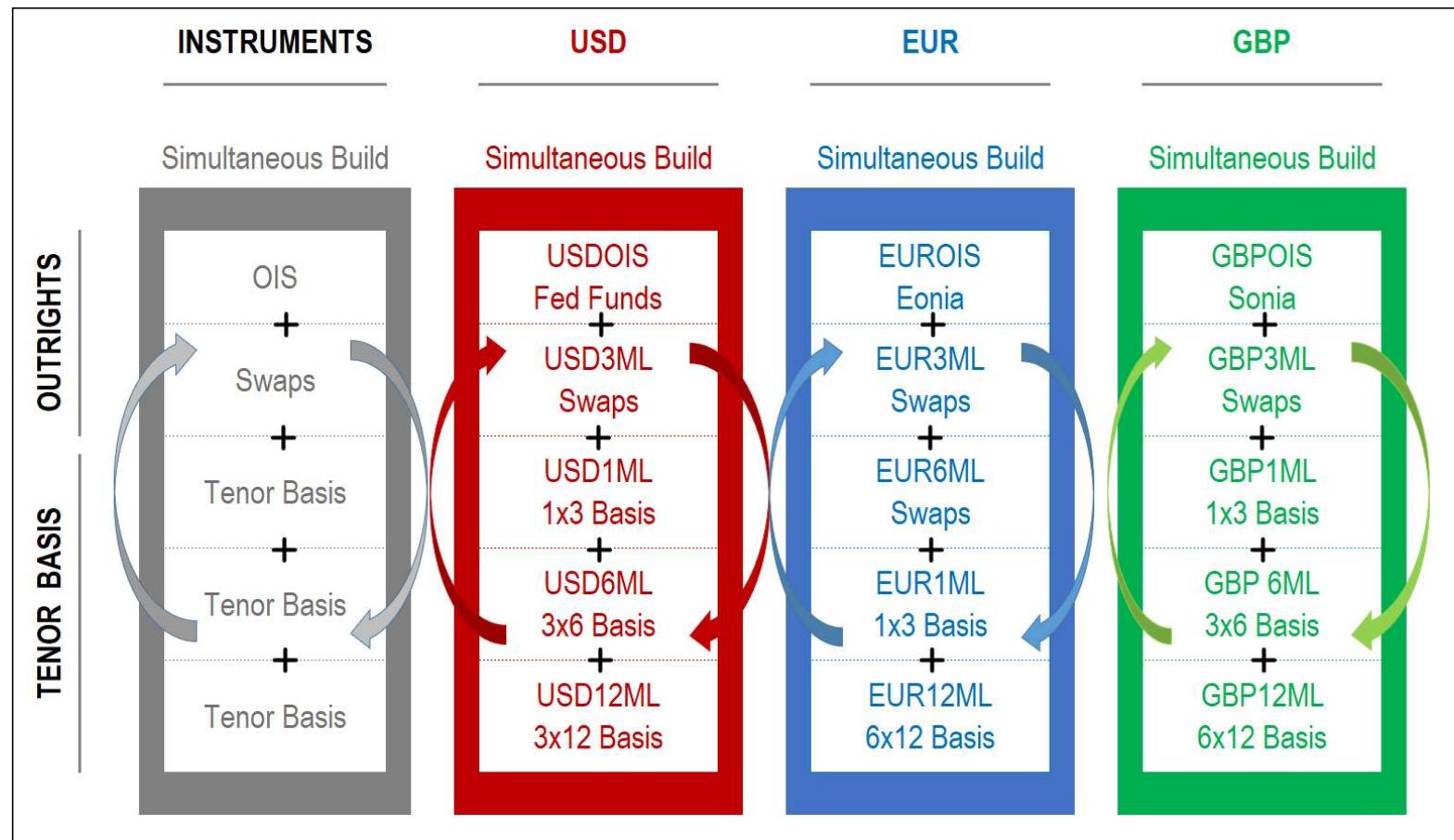
## Curve Bootstrapping



## CSA & XCCY Curve Dependencies



## Curve Build Order



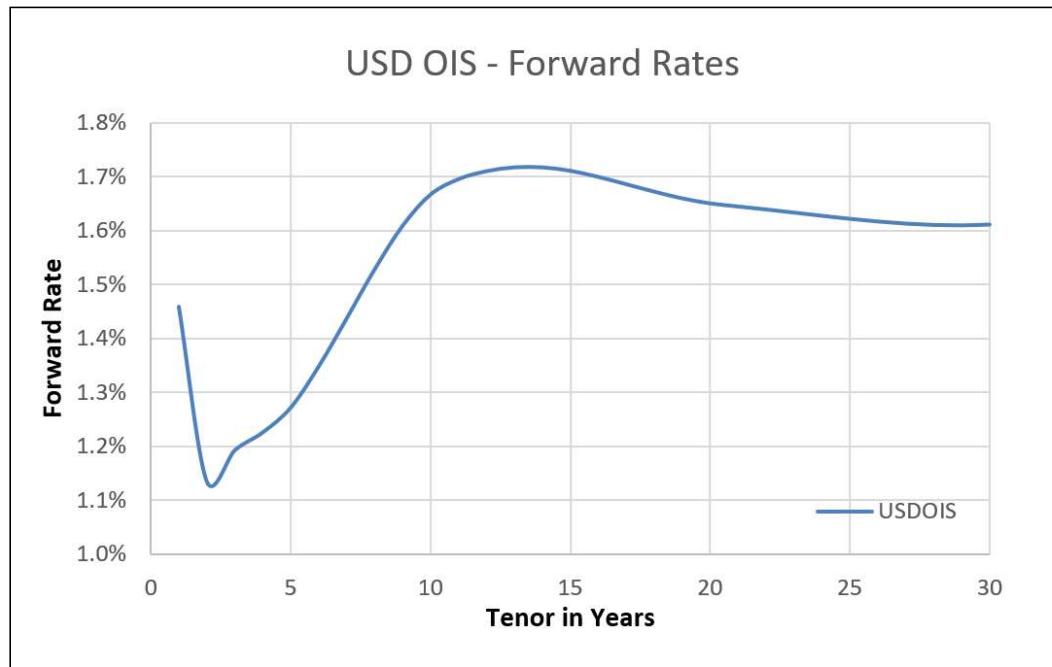
## Bootstrapping – Risk Constraints

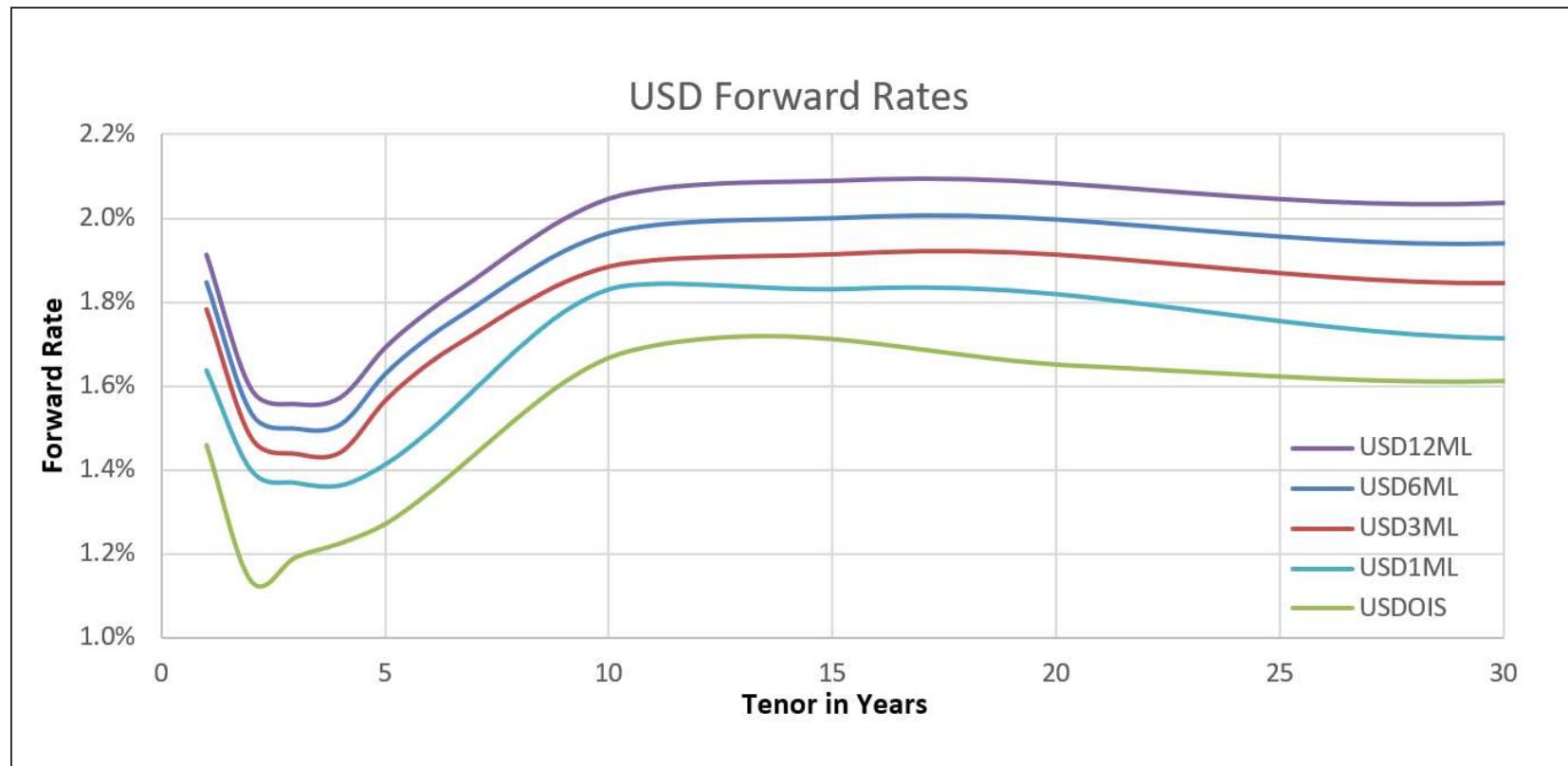
OIS Curve (1D)			
Instrument	Tenor	Quote	Interpolation Style
Cash Deposit	1D	2.02480	Linear
OIS Swap	6M	7.73450	Spline
OIS Swap	1Y	1.59890	Spline
OIS Swap	18M	1.52050	Spline
OIS Swap	2Y	1.46050	Spline
LIBOR-OIS Basis Swap	3Y	0.27500	Spline
LIBOR-OIS Basis Swap	5Y	0.26625	Spline
LIBOR-OIS Basis Swap	7Y	0.26563	Spline
LIBOR-OIS Basis Swap	10Y	0.26063	Spline
LIBOR-OIS Basis Swap	15Y	0.25500	Spline
LIBOR-OIS Basis Swap	20Y	0.25375	Spline
LIBOR-OIS Basis Swap	30Y	0.25375	Spline
LIBOR-OIS Basis Swap	40Y	0.25375	Spline
LIBOR-OIS Basis Swap	50Y	0.25375	Spline

## Bootstrapping – Risk Constraints

Swap Curve (USD3ML)			
Instrument	Tenor	Quote	Interpolation Style
Cash Deposit	3M	2.13940	Linear
Future1	SEP-19	97.85500	Linear
Future2	DEC-19	97.97500	Linear
Future3	MAR-20	98.23500	Linear
Future4	JUN-20	98.33500	Linear
Future5	SEP-20	98.39500	Linear
Future6	DEC-20	98.38000	Linear
Future7	MAR-21	98.37500	Linear
Future8	JUN-21	98.37000	Linear
LIBOR Swap	5Y	1.65880	Spline
LIBOR Swap	7Y	1.67880	Spline
LIBOR Swap	10Y	1.74720	Spline
LIBOR Swap	15Y	1.84090	Spline
LIBOR Swap	20Y	1.89680	Spline
LIBOR Swap	30Y	1.92460	Spline
LIBOR Swap	40Y	1.92460	Spline
LIBOR Swap	50Y	1.92460	Spline

## Curve Bootstrapping





## Curve Calibration using Global Optimization

Multi-Dimensional Newton-Raphson Algorithm				Tolerance $X_{n+1} = X_n - J^{-1} f(X_n)$	RMSE	USDOIS Discount Factors	
				1.00E-08	8.72E-12	Integrate USDOIS Forward Polynomial	
Iteration: 4				Initial Guess			
Curve	Term	Time, t	$X_{n+1}$	$X_n$	$X_0$	$f(X_n)$	Epsilon
USDOIS	1Y	1.00	1.4359%	1.4359%	2.0000%	0.0000%	0.00E+00
USDOIS	2Y	2.00	1.2332%	1.2332%	2.0000%	0.0000%	2.69E-12
USDOIS	3Y	3.00	1.2511%	1.2511%	2.0000%	0.0000%	3.86E-12
USDOIS	4Y	4.00	1.2913%	1.2913%	2.0000%	0.0000%	1.00E-12
USDOIS	5Y	5.00	1.3978%	1.3978%	2.0000%	0.0000%	-3.89E-12
USD3ML	1Y	1.00	1.7090%	1.7090%	2.0000%	0.0000%	0.00E+00
USD3ML	2Y	2.00	1.4736%	1.4736%	2.0000%	0.0000%	3.13E-12
USD3ML	3Y	3.00	1.4953%	1.4953%	2.0000%	0.0000%	4.44E-12
USD3ML	4Y	4.00	1.5593%	1.5593%	2.0000%	0.0000%	5.28E-14
USD3ML	5Y	5.00	1.6300%	1.6300%	2.0000%	0.0000%	-2.89E-12

Time, t DiscFactor Integrand

1.00	0.98228	1.7878%
2.00	0.96958	3.0894%
3.00	0.95767	4.3251%
4.00	0.94557	5.5963%
5.00	0.93307	6.9271%

Update Solver



## Curve Calibration Results

Iteration Results											
Term	$X_0$	$X_1$	$X_2$	$X_3$	$X_4$	$X_5$	$X_6$	$X_7$	$X_8$	$X_9$	$X_{10}$
1Y	2.0000%	1.4359%	1.4359%	1.4359%	1.4359%						
2Y	2.0000%	1.2325%	1.2332%	1.2332%	1.2332%						
3Y	2.0000%	1.2504%	1.2511%	1.2511%	1.2511%						
4Y	2.0000%	1.2911%	1.2913%	1.2913%	1.2913%						
5Y	2.0000%	1.3992%	1.3978%	1.3978%	1.3978%						
1Y	2.0000%	1.7090%	1.7090%	1.7090%	1.7090%						
2Y	2.0000%	1.4728%	1.4736%	1.4736%	1.4736%						
3Y	2.0000%	1.4946%	1.4953%	1.4953%	1.4953%						
4Y	2.0000%	1.5593%	1.5593%	1.5593%	1.5593%						
5Y	2.0000%	1.6310%	1.6300%	1.6300%	1.6300%						



## Curve Risk Jacobian

	Jacobian, $dP/dL$									
	$L_{1Y}^{OIS}$	$L_{2Y}^{OIS}$	$L_{3Y}^{OIS}$	$L_{4Y}^{OIS}$	$L_{5Y}^{OIS}$	$L_{1Y}^{IRS}$	$L_{2Y}^{IRS}$	$L_{3Y}^{IRS}$	$L_{4Y}^{IRS}$	$L_{5Y}^{IRS}$
$OIS_{1Y}$	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
$OIS_{2Y}$	0.50	0.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
$OIS_{3Y}$	0.34	0.33	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00
$OIS_{4Y}$	0.25	0.25	0.25	0.25	0.00	0.00	0.00	0.00	0.00	0.00
$OIS_{5Y}$	0.21	0.20	0.20	0.20	0.19	0.00	0.00	0.00	0.00	0.00
$IRS_{1Y}$	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00
$IRS_{2Y}$	0.00	0.00	0.00	0.00	0.00	0.50	0.50	0.00	0.00	0.00
$IRS_{3Y}$	0.00	0.00	0.00	0.00	0.00	0.34	0.33	0.33	0.00	0.00
$IRS_{4Y}$	0.00	0.00	0.00	0.00	0.00	0.25	0.25	0.25	0.25	0.00
$IRS_{5Y}$	0.00	0.00	0.00	0.00	0.00	0.21	0.20	0.20	0.20	0.19



## Ultra-Fast Curves using Inverse Jacobian

### Ultra-Fast Yield Curves using Inverse Jacobian

$$L_{\text{NEW}} = L_{\text{OLD}} + dL$$

New Fwds      Chg in Mkt Data      Inverse Jacobian,  $J^{-1}$  (or  $dL/dP$ )

	$L_{\text{NEW}}$	$dP (\%)$	$L_{\text{OLD}}$	$OIS_{1Y}$	$OIS_{2Y}$	$OIS_{3Y}$	$OIS_{4Y}$	$OIS_{5Y}$	$IRS_{1Y}$	$IRS_{2Y}$	$IRS_{3Y}$	$IRS_{4Y}$	$IRS_{5Y}$
$L_{1Y}^{\text{OIS}}$	1.44591%	O/S 1Y 0.0100%	$L_{1Y}^{\text{OIS}}$	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
$L_{2Y}^{\text{OIS}}$	1.24323%	O/S 2Y 0.0100%	$L_{2Y}^{\text{OIS}}$	-1.01	2.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
$L_{3Y}^{\text{OIS}}$	1.26107%	O/S 3Y 0.0100%	$L_{3Y}^{\text{OIS}}$	0.00	-2.04	3.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00
$L_{4Y}^{\text{OIS}}$	1.30130%	O/S 4Y 0.0100%	$L_{4Y}^{\text{OIS}}$	0.00	0.00	-3.08	4.08	0.00	0.00	0.00	0.00	0.00	0.00
$L_{5Y}^{\text{OIS}}$	1.40782%	O/S 5Y 0.0100%	$L_{5Y}^{\text{OIS}}$	0.00	0.00	0.00	-4.13	5.13	0.00	0.00	0.00	0.00	0.00
$L_{1Y}^{\text{IRS}}$	1.71896%	IRS 1Y 0.0100%	$L_{1Y}^{\text{IRS}}$	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00
$L_{2Y}^{\text{IRS}}$	1.48359%	IRS 2Y 0.0100%	$L_{2Y}^{\text{IRS}}$	0.00	0.00	0.00	0.00	0.00	-1.01	2.01	0.00	0.00	0.00
$L_{3Y}^{\text{IRS}}$	1.50531%	IRS 3Y 0.0100%	$L_{3Y}^{\text{IRS}}$	0.00	0.00	0.00	0.00	0.00	0.00	-2.04	3.04	0.00	0.00
$L_{4Y}^{\text{IRS}}$	1.56934%	IRS 4Y 0.0100%	$L_{4Y}^{\text{IRS}}$	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-3.08	4.08	0.00
$L_{5Y}^{\text{IRS}}$	1.63999%	IRS 5Y 0.0100%	$L_{5Y}^{\text{IRS}}$	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-4.13	5.13

### Use Jacobian to Imply Change in Forward Rates

$$\text{Change in Forwards} = J^{-1} \cdot dP = (dL/dP) \cdot dP = dL$$



## Ultra-Fast Curves using Inverse Jacobian

New Fwds From Calibration			New Fwds From Jacobian			Inverse Jacobian, $J^{-1}$ (or $dL/dP$ )									
	$L_{\text{NEW}}$	$+/-$		$L_{\text{NEW}}$		$OIS_{1Y}$	$OIS_{2Y}$	$OIS_{3Y}$	$OIS_{4Y}$	$OIS_{5Y}$	$IRS_{1Y}$	$IRS_{2Y}$	$IRS_{3Y}$	$IRS_{4Y}$	$IRS_{5Y}$
$L_{1Y}^{\text{OIS}}$	1.44591%	0.0000%	$L_{1Y}^{\text{OIS}}$	1.4459%		1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
$L_{2Y}^{\text{OIS}}$	1.24322%	0.0000%	$L_{2Y}^{\text{OIS}}$	1.2432%		-1.01	2.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
$L_{3Y}^{\text{OIS}}$	1.26107%	0.0000%	$L_{3Y}^{\text{OIS}}$	1.2611%		0.00	-2.04	3.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00
$L_{4Y}^{\text{OIS}}$	1.30130%	0.0000%	$L_{4Y}^{\text{OIS}}$	1.3013%		0.00	0.00	-3.08	4.08	0.00	0.00	0.00	0.00	0.00	0.00
$L_{5Y}^{\text{OIS}}$	1.40784%	0.0000%	$L_{5Y}^{\text{OIS}}$	1.4078%		0.00	0.00	0.00	-4.13	5.13	0.00	0.00	0.00	0.00	0.00
$L_{1Y}^{\text{IRS}}$	1.71896%	0.0000%	$L_{1Y}^{\text{IRS}}$	1.7190%		0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00
$L_{2Y}^{\text{IRS}}$	1.48358%	0.0000%	$L_{2Y}^{\text{IRS}}$	1.4836%		0.00	0.00	0.00	0.00	0.00	-1.01	2.01	0.00	0.00	0.00
$L_{3Y}^{\text{IRS}}$	1.50530%	0.0000%	$L_{3Y}^{\text{IRS}}$	1.5053%		0.00	0.00	0.00	0.00	0.00	0.00	-2.04	3.04	0.00	0.00
$L_{4Y}^{\text{IRS}}$	1.56934%	0.0000%	$L_{4Y}^{\text{IRS}}$	1.5693%		0.00	0.00	0.00	0.00	0.00	0.00	0.00	-3.08	4.08	0.00
$L_{5Y}^{\text{IRS}}$	1.64000%	0.0000%	$L_{5Y}^{\text{IRS}}$	1.6400%		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-4.13	5.13



## Real-Time Risk using Inverse Jacobian

Inverse Curve Jacobian, $J = dL/dP$ Change in Libor rate per unit change in market par rates						Shift Size, $dP$ Change in market par rates					
						Shift, Bp:Shift, %					
$dL_{1Y}^{IRS}$	$dP_{1Y}^{IRS}$	$dP_{2Y}^{IRS}$	$dP_{3Y}^{IRS}$	$dP_{4Y}^{IRS}$	$dP_{5Y}^{IRS}$	$dP_{1Y}^{IRS}$	1.00	0.01%	$dP_{2Y}^{IRS}$	1.00	0.01%
$dL_{2Y}^{IRS}$	-1.01	2.01	0.00	0.00	0.00	$dP_{3Y}^{IRS}$	1.00	0.01%	$dP_{4Y}^{IRS}$	1.00	0.01%
$dL_{3Y}^{IRS}$	0.00	-2.04	3.04	0.00	0.00	$dP_{5Y}^{IRS}$	1.00	0.01%	$dL_{4Y}^{IRS}$	0.00	0.01%
$dL_{4Y}^{IRS}$	0.00	0.00	-3.08	4.08	0.00	$dL_{5Y}^{IRS}$	0.00	0.01%	$dL_{5Y}^{IRS}$	0.00	0.01%
$dL_{5Y}^{IRS}$	0.00	0.00	0.00	-4.13	5.13						

Swap Jacobian, $dS/dL$ Change in swap value per unit change in Libor Rate						Risk, $dS/dP = dS/dL \times dL/dP$ Change in swap value per unit change in market par rates					
						Total					
$dS_{1Y}^{IRS}$	$dL_{1Y}$	$dL_{2Y}$	$dL_{3Y}$	$dL_{4Y}$	$dL_{5Y}$	$dP_{1Y}^{IRS}$	98	0	$dP_{2Y}^{IRS}$	0	0
$dS_{2Y}^{IRS}$	98	97	0	0	0	$dP_{3Y}^{IRS}$	0	195	$dP_{4Y}^{IRS}$	0	0
$dS_{3Y}^{IRS}$	98	97	96	0	0	$dP_{5Y}^{IRS}$	0	0	$dL_{4Y}^{IRS}$	95	0
$dS_{4Y}^{IRS}$	98	97	96	95	0	$dL_{5Y}^{IRS}$	0	0	$dL_{4Y,5Y}^{IRS}$	0	479
$dS_{5Y}^{IRS}$	98	97	96	95	93	$dS_{4Y,5Y}^{IRS}$	0	0	$dS_{4,5Y}^{IRS}$	0	432
$dS_{4Y,5Y}^{IRS}$	0	0	0	0	93	$dS_{4,5Y}^{IRS}$	0	0	$dS_{4,5Y}^{IRS}$	0	432
$dS_{4,5Y}^{IRS}$	98	97	96	95	47						

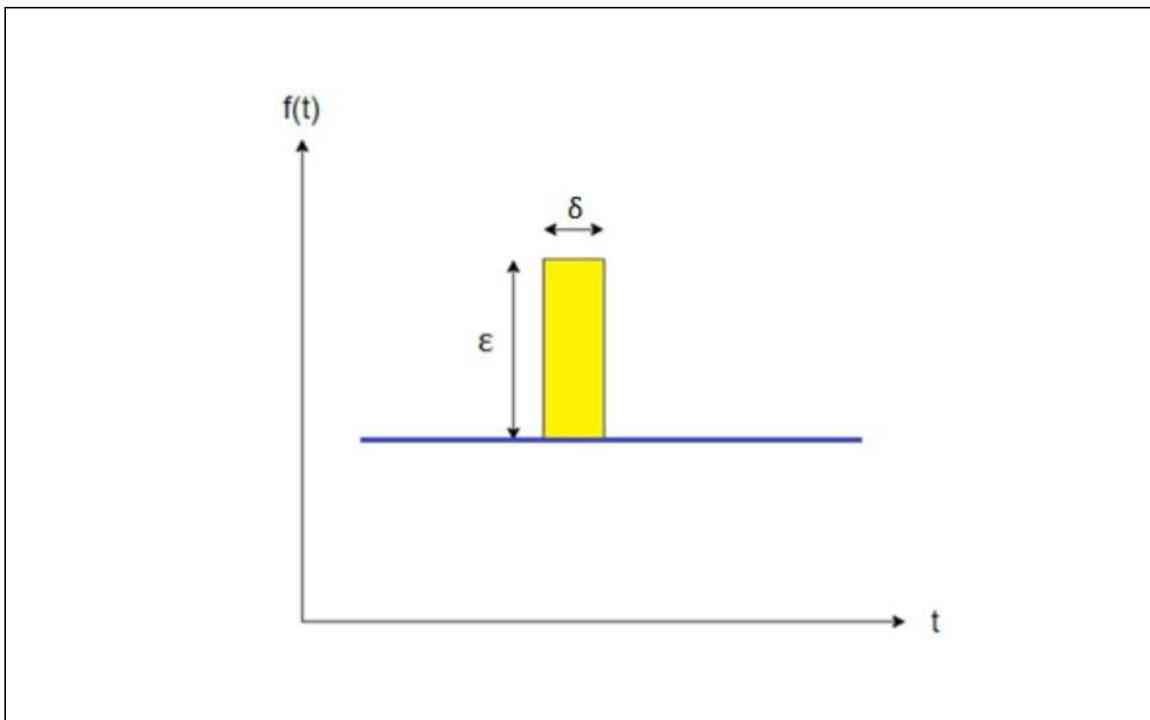
  

$$\text{Swap Delta} = \frac{dS}{dP} = \frac{dS}{dL} \cdot \frac{dL}{dP} \times \text{Shift Size}$$

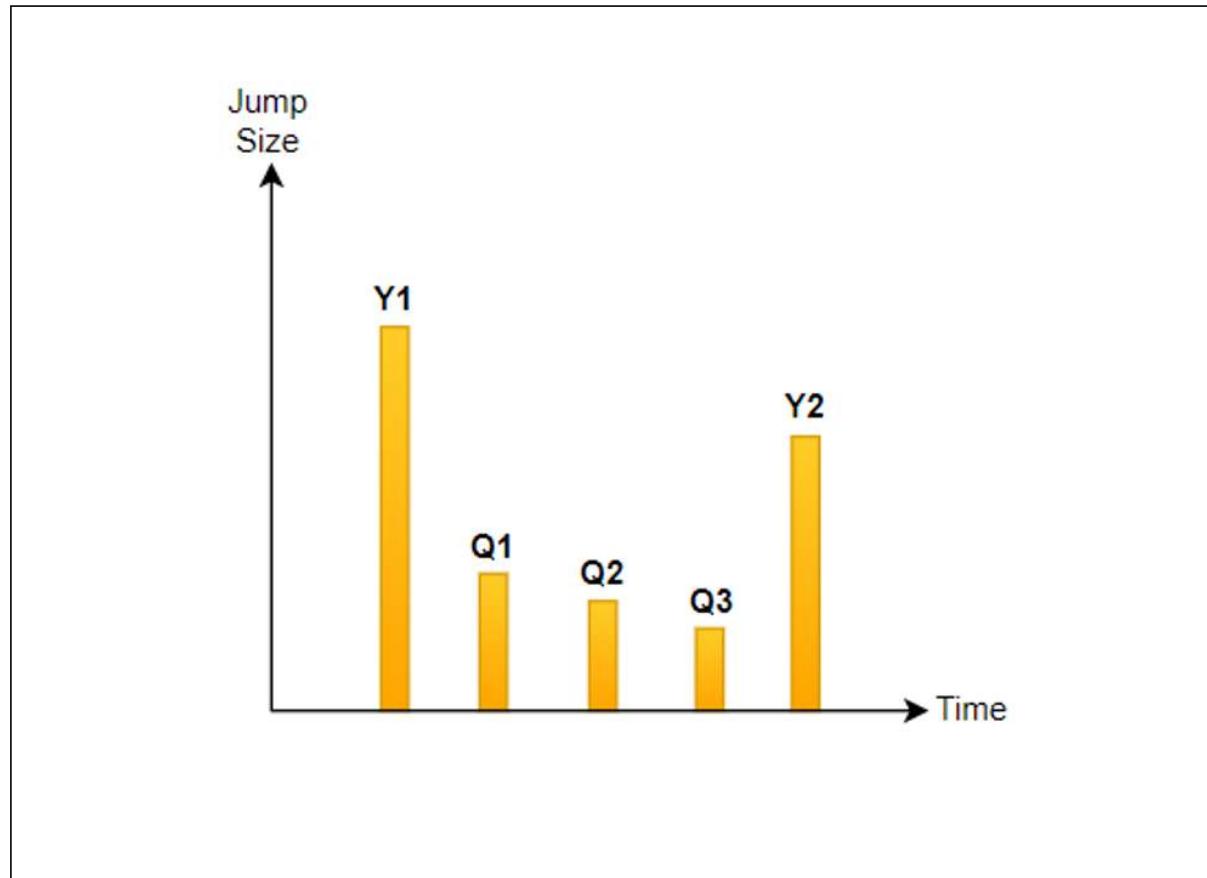

## USD SOFR Curve Calibration Instruments

Instrument	Maturity	Quote	Interpolation Style
Cash Deposit	1D	2.12000	Linear
Future 1M	1M	97.78734	Linear
Future 1M	2M	98.14013	Linear
Future 1M	3M	98.42061	Linear
Future 1M	4M	98.61140	Linear
Future 3M	6M	98.69700	Linear
Future 3M	9M	98.79400	Linear
Future 3M	12M	98.84100	Linear
Future 3M	15M	98.81700	Linear
Future 3M	18M	98.02500	Linear
SOFR Swap	3Y	1.22559	Spline
SOFR Swap	5Y	1.20502	Spline
SOFR Swap	7Y	1.23028	Spline
SOFR Swap	10Y	1.29071	Spline
SOFR Swap	15Y	1.36849	Spline
SOFR Swap	20Y	1.41102	Spline
SOFR Swap	30Y	1.42135	Spline
SOFR Swap	40Y	1.40063	Spline
SOFR Swap	50Y	1.36656	Spline

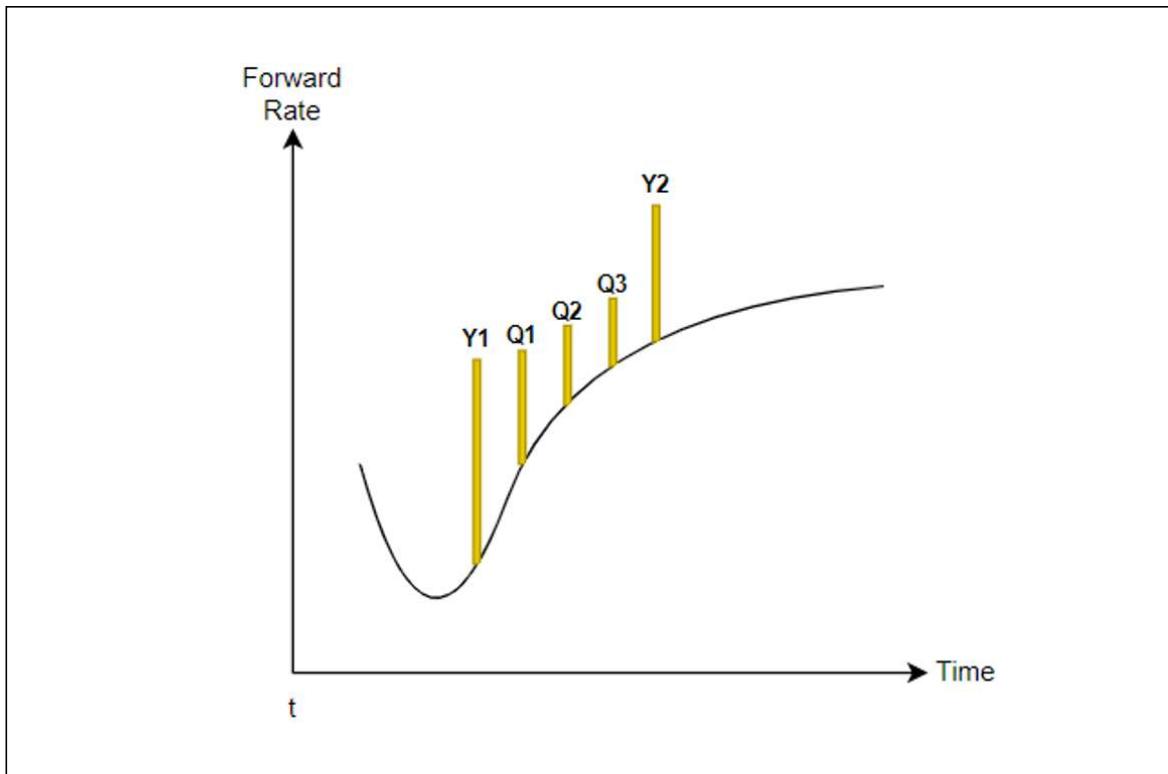
## Curve Jumps & Turn-of-Year Effects



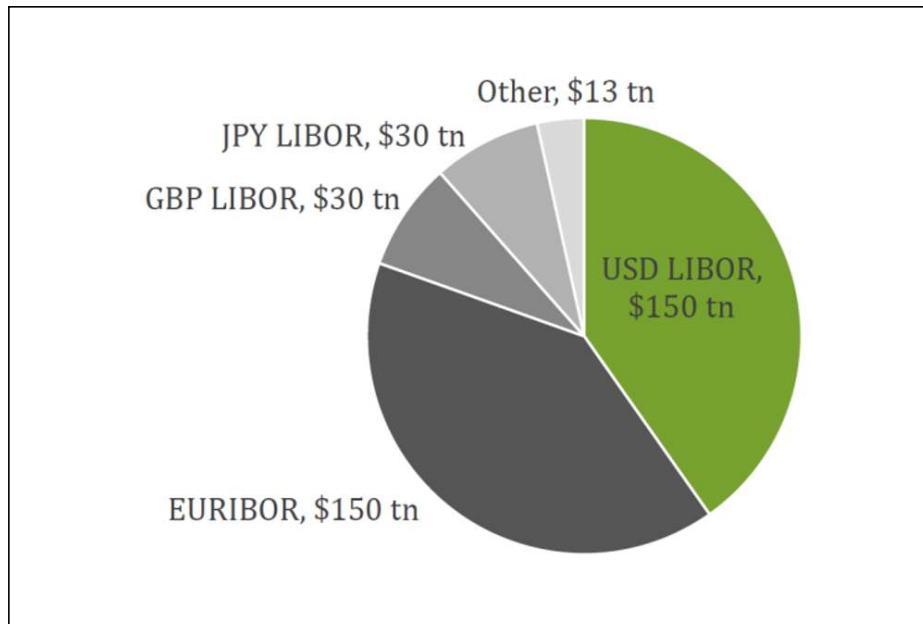
## Curve Jumps & Turn-of-Year Effects



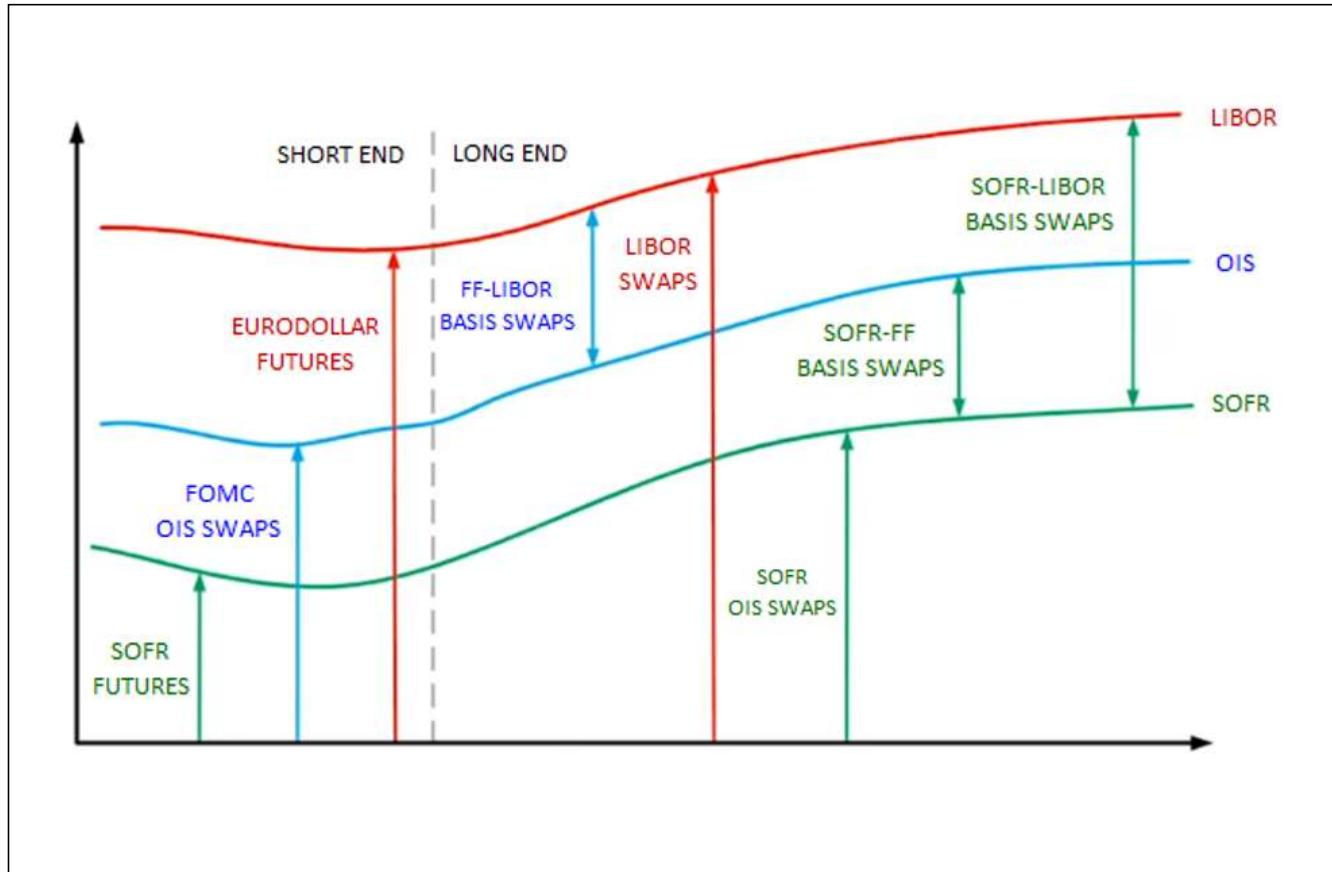
## Curve Jumps & Turn-of-Year Effects



## IBOR Market Size (2019)



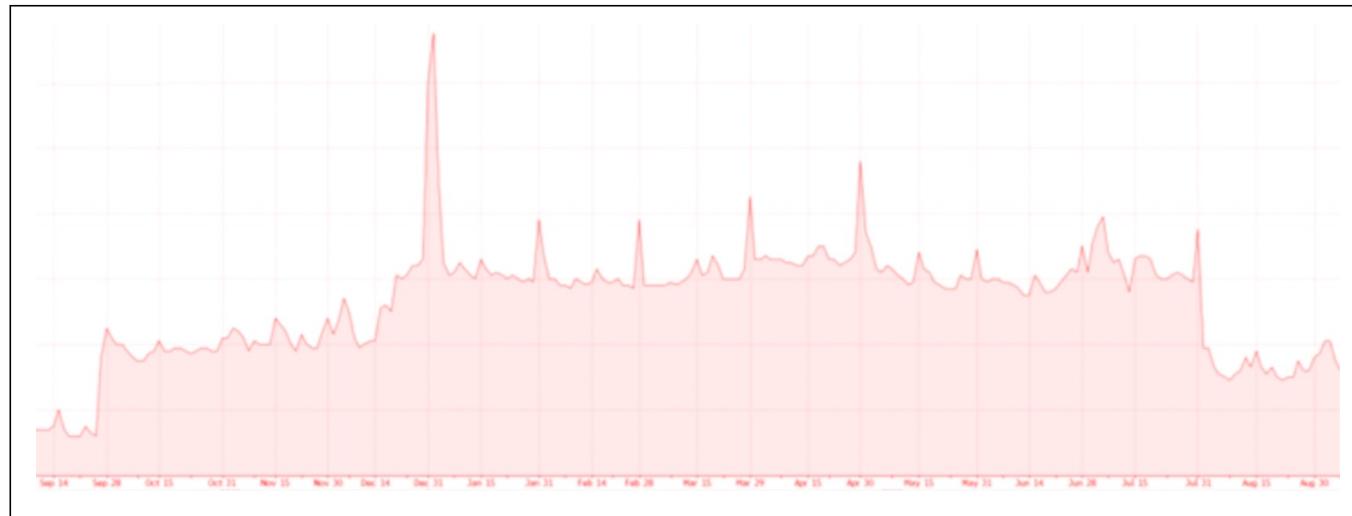
## USD SOFR / LIBOR Basis Instruments



## USD SOFR / LIBOR Curve Calibration

Instrument	Maturity	Quote	Interpolation Style
Cash Deposit	0.00	2.12000	Linear
Monetary Policy SOFR Swap	1M	2.21266	Piecewise-Constant with Jumps
Monetary Policy SOFR Swap	2M	1.85987	Piecewise-Constant with Jumps
Monetary Policy SOFR Swap	3M	1.57939	Piecewise-Constant with Jumps
Monetary Policy SOFR Swap	4M	1.38860	Piecewise-Constant with Jumps
Future 3M	6M	98.69700	Linear
Future 3M	9M	98.79400	Linear
Future 3M	12M	98.84100	Linear
Future 3M	15M	98.81700	Linear
Future 3M	18M	98.02500	Linear
SOFR Swap	3Y	1.22559	Spline
SOFR Swap	5Y	1.20502	Spline
SOFR Swap	7Y	1.23028	Spline
SOFR-OIS Basis Swap	10Y	0.01000	Spline
SOFR-OIS Basis Swap	15Y	0.02500	Spline
SOFR-OIS Basis Swap	20Y	0.05000	Spline
SOFR-LIBOR Basis Swap	30Y	0.07500	Spline
SOFR-LIBOR Basis Swap	40Y	0.08000	Spline
SOFR-LIBOR Basis Swap	50Y	0.10000	Spline

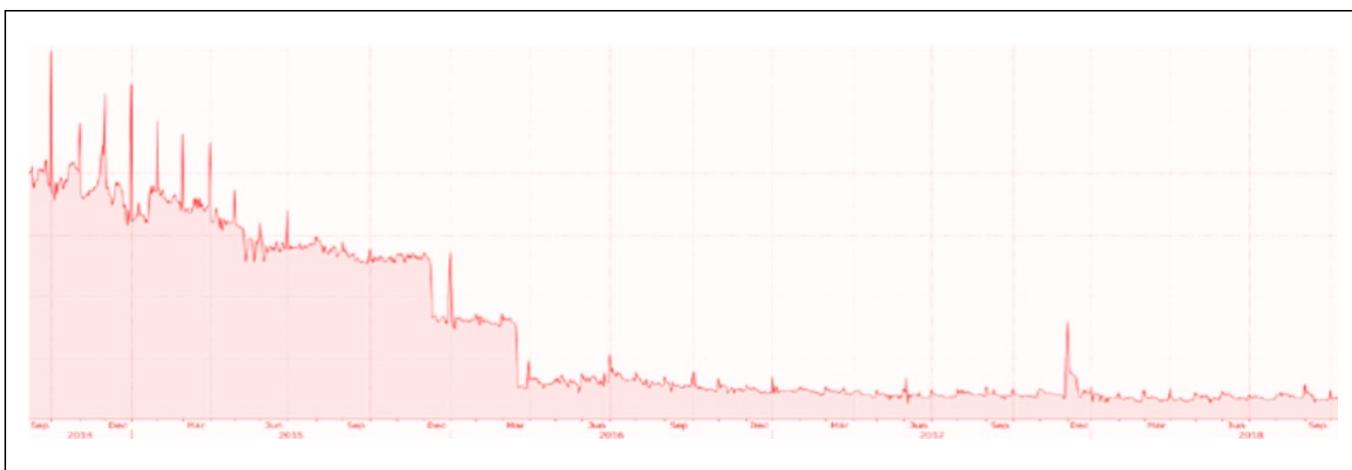
## RFR Curve Shape and Behaviour



## USD FED Fund Curve Behaviour



## EUR EONIA Curve Behaviour



## Chapter 5 – Interest Rate Risk

## USD Swap Pricing & Risk

Trade Template			USD IRS 5% USD3ML 5Y	
Swap			LEG1:FIXED	LEG2:FLOAT
Pay / Receive			RECEIVE	PAY
Notional			1,000,000	1,000,000
Currency			USD	USD
Effective Date			2D Tue, 25-Aug-2015	2D Tue, 25-Aug-2015
Maturity Date			5Y Tue, 25-Aug-2020	5Y Tue, 25-Aug-2020
Fixed Rate (%)			5.000000%	
Float Index				3M USD3ML
Float Spread (bps)				0.000
Reset Frequency				QUARTERLY
Pay Frequency			SEMI-ANNUAL	QUARTERLY
Day Count			30/360	ACT/360
Market				
Curve Date			Fri, 21-Aug-2015	Fri, 21-Aug-2015
Forecast Curve				USD3ML
Discount Curve			USDOIS	USDOIS
Valuation Results				
Valuation Date			Fri, 21-Aug-2015	
Par Rate			1.548250%	
NPV			167,892.11	
PV01			486.40	
DV01			532.42	

## USD SOFR Swap Portfolio

EffectiveLag	Maturity	SwapTemplate	FixedLeg	Notional	FixedRate	FloatSpread
2D	1Y	USD_SOFR_SWAP:0	PAY	1,000,000	1.89350%	0.00
2D	2Y	USD_SOFR_SWAP:0	PAY	1,000,000	1.68360%	0.00
2D	3Y	USD_SOFR_SWAP:0	PAY	1,000,000	1.62600%	0.00
2D	4Y	USD_SOFR_SWAP:0	PAY	1,000,000	1.61700%	0.00
2D	5Y	USD_SOFR_SWAP:0	PAY	1,000,000	1.64200%	0.00
2D	6Y	USD_SOFR_SWAP:0	PAY	1,000,000	1.67900%	0.00
2D	7Y	USD_SOFR_SWAP:0	PAY	1,000,000	1.71600%	0.00
2D	8Y	USD_SOFR_SWAP:0	PAY	1,000,000	1.75700%	0.00
2D	9Y	USD_SOFR_SWAP:0	PAY	1,000,000	1.79800%	0.00
2D	10Y	USD_SOFR_SWAP:0	PAY	1,000,000	1.83200%	0.00
2D	15Y	USD_SOFR_SWAP:0	PAY	1,000,000	1.96800%	0.00
2D	20Y	USD_SOFR_SWAP:0	PAY	1,000,000	2.03300%	0.00
2D	25Y	USD_SOFR_SWAP:0	PAY	1,000,000	2.04100%	0.00
2D	30Y	USD_SOFR_SWAP:0	PAY	1,000,000	2.04900%	0.00

## USD SOFR Swap Portfolio – Pricing & Risk

Swap	YieldCurve	PV	ParRate	PV01	DV01
USD_SOFR_SWAP_1Y:0	USDYC_SOFR	0.00	1.8935%	99	99
USD_SOFR_SWAP_2Y:0	USDYC_SOFR	0.00	1.6836%	198	198
USD_SOFR_SWAP_3Y:0	USDYC_SOFR	0.00	1.6260%	294	294
USD_SOFR_SWAP_4Y:0	USDYC_SOFR	0.00	1.6170%	389	389
USD_SOFR_SWAP_5Y:0	USDYC_SOFR	0.00	1.6420%	482	482
USD_SOFR_SWAP_6Y:0	USDYC_SOFR	0.00	1.6790%	574	574
USD_SOFR_SWAP_7Y:0	USDYC_SOFR	0.00	1.7160%	665	665
USD_SOFR_SWAP_8Y:0	USDYC_SOFR	0.00	1.7570%	752	752
USD_SOFR_SWAP_9Y:0	USDYC_SOFR	0.00	1.7980%	838	838
USD_SOFR_SWAP_10Y:0	USDYC_SOFR	0.00	1.8320%	922	922
USD_SOFR_SWAP_15Y:0	USDYC_SOFR	0.00	1.9680%	1,315	1,315
USD_SOFR_SWAP_20Y:0	USDYC_SOFR	0.00	2.0330%	1,664	1,664
USD_SOFR_SWAP_25Y:0	USDYC_SOFR	0.00	2.0410%	1,977	1,977
USD_SOFR_SWAP_30Y:0	USDYC_SOFR	0.00	2.0490%	2,259	2,259
			Total Risk	12,428	12,428

## USD SOFR Swap Portfolio – Bucketed DV01 Risk

USD SOFR YIELD CURVE - CALIBRATION INSTRUMENTS			Bucketed DV01, USD		
Instrument	Term	Rate	Instrument	Tenor	DV01
USD SOFR Swap	ON	2.37000%	USD SOFR Swap	ON	8
USD SOFR Swap	1W	2.36510%	USD SOFR Swap	1W	0
USD SOFR Swap	2W	2.34960%	USD SOFR Swap	2W	0
USD SOFR Swap	3W	2.35200%	USD SOFR Swap	3W	0
USD SOFR Swap	1M	2.34550%	USD SOFR Swap	1M	0
USD SOFR Swap	2M	2.30320%	USD SOFR Swap	2M	0
USD SOFR Swap	3M	2.25590%	USD SOFR Swap	3M	0
USD SOFR Swap	4M	2.19610%	USD SOFR Swap	4M	0
USD SOFR Swap	5M	2.14750%	USD SOFR Swap	5M	-1
USD SOFR Swap	6M	2.10350%	USD SOFR Swap	6M	1
USD SOFR Swap	1Y	1.89350%	USD SOFR Swap	1Y	92
USD SOFR Swap	2Y	1.68360%	USD SOFR Swap	2Y	213
USD SOFR Swap	3Y	1.62600%	USD SOFR Swap	3Y	294
USD SOFR Swap	4Y	1.61700%	USD SOFR Swap	4Y	409
USD SOFR Swap	5Y	1.64200%	USD SOFR Swap	5Y	453
USD SOFR Swap	6Y	1.67900%	USD SOFR Swap	6Y	541
USD SOFR Swap	7Y	1.71600%	USD SOFR Swap	7Y	723
USD SOFR Swap	8Y	1.75700%	USD SOFR Swap	8Y	736
USD SOFR Swap	9Y	1.79800%	USD SOFR Swap	9Y	852
USD SOFR Swap	10Y	1.83200%	USD SOFR Swap	10Y	892
USD SOFR Swap	15Y	1.96800%	USD SOFR Swap	15Y	1,320
USD SOFR Swap	20Y	2.03300%	USD SOFR Swap	20Y	1,662
USD SOFR Swap	25Y	2.04100%	USD SOFR Swap	25Y	1,979
USD SOFR Swap	30Y	2.04900%	USD SOFR Swap	30Y	2,252
			Total Risk		12,428

## Pricing Jacobian for a Single Trade

Pricing Jacobian - Single Trade										
Trade	OIS Rates (Discount Risk)					LIBOR Rates (Forward Risk)				
	dO <sub>1Y</sub>	dO <sub>2Y</sub>	dO <sub>3Y</sub>	dO <sub>4Y</sub>	dO <sub>5Y</sub>	dL <sub>1Y</sub>	dL <sub>2Y</sub>	dL <sub>3Y</sub>	dL <sub>4Y</sub>	dL <sub>5Y</sub>
dS <sub>3Y</sub> <sup>IRS</sup>	0	0	0	0	0	98	97	96	0	0

## Pricing Jacobian for a Trade Portfolio

Pricing Jacobian - Trade Portfolio									
Trade	OIS Rates (Discount Risk)					LIBOR Rates (Forward Risk)			
	dO <sub>1Y</sub>	dO <sub>2Y</sub>	dO <sub>3Y</sub>	dO <sub>4Y</sub>	dO <sub>5Y</sub>	dL <sub>1Y</sub>	dL <sub>2Y</sub>	dL <sub>3Y</sub>	dL <sub>4Y</sub>
dS <sub>1Y</sub> <sup>IRS</sup>	0	0	0	0	0	98	0	0	0
dS <sub>2Y</sub> <sup>IRS</sup>	0	0	0	0	0	98	97	0	0
dS <sub>3Y</sub> <sup>IRS</sup>	0	0	0	0	0	98	97	96	0
dS <sub>4Y</sub> <sup>IRS</sup>	0	0	0	0	0	98	97	96	95
dS <sub>5Y</sub> <sup>IRS</sup>	0	0	0	0	0	98	97	96	95
dS <sub>4Y,5Y</sub> <sup>IRS</sup>	0	0	0	0	0	0	0	0	93
dS <sub>4.5Y</sub> <sup>IRS</sup>	0	0	0	0	0	98	97	96	95
									47



## Swap Curve Jacobian

		Curve Jacobian									
		OIS Curve Instruments					Swap Curve Instruments				
		$dP_{1Y}^{OIS}$	$dP_{2Y}^{OIS}$	$dP_{3Y}^{OIS}$	$dP_{4Y}^{OIS}$	$dP_{5Y}^{OIS}$	$dP_{1Y}^{IRS}$	$dP_{2Y}^{IRS}$	$dP_{3Y}^{IRS}$	$dP_{4Y}^{IRS}$	$dP_{5Y}^{IRS}$
OIS and LIBOR Forward Rates	$dO_{1Y}$	1.00	0	0	0	0	0	0	0	0	0
	$dO_{2Y}$	-1.01	2.01	0	0	0	0	0	0	0	0
	$dO_{3Y}$	0.00	-2.04	3.04	0	0	0	0	0	0	0
	$dO_{4Y}$	0.00	0.00	-3.08	4.08	0	0	0	0	0	0
	$dO_{5Y}$	0.00	0.00	0.00	-4.13	5.13	0	0	0	0	0
	$dL_{1Y}$	0	0	0	0	0	1.00	0	0	0	0
	$dL_{2Y}$	0	0	0	0	0	-1.01	2.01	0	0	0
	$dL_{3Y}$	0	0	0	0	0	0.00	-2.04	3.04	0	0
	$dL_{4Y}$	0	0	0	0	0	0.00	0.00	-3.08	4.08	0
	$dL_{5Y}$	0	0	0	0	0	0.00	0.00	0.00	-4.13	5.13



## Real-Time Portfolio Bucketed DV01 Risk

Risk Bucket	Trade DV01						
	IRS 1Y	IRS 2Y	IRS 3Y	IRS 4Y	IRS 5Y	IRS(4Y, 5Y)	IRS(4.5Y)
OIS 1Y	0	0	0	0	0	0	0
OIS 2Y	0	0	0	0	0	0	0
OIS 3Y	0	0	0	0	0	0	0
OIS 4Y	0	-1	-1	-1	0	0	0
OIS 5Y	0	1	1	1	0	0	0
IRS 1Y	98	0	0	0	0	0	0
IRS 2Y	0	195	0	0	0	0	0
IRS 3Y	0	0	291	0	0	0	0
IRS 4Y	0	0	0	386	0	-386	193
IRS 5Y	0	0	0	0	479	479	239

Total Trade DV01							
IRS 1Y	IRS 2Y	IRS 3Y	IRS 4Y	IRS 5Y	IRS(4Y, 5Y)	IRS(4.5Y)	
98	195	291	386	479	93	432	

X

## Portfolio IR Risk Hedging

Risk Bucket	Total Risk	Hedge	Qty
OIS 1Y	0	OIS 1Y	-
OIS 2Y	0	OIS 2Y	-
OIS 3Y	0	OIS 3Y	-
OIS 4Y	-2	OIS 4Y	-
OIS 5Y	2	OIS 5Y	-
IRS 1Y	98	IRS 1Y	-1.00
IRS 2Y	195	IRS 2Y	-1.00
IRS 3Y	291	IRS 3Y	-1.00
IRS 4Y	193	IRS 4Y	-0.50
IRS 5Y	1,197	IRS 5Y	-2.50

Portfolio DV01  
1,975



## Curve Jacobian – Hedge Instrument Modifications

Forwards	Calibration Instruments							
	$dP_{1Y}^{OIS}$	$dP_{2Y}^{OIS}$	$dP_{4Y}^{OIS}$	$dP_{5Y}^{OIS}$	$dP_{1Y}^{IRS}$	$dP_{2Y}^{IRS}$	$dP_{4Y}^{IRS}$	$dP_{5Y}^{IRS}$
$dO_{1Y}$	1.00	0	0	0	0	0	0	0
$dO_{2Y}$	-1.01	2.01	0	0	0	0	0	0
$dO_{4Y}$	0.34	-2.05	2.71	0	0	0	0	0
$dO_{5Y}$	0.00	0.00	-4.13	5.13	0	0	0	0
$dL_{1Y}$	0	0	0	0	1.00	0	0	0
$dL_{2Y}$	0	0	0	0	-1.01	2.01	0	0
$dL_{4Y}$	0	0	0	0	0.34	-2.05	2.71	0
$dL_{5Y}$	0	0	0	0	0.00	0.00	-4.13	5.13



## Portfolio Risk – Hedge Instrument Modification

Pricing Jacobian								
	OIS Rates (Discount Risk)				LIBOR Rates (Forward Risk)			
	$dO_{1Y}$	$dO_{2Y}$	$dO_{4Y}$	$dO_{5Y}$	$dL_{1Y}$	$dL_{2Y}$	$dL_{4Y}$	$dL_{5Y}$
$dS_{1Y}^{IRS}$	0	0	0	0	98	0	0	0
$dS_{2Y}^{IRS}$	0	0	0	0	98	97	0	0
$dS_{3Y}^{IRS}$	0	0	0	0	98	145	48	0
$dS_{4Y}^{IRS}$	0	0	0	0	98	145	142	0
$dS_{5Y}^{IRS}$	0	0	0	0	98	145	142	93
$dS_{4Y,5Y}^{IRS}$	0	0	0	0	0	0	0	93
$dS_{4,5Y}^{IRS}$	0	0	0	0	98	145	142	47



## Portfolio Risk Bucket Modification

Bucketed Trade DV01 Risk							
Risk Bucket	IRS 1Y #	IRS 2Y #	IRS 3Y	IRS 4Y #	IRS 5Y #	IRS(4Y, 5Y)	IRS(4.5Y)
OIS 1Y	0	0	0	0	0	0	0
OIS 2Y	0	0	0	0	0	0	0
OIS 4Y	0	-1	-1	-1	0	0	0
OIS 5Y	0	1	1	1	0	0	0
IRS 1Y	98	0	-32	0	0	0	0
IRS 2Y	0	195	194	0	0	0	0
IRS 4Y	0	0	130	386	0	-386	193
IRS 5Y	0	0	0	0	479	479	239

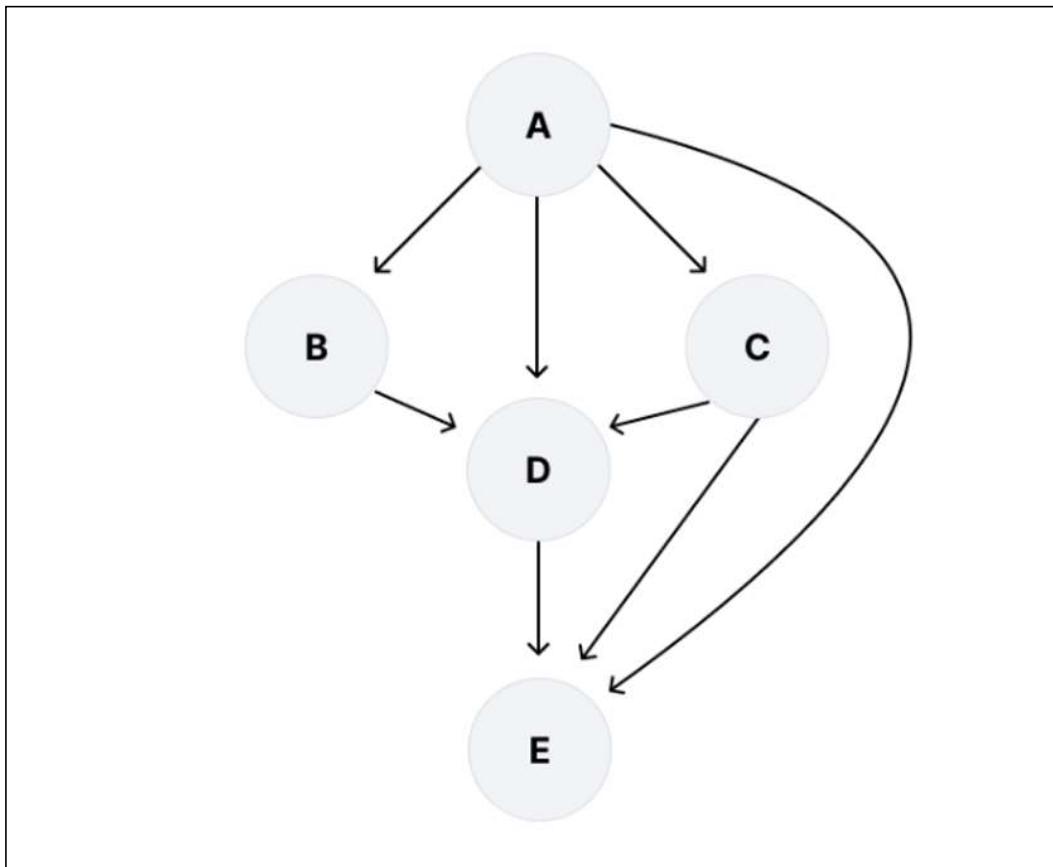
Total Trade DV01							
IRS 1Y #	IRS 2Y #	IRS 3Y	IRS 4Y #	IRS 5Y #	IRS(4Y, 5Y)	IRS(4.5Y)	
98	195	291	386	479	93	432	



## Portfolio Hedging with Hedge Instrument Modification

Risk Bucket	Risk Total	Hedge	Qty
OIS 1Y	0	OIS 1Y	-
OIS 2Y	0	OIS 2Y	-
OIS 4Y	-2	OIS 4Y	-
OIS 5Y	2	OIS 5Y	-
IRS 1Y	66	IRS 1Y	-0.7
IRS 2Y	389	IRS 2Y	-2.0
IRS 4Y	322	IRS 4Y	-0.8
IRS 5Y	1,197	IRS 5Y	-2.5
Total DV01		X	
1,975			

## AAD Computation – Directional Acyclic Graphs (DAGs)



## AAD Function

```
01 double function( double x1, double x2 )
02 {
03     double a = x1*x1;           // Step 1:     $a = x_1^2$ 
04     double b = 2*a;            // Step 2:     $b = 2x_1^2$ 
05     double c = x2;             // Step 3:     $c = x_2$ 
06     double d = 3*c;            // Step 4:     $d = 3x_2$ 
07     double f = b + d;          // Step 5:     $f = 2x_1^2 + 3x_2$ 
08     return f;
09 }
```



## AAD Function – Tangent Mode (Forward)

```
01 double tangent( double x1, double x2, double x1_dot, double x2_dot )
02 {
03     double a = x1*x1;           // Step 1:    $a = x_1^2$ 
04     double a_dot = 2*x1*x1_dot; // Tangent:   $\dot{a} = 2x_1 \cdot \dot{x}_1$        $\dot{a} = 2x_1$ 
05     double b = 2*a;           // Step 2:    $b = a$ 
06     double b_dot = 2*a_dot;   // Tangent:   $\dot{b} = 2 \cdot \dot{a}$          $\dot{b} = 4x_1$ 
07     double c = x2;           // Step 3:    $c = x_2$ 
08     double c_dot = x2_dot;    // Tangent:   $\dot{c} = \dot{x}_2$            $\dot{c} = 1$ 
09     double d = 3*c;           // Step 4:    $d = 3c$ 
10     double d_dot = 3*c_dot;   // Tangent:   $\dot{d} = 3 \cdot \dot{c}$         $\dot{d} = 3$ 
11     double f = b + d;         // Step 5:    $f = 2x_1^2 + 3x_2$ 
12     double f_dot = b_dot + d_dot; // Tangent:  $\dot{f} = \dot{b} + \dot{d}$ 
13     return f_dot;            // Result:    $\dot{f} = 4x_1 + 3$ 
14 }
```



## AAD Function – Tangent Mode (Forward)

```
01  tangent(2.0, 3.0, 1.0, 0.0);      // Input: x1 = 2, x2 = 3, x1_d = 1, x2_d = 0      Output: 8
02  tangent(2.0, 3.0, 0.0, 1.0);      // Input: x1 = 2, x2 = 3, x1_d = 0, x2_d = 1      Output: 3
```



## AAD Function – Adjoint Mode (Backwards)

```
01 void adjoint( double x1, double x2, double f_bar )
02 {
03     // Forward Sweep
04     double a = x1*x1;           // Step 1:   a =  $x_1^2$ 
05     double b = 2*a;            // Step 2:   b =  $2x_1^2$ 
06     double c = x2;             // Step 3:   c = x2
07     double d = 3*c;            // Step 4:   d =  $3x_2$ 
08     double f = b + d;          // Step 5:   f =  $2x_1^2 + 3x_2$ 
09
10    // Back Propagation
11    double b_bar = f_bar;       // Step 5:   b_bar = 1   from input variable
12    double d_bar = f_bar;       // Step 5:   d_bar = 1   from input variable
13    double c_bar = 3*d_bar;     // Step 4:   c_bar = 3
14    double x2_bar = c_bar;      // Step 3:   x2_bar = 3    $df/dx_2 = 3$ 
15    double a_bar = 2*b_bar;     // Step 2:   a_bar = 2
16    double x1_bar = 2*x1*a_bar; // Step 1:   x1_bar =  $4x_1$     $df/dx_1 = 4x_1$ 
17
18    std::cout << "df/dx1: " << x1_bar << std::endl;           //  $\bar{x}_1 = df/dx_1 = 4x_1$ 
19    std::cout << "df/dx2: " << x2_bar << std::endl;           //  $\bar{x}_2 = df/dx_2 = 3$ 
20 }
```



## AAD Function – Adjoint Mode (Backwards)

```
01     adjoint(2.0, 3.0, 1.0); // Input: x1 = 3, x2 = 2, f_bar Output: df/dx1=8 and df/dx2=3
```



## AAD Swap Pricing & Risk

```
01 // Swap Inputs
02 // phi      Pay or Receive Fixed: Pay = 1, Receive = -1
03 // n       Swap Notional
04 // r       Fixed rate
05 // tau     Accrual year fraction
06 // t       Coupon Payment Time
07 // f       Floating Forward Rate
08 // s       Floating Spread
09 // z       Discounting Zero Rate for Discount Factor, where df = exp(-z*t)
10
11 double swap_pv(double phi, double n, double r, double tau, double t, double f, double s,
12                  double z)
13 {
14     double df          = exp(-z*t);           // Step 1. Discount Factor using zero rate, z
15     double pv_fixed = phi*n*r*tau*df;        // Step 2. Fixed PV =  $\varphi N r \tau_1 P(0, t_1)$ 
16     double pv_float  = -phi*n*(f+s)*tau*df; // Step 3. Float PV =  $\varphi N(l_1 + s) \tau_1 P(0, t_1)$ 
17     double pv_swap   = pv_fixed+pv_float;    // Step 4. Swap PV = Fixed PV + Float PV
18 }
```



## AAD Swap Pricing & Risk – Tangent Mode (Forwards)

```
01 double tangent(double phi, double n, double r, double tau, double t, double f, double s,
02                 double z, double f_dot, double z_dot)
03 {
04     double df          = exp(-z*t);           // Step 1.
05     double df_dot      = -t*exp(-z*t)*z_dot;
06     double pv_fixed    = phi*n*r*tau*df;       // Step 2.
07     double pv_fixed_dot = phi*n*r*tau*df_dot;
08     double pv_float    = -phi*n*(f+s)*tau*df;
09     double pv_float_dot = -phi*n*tau*df*f_dot
09          - phi*n*f*tau*df_dot;
10     double pv_swap     = pv_fixed+pv_float;    // Step 4.
11     double pv_swap_dot = pv_fixed_dot + pv_float_dot;
12     return pv_swap_dot;
13 }
```



## AAD Swap Pricing & Risk – Tangent Mode (Forwards)

```
01 // inputs( phi, n, r, tau, t, f, s, z, f_dot, z_dot )
02 tangent( 1, 1000000, 0.02, 1, 1, 0.01, 0, 0.02, 0.0001, 0.0001 ); // Output DV01 Risk
```



## AAD Swap Pricing & Risk – Adjoint Mode (Backwards)

```
01 double adjoint(double phi, double n, double r, double tau, double t, double f, double s, double z,  
02 double pv_bar)  
03 {  
04     double df          = exp(-z*t);           // Step 1. Discount Factor using zero rate, z  
05     double pv_fixed    = phi*n*r*tau*df;      // Step 2. Fixed PV = φ N r τ_1 P(0,t_1 )  
06     double pv_float    = -phi*n*(f+s)*tau*df; // Step 3. Float PV = φ N(l_1+s) τ_1 P(0,t_1 )  
07     double pv_swap     = pv_fixed+pv_float;   // Step 4. Swap PV = Fixed PV + Float PV  
08  
09     // Backward Propagation  
10    double pv_fixed_bar = pv_bar;             // Step 4.  
11    double pv_float_bar = pv_bar;             // Step 4.  
12    double f_bar        = -phi*n*tau*df*pv_float_bar*shift_size_f; // Step 3. *  
13    double df_bar       = -phi*n*f*tau*pv_float_bar*shift_size_df; // Step 3. *  
14    df_bar              += phi*n*r*tau*pv_fixed_bar*shift_size_df; // Step 2. *  
15    double z_bar        = -t*exp(-z*t)*df_bar;           // Step 1.  
16  
17     // DV01 Result  
18     return f_bar + df_bar; // Sensitivity to 1 bps change in forwards and discount factors  
19 }
```



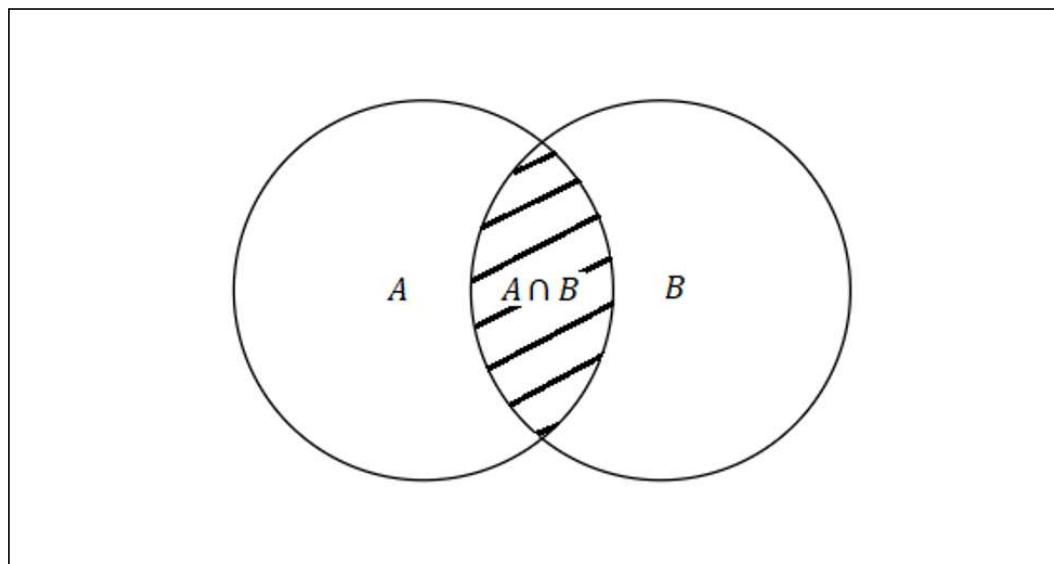
## AAD Swap Pricing & Risk – Adjoint Mode (Backwards)

```
01 // inputs( phi, n, r, tau, t, f, s, z, pv_bar )
02 adjoint( 1, 1000000, 0.02, 1, 1, 0.01, 0, 0.02, 1 ); // Output DV01 Risk
```

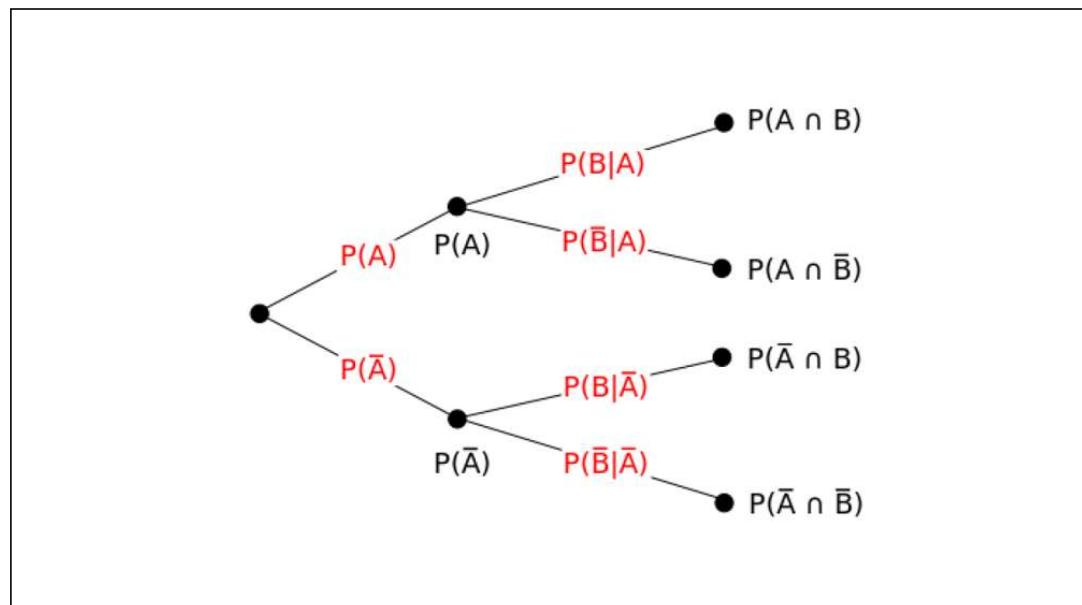


## Chapter 6 – Credit Models

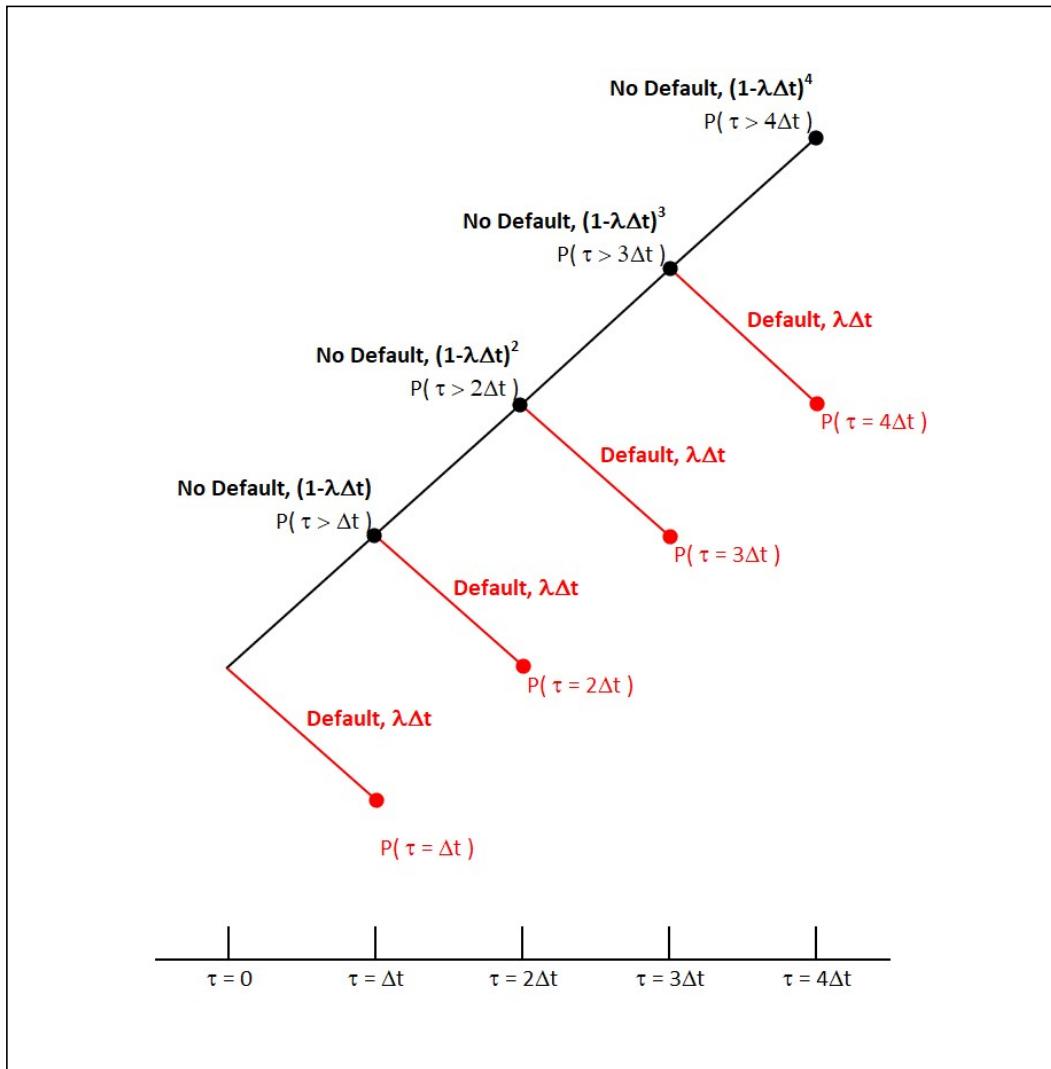
## Credit Pricing – Probability Spaces & Venn Diagrams



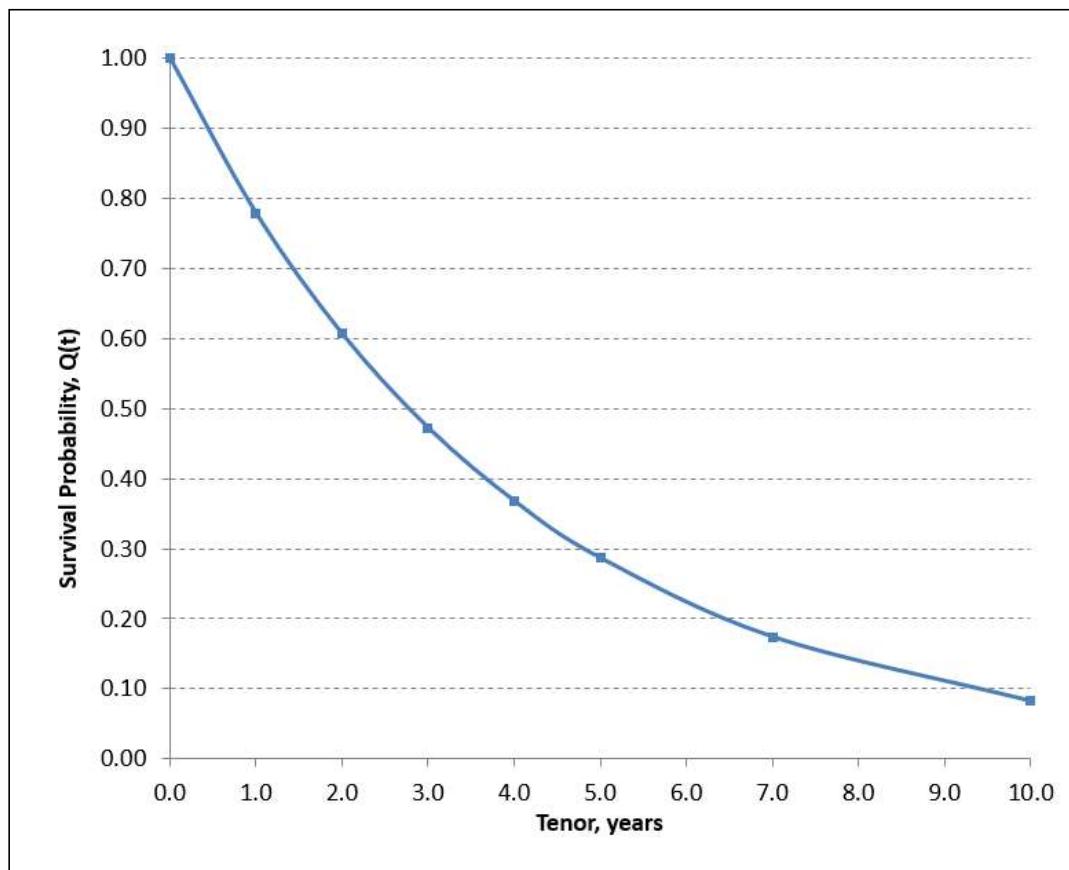
## Credit Pricing – Probability Trees



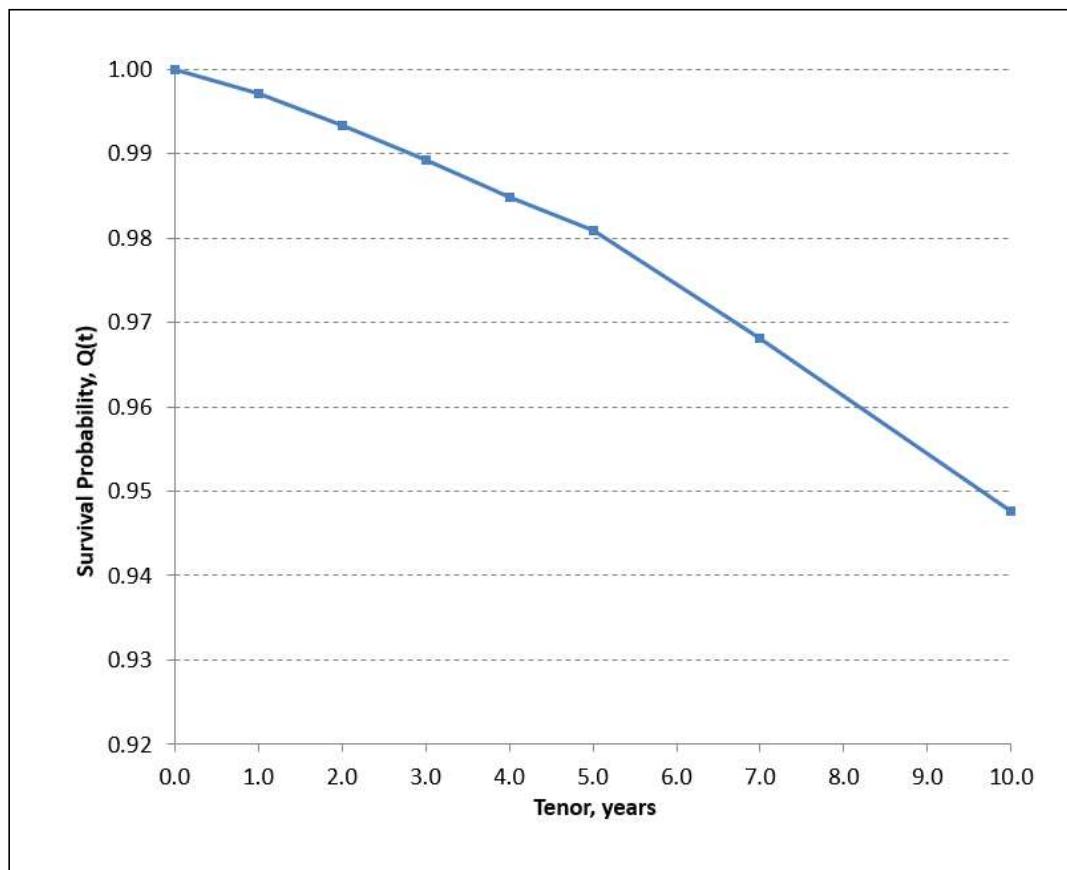
## Credit Pricing – Binomial Probability of Default



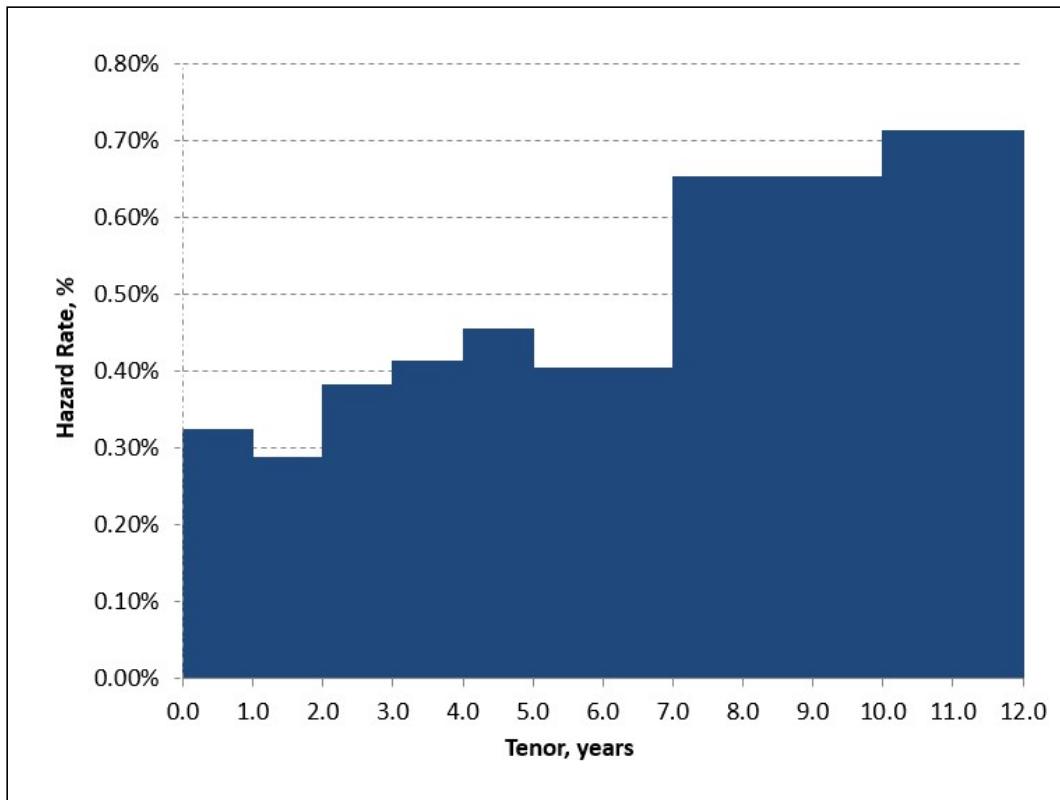
## Credit Pricing – Survival Probability



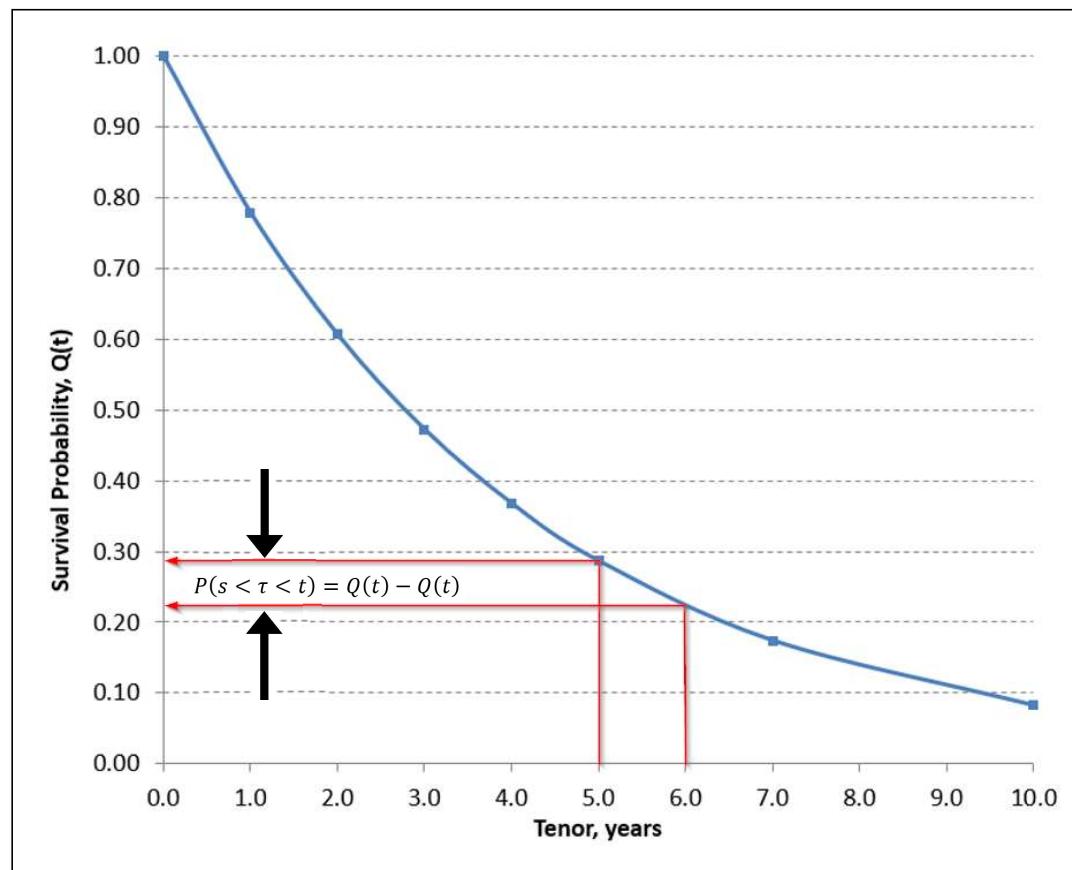
## Credit Pricing – Survival Probability



## Credit Pricing – Default / Hazard Rates



## Credit Pricing – Default Probability



## USD IRS Transaction (LIBOR)

Trade Template		
USD IRS 5% USD3ML 5Y		
Swap	LEG1:FIXED	LEG2:FLOAT
Pay / Receive	RECEIVE	PAY
Notional	1,000,000	1,000,000
Currency	USD	USD
Effective Date	2D Tue, 25-Aug-2015	2D Tue, 25-Aug-2015
Maturity Date	5Y Tue, 25-Aug-2020	5Y Tue, 25-Aug-2020
Fixed Rate (%)	5.000000%	
Float Index		3M USD3ML
Float Spread (bps)		0.000
Reset Frequency		QUARTERLY
Pay Frequency	SEMI-ANNUAL	QUARTERLY
Day Count	30/360	ACT/360
Market		
Curve Date	Fri, 21-Aug-2015	Fri, 21-Aug-2015
Forecast Curve		USD3ML
Discount Curve	USDOIS	USDOIS
Valuation Results		
Valuation Date	Fri, 21-Aug-2015	
Par Rate	1.548250%	
NPV	167,892.11	
PV01	486.40	
DV01	532.42	

## EUR IRS Transaction (LIBOR)

Trade Template		
EUR IRS 5% EUR6ML 5Y		
<b>Swap</b>	<b>LEG1:FIXED</b>	<b>LEG2:FLOAT</b>
Pay / Receive	RECEIVE	PAY
Notional	1,000,000	1,000,000
Currency	EUR	EUR
Effective Date	2D Tue, 25-Aug-2015	2D Tue, 25-Aug-2015
Maturity Date	5Y Tue, 25-Aug-2020	5Y Tue, 25-Aug-2020
Fixed Rate (%)	5.000000%	
Float Index		6M EUR6ML
Float Spread (bps)		0.000
Reset Frequency		SEMI-ANNUAL
Pay Frequency	ANNUAL	SEMI-ANNUAL
Day Count	30/360	ACT/360
<b>Market</b>		
Curve Date	Fri, 21-Aug-2015	Fri, 21-Aug-2015
Forecast Curve		EUR6ML
Discount Curve	EUROIS	EUROIS
<b>Valuation Results</b>		
Valuation Date	Fri, 21-Aug-2015	
Par Rate	0.349000%	
NPV	232,643.20	
PV01	500.20	
DV01	571.01	

## USD IRS Transaction (RFR SOFR)

Trade Template		USD IRS USDSOFR 1Y	
Swap		LEG1:FIXED	LEG2:FLOAT
Pay / Receive	RECEIVE	PAY	
Notional	10,000,000	10,000,000	
Currency	USD	USD	
Effective Date	0D Mon, 13-Jun-2022	0D Mon, 13-Jun-2022	
Maturity Date	1Y Tue, 13-Jun-2023	1Y Tue, 13-Jun-2023	
Fixed Rate (%)	3.315906%		
Float Index		1D USDSOFR	
Float Spread (bps)		0.000	
Reset Frequency		DAILY	
Pay Frequency	SEMI-ANNUAL	QUARTERLY	
Day Count	30/360	ACT/360	
Market			
Curve Date	Mon, 13-Jun-2022	Mon, 13-Jun-2022	
Forecast Curve		USDSOFR	
Discount Curve	USDSOFR	USDSOFR	
Valuation Results			
Valuation Date	Mon, 13-Jun-2022		
Par Rate	3.158335%		
NPV	15,416.96		
PV01	978.41		
DV01	973.45		

## EUR IRS Transaction (RFR ESTR)

Trade Template		EUR IRS EURESTR 1Y	
<b>Swap</b>		<b>LEG1:FIXED</b>	<b>LEG2:FLOAT</b>
Pay / Receive		RECEIVE	PAY
Notional		10,000,000	10,000,000
Currency		EUR	EUR
Effective Date	0D	Mon, 13-Jun-2022	0D Mon, 13-Jun-2022
Maturity Date	1Y	Tue, 13-Jun-2023	1Y Tue, 13-Jun-2023
Fixed Rate (%)		0.964683%	
Float Index		1D	EURESTR
Float Spread (bps)			0.000
Reset Frequency			DAILY
Pay Frequency		ANNUAL	SEMI-ANNUAL
Day Count		30/360	ACT/360
<b>Market</b>			
Curve Date		Mon, 13-Jun-2022	Mon, 13-Jun-2022
Forecast Curve			EURESTR
Discount Curve		EURESTR	EURESTR
<b>Valuation Results</b>			
Valuation Date		Mon, 13-Jun-2022	
Par Rate		0.797643%	
NPV		16,570.96	
PV01		992.03	
DV01		1,004.73	

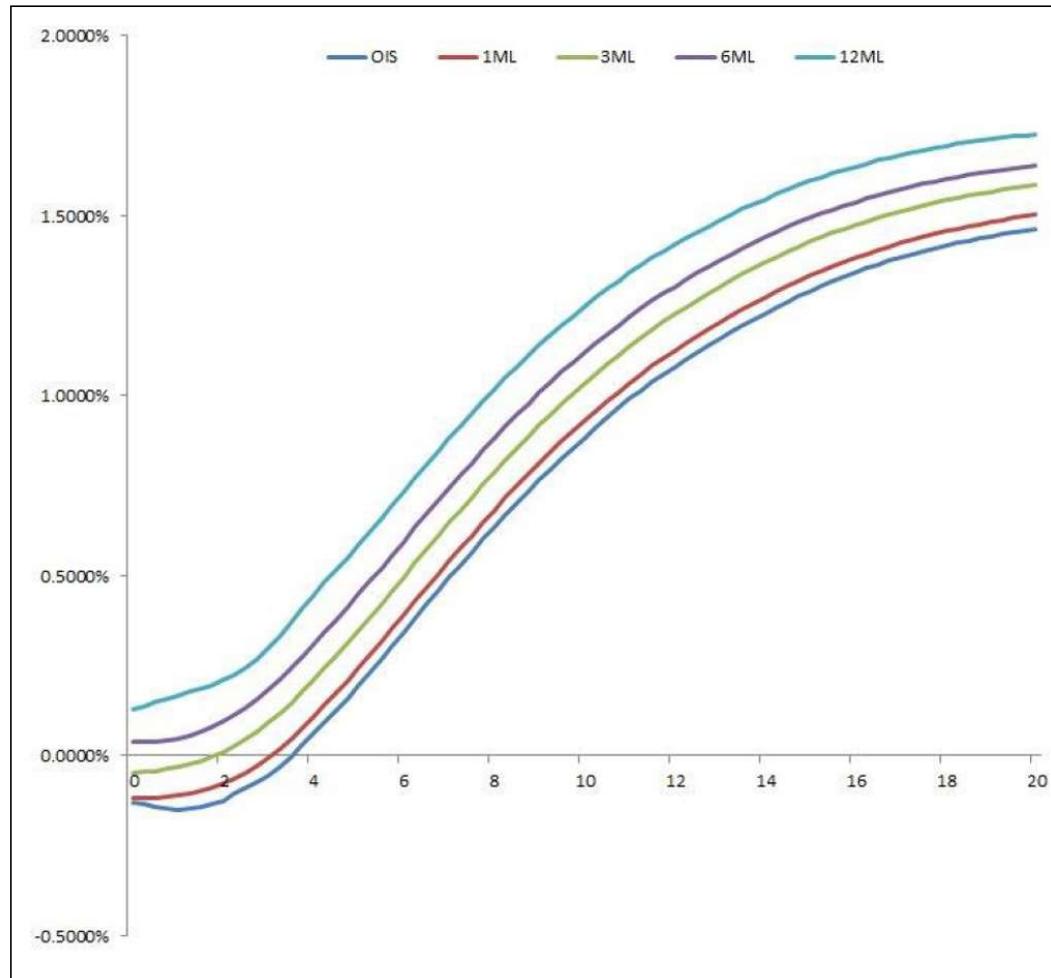
## GBP IRS Transaction – Reformed SONIA

Trade Template		GBP IRS GBPSONIA 1Y	
Swap	LEG1:FIXED		LEG2:FLOAT
	RECEIVE	PAY	
	10,000,000	10,000,000	
	GBP	GBP	
	0D Mon, 13-Jun-2022	0D Mon, 13-Jun-2022	
	1Y Tue, 13-Jun-2023	1Y Tue, 13-Jun-2023	
	2.750713%		
		1D GBPSONIA	
		0.000	
		DAILY	
Reset Frequency	SEMI-ANNUAL	SEMI-ANNUAL	
Pay Frequency	ACT/365	ACT/365	
Day Count			
Market			
Curve Date	Mon, 13-Jun-2022	Mon, 13-Jun-2022	
Forecast Curve		GBPSONIA	
Discount Curve	GBPSONIA	GBPSONIA	
Valuation Results			
Valuation Date	Mon, 13-Jun-2022		
Par Rate	2.501760%		
NPV	24,474.58		
PV01	983.10		
DV01	968.51		

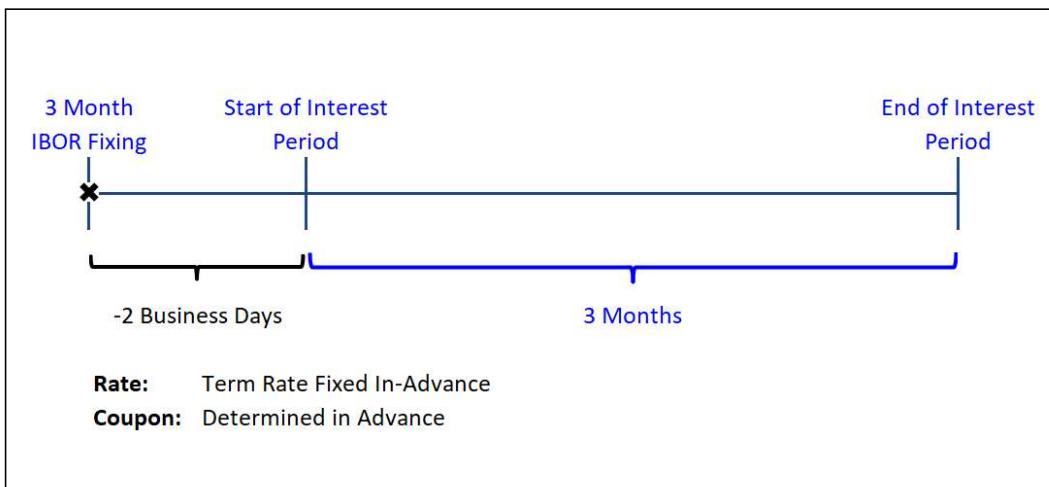
## JPY IRS Transaction - TONAR

Trade Template		JPY IRS JPYTONAR 1Y	
<b>Swap</b>		<b>LEG1:FIXED</b>	<b>LEG2:FLOAT</b>
Pay / Receive		RECEIVE	PAY
Notional		10,000,000	10,000,000
Currency		JPY	JPY
Effective Date	0D	Mon, 13-Jun-2022	0D
Maturity Date	1Y	Tue, 13-Jun-2023	Tue, 13-Jun-2023
Fixed Rate (%)		0.072396%	
Float Index			1D JPYTONAR
Float Spread (bps)			0.000
Reset Frequency			DAILY
Pay Frequency		SEMI-ANNUAL	SEMI-ANNUAL
Day Count		ACT/365F	ACT/360
<b>Market</b>			
Curve Date		Mon, 13-Jun-2022	Mon, 13-Jun-2022
Forecast Curve			JPYTONAR
Discount Curve		JPYTONAR	JPYTONAR
<b>Valuation Results</b>			
Valuation Date		Mon, 13-Jun-2022	
Par Rate		0.015548%	
NPV		5,684.00	
PV01		999.00	
DV01		1,011.00	

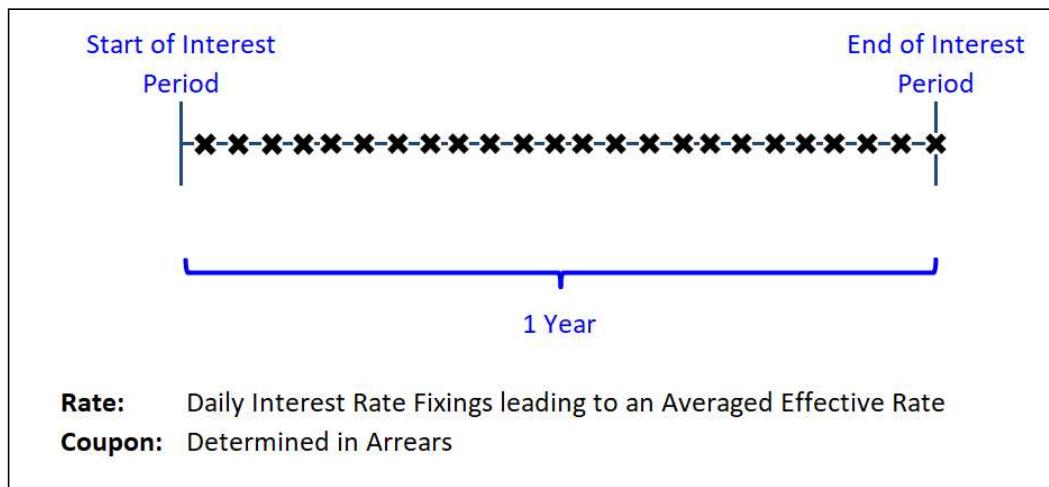
## EUR Swap Curve with Negative Rates on Short-End



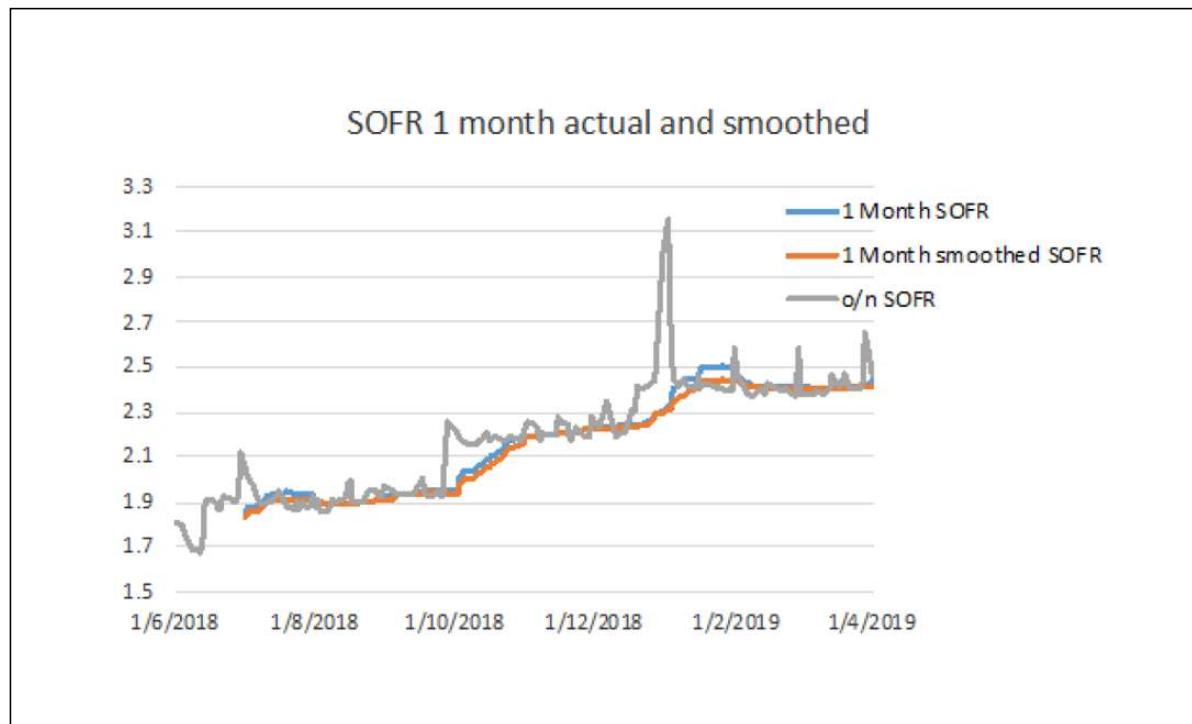
## LIBOR Fixing In-Advance



## RFR Rates – Daily Fixing with Term Rate Known In-Arrears



## USD SOFR Rate Behaviour



## PART TWO – PRICING & PRACTICE

Case Studies  
Interest Rate Swaps & Asset Swaps

## Chapter 7 – Interest Rate Swap Pricing & Risk

## EUR IRS Pricing and Risk

Trade Template		EUR IRS 1% EUR6ML 5Y	
Swap		LEG1:FIXED	LEG2:FLOAT
Pay / Receive	RECEIVE	PAY	
Notional	1,000,000	1,000,000	
Currency	EUR	EUR	
Effective Date	2D Tue, 25-Aug-2015	2D Tue, 25-Aug-2015	
Maturity Date	5Y Tue, 25-Aug-2020	5Y Tue, 25-Aug-2020	
Fixed Rate (%)	1.000000%		
Float Index		6M EUR6ML	
Float Spread (bps)		0.000	
Reset Frequency		SEMI-ANNUAL	
Pay Frequency	ANNUAL	SEMI-ANNUAL	
Day Count	30/360	ACT/360	
Market			
Curve Date	Fri, 21-Aug-2015	Fri, 21-Aug-2015	
Forecast Curve		EUR6ML	
Discount Curve	EUROIS	EUROIS	
Valuation Results			
Valuation Date	Fri, 21-Aug-2015		
Par Rate	0.349000%		
NPV	32,563.05		
PV01	500.20		
DV01	510.11		

## USD IRS Trader Quotes / Runs

USD Semi Fixed vs 3M Libor					Spreads vs Treasuries				
Tenor	Bid		Ask	Change	Tenor	Bid		Ask	Change
1Y	0.750	/	0.754	+0.014	1Y	14.627	/	15.614	-0.794
2Y	1.045	/	1.049	+0.017	2Y	9.991	/	10.374	+0.068
3Y	1.284	/	1.287	+0.018	3Y	8.082	/	8.432	-0.262
4Y	1.467	/	1.471	+0.015	4Y	5.250	/	5.535	-0.385
5Y	1.617	/	1.621	+0.014	5Y	5.053	/	5.446	-0.360
6Y	1.750	/	1.754	+0.012	6Y	2.500	/	2.875	-0.253
7Y	1.866	/	1.870	+0.011	7Y	0.356	/	0.671	-0.308
8Y	1.966	/	1.970	+0.011	8Y	0.503	/	0.809	-0.877
9Y	2.052	/	2.056	+0.011	9Y	-0.125	/	0.500	-0.377
10Y	2.126	/	2.129	+0.011	10Y	0.072	/	0.441	-0.471
12Y	2.250	/	2.254	+0.007	12Y	6.113	/	6.424	-1.038
15Y	2.376	/	2.380	+0.006	15Y	1.123	/	1.375	-0.563
20Y	2.497	/	2.501	+0.003	20Y	-4.875	/	-4.500	-0.565
25Y	2.558	/	2.563	+0.003	25Y	-13.500	/	-13.000	-1.125
30Y	2.592	/	2.597	+0.003	30Y	-24.171	/	-23.786	-0.715

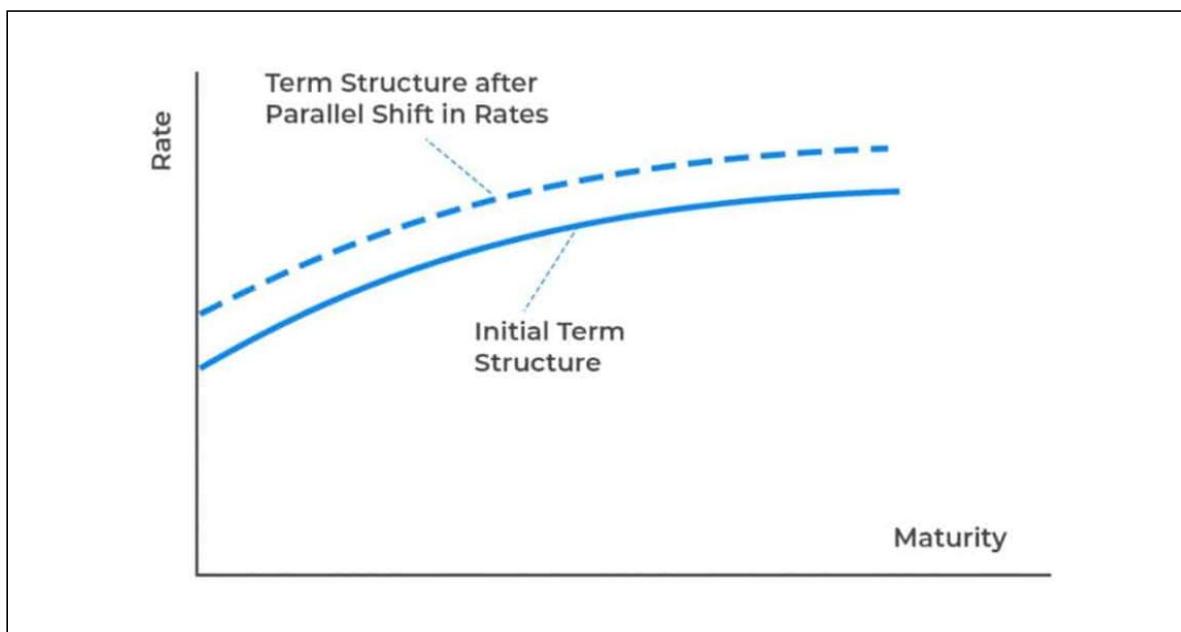
## EUR IRS Quotes / Runs

EUR 6M EURIBOR			
Tenor	Bid	Ask	Change
1Y	0.041	/ 0.046	-0.002
18M	0.052	/ 0.058	-0.002
2Y	0.075	/ 0.080	-0.001
3Y	0.146	/ 0.151	-0.001
4Y	0.241	/ 0.246	-0.004
5Y	0.351	/ 0.356	-0.004
6Y	0.470	/ 0.475	-0.007
7Y	0.592	/ 0.597	-0.009
8Y	0.711	/ 0.716	-0.011
9Y	0.820	/ 0.825	-0.014
10Y	0.917	/ 0.922	-0.015
15Y	1.243	/ 1.251	-0.024
20Y	1.377	/ 1.385	-0.030
25Y	1.407	/ 1.416	-0.035
30Y	1.413	/ 1.423	-0.038

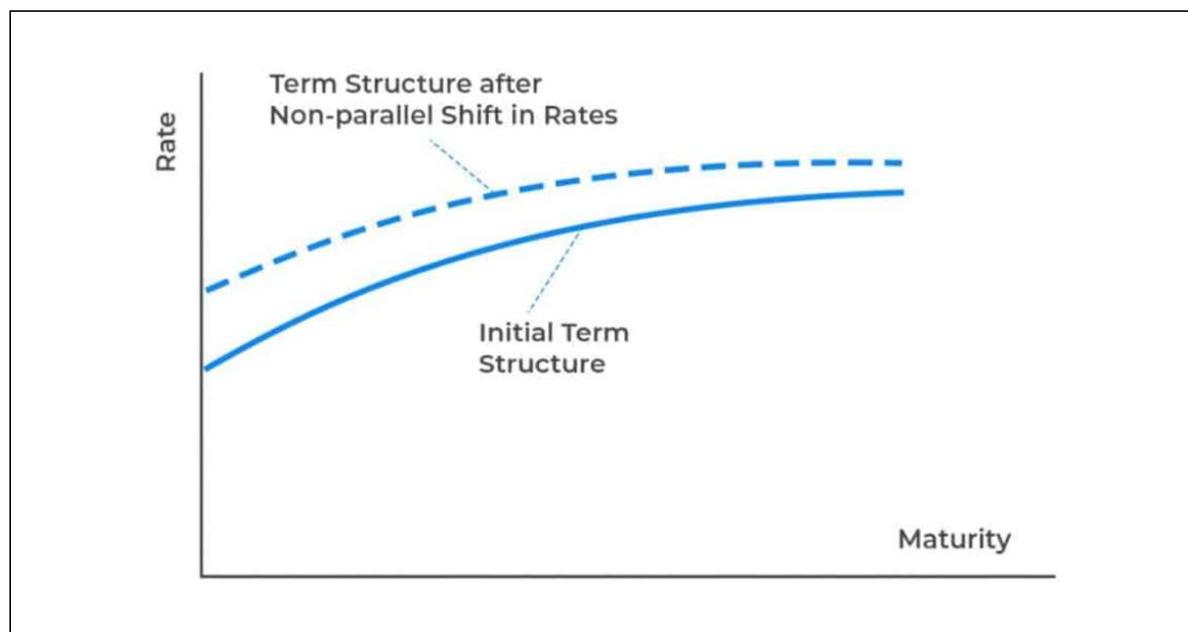
## EUR Bund Trading

EUR Bund Trading						
Tenor	Security	Bid Px	Ask Px	Bid Yield	Ask Yield	Px Change
3M	BUBILL 0% 10/02/16	100.081	/	100.099	-0.347%	/ -0.424%
6M	BUBILL 0% 18/05/16	100.174	/	100.208	-0.343%	/ -0.411%
1Y	BUBILL 0% 27/07/16	100.262	/	100.298	-0.373%	/ -0.424%
2Y	BKO 0% 15/09/17	100.680	/	100.695	-0.371%	/ -0.379%
3Y	OBL 1% 11/10/19	103.900	/	103.905	-0.336%	/ -0.338%
4Y	OBL 0.25% 11/10/19	101.975	/	101.985	-0.254%	/ -0.256%
5Y	OBL 0.25% 16/10/20	101.830	/	101.845	-0.121%	/ -0.124%
6Y	DBR 2.25% 04/09/21	113.310	/	113.325	-0.043%	/ -0.046%
7Y	DBR 1.5% 04/09/22	109.685	/	109.705	0.072%	/ 0.068%
8Y	DBR 2% 15/08/23	113.685	/	113.695	0.215%	/ 0.214%
9Y	DBR 1% 15/08/24	105.365	/	105.375	0.375%	/ 0.374%
10Y	DBR 1% 15/08/25	104.455	/	104.465	0.529%	/ 0.528%
15Y	DBR 6.25% 04/01/30	172.160	/	172.240	0.820%	/ 0.816%
20Y	DBR 4.75% 04/07/34	160.820	/	160.925	1.115%	/ 1.111%
30Y	DBR 2.5% 15/08/46	127.850	/	127.950	1.382%	/ 1.378%

## Forward Curve – Parallel Shift



## Forward Curve – Non-Parallel Shift



## Chapter 8 – Interest Rate Swap Case Study Examples

## Interest Rate Swap (USD 5Y)

Trade Templates		USD IRS 5% USD3ML 5Y	
Swap		LEG1:FIXED	LEG2:FLOAT
Pay / Receive		RECEIVE	PAY
Notional		1,000,000	1,000,000
Currency		USD	USD
Effective Date	2D	Tue, 25-Aug-2015	2D Tue, 25-Aug-2015
Maturity Date	5Y	Tue, 25-Aug-2020	5Y Tue, 25-Aug-2020
Fixed Rate (%)		5.000000%	
Float Index			3M USD3ML
Float Spread (bps)			0.000
Reset Frequency			QUARTERLY
Pay Frequency		SEMI-ANNUAL	QUARTERLY
Day Count		30/360	ACT/360
Market			
Curve Date		Fri, 21-Aug-2015	Fri, 21-Aug-2015
Forecast Curve			USD3ML
Discount Curve		USDOIS	USDOIS
Valuation Results			
Valuation Date		Fri, 21-Aug-2015	
Par Rate		1.548250%	
NPV		167,892.11	
PV01		486.40	
DV01		532.42	

## Interest Rate Swap – Fixed Leg (USD 5Y)

	Fixed Leg									
	Accrual Start	Accrual End	Pay Date	$t_i$	N	$r^{\text{Fixed}}$	$\tau_i$	Cash Flow	$P(t_0, t_i)$	$PV^{\text{Fixed}}$
1	23-Apr-22	22-Oct-22	22-Oct-22	0.50	1,000,000	1.0000%	0.50	5,000	0.997824	4,989
2	22-Oct-22	23-Apr-23	23-Apr-23	1.00	1,000,000	1.0000%	0.50	5,000	0.994549	4,973
3	23-Apr-23	22-Oct-23	22-Oct-23	1.50	1,000,000	1.0000%	0.50	5,000	0.991815	4,959
4	22-Oct-23	22-Apr-24	22-Apr-24	2.00	1,000,000	1.0000%	0.50	5,000	0.987801	4,939
5	22-Apr-24	22-Oct-24	22-Oct-24	2.50	1,000,000	1.0000%	0.50	5,000	0.983373	4,917
6	22-Oct-24	22-Apr-25	22-Apr-25	3.00	1,000,000	1.0000%	0.50	5,000	0.979783	4,899
7	22-Apr-25	22-Oct-25	22-Oct-25	3.50	1,000,000	1.0000%	0.50	5,000	0.974642	4,873
8	22-Oct-25	23-Apr-26	23-Apr-26	4.00	1,000,000	1.0000%	0.50	5,000	0.969104	4,846
9	23-Apr-26	22-Oct-26	22-Oct-26	4.50	1,000,000	1.0000%	0.50	5,000	0.964693	4,823
10	22-Oct-26	23-Apr-27	23-Apr-27	5.00	1,000,000	1.0000%	0.50	5,000	0.958476	4,792



## Interest Rate Swap – Float Leg (USD 5Y)

	Float Leg										
	Fixing Date	Accrual Start	Accrual End	Pay Date	$t_j$	N	$I_{j-1} + s$	$\tau_j$	Cash Flow	$P(t_0, t_j)$	$PV^{\text{Float}}$
1	21-Apr-22	23-Apr-22	23-Jul-22	23-Jul-22	0.25	1,000,000	0.2800%	0.25	700	0.999302	700
2	21-Jul-22	23-Jul-22	22-Oct-22	22-Oct-22	0.50	1,000,000	0.2995%	0.25	749	0.997824	747
3	20-Oct-22	22-Oct-22	21-Jan-23	21-Jan-23	0.75	1,000,000	0.3385%	0.25	846	0.996240	843
4	19-Jan-23	21-Jan-23	23-Apr-23	23-Apr-23	1.00	1,000,000	0.3775%	0.25	944	0.994549	939
5	21-Apr-23	23-Apr-23	23-Jul-23	23-Jul-23	1.25	1,000,000	0.4165%	0.25	1,041	0.992752	1,034
6	21-Jul-23	23-Jul-23	22-Oct-23	22-Oct-23	1.50	1,000,000	0.4555%	0.25	1,139	0.991815	1,129
7	20-Oct-23	22-Oct-23	22-Jan-24	22-Jan-24	1.75	1,000,000	0.4750%	0.25	1,188	0.989860	1,175
8	20-Jan-24	22-Jan-24	22-Apr-24	22-Apr-24	2.00	1,000,000	0.5140%	0.25	1,285	0.987801	1,269
9	20-Apr-24	22-Apr-24	22-Jul-24	22-Jul-24	2.25	1,000,000	0.5530%	0.25	1,383	0.985638	1,363
10	20-Jul-24	22-Jul-24	22-Oct-24	22-Oct-24	2.50	1,000,000	0.5920%	0.25	1,480	0.983373	1,455
11	20-Oct-24	22-Oct-24	21-Jan-25	21-Jan-25	2.75	1,000,000	0.6310%	0.25	1,578	0.981005	1,548
12	19-Jan-25	21-Jan-25	22-Apr-25	22-Apr-25	3.00	1,000,000	0.6700%	0.25	1,675	0.979783	1,641
13	20-Apr-25	22-Apr-25	23-Jul-25	23-Jul-25	3.25	1,000,000	0.6895%	0.25	1,724	0.977262	1,685
14	21-Jul-25	23-Jul-25	22-Oct-25	22-Oct-25	3.50	1,000,000	0.7285%	0.25	1,821	0.974642	1,775
15	20-Oct-25	22-Oct-25	21-Jan-26	21-Jan-26	3.75	1,000,000	0.7675%	0.25	1,919	0.971922	1,865
16	19-Jan-26	21-Jan-26	23-Apr-26	23-Apr-26	4.00	1,000,000	0.8065%	0.25	2,016	0.969104	1,954
17	21-Apr-26	23-Apr-26	23-Jul-26	23-Jul-26	4.25	1,000,000	0.8455%	0.25	2,114	0.966188	2,042
18	21-Jul-26	23-Jul-26	22-Oct-26	22-Oct-26	4.50	1,000,000	0.8845%	0.25	2,211	0.964693	2,133
19	20-Oct-26	22-Oct-26	21-Jan-27	21-Jan-27	4.75	1,000,000	0.9040%	0.25	2,260	0.961632	2,173
20	19-Jan-27	21-Jan-27	23-Apr-27	23-Apr-27	5.00	1,000,000	0.9430%	0.25	2,358	0.958476	2,260



## Interest Rate Swap – Fixed Leg (USD 5Y)

Fixed Leg

	Accrual Start	Accrual End	Pay Date	$t_i$	N	$r^{\text{Fixed}}$	$\tau_i$	Cash Flow	$P(t_0, t_i)$	$PV^{\text{Fixed}}$
1	01-Aug-22	01-Aug-23	03-Aug-23	1.00	1,000,000	1.0000%	1.00	10,000	0.9900	9,900
2	01-Aug-23	01-Aug-24	03-Aug-24	2.00	1,000,000	1.0000%	1.00	10,000	0.9804	9,804
3	01-Aug-24	01-Aug-25	03-Aug-25	3.00	1,000,000	1.0000%	1.00	10,000	0.9708	9,708
4	01-Aug-25	01-Aug-26	03-Aug-26	4.00	1,000,000	1.0000%	1.00	10,000	0.9612	9,612
5	01-Aug-26	01-Aug-27	03-Aug-27	5.00	1,000,000	1.0000%	1.00	10,000	0.9516	9,516

Total NPV 48,540.00



## Interest Rate Swap – Fixed Leg (USD 5Y)

Float Leg											
	Fixing Date	Accrual Start	Accrual End	Pay Date	$t_j$	N	$I_{j-1} + s$	$\tau_j$	Cash Flow	$P(t_0, t_j)$	$PV^{\text{float}}$
1	30-Jul-22	01-Aug-22	01-Aug-23	03-Aug-23	1.00	1,000,000	0.2800%	1.00	2,800	0.9900	2,772
2	30-Jul-23	01-Aug-23	01-Aug-24	03-Aug-24	2.00	1,000,000	0.5140%	1.00	5,140	0.9804	5,039
3	30-Jul-24	01-Aug-24	01-Aug-25	03-Aug-25	3.00	1,000,000	0.7480%	1.00	7,480	0.9708	7,262
4	30-Jul-25	01-Aug-25	01-Aug-26	03-Aug-26	4.00	1,000,000	0.9820%	1.00	9,820	0.9612	9,439
5	30-Jul-26	01-Aug-26	01-Aug-27	03-Aug-27	5.00	1,000,000	1.2160%	1.00	12,160	0.9516	11,571

Total NPV 36,083.28



## Interest Rate Swap – Fixed Leg (EUR 2Y)

Fixed Leg										
	Accrual Start	Accrual End	Pay Date	$t_i$	N	$r^{\text{Fixed}}$	$\tau_i$	Cash Flow	$P(t_0, t_i)$	$PV^{\text{Fixed}}$
1	01-Aug-22	01-Aug-23	03-Aug-23	1.00	5,000,000	0.5000%	1.00	25,000	1.0380	25,950
2	01-Aug-23	01-Aug-24	03-Aug-24	2.00	5,000,000	0.5000%	1.00	25,000	1.0260	25,650
Total NPV 51,600.00										

## Interest Rate Swap – Fixed Leg (EUR 2Y)

Float Leg											
	Fixing Date	Accrual Start	Accrual End	Pay Date	$t_j$	N	$I_{j-1} + s$	$\tau_j$	Cash Flow	$P(t_0, t_j)$	$PV^{\text{float}}$
1	30-Jul-22	01-Aug-22	01-Aug-23	03-Aug-23	0.50	5,000,000	0.0487%	0.50	1,218	1.0440	1,271
2	30-Jul-23	01-Aug-23	01-Aug-24	03-Aug-24	1.00	5,000,000	0.1687%	0.50	4,218	1.0380	4,378
3	30-Jul-24	01-Aug-24	01-Aug-25	03-Aug-25	1.50	5,000,000	0.2887%	0.50	7,218	1.0320	7,448
4	30-Jul-25	01-Aug-25	01-Aug-26	03-Aug-26	2.00	5,000,000	0.4087%	0.50	10,218	1.0260	10,483

Total NPV 23,580.45



## Annuity Fixed Leg

Annuity - Fixed Leg			
N	$\tau_i$	$P(t_0, t_i)$	$A_N^{\text{Fixed}}$
10,000,000	1.00	0.9900	9,900,000
10,000,000	1.00	0.9804	9,804,000
Total $A_N^{\text{Fixed}}$ 19,704,000			

## Annuity Float Leg

Annuity - Float Leg			
N	$\tau_i$	$P(t_0, t_i)$	$A_N^{\text{Float}}$
10,000,000	1.00	0.9900	9,900,000
10,000,000	1.00	0.9804	9,804,000
Total $A_N^{\text{Float}}$ 19,704,000			

$$A_N = N \sum_{i=1}^n \tau_i P(t_0, t_i)$$

## Swap Par Rate

Par Rate		
PV <sup>Float</sup>	A <sub>N</sub> <sup>Fixed</sup>	p <sup>Trade</sup>
78,112.56	19,704,000	0.396430%



$$p^{Trade} = \frac{PV^{Float\ Leg}}{A_N^{Fixed}}$$

## Swap PV

Swap PV				
Pay/Rec, $\phi$	r <sup>Fixed</sup>	p <sup>Trade</sup>	A <sub>N</sub> <sup>Fixed</sup>	PV <sup>Swap</sup>
1	1.5000%	0.396430%	19,704,000	217,447.44



$$PV^{Swap} = \phi(r - p^{Trade}) A_{N_i}^{Fixed}$$

## Macaulay's Duration – Fixed Leg

Duration - Fixed Leg						
$t_i$	N	$\tau_i$	$P(t_0, t_i)$	$A_N^{\text{Fixed}}$	$D_{\text{MAC}}^{\text{Fixed}}$	
1.00	10,000,000	1.00	0.9900	19,704,000	0.5024	
2.00	10,000,000	1.00	0.9804	19,704,000	0.9951	
Total $D_{\text{MAC}}^{\text{Fixed}}$					1.4976	

$$D_{\text{MAC}}^{\text{Fixed}} = \sum_{i=1}^n \left( \frac{t_i N_i \tau_i P(t_0, t_i)}{N_i \tau_i P(t_0, t_i)} \right) = \left( \frac{\sum_{i=1}^n t_i N_i \tau_i P(t_0, t_i)}{A_{N_i}^{\text{Fixed}}} \right)$$

## Macaulay's Duration – Float Leg

Duration - Float Leg						
$t_j$	N	$\tau_j$	$ _{j-1} + s$	$P(t_0, t_j)$	$PV^{\text{Float}}$	$D_{\text{MAC}}^{\text{Float}}$
1.00	10,000,000	1.00	0.2800%	0.9900	27,720	0.3549
2.00	10,000,000	1.00	0.5140%	0.9804	50,393	1.2903
Total $D_{\text{MAC}}^{\text{Float}}$					1.6451	

$$D_{\text{MAC}}^{\text{Float}} = \sum_{j=1}^m t_i \left( \frac{PV \text{ of } jth \text{ Float Coupon}}{PV \text{ Float Leg}} \right) = \sum_{j=1}^m \left( \frac{t_j N_j l_{j-1} \tau_j P(t_0, t_j)}{N_j l_{j-1} \tau_j P(t_0, t_j)} \right)$$

## Modified Duration – Fixed Leg

Modified Duration - Fixed Leg		
D <sub>MAC</sub> <sup>Fixed</sup>	p <sup>Trade</sup>	D <sub>MOD</sub> <sup>Fixed</sup>
1.4976	0.396430%	1.4917



$$D_{MOD}^{Fixed} = \left( \frac{\sum_{i=1}^n t_i N_i \tau_i P(t_0, t_i)}{A_{N_i}^{Fixed} (1 + p^{Trade})} \right)$$

## Modified Duration – Float Leg

Modified Duration - Float Leg		
D <sub>MAC</sub> <sup>Float</sup>	p <sup>Trade</sup>	D <sub>MOD</sub> <sup>Float</sup>
1.6451	0.396430%	1.6386



$$D_{MOD}^{Float} = \sum_{j=1}^m \left( \frac{t_j N_j l_{j-1} \tau_j P(t_0, t_j)}{N_j l_{j-1} \tau_j P(t_0, t_j) (1 + p^{Trade})} \right)$$

## Swap Risk

Swap PV01		
Pay/Rec, $\phi$	$A_N^{\text{Fixed}}$	PV01
1	19,704,000	1,970.40



$$\begin{aligned} PV01^{\text{Swap}} &= \phi A_{N_i}^{\text{Fixed}} \times 1 \text{ Basis Point} \\ &= (\phi A_{N_i}^{\text{Fixed}}) / 10,000 \end{aligned}$$

### Analytical Swap DV01

Pay/Rec, $\phi$	PV01	PV <sup>Swap</sup>	D <sub>MOD</sub> Fixed	DV01
1	1,970.40	217,447.44	1.4917	2,002.84



$$DV01^{\text{Swap}} = \underbrace{\phi PV01}_{\text{Forward Risk}}$$

$$+ \underbrace{\phi(PV^{\text{Swap No Spread}} D_{MOD}^{\text{Fixed}} + PV^{\text{Swap Spread}} D_{MOD}^{\text{Float}})}_{\text{Discounting Risk}} / 10,000$$

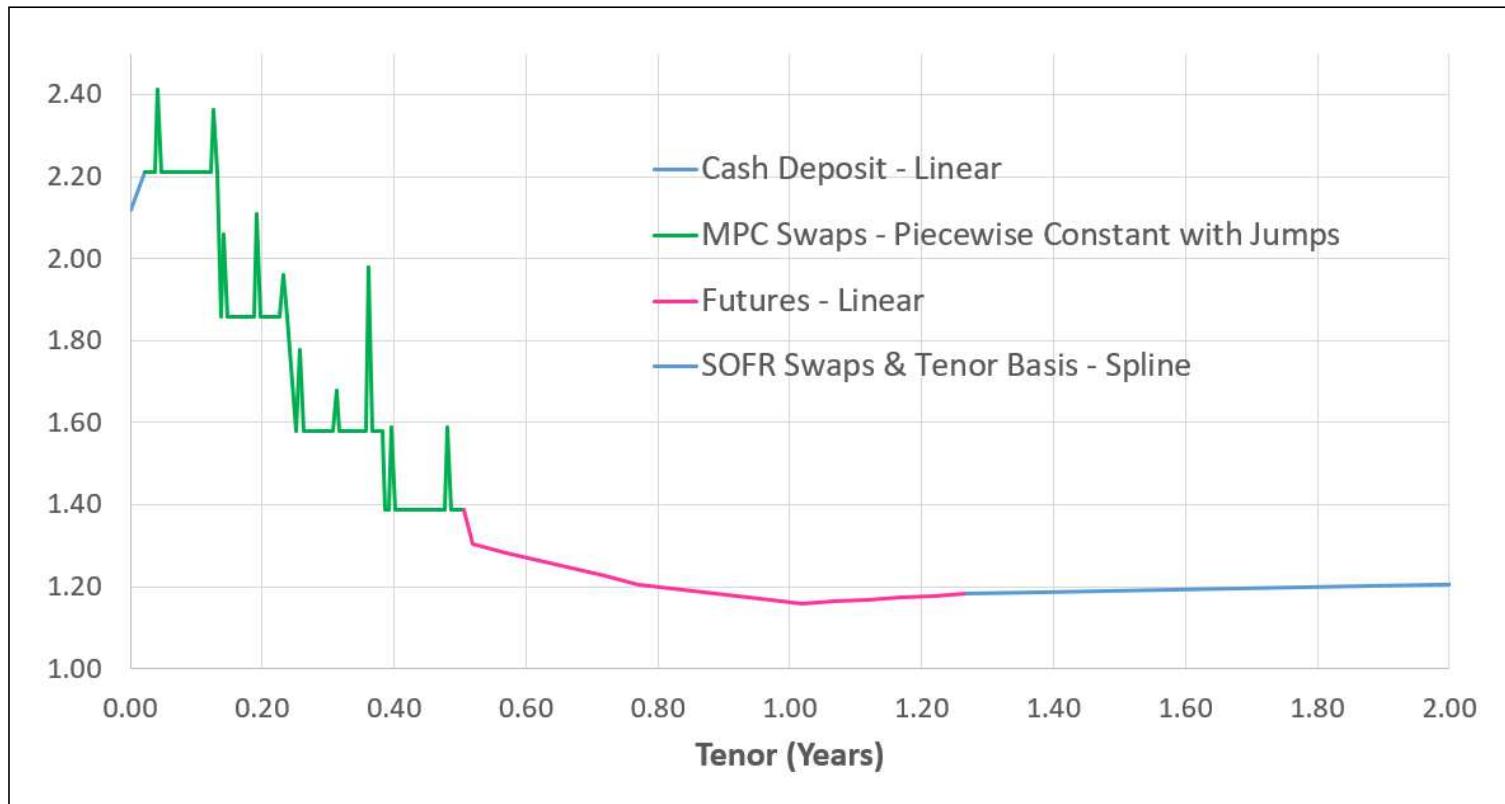
### DV01 Decomposition

PV01	1,970.40	Forward Risk
DF01	32.44	Discount Risk
DV01	2,002.84	Total Risk

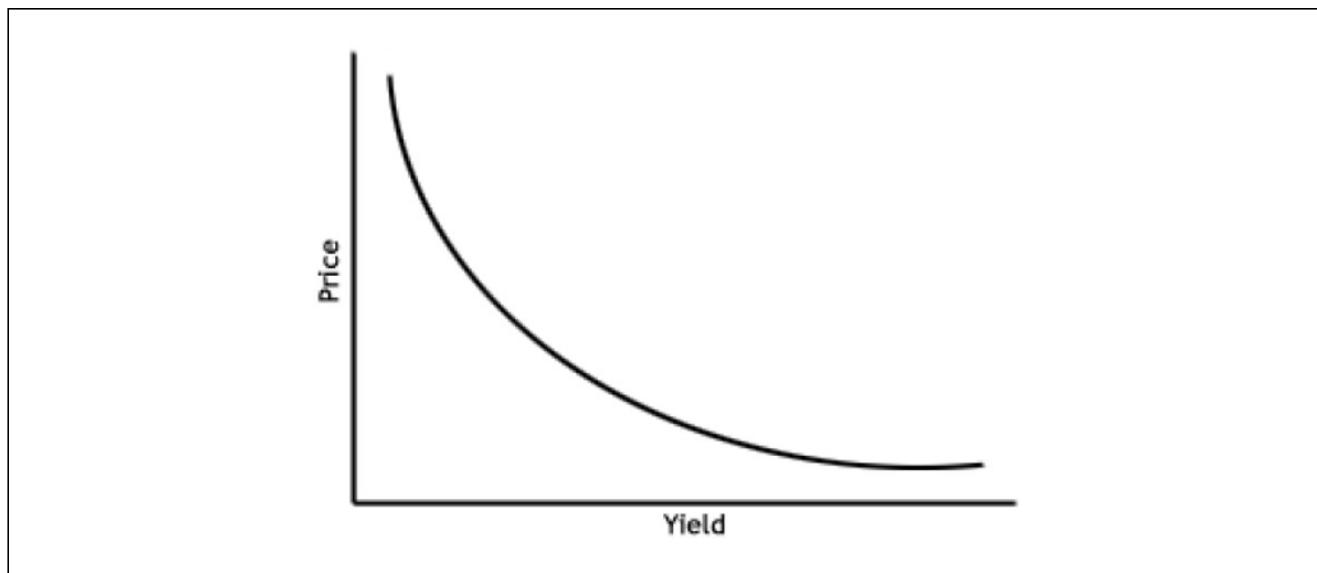


# Chapter 9 – Asset Swap Structuring

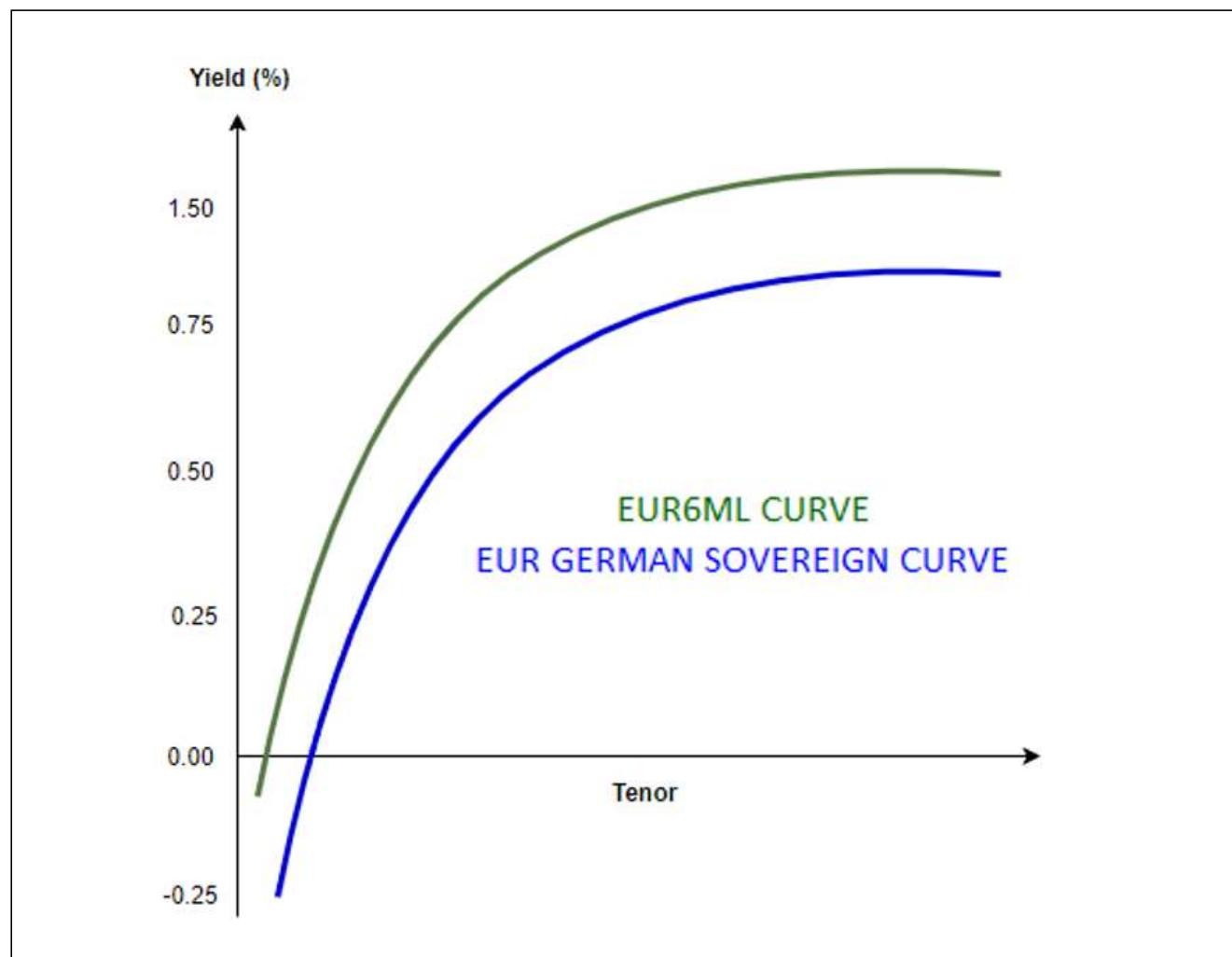
## USD SOFR Forward Curve



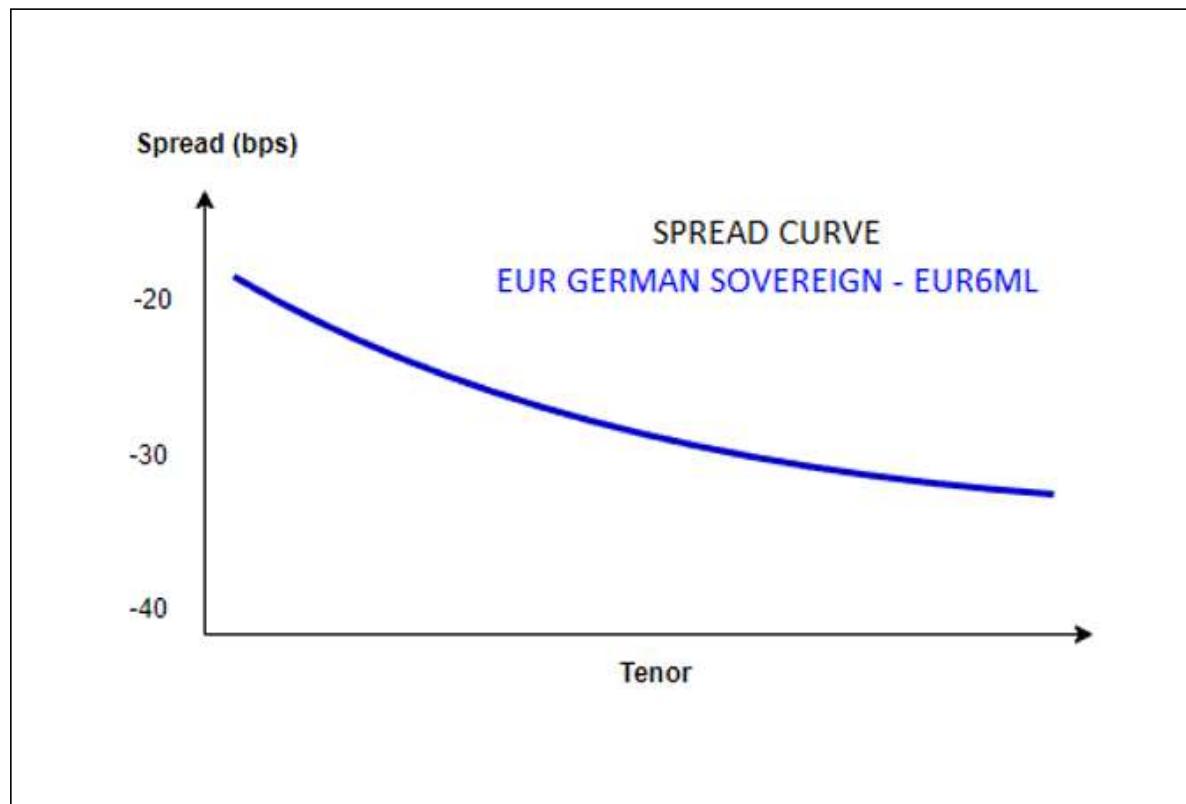
## Price – Yield Relationship



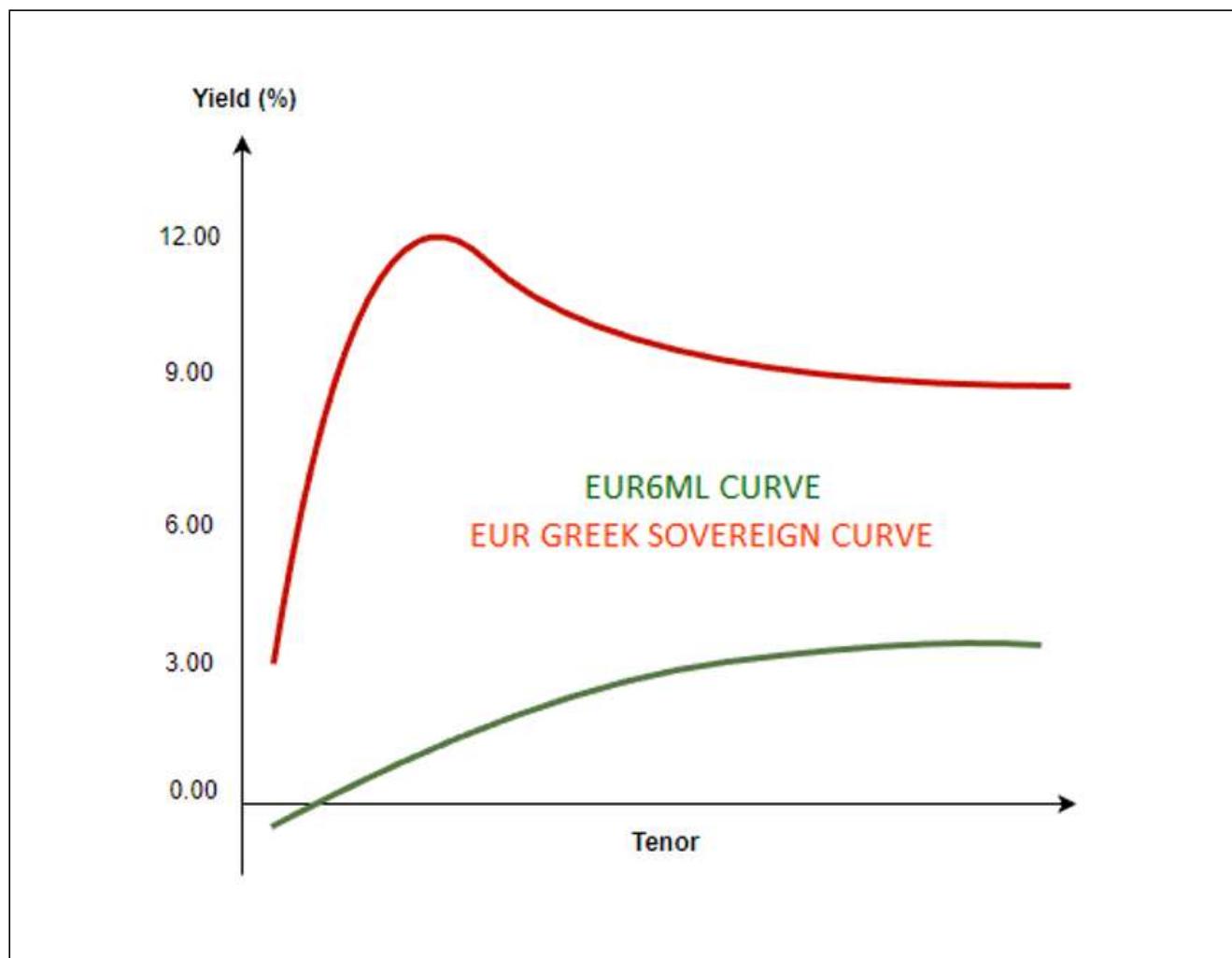
## German Sovereign Yields vs EUR 6M Swap Rates



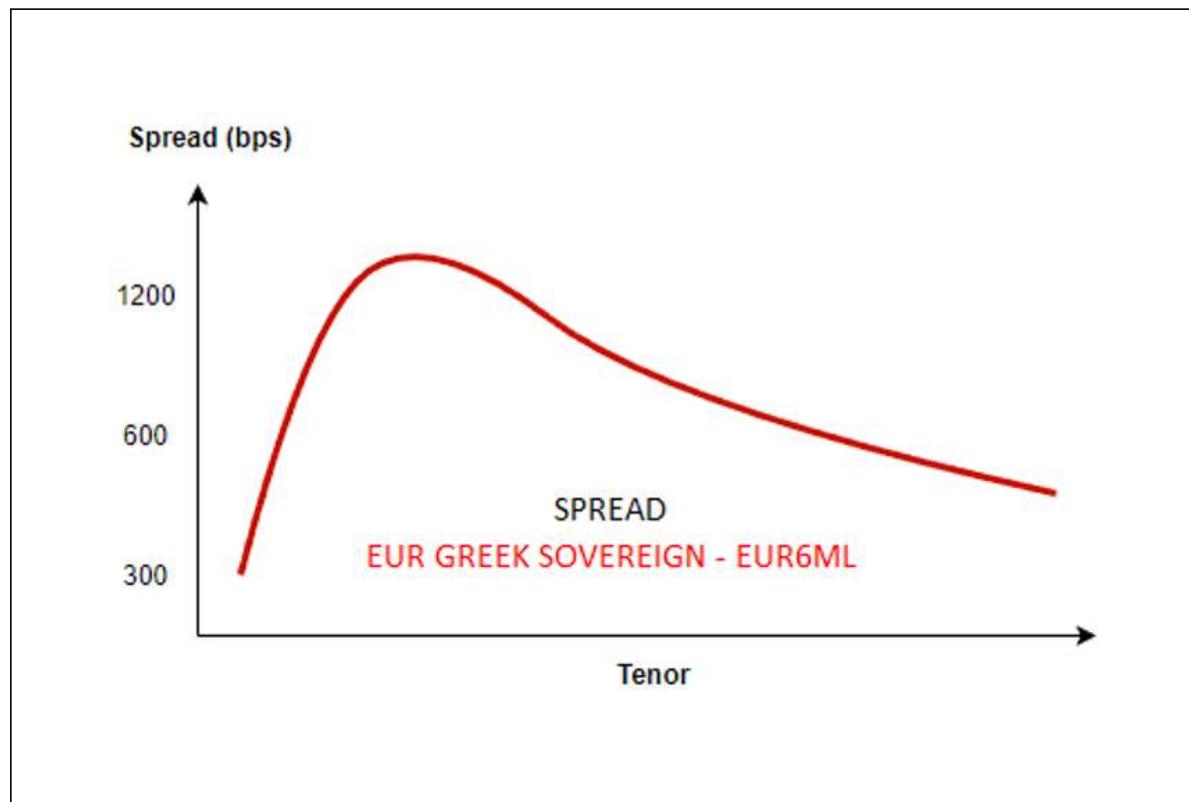
## German Sovereign Asset Swap Spreads



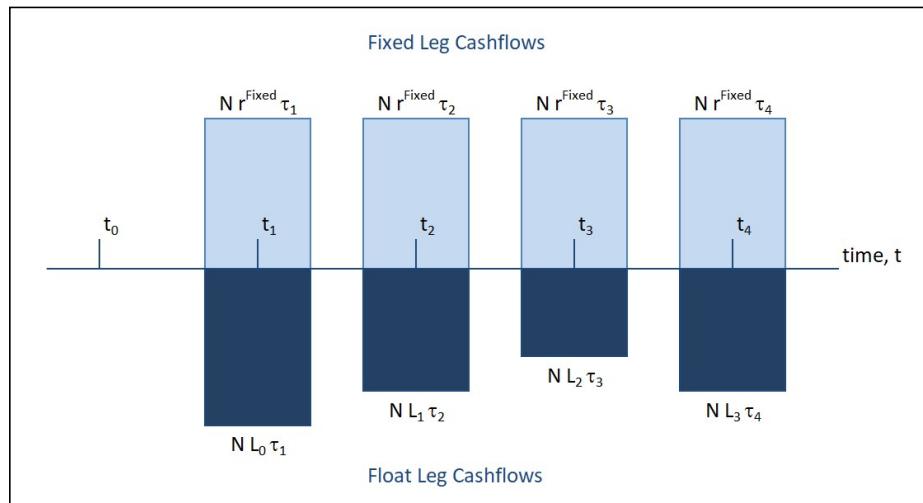
## Greek Sovereign Yields vs EUR 6M Swap Rates



## Greek Sovereign Asset Swap Spreads



## Interest Rate Swap Cash Flows



### Interest Rate Swap Quotes as a Spread to Treasuries or as a Swap Rate

Year	UST Yield	Spread	Swap Rate
1Y	0.062%	0.105%	0.167%
2Y	0.225%	0.091%	0.316%
3Y	0.444%	0.099%	0.543%
5Y	0.786%	0.079%	0.865%
7Y	1.057%	0.012%	1.069%
10Y	1.261%	0.006%	1.267%
30Y	1.874%	-0.281%	1.593%

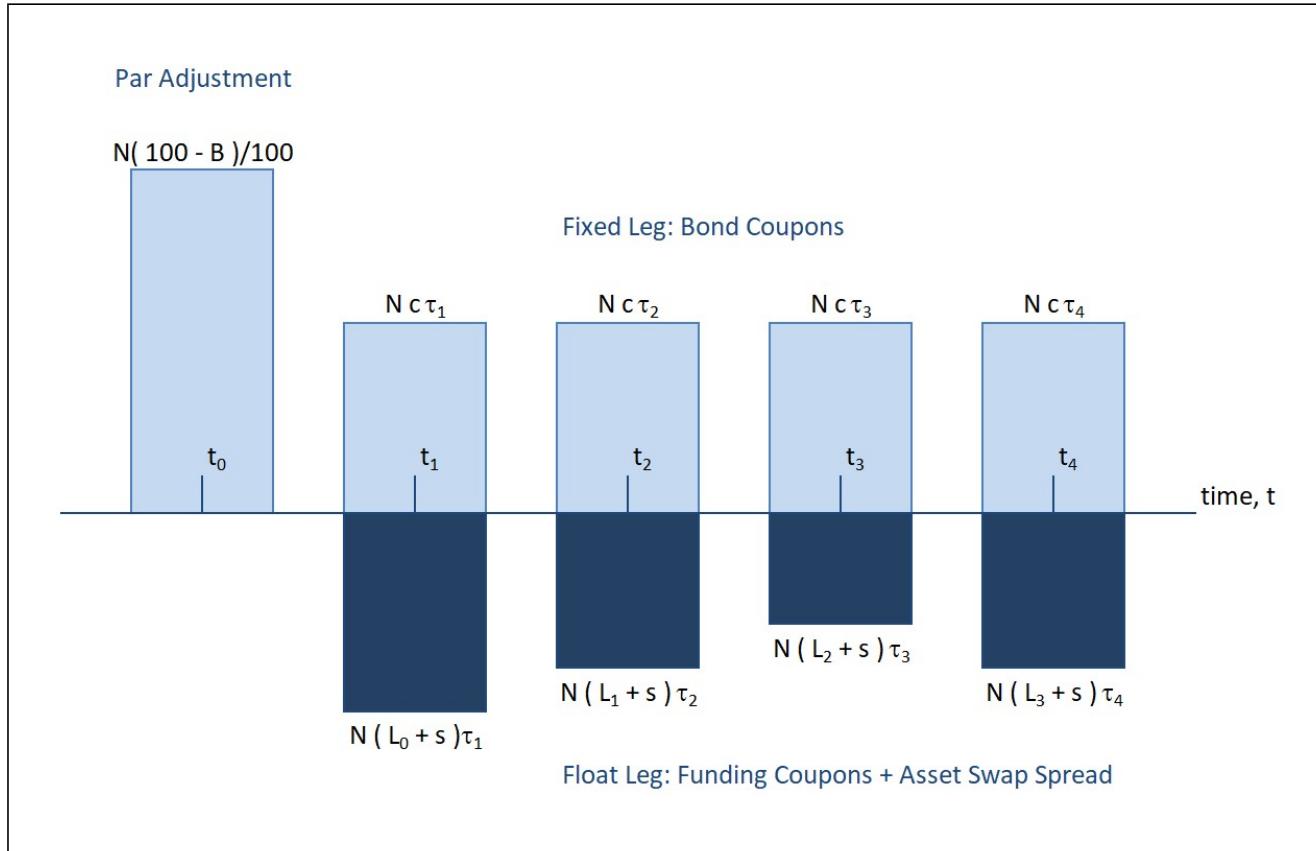
## Interest Rate Swaps as a Spread to US Treasury Bonds

Spreads vs Treasuries				
Tenor	Bid	/	Ask	Change
1Y	14.627	/	15.614	-0.794
2Y	<b>9.991</b>	/	<b>10.374</b>	<b>+0.068</b>
3Y	<b>8.082</b>	/	<b>8.432</b>	<b>-0.262</b>
4Y	5.250	/	5.535	-0.385
5Y	<b>5.053</b>	/	<b>5.446</b>	<b>-0.360</b>
6Y	2.500	/	2.875	-0.253
7Y	<b>0.356</b>	/	<b>0.671</b>	<b>-0.308</b>
8Y	0.503	/	0.809	-0.877
9Y	-0.125	/	0.500	-0.377
10Y	<b>0.072</b>	/	<b>0.441</b>	<b>-0.471</b>
12Y	6.113	/	6.424	-1.038
15Y	1.123	/	1.375	-0.563
20Y	-4.875	/	-4.500	-0.565
25Y	-13.500	/	-13.000	-1.125
30Y	<b>-24.171</b>	/	<b>-23.786</b>	<b>-0.715</b>

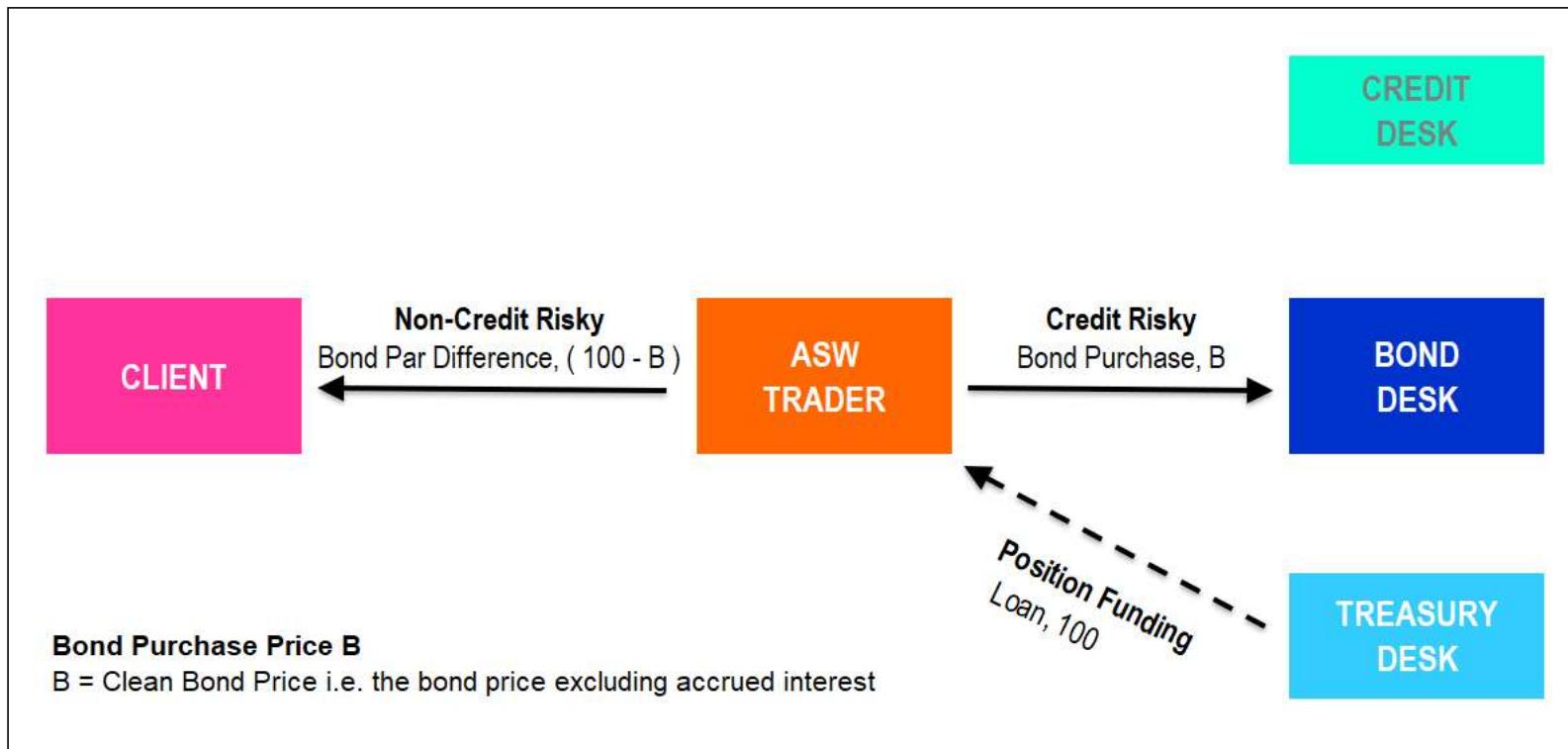
## Trader Runs – EUR 6M EURIBOR

EUR 6M EURIBOR				
Tenor	Bid	/	Ask	Change
1Y	0.041	/	0.046	-0.002
18M	0.052	/	0.058	-0.002
2Y	0.075	/	0.080	-0.001
3Y	0.146	/	0.151	-0.001
4Y	0.241	/	0.246	-0.004
5Y	0.351	/	0.356	-0.004
6Y	0.470	/	0.475	-0.007
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10Y	0.917	/	0.922	-0.015
15Y	1.243	/	1.251	-0.024
20Y	1.377	/	1.385	-0.030
25Y	1.407	/	1.416	-0.035
30Y	1.413	/	1.423	-0.038

## Asset Swap Cash Flows



## Asset Swap Cash Flows @ Inception



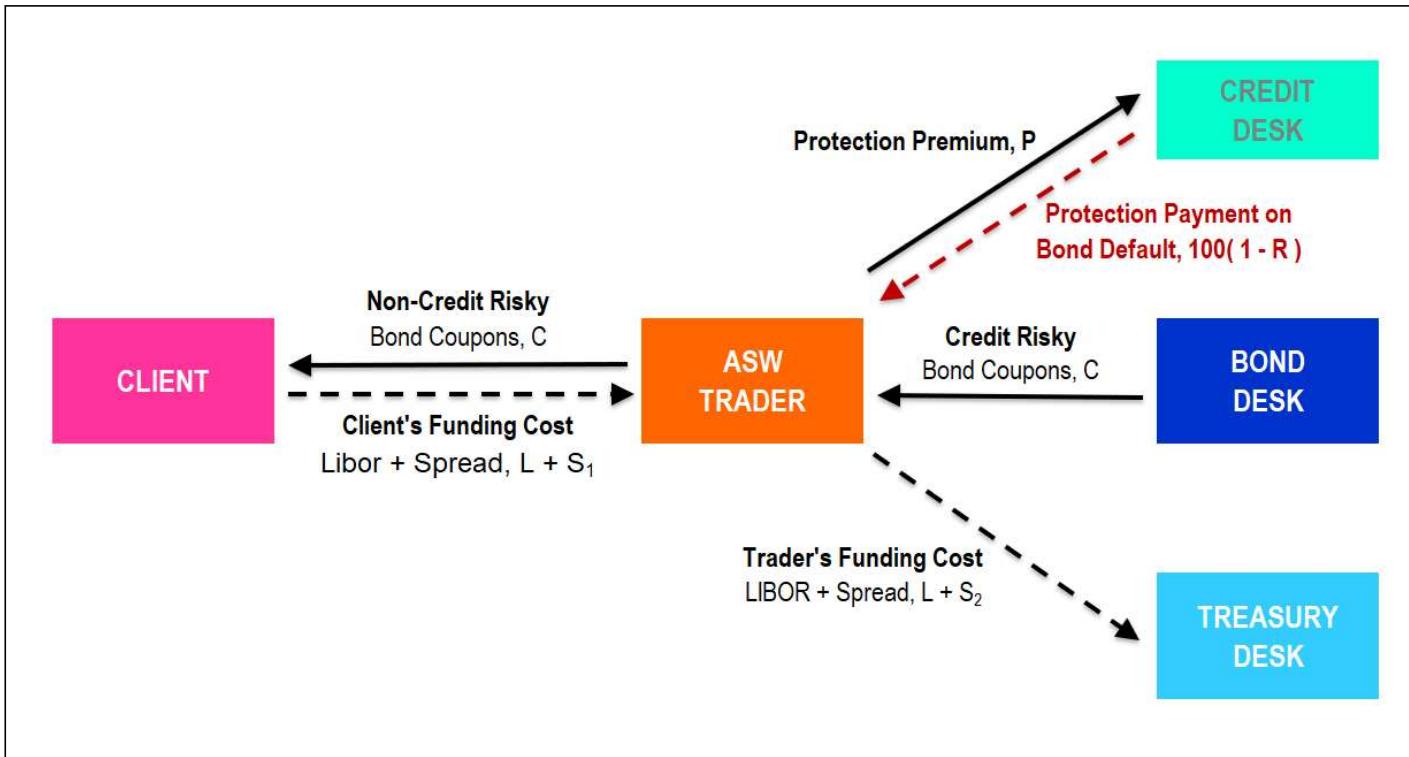
### ASW Trader - Initial Cash Flows

Counterparty	Cash Flow	Description
Treasury Desk	+100	Loan Funds to purchase Bond
Bond Desk	- B	Bond Purchase ( B = Clean Price )
Client	- ( 100 - B )	Difference
Net Cashflow	0	

### Client - Initial Cash Flows

Counterparty	Cash Flow	Description
ASW Trader	( 100 - B )	Credit / Debit difference arising from Position Funding and the Bond Purchase.
Net Cashflow	( 100 - B )	

## Asset Swap Cash Flows @ Interim Coupons



### ASW Trader - Interim Cash Flows

Counterparty	Cash Flow	Description
Bond Desk	+ C	Bond Coupons
Treasury Desk	- ( L+S <sub>2</sub> )	Funding Cost: Libor + Spread S <sub>2</sub>
Credit Desk	- P	Credit Protection Premium
Client	- C	Bond Coupons
Client	+ ( L+S <sub>1</sub> )	Funding Cost: Libor + Spread S <sub>1</sub>
Net Cashflow	S <sub>1</sub> - S <sub>2</sub> - P	Difference between spreads <sup>†</sup>
	= F	This equals trader commission / fee ( F )

### Asset Swap Spread Details:

<sup>†</sup>Spreads       $S_1 = S_2 + P + F$   
 $S_1 > S_2$

### ASW Trader - Cash Flows in the Event of a Bond Default

Counterparty	Cash Flow	Description
Credit Desk	+ 100 ( 1 - R )	Credit Protection in Event of Bond Default Where R = Recovery Rate % from Bond Default

### Client - Interim Cash Flows

Counterparty	Cash Flow	Description
ASW Trader	+ C	Bond Coupons
ASW Trader	- ( L+S <sub>1</sub> )	Funding Cost: Libor + Spread S <sub>1</sub>
Net Cashflow	C - ( L + S <sub>1</sub> ) Bond Coupons less Funding	

### Asset Swap Spread Details:

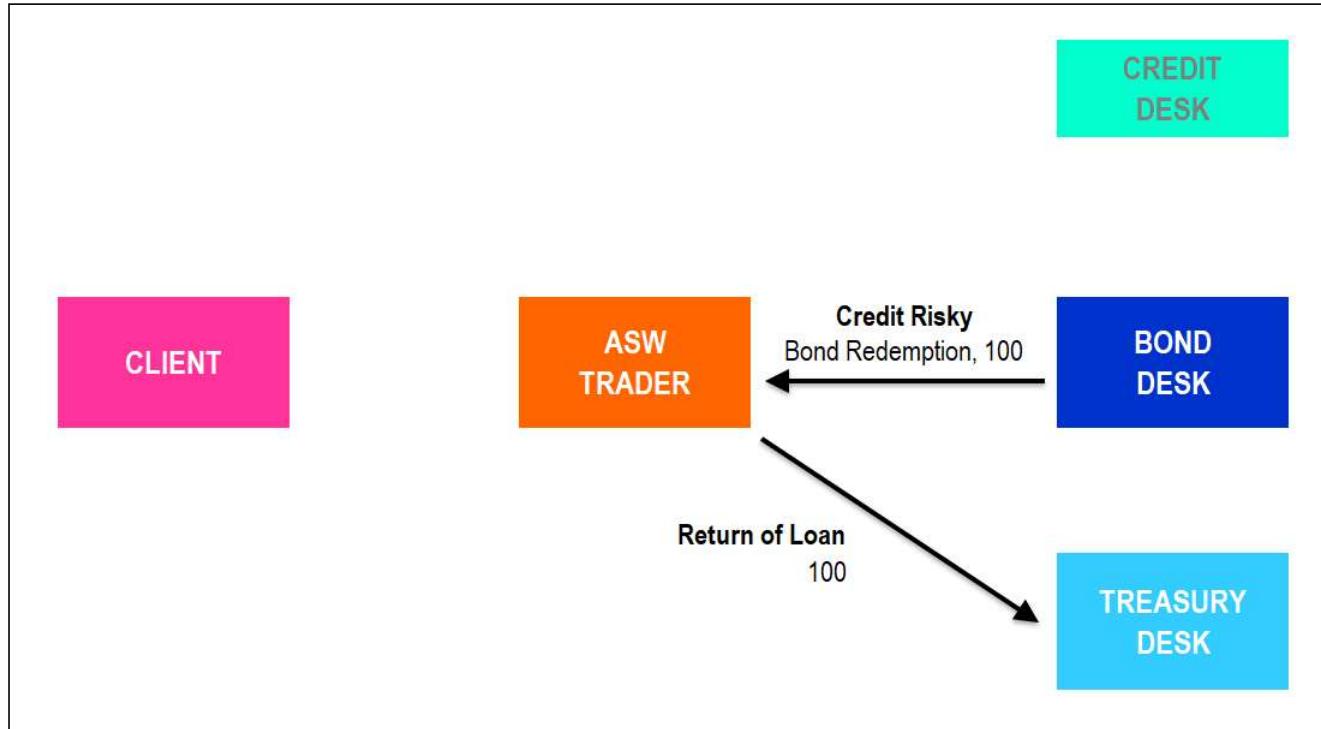
Libor Spreads S<sub>1</sub> and S<sub>2</sub>

S<sub>1</sub> > S<sub>2</sub>

Spread S<sub>1</sub> includes funding spread ( S<sub>2</sub> ), credit risk premium ( P ) and  
trader commission / fee ( F )

$$S_1 = S_2 + P + F$$

## Asset Swap Cash Flows @ Maturity



**ASW Trader - Final Cash Flows at Maturity**

Counterparty	Cash Flow	Description
Bond Desk	+100	Bond Redemption
Treasury Desk	-100	Return of Loan
Net Cashflow		0

**Client - Final Cash Flows at Maturity**

Counterparty	Cash Flow	Description
None		
Net Cashflow		0

## Interest Rate Swap – USD 3M LIBOR

Trade Template		USD IRS 5% USD3ML 5Y	
Swap	LEG1:FIXED		LEG2:FLOAT
	RECEIVE		PAY
	1,000,000		1,000,000
	USD		USD
	2D	Tue, 25-Aug-2015	2D
	5Y	Tue, 25-Aug-2020	5Y
	5.000000%		
	3M		USD3ML
	0.000		
Market			
Curve Date	Fri, 21-Aug-2015		Fri, 21-Aug-2015
Forecast Curve			USD3ML
Discount Curve	USDOIS		USDOIS
Valuation Results			
Valuation Date	Fri, 21-Aug-2015		
Par Rate	1.548250%		
NPV	167,892.11		
PV01	486.40		
DV01	532.42		

## Chapter 10 – Asset Swap Pricing Examples

## Asset Swap – German Government Bond

Trade Template																																						
EUR ASW DBR 0.5% 15/02/26																																						
<b>Bond</b>																																						
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## Asset Swap – Greek Government Bond

Trade Template																																						
EUR ASW GGB 3.0% 24/02/26																																						
<b>Bond</b>																																						
<table><tr><td>Bond</td><td colspan="2">EJ044543</td></tr><tr><td>Description</td><td colspan="2">GGB 3% 24/02/26</td></tr><tr><td>Coupon (%)</td><td colspan="2">3.000000%</td></tr><tr><td>Cpn Frequency</td><td colspan="2">ANNUAL</td></tr><tr><td>Day Count</td><td colspan="2">ACT/ACT</td></tr><tr><td>Accrual Start Date</td><td colspan="2">Wed, 24-Feb-2016</td></tr><tr><td>Maturity Date</td><td colspan="2">Tue, 24-Feb-2026</td></tr><tr><td>Maturity Price</td><td colspan="2">100.0000</td></tr><tr><td>Price Type</td><td colspan="2">CLEAN</td></tr><tr><td>Price</td><td colspan="2" rowspan="3">75.2800</td></tr></table>			Bond	EJ044543		Description	GGB 3% 24/02/26		Coupon (%)	3.000000%		Cpn Frequency	ANNUAL		Day Count	ACT/ACT		Accrual Start Date	Wed, 24-Feb-2016		Maturity Date	Tue, 24-Feb-2026		Maturity Price	100.0000		Price Type	CLEAN		Price	75.2800							
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## Chapter 11 – Multiples Pricing, Trader Tricks & Rules of Thumb

## Asset Swap – German Government Bond

Trade Template	EUR ASW DBR 0.5% 15/02/26																																					
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## Asset Swap – Greek Government Bond

Trade Template	EUR ASW GGB 3.0% 24/02/26																																					
<b>Bond</b>																																						
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## Interest Rate Swap – USD 3M LIBOR

Trade Template		USD IRS 5% USD3ML 5Y	
Swap		LEG1:FIXED	LEG2:FLOAT
Pay / Receive		RECEIVE	PAY
Notional		1,000,000	1,000,000
Currency		USD	USD
Effective Date	2D	Tue, 25-Aug-2015	2D Tue, 25-Aug-2015
Maturity Date	5Y	Tue, 25-Aug-2020	5Y Tue, 25-Aug-2020
Fixed Rate (%)		5.000000%	
Float Index		3M	USD3ML
Float Spread (bps)			0.000
Reset Frequency			QUARTERLY
Pay Frequency		SEMI-ANNUAL	QUARTERLY
Day Count		30/360	ACT/360
Market			
Curve Date		Fri, 21-Aug-2015	Fri, 21-Aug-2015
Forecast Curve			USD3ML
Discount Curve		USDOIS	USDOIS
Valuation Results			
Valuation Date		Fri, 21-Aug-2015	
Par Rate		1.548250%	
NPV		167,892.11	
PV01		486.40	
DV01		532.42	

## Credit Default Swap - US Corporate

Trade Template		USD CDS 5% FORD MOTOR 5Y	
Swap	LEG1:PREMIUM		LEG2:PROTECTION
Pay / Receive	PAY	RECEIVE	
Notional	10,000,000	10,000,000	
Currency	USD	USD	
Reference Entity	US35370BX76	Ford Motor Company	
Accrual Start	IMM	Wed, 16-Mar-2016	
Effective Date	5D	Mon, 23-May-2016	5D Mon, 23-May-2016
Maturity Date	5Y	Tue, 16-Mar-2021	5Y Tue, 16-Mar-2021
Fixed Rate (bps)	500.000		
Recovery Rate (%)		40.000%	
Pay Frequency	QUARTERLY		
Day Count	ACT/360		
Market			
Curve Date	Mon, 16-May-2016		Mon, 16-May-2016
Credit Curve	USD_FORD_MOTOR_CO		
Discount Curve	USDOIS		USDOIS
Valuation Results			
Valuation Date	Mon, 16-May-2016		
Par Spread (bps)	139.173800		
Clean PV	-1,669,036		
Accrued	-87,500		
Dirty PV	-1,786,536		
DV01	4,357.30		
CS01	4,951.24		

## Asset Swap – German Bund

Trade Template																																						
EUR ASW DBR 0.5% 15/02/26																																						
<b>Bond</b>																																						
<table><tr><td>Bond</td><td>JW503423</td></tr><tr><td>Description</td><td>DBR 0.5% 15/02/26</td></tr><tr><td>Coupon (%)</td><td>0.500000%</td></tr><tr><td>Cpn Frequency</td><td>ANNUAL</td></tr><tr><td>Day Count</td><td>ACT/ACT</td></tr><tr><td>Accrual Start Date</td><td>Thu, 15-Jan-2026</td></tr><tr><td>Maturity Date</td><td>Sun, 15-Feb-2026</td></tr><tr><td>Maturity Price</td><td>100.0000</td></tr><tr><td>Price Type</td><td>CLEAN</td></tr><tr><td>Price</td><td>104.5800</td></tr></table>			Bond	JW503423	Description	DBR 0.5% 15/02/26	Coupon (%)	0.500000%	Cpn Frequency	ANNUAL	Day Count	ACT/ACT	Accrual Start Date	Thu, 15-Jan-2026	Maturity Date	Sun, 15-Feb-2026	Maturity Price	100.0000	Price Type	CLEAN	Price	104.5800																
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## Multiples – Swap Pricing

Notional, N'	<i>Net Rate, r<sup>Net Bps</sup></i>	Maturity, T	Base Multiple	PV (USD)
1,000,000	1 bps	1.0	1	100
2,000,000	25 bps	2.0	100	10,000
5,000,000	50 bps	2.0	500	50,000
5,000,000	75 bps	2.0	750	75,000
10,000,000	100 bps	5.0	5000	500,000

## Multiples – Swap Risk

Notional, N'	Maturity, T	Base Multiple	PV01 (USD)	DV01 (USD)
1,000,000	1.0	1	100	100
2,000,000	1.0	2	200	200
5,000,000	1.0	5	500	500
5,000,000	2.0	10	1,000	1,000
10,000,000	5.0	50	5,000	5,000

## Swap Risk Profile – Calibration / Hedge Instruments

Actual Risk					
Hedge Trade Risk					
Risk Bucket	Hedge Trades				
	IRS 1Y	IRS 2Y	IRS 3Y	IRS 4Y	IRS 5Y
	OIS 1Y	0	0	0	0
	OIS 2Y	0	0	0	0
	OIS 3Y	0	0	0	0
	OIS 4Y	0	0	0	0
	OIS 5Y	0	0	0	0
	IRS 1Y	98	0	0	0
	IRS 2Y	0	195	0	0
	IRS 3Y	0	0	291	0
	IRS 4Y	0	0	0	386
	IRS 5Y	0	0	0	479

Total Trade DV01					
IRS 1Y	IRS 2Y	IRS 3Y	IRS 4Y	IRS 5Y	
98	195	291	386	479	

X

## Swap Risk Profile – Trade Portfolio

Actual Risk			Actual Risk				
Portfolio Risk - Trade Level			Portfolio Risk - Total		Actual Risk		
Risk Bucket	IRS 1Y	IRS(4Y, 5Y)	IRS(4.5Y)	Risk Bucket	Risk Total	Hedge	Qty
OIS 1Y	0	0	0	OIS 1Y	0	OIS 1Y	0
OIS 2Y	0	0	0	OIS 2Y	0	OIS 2Y	0
OIS 3Y	0	0	0	OIS 3Y	0	OIS 3Y	0
OIS 4Y	0	0	0	OIS 4Y	0	OIS 4Y	0
OIS 5Y	0	0	0	OIS 5Y	0	OIS 5Y	0
IRS 1Y	98	0	0	IRS 1Y	98	IRS 1Y	-1
IRS 2Y	0	0	0	IRS 2Y	0	IRS 2Y	0
IRS 3Y	0	0	0	IRS 3Y	0	IRS 3Y	0
IRS 4Y	0	-386	193	IRS 4Y	-193	IRS 4Y	0.50
IRS 5Y	0	479	239	IRS 5Y	718	IRS 5Y	-1.50

## Multiples Risk Profile – Calibration / Hedge Instruments

Quick Risk					
Hedge Trade Risk					
Hedge Trades					
Risk Bucket	IRS 1Y	IRS 2Y	IRS 3Y	IRS 4Y	IRS 5Y
OIS 1Y	0	0	0	0	0
OIS 2Y	0	0	0	0	0
OIS 3Y	0	0	0	0	0
OIS 4Y	0	0	0	0	0
OIS 5Y	0	0	0	0	0
IRS 1Y	100	0	0	0	0
IRS 2Y	0	200	0	0	0
IRS 3Y	0	0	300	0	0
IRS 4Y	0	0	0	400	0
IRS 5Y	0	0	0	0	500

Total Trade DV01					
IRS 1Y	IRS 2Y	IRS 3Y	IRS 4Y	IRS 5Y	
100	200	300	400	500	

X


## Multiples Risk Profile – Trade Portfolio

Quick Risk			Quick Risk		Quick Risk	
Portfolio Risk - Trade Level			Portfolio Risk - Total		Portfolio Hedges	
Risk Bucket	IRS 1Y	IRS(4Y, 5Y)	Risk Bucket	Risk Total	Hedge	Qty
OIS 1Y	0	0	OIS 1Y	0	OIS 1Y	0
OIS 2Y	0	0	OIS 2Y	0	OIS 2Y	0
OIS 3Y	0	0	OIS 3Y	0	OIS 3Y	0
OIS 4Y	0	0	OIS 4Y	0	OIS 4Y	0
OIS 5Y	0	0	OIS 5Y	0	OIS 5Y	0
IRS 1Y	100	0	IRS 1Y	100	IRS 1Y	-1
IRS 2Y	0	0	IRS 2Y	0	IRS 2Y	0
IRS 3Y	0	0	IRS 3Y	0	IRS 3Y	0
IRS 4Y	0	-400	IRS 4Y	-200	IRS 4Y	0.50
IRS 5Y	0	500	IRS 5Y	750	IRS 5Y	-1.50

Total Trade DV01	Total DV01
IRS 1Y    IRS(4Y, 5Y)    IRS(4.5Y)	650
100            100            450	



# References



Quant Research Papers

<https://ssrn.com/author=1728976>

Support Materials, C++ & Excel Examples

<https://github.com/nburgessx/SwapsBook>

The image shows the front cover of the book "Low Latency Interest Rate Markets: Theory, Pricing and Practice" by Nicholas Burgess. The cover is white with black text. At the top right is the ELiVA PRESS logo. Below it is the title "Low Latency Interest Rate Markets" in bold, followed by "Theory, Pricing and Practice" in a smaller font. In the center is a portrait photo of the author, Nicholas Burgess, wearing a tuxedo and bow tie. To the left of the photo is a short bio: "Nicholas Burgess specializes in electronic swaps trading, low latency pricing and risk analytics. He has written and published many quantitative and finance research papers and is well-qualified having read Financial Strategy at Said Business School, University of Oxford, Quant Finance at Henley Business School, University of Reading and Mathematics at the University of Manchester." Below the bio is a paragraph about his professional experience: "He has managed Quant teams and worked on busy trading floors at investment banks and hedge funds including Citigroup, UBS, Credit Suisse, Bank of America, COS Hedge Fund, Deutsche Bank, Commerzbank, Société Générale, ANZ, MUFG, Mizuho, HSBC and XP Investments. This provided the author with a wide breadth of experience in trading, pricing and risk management of interest rates, fixed income, equities, credit, commodities, FX, hybrids &amp; exotics, inflation and XVA." At the bottom left is a quote from Ronald T. Slivka: "In today's interest rate derivatives markets, there is a rising urgency to provide timely, accurate computations to adequately support for electronic pricing, trading and risk management. The construction of low latency interest rate systems is a challenging task at the leading edge of quantitative and practical applications. For readers with a need to understand the theoretical and practical content of such systems there is no other source needed except this one book. With great clarity of text and its emphasis on pragmatic applications, all written by an industry practitioner, this book sets the standard for low latency practice in today's interest rate derivatives markets." Below that is another quote from Ian Castleton: "The world of quantitative finance is constantly evolving to meet the requirements of an ever-changing market, new regulations, improvements in technology and the greater need for real-time calculations. This book addresses these challenges and is the result of years of experience at leading financial institutions. It is remarkable in the wide-ranging topics it covers, and the level of mathematical detail it contains while remaining accessible. This book is a worthy reference on every quant bookshelf." At the very bottom left is a quote from Karim Henide: "Nicholas is a world-class Quant and thinker, who capably traverses academic theory for market practitioners to integrate into their investment and risk processes. This book is poised to be a critical compendium on rates markets for years to come." On the right side of the cover, the author's name "Nicholas Burgess" is printed vertically. The bottom right corner features a photograph of a city street at night with blurred lights from moving vehicles.

Available at Amazon:

<https://www.amazon.co.uk/dp/9994985949>