TAB: SUMMARY OF THE RESULTS

Model Parameters

Interest rate model	Vasicek		1
Credit rating	BB-		
Maturity term	5.0		
Coupon rate	4.79%	Bond coupon rate (MYCA rate)	
dt	0.25	Length of the tree step (in years)	
Short-term yield rate at t=0	3.444%	Calibrated so that bond value = par	
Drift parameter (ϑ)	0.575%	Calibrated from the term structure	
Mean-reversion parameter (α)	0.000%	Default value is zero	
Volatility (σ)	0.759%	Estimated using historical data sample	

Model Output

Bond actual value	-99.05
Bond bullet value	-100.00
Bond option value	**0.947**
Coupon frequency	2
First period duration	0
Remaining period duration	5.0
First period discount factor	1.000
Annuity adjustment factor	4.4001
Bond option premium / discount	**0.215**

Testing

Model name	Bullet value	μ_T	σ_T
This numerical model	**-100.00**	**6.32%**	**1.69%**
Vasicek	**-99.68**	**6.32%**	**1.70%**
Cox-Ingersoll-Ross (CIR)			
Hull-White, extended Vasicek	-99.66	6.32%	1.70%
Hull-White, extended CIR	-99.59	6.32%	0.00%
Difference between numerical model and theory	***-0.32***	***0.00%***	***-0.01%***

Process Summary

Number of Markov process states	31
Terminal distribution mean	6.316%
Terminal distribution stdev	1.690%
Bond price (dirty/full)	-99.052
Bond price bullet (dirty/full)	-99.999

Markov process models

Vasicek
Cox-Ingersoll-Ross (CIR)
Hull-White, extended Vasicek
Hull-White, extended CIR
Other

TAB: BOND PARAMETERS

Terms

General parameters

Parameter	Value	Description
T (Covered Transaction)	5.00	Covered Transaction term to maturity
T (tree)	5.00	
dt	0.25	Time increment
principal	100.0	Bond principal amount
coupon-rate	4.79%	Coupon / dividend rate
coupon-frequency	2	Coupon payment frequency (measured in the # of tree periods)
n (Covered Transaction)	21	Number of periods in the tree that measure the bond life
n (tree)	21	

Bond redemption premium / discount

Period	Value	Description
1	0.00%	Bond redemption premium in period t=0
20	0.00%	Bond redemption premium in period t=3
40	0.00%	Bond redemption premium at maturity

redemption premium	java.util.Linke	Premium at which the bond is redeemed if option is exercised

Bond option parameters

Parameter	Value	Description
option	call	Option type (put or call)

Schedules

Bond amortization schedule

Period	Value	Description
1	0%	% of bond amortization in period t=0
2	0%	% of bond amortization in period t=2
3	0%	% of bond amortization in period t=3
20	100%	% of bond amortization at maturity

amortization map	java.util.LinkedHashM	Bond amortization schedule

Interest deferral schedule

Parameter	Value	Description
interest deferral period	0	The latest coupon payments deferral period
is compounded	1	1 if deferred interest is compounded and zero otherwise

TAB: OPTION CALCULATION FOR A SAMPLE OF BONDS/NOTES

Valuation Date	2-Mar-18
Max remaining ter	5.00

Parameters

period end	20
dt	0.25
coupon rate	4.79%
coupon frequency	2
maturity term	5.00
annuity adjustment	4.40

List of keys	java.util.ArrayList@Sun, 24 Jun 2018 13:20:43:690..380214678
List of bond data	java.util.ArrayList@Sun, 24 Jun 2018 13:20:43:699..292510975
Bond sample cash flows	java.util.ArrayList@Sun, 24 Jun 2018 13:20:43:898..170356485
Bond sample prices	java.util.ArrayList@Sun, 24 Jun 2018 13:20:44:501..534398940

Assumptions:

1. *The same interest rate tree (same volatility and other parameters) is used for each option calulation*
2. *The coupon rate and coupon frequency of the Covered Transaction are used for each option calculation*
3. *Effectively terms of each bond in the sample are adjusted to the terms of Covered Transaction but assumed to have bond-specific prepayment penalty structure*

Covered Transaction premium	0.22

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Derived Data

#	Ticker	Issuer Name	Maturity Date	Make-Whole Termination Date	Redemption Premium, in %	Remaining Tenor		Remaining Tenor (adjusted)	Coupon Rate	Coupon Frequency	Make-Whole Remaining Duration		Redemption Premium, in %	Bond Bullet Price	Bond Price	Option Price	Annuity Adjustment Factor	Option Premium / Discount	**Option Adjustment**
						tenor, years	MWC years	tenor-remaining	coupon-rate	coupon-frequency	make-whole-duration	penalty slope	redemption-premium-post-make-whole			%	years	bps	**bps**
1	EK775769 Corp	CDW LLC/CDW FINANCE	1-Sep-23	1-Mar-18	3.75%	5.50	0.00	5.00	4.79%	2	0.00	0.68%	3.41%	-100.00	-99.75	0.25	4.40	0.06	**-0.06**
2	EK623646 Corp	CDW LLC/CDW FINANCE	1-Dec-24	1-Jun-24	0.00%	6.75	6.25	5.00	4.79%	2	4.63	0.00%	0.00%	-100.00	-99.96	0.04	4.40	0.01	**-0.01**
3	JK984281 Corp	PTC INC	15-May-24	15-May-19	4.50%	6.20	1.20	5.00	4.79%	2	0.97	0.90%	3.63%	-100.00	-99.82	0.18	4.40	0.04	**-0.04**
4	LW445537 Corp	NUANCE COMMUNICATIONS	1-Jul-24	1-Jul-19	4.50%	6.33	1.33	5.00	4.79%	2	1.05	0.90%	3.55%	-100.00	-99.84	0.16	4.40	0.04	**-0.04**
5	EK884818 Corp	MICRON TECHNOLOGY INC	15-Jan-24	1-May-18	3.94%	5.87	0.16	5.00	4.79%	2	0.14	0.69%	3.35%	-100.00	-99.74	0.26	4.40	0.06	**-0.06**
6	EK281889 Corp	COMMSCOPE INC	15-Jun-21	15-Jun-17	2.50%	3.29	0.00	5.00	4.79%	2	0.00	0.76%	3.80%	-100.00	-99.78	0.22	4.40	0.05	**-0.05**
7	EK281901 Corp	COMMSCOPE INC	15-Jun-24	15-Jun-19	2.75%	6.29	1.29	5.00	4.79%	2	1.02	0.55%	2.19%	-100.00	-99.69	0.30	4.40	0.07	**-0.07**
8	EK477772 Corp	AMSTED INDUSTRIES	15-Sep-24	15-Sep-19	2.69%	6.54	1.54	5.00	4.79%	2	1.18	0.54%	2.05%	-100.00	-99.68	0.32	4.40	0.07	**-0.07**
9	EK614026 Corp	MOOG INC	1-Dec-22	1-Dec-17	3.94%	4.75	0.00	5.00	4.79%	2	0.00	0.83%	4.15%	-100.00	-99.81	0.19	4.40	0.04	**-0.04**
10	EK106995 Corp	AMSTED INDUSTRIES	15-Mar-22	15-Mar-18	2.50%	4.04	0.04	5.00	4.79%	2	0.04	0.63%	3.10%	-100.00	-99.71	0.29	4.40	0.06	**-0.06**

TAB: INTEREST RATE TREE PARAMETERS

Interest rate tree and tree calculator parameters

General parameters

Parameter	Value	Description
Input parameters		
model	Vasicek	
theta	0.57%	Drift parameter, ϑ
sigma	0.76%	Standard deviation parameter, σ
alpha	0.00%	Diffusion mean reversion parameter, α
gamma	1.07%	Diffusion heteroscedasticity parameter, γ

Tree parameters

Parameter	Value	Description
States		
dx-down	3.00	Normalized downward change in state over dt period ($x_{min} = E\, x_T - \Sigma_T \times dx_{down}$)
dx-up	3.00	Normalized upward change in state over dt period ($x_{max} = E\, x_T + \Sigma_T \times dx_{up}$)
X-min	-10.0%	Lower boundary on minimum state value
X-max	20.0%	Upper boundary on maximum state value
X-count	30	Number of process discrete states $\{x_t\}$
iter-count	10	Number of iterations used to construct $\sigma(T, x)$ - uniform set of states in period T
Diffusion tree parameter		
Q-adjusted	1	Set to 1 if the tree probabilities are adjusted to match drift and volatility values

Calculator parameters

Parameter	Value	Description
Calculator option parameters		
option	call	Evaluated option (put or call)
adjust-to-par	1	Set to 1 if the term structure is shifted so that the bullet price equals to par
yield	4.79%	Coupon rate for which 'adjusted-to-par' term structure is estimated
yield-min	-10%	Minimum yield bound in term structure shift search estimation
yield-max	20%	Maximum yield bound in term structure shift search estimation
yield-iter	10	Maximum number of term structure shift iterations
npv-delta	0.1	Maximum difference between bond cash flow yield-based NPV and bond clean price
Calculator option executed methods		
par-value		Estimate the value y_0 such that the bond bullet value is equal to par
value-option		Estimate the bond bullet prices and prices in the presence of the option
bond-yields		Estimate the bond bullet yields and yields in the presence of the option

Transition probability functions

Function arguments

Parameter	Value	Description
Drift function	jkr.datalink.lib.data.math.factory.Factor	Diffusion drift function object
Volatility function	jkr.datalink.lib.data.math.factory.Factor	Diffusion dvolatility function object
Derived parameters		
$(\mu - \sigma^2/2) \times dt$	0.14%	Adjusted one-period drift parameter
y_0	3.07%	Initial short-term yield rate (prior to curve shift)

Transition probability tree structure

Movement direction	a_i	p_i	Restrictions on the
up	1.732	0.17	$\Sigma\, a_i^2 \times p_i = 1$
zero	0.000	0.67	$\Sigma\, p_i = 1$
down	-1.732	0.17	
Q tree structure	java.util.LinkedHashMap@		
Use tree structure	0		Set to 1 if the above tree structure is used Otherwise, normal approximation is applied

Parameter objects

Parameter	Value	Description
Parameter mappings objects		
process parameters	java.util.LinkedHashMap@	Mapping with Markov process parameters
States mapping	java.util.LinkedHashMap@	State mapping object
Tree parameters	java.util.LinkedHashMap@	Diffusion tree parameter mapping object
Calculator option parameter mapping	java.util.LinkedHashMap@	Calculator parameter mapping object
Calculator executed methods list	java.util.ArrayList@Sun, 24	Calculator option executed methods list object

TAB: INTERIOR RATE TREE MODELING

Controlled diffusion tree inputs and objects

Interest rate tree objects

Diffusion tree

Parameter	Value
T	5.00
dt	0.25
y_0	3.07%
states	java.util.LinkedHashMap@Sun, 24 Jun 2018 13:20:43:699..6313
process-params	java.util.LinkedHashMap@Sun, 24 Jun 2018 13:20:40:294..6327
Drift function	jkr.datalink.lib.data.math.factory.FactoryFunctionX1$F1Fn@Sun
Volatility function	jkr.datalink.lib.data.math.factory.FactoryFunctionXn$Const@Su
Q tree structure	-
parameters	java.util.LinkedHashMap@Sun, 24 Jun 2018 13:20:43:698..1007

jeconkr.finance.HW.Derivatives2003.lib.ch23_srm.ShortRateModel@Sun, 24 Jun 2018 13:3

Interest rate tree calculator objects

Markov tree calculator

Parameter	Value
Interest rate tree model	jeconkr.finance.HW.Derivatives2003.lib.ch23_srm.ShortF
Covered Transaction cash flows	java.util.LinkedHashMap@Sun, 24 Jun 2018 13:20:43:74
Sample bonds cash flows	java.util.ArrayList@Sun, 24 Jun 2018 13:20:43:898..1703
Parameters	java.util.LinkedHashMap@Sun, 24 Jun 2018 13:20:43:70
Executed methods	java.util.ArrayList@Sun, 24 Jun 2018 13:20:43:698..7177

jeconkr.finance.HW.Derivatives2003.lib.ch23_srm.calculator.CalculatorSRM@Sun, 24 Jun 20

Tree output parameters

Tree keys:	Description
field	Markov tree field
state-value	State values (as a tree)
tree-states	State values (as a list)
stats-tree-bounds	The bounds of the tree (minimum and amximum state path)
Q	Transition probabilities (as array for period t)
P	State probabilities (as a tree)
action-switch-node	State at which the action switches from non-exercise to exercise
stats-distribution	State distribution at maturity date
summary-table	Summary of the key Markov process output data
tree-params	Parameters used to construct and estimate the tree

Calculator and tree parameter mapping

key	value	
t		100
path-avg		
path-stdev		
path-pct	java.util.ArrayList@Sun, 24 Jun 2018 12:54:35:739..266162823724	
Lower percentile		0.25
Upper percentile		0.75

java.util.LinkedHashMap Calculator parameters mapping

Tree calculator output parameters

Tree keys:	Description
field	*Markov tree calculator field*
bond-price	The full (dirty) price of the bond
bond-price-bullet	The full (dirty) bullet price of the bond (option-adjusted)
bond-ytm	The bond yield to maturity (based on bond clean price)
bond-ytm-bullet	The bond bullet yield to maturity
mode-action	Optimal mode action estimated for the tree
objective	Objective function defined on tree states
discount	Discount function defined on tree states
yield-par	Initial short-rate value estimated so that bond value equals par

Test tree input parameters

T		5.00
dt		0.25
x0		3.066%
states	mapping:	
dx-down		3
dx-up		3
X-min		-10.0%
X-max		20.0%
X-count		30
iter-count		10
process-params	mapping:	
theta		0.575%
sigma		0.759%
alpha		0.000%
gamma		1.073%
mu-function	jkr.datalink.lib.data.math.factory.FactoryFunctionX1$F1Fn	
sigma-function	jkr.datalink.lib.data.math.factory.FactoryFunctionXn$Const	
Qx	null	
params	mapping:	
Q-adjusted		1

TAB: BOND INTEREST AND PRINCIPAL PAYMENTS CASH FLOWS

Bond cash flows inputs

Parameter	Value	Description
first period	0	
bond maturity period	20	
last period	20	Cash flow values are set to 0 after bond maturity
principal	100.0	Bond principal amount
coupon-rate	4.79%	Coupon rate
coupon-frequency	2	Coupon payment frequency
dt	0.25	
interest deferral period	0	
is compounded	1	Indicator of compounded interest
amortization map	java.util.LinkedHas	Bond amortization schedule
bond redemption premiums	java.util.LinkedHas	
bond default redemption premium	0.00%	
java.util.LinkedHashMap@Sun, 24 Jun 2018 13:20:43:7		

Bond cash flows output

period	time	principal outstanding	principal paid	interest accrued	interest paid	**Total amount paid**	**Redemption value**
0	0.00	100.0	0.0	0.00	0.00	**0.00**	**100.00**
1	0.25	100.0	0.0	1.20	0.00	**0.00**	**101.20**
2	0.50	100.0	0.0	2.39	2.39	**2.39**	**102.39**
3	0.75	100.0	0.0	1.20	0.00	**0.00**	**101.20**
4	1.00	100.0	0.0	2.39	2.39	**2.39**	**102.39**
5	1.25	100.0	0.0	1.20	0.00	**0.00**	**101.20**
6	1.50	100.0	0.0	2.39	2.39	**2.39**	**102.39**
7	1.75	100.0	0.0	1.20	0.00	**0.00**	**101.20**
8	2.00	100.0	0.0	2.39	2.39	**2.39**	**102.39**
9	2.25	100.0	0.0	1.20	0.00	**0.00**	**101.20**
10	2.50	100.0	0.0	2.39	2.39	**2.39**	**102.39**
11	2.75	100.0	0.0	1.20	0.00	**0.00**	**101.20**
12	3.00	100.0	0.0	2.39	2.39	**2.39**	**102.39**
13	3.25	100.0	0.0	1.20	0.00	**0.00**	**101.20**
14	3.50	100.0	0.0	2.39	2.39	**2.39**	**102.39**
15	3.75	100.0	0.0	1.20	0.00	**0.00**	**101.20**
16	4.00	100.0	0.0	2.39	2.39	**2.39**	**102.39**
17	4.25	100.0	0.0	1.20	0.00	**0.00**	**101.20**
18	4.50	100.0	0.0	2.39	2.39	**2.39**	**102.39**
19	4.75	100.0	0.0	1.20	0.00	**0.00**	**101.20**
20	5.00	100.0	100.0	2.39	2.39	**102.39**	**102.39**

TAB: OPTION PARAMETERS ESTIMATION

Model	Vasicek	
Sample size	250	Sample size in number of business days
Tenor, T	10	Tenor for ϑ calibration

Short-term (3-months) yield 15.8

Parameter estimates

Date	3-month yield	Δ yield	Δ yield / √ yield	Sample size	Volatility (Vasicek)	Volatility (CIR)
		%	%	days	%	%
26-Mar-18	3.07	0.03%	0.16%	21	0.33%	1.96%
23-Mar-18	3.04	0.02%	0.14%	22	0.32%	1.91%
22-Mar-18	3.01	0.02%	0.12%	23	0.35%	2.07%
21-Mar-18	2.99	0.03%	0.16%	24	0.35%	2.06%
20-Mar-18	2.97	0.01%	0.04%	25	0.36%	2.17%
19-Mar-18	2.96	0.03%	0.16%	26	0.36%	2.13%
16-Mar-18	2.93	0.04%	0.22%	27	0.41%	2.43%
15-Mar-18	2.89	0.01%	0.06%	28	0.40%	2.40%
14-Mar-18	2.88	0.03%	0.17%	29	0.40%	2.35%
13-Mar-18	2.85	0.02%	0.14%	30	0.41%	2.43%
12-Mar-18	2.83	-0.02%	-0.11%	31	0.40%	2.39%
9-Mar-18	2.85	0.01%	0.08%	32	0.40%	2.39%
8-Mar-18	2.83	-0.03%	-0.17%	33	0.40%	2.41%
7-Mar-18	2.86	0.04%	0.25%	34	0.40%	2.38%
6-Mar-18	2.82	-0.02%	-0.10%	35	0.41%	2.49%
5-Mar-18	2.84	0.01%	0.05%	36	0.41%	2.47%
2-Mar-18	2.83	0.03%	0.16%	37	0.41%	2.45%
1-Mar-18	2.80	0.03%	0.16%	38	0.40%	2.42%
28-Feb-18	2.78	0.00%	0.01%	39	0.40%	2.39%
27-Feb-18	2.77	-0.01%	-0.05%	40	0.41%	2.45%
26-Feb-18	2.78	-0.03%	-0.16%	41	0.43%	2.59%
23-Feb-18	2.81	0.01%	0.09%	42	0.46%	2.79%
22-Feb-18	2.79	0.06%	0.34%	43	0.45%	2.76%
21-Feb-18	2.74	-0.01%	-0.04%	44	0.45%	2.73%
20-Feb-18	2.74	-0.03%	-0.17%	45	0.45%	2.72%
16-Feb-18	2.77	0.02%	0.10%	46	0.44%	2.70%
15-Feb-18	2.76	-0.06%	-0.34%	47	0.45%	2.76%
14-Feb-18	2.81	0.00%	-0.03%	48	0.46%	2.83%
13-Feb-18	2.82	0.01%	0.04%	49	0.46%	2.81%
12-Feb-18	2.81	0.05%	0.31%	50	0.45%	2.78%
9-Feb-18	2.76	0.02%	0.10%	51	0.47%	2.86%
8-Feb-18	2.74	0.04%	0.22%	52	0.47%	2.89%

Model	Volatility, σ	Theta, ϑ		Tenor	Theta, ϑ: Hull-White, extended Vasicek	Theta, ϑ: Hull-White, extended CIR
	sample	calibrated	sample		calibrated	
Vasicek	0.76%	0.57%	0.54%	0.25		
Cox-Ingersoll-Ross (CIR)	5.14%		0.54%	0.50		
Hull-White, extended Vasicek				1.00		
Hull-White, extended CIR				2.00		
Other				3.00		
				4.00		
				5.00		
y_T 5.84%				7.00		
σ 0.76%				8.00		
				9.00		
Term structure interpolation:	jkr.datalink.lib.data.math.factory.Fact			10.00		

Yield term-structure

Tenor	In years	Actual Yield	Estimated: Vasicek	CIR	HW, Vasicek	HW, CIR
3m Index	0.25	3.07	3.07			
6m Index	0.5	3.18	3.21			
1Y Index	1	3.39	3.35			
2Y Index	2	3.80	3.64			
3Y Index	3	4.18	3.92			
4Y Index	4	4.49	4.20			
5Y Index	5	4.79	4.48			
7Y Index	7	5.30	5.03			
8Y Index	8	5.50	5.30			
9Y Index	9	5.67	5.57			
10Y Index	10	5.84	5.84			
15Y Index	15	6.58	7.16			
20Y Index	20		8.43			
25Y Index	25		9.65			
30Y Index	30		10.82			

TAB: FUNCTIONS MODELLING

Parameters

Name	Value	Description	Function Object
theta	0.57%	Linear: ϑ - αx	jkr.datalink.lib.data.math.factory.FactoryFunctionX1$Linear@Sun, 24 Jun 2018 13:32:02:061..81434935219320017
sigma	0.76%	Constant: σ	jkr.datalink.lib.data.math.factory.FactoryFunctionXn$Const@Sun, 24 Jun 2018 13:32:02:066..50184156995592803
alpha	0.00%	Power: σ $\|x\|^{0.5}$	jkr.datalink.lib.data.math.factory.FactoryFunctionX1$PowAbs@Sun, 24 Jun 2018 13:32:02:068..128973154713069
gamma	1.07%		

Drift Function

Vasicek	jkr.datalink.lib.data.math.factory.FactoryFunctionX1$F1Fn@Sun, 24 Jun 2018 13:32:02:062..50314008311580713
Cox-Ingersoll-Ross (CIR)	jkr.datalink.lib.data.math.factory.FactoryFunctionX1$F1Fn@Sun, 24 Jun 2018 13:32:02:062..50314008311580713
Hull-White, extended Vasicek	
Hull-White, extended CIR	
Other	

Volatility Function

Vasicek	jkr.datalink.lib.data.math.factory.FactoryFunctionXn$Const@Sun, 24 Jun 2018 13:32:02:066..50184156995592803
Cox-Ingersoll-Ross (CIR)	jkr.datalink.lib.data.math.factory.FactoryFunctionX1$F1Fn@Sun, 24 Jun 2018 13:32:02:068..286402036891836140
Hull-White, extended Vasicek	
Hull-White, extended CIR	
Other	

Discount Function

Vasicek
Cox-Ingersoll-Ross (CIR)
Hull-White, extended Vasicek
Hull-White, extended CIR
Other

Bond value in the presence of the option (full value including accrued interest)

			time period																																						
#			0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
1		1.1%			-102.4	-101.2	-102.4	-101.2	-102.4	-101.2	-102.4	-101.2	-102.4	-101.2	-102.4	-101.2	-102.4	-101.2	-102.4	-101.2	-102.4	-101.2	-102.4																				
2		1.4%			-102.4	-101.2	-102.4	-101.2	-102.4	-101.2	-102.4	-101.2	-102.4	-101.2	-102.4	-101.2	-102.4	-101.2	-102.4	-101.2	-102.4	-101.2	-102.4																				
3		1.7%			-102.4	-101.2	-102.4	-101.2	-102.4	-101.2	-102.4	-101.2	-102.4	-101.2	-102.4	-101.2	-102.4	-101.2	-102.4	-101.2	-102.4	-101.2	-102.4																				
4		2.1%		-101.2	-102.4	-101.2	-102.4	-101.2	-102.4	-101.2	-102.4	-101.2	-102.4	-101.2	-102.4	-101.2	-102.4	-101.2	-102.4	-101.2	-102.4	-101.2	-102.4																				
5		2.4%		-101.2	-102.4	-101.2	-102.4	-101.2	-102.4	-101.2	-102.4	-101.2	-102.4	-101.2	-102.4	-101.2	-102.4	-101.2	-102.4	-101.2	-102.4	-101.2	-102.4																				
6		2.8%		-101.2	-102.4	-101.2	-102.4	-101.2	-102.4	-101.2	-102.4	-101.2	-102.4	-101.2	-102.4	-101.2	-102.4	-101.2	-102.4	-101.2	-102.4	-101.2	-102.4																				
7		3.1%		-101.2	-102.4	-101.2	-102.4	-101.2	-102.4	-101.2	-102.4	-101.2	-102.4	-101.2	-102.4	-101.2	-102.4	-101.2	-102.4	-101.2	-102.4	-101.2	-102.4																				
8		3.4%	-99.052	-100.5	-101.9	-100.8	-102.2	-101.1	-102.4	-101.2	-102.4	-101.2	-102.4	-101.2	-102.4	-101.2	-102.4	-101.2	-102.4	-101.2	-102.4	-101.2	-102.4																				
9		3.8%		-99.5	-101.0	-100.0	-101.5	-100.5	-101.9	-100.8	-102.2	-101.1	-102.4	-101.2	-102.4	-101.2	-102.4	-101.2	-102.4	-101.2	-102.4	-101.2	-102.4																				
10		4.1%		-98.3	-99.9	-99.0	-100.5	-99.6	-101.1	-100.2	-101.6	-100.6	-102.0	-100.9	-102.2	-101.1	-102.4	-101.2	-102.4	-101.2	-102.4	-101.2	-102.4																				
11		4.5%		-97.0	-98.6	-97.9	-99.5	-98.6	-100.2	-99.3	-100.8	-99.9	-101.4	-100.4	-101.8	-100.8	-102.1	-101.0	-102.3	-101.2	-102.4	-101.2	-102.4																				
12		4.8%		-95.7	-97.4	-96.7	-98.3	-97.6	-99.2	-98.4	-100.0	-99.1	-100.7	-99.8	-101.2	-100.3	-101.7	-100.7	-102.1	-101.0	-102.3	-101.2	-102.4																				
13		5.1%		-94.4	-96.1	-95.5	-97.2	-96.5	-98.2	-97.4	-99.1	-98.3	-99.9	-99.1	-100.6	-99.7	-101.3	-100.3	-101.8	-100.8	-102.1	-101.1	-102.4																				
14		5.5%			-94.9	-94.2	-96.0	-95.4	-97.1	-96.5	-98.2	-97.5	-99.1	-98.4	-100.0	-99.2	-100.8	-99.9	-101.4	-100.5	-102.0	-101.0	-102.4																				
15		5.8%			-93.6	-93.0	-94.9	-94.3	-96.1	-95.5	-97.3	-96.6	-98.4	-97.7	-99.4	-98.6	-100.3	-99.5	-101.1	-100.3	-101.8	-100.9	-102.4																				
16		6.2%			-92.4	-91.8	-93.7	-93.2	-95.1	-94.5	-96.4	-95.8	-97.6	-97.0	-98.7	-98.1	-99.8	-99.1	-100.8	-100.0	-101.6	-100.8	-102.4																				
17		6.5%			-91.1	-90.7	-92.6	-92.1	-94.1	-93.6	-95.5	-94.9	-96.8	-96.3	-98.1	-97.5	-99.3	-98.7	-100.4	-99.8	-101.5	-100.7	-102.4																				
18		6.9%			-90.0	-89.5	-91.5	-91.1	-93.1	-92.6	-94.6	-94.1	-96.1	-95.6	-97.5	-97.0	-98.8	-98.3	-100.1	-99.5	-101.3	-100.7	-102.4																				
19		7.2%				-88.4	-90.4	-90.1	-92.1	-91.7	-93.7	-93.3	-95.3	-94.9	-96.9	-96.4	-98.4	-97.9	-99.8	-99.3	-101.1	-100.6	-102.4																				
20		7.5%				-87.3	-89.4	-89.0	-91.1	-90.8	-92.8	-92.5	-94.6	-94.2	-96.2	-95.9	-97.9	-97.5	-99.5	-99.0	-101.0	-100.5	-102.4																				
21		7.9%				-86.3	-88.4	-88.1	-90.2	-89.9	-92.0	-91.7	-93.8	-93.5	-95.6	-95.3	-97.4	-97.1	-99.1	-98.8	-100.8	-100.4	-102.4																				
22		8.2%				-85.3	-87.4	-87.2	-89.3	-89.0	-91.2	-90.9	-93.1	-92.9	-95.0	-94.8	-96.9	-96.7	-98.8	-98.5	-100.6	-100.3	-102.4																				
23		8.6%				-84.4	-86.6	-86.3	-88.4	-88.2	-90.4	-90.2	-92.4	-92.2	-94.4	-94.2	-96.5	-96.3	-98.5	-98.3	-100.5	-100.2	-102.4																				
24		8.9%					-85.7	-85.5	-87.7	-87.4	-89.7	-89.5	-91.7	-91.6	-93.8	-93.7	-96.0	-95.9	-98.2	-98.0	-100.3	-100.1	-102.4																				
25		9.2%					-85.0	-84.8	-87.0	-86.7	-89.0	-88.8	-91.1	-91.0	-93.3	-93.2	-95.5	-95.5	-97.8	-97.8	-100.1	-100.1	-102.4																				
26		9.6%					-84.4	-84.1	-86.3	-86.1	-88.4	-88.2	-90.5	-90.4	-92.8	-92.7	-95.1	-95.1	-97.5	-97.5	-100.0	-100.0	-102.4																				
27		9.9%					-83.9	-83.6	-85.8	-85.6	-87.9	-87.7	-90.0	-90.0	-92.3	-92.3	-94.7	-94.7	-97.2	-97.3	-99.8	-99.9	-102.4																				
28		10.3%					-83.5	-83.2	-85.4	-85.2	-87.5	-87.4	-89.7	-89.6	-92.0	-91.9	-94.4	-94.4	-96.9	-97.1	-99.6	-99.8	-102.4																				
29		10.6%						-83.0	-85.2	-85.0	-87.2	-87.1	-89.4	-89.3	-91.7	-91.7	-94.1	-94.2	-96.7	-96.9	-99.5	-99.7	-102.4																				
30		10.9%						-82.9	-85.1	-84.9	-87.1	-87.0	-89.3	-89.2	-91.6	-91.6	-94.0	-94.1	-96.6	-96.8	-99.4	-99.6	-102.4																				
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Bond value in the presence of the option (full value including accrued interest)

			time period																																							
#			0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
1		1.06%			-113.0	-111.6	-112.5	-110.9	-111.7	-110.1	-110.9	-109.2	-109.8	-108.1	-108.7	-106.8	-107.3	-105.4	-105.9	-103.9	-104.2	-102.1	-102.4																				
2		1.40%			-111.6	-110.2	-111.2	-109.7	-110.6	-109.1	-109.9	-108.3	-109.0	-107.3	-108.0	-106.3	-106.8	-105.0	-105.5	-103.6	-104.0	-102.0	-102.4																				
3		1.74%			-110.2	-108.8	-109.9	-108.5	-109.5	-108.0	-108.9	-107.4	-108.2	-106.6	-107.3	-105.7	-106.3	-104.6	-105.2	-103.3	-103.9	-101.9	-102.4																				
4		2.08%		-107.5	-108.7	-107.4	-108.6	-107.2	-108.3	-106.9	-107.9	-106.4	-107.3	-105.8	-106.7	-105.1	-105.8	-104.1	-104.8	-103.1	-103.7	-101.9	-102.4																				
5		2.42%		-106.0	-107.2	-106.0	-107.2	-106.0	-107.1	-105.8	-106.9	-105.5	-106.5	-105.0	-106.0	-104.5	-105.3	-103.7	-104.5	-102.8	-103.5	-101.8	-102.4																				
6		2.76%		-104.5	-105.8	-104.7	-105.9	-104.8	-106.0	-104.7	-105.9	-104.6	-105.6	-104.3	-105.3	-103.9	-104.8	-103.3	-104.1	-102.6	-103.3	-101.7	-102.4																				
7		3.10%		-102.9	-104.3	-103.3	-104.6	-103.5	-104.8	-103.7	-104.9	-103.7	-104.8	-103.5	-104.6	-103.3	-104.3	-102.9	-103.8	-102.3	-103.2	-101.6	-102.4																				
8		3.44%	-99.999	-101.5	-102.9	-101.9	-103.4	-102.3	-103.7	-102.6	-103.9	-102.7	-104.0	-102.8	-103.9	-102.7	-103.8	-102.4	-103.5	-102.0	-103.0	-101.5	-102.4																				
9		3.79%		-100.0	-101.5	-100.6	-102.1	-101.1	-102.6	-101.5	-102.9	-101.8	-103.2	-102.0	-103.3	-102.1	-103.3	-102.0	-103.1	-101.8	-102.8	-101.4	-102.4																				
10		4.13%		-98.6	-100.2	-99.3	-100.9	-100.0	-101.5	-100.5	-102.0	-101.0	-102.3	-101.3	-102.6	-101.5	-102.8	-101.6	-102.8	-101.5	-102.7	-101.3	-102.4																				
11		4.47%		-97.2	-98.8	-98.0	-99.6	-98.8	-100.4	-99.5	-101.0	-100.1	-101.5	-100.6	-102.0	-100.9	-102.3	-101.2	-102.4	-101.3	-102.5	-101.3	-102.4																				
12		4.81%		-95.8	-97.5	-96.7	-98.4	-97.7	-99.3	-98.5	-100.1	-99.2	-100.7	-99.8	-101.3	-100.3	-101.8	-100.8	-102.1	-101.0	-102.3	-101.2	-102.4																				
13		5.15%		-94.4	-96.2	-95.5	-97.2	-96.5	-98.2	-97.5	-99.1	-98.3	-99.9	-99.1	-100.7	-99.8	-101.3	-100.3	-101.8	-100.8	-102.2	-101.1	-102.4																				
14		5.49%			-94.9	-94.3	-96.0	-95.4	-97.2	-96.5	-98.2	-97.5	-99.1	-98.4	-100.0	-99.2	-100.8	-99.9	-101.4	-100.5	-102.0	-101.0	-102.4																				
15		5.83%			-93.6	-93.0	-94.9	-94.3	-96.1	-95.5	-97.3	-96.6	-98.4	-97.7	-99.4	-98.6	-100.3	-99.5	-101.1	-100.3	-101.8	-100.9	-102.4																				
16		6.17%			-92.4	-91.8	-93.7	-93.2	-95.1	-94.5	-96.4	-95.8	-97.6	-97.0	-98.7	-98.1	-99.8	-99.1	-100.8	-100.0	-101.6	-100.8	-102.4																				
17		6.51%			-91.1	-90.7	-92.6	-92.1	-94.1	-93.6	-95.5	-94.9	-96.8	-96.3	-98.1	-97.5	-99.3	-98.7	-100.4	-99.8	-101.5	-100.7	-102.4																				
18		6.85%			-90.0	-89.5	-91.5	-91.1	-93.1	-92.6	-94.6	-94.1	-96.1	-95.6	-97.5	-97.0	-98.8	-98.3	-100.1	-99.5	-101.3	-100.7	-102.4																				
19		7.19%				-88.4	-90.4	-90.1	-92.1	-91.7	-93.7	-93.3	-95.3	-94.9	-96.9	-96.4	-98.4	-97.9	-99.8	-99.3	-101.1	-100.6	-102.4																				
20		7.53%				-87.3	-89.4	-89.0	-91.1	-90.8	-92.8	-92.5	-94.6	-94.2	-96.2	-95.9	-97.9	-97.5	-99.5	-99.0	-101.0	-100.5	-102.4																				
21		7.87%				-86.3	-88.4	-88.1	-90.2	-89.9	-92.0	-91.7	-93.8	-93.5	-95.6	-95.3	-97.4	-97.1	-99.1	-98.8	-100.8	-100.4	-102.4																				
22		8.21%				-85.3	-87.4	-87.2	-89.3	-89.0	-91.2	-90.9	-93.1	-92.9	-95.0	-94.8	-96.9	-96.7	-98.8	-98.5	-100.6	-100.3	-102.4																				
23		8.55%				-84.4	-86.6	-86.3	-88.4	-88.2	-90.4	-90.2	-92.4	-92.2	-94.4	-94.2	-96.5	-96.3	-98.5	-98.3	-100.5	-100.2	-102.4																				
24		8.89%					-85.7	-85.5	-87.7	-87.4	-89.7	-89.5	-91.7	-91.6	-93.8	-93.7	-96.0	-95.9	-98.2	-98.0	-100.3	-100.1	-102.4																				
25		9.23%					-85.0	-84.8	-87.0	-86.7	-89.0	-88.8	-91.1	-91.0	-93.3	-93.2	-95.5	-95.5	-97.8	-97.8	-100.1	-100.1	-102.4																				
26		9.58%					-84.4	-84.1	-86.3	-86.1	-88.4	-88.2	-90.5	-90.4	-92.8	-92.7	-95.1	-95.1	-97.5	-97.5	-100.0	-100.0	-102.4																				
27		9.92%					-83.9	-83.6	-85.8	-85.6	-87.9	-87.7	-90.0	-90.0	-92.3	-92.3	-94.7	-94.7	-97.2	-97.3	-99.8	-99.9	-102.4																				
28		10.26%					-83.5	-83.2	-85.4	-85.2	-87.5	-87.4	-89.7	-89.6	-92.0	-91.9	-94.4	-94.4	-96.9	-97.1	-99.6	-99.8	-102.4																				
29		10.60%						-83.0	-85.2	-85.0	-87.2	-87.1	-89.4	-89.3	-91.7	-91.7	-94.1	-94.2	-96.7	-96.9	-99.5	-99.7	-102.4																				
30		10.94%						-82.9	-85.1	-84.9	-87.1	-87.0	-89.3	-89.2	-91.6	-91.6	-94.0	-94.1	-96.6	-96.8	-99.4	-99.6	-102.4																				
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Option exercise action function

			time period																																						
#			0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
1		1.1%			1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0																				
2		1.4%			1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0																				
3		1.7%			1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0																				
4		2.1%		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0																				
5		2.4%		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0																				
6		2.8%		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0																				
7		3.1%		0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0																				
8		3.4%	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0																				
9		3.8%		0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	0																				
10		4.1%		0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	0																				
11		4.5%		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0																				
12		4.8%		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0																				
13		5.1%		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0																				
14		5.5%			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0																				
15		5.8%			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0																				
16		6.2%			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0																				
17		6.5%			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0																				
18		6.9%			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0																				
19		7.2%				0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0																				
20		7.5%				0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0																				
21		7.9%				0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0																				
22		8.2%				0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0																				
23		8.6%				0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0																				
24		8.9%					0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0																				
25		9.2%					0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0																				
26		9.6%					0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0																				
27		9.9%					0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0																				
28		10.3%					0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0																				
29		10.6%						0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0																				
30		10.9%						0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0																				
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State distribution

			time period																																						
#			0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
1		1.1%			0.0%	0.0%	0.0%	0.0%	0.1%	0.1%	0.1%	0.1%	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%																				
2		1.4%			0.0%	0.0%	0.0%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%																				
3		1.7%			0.0%	0.1%	0.2%	0.3%	0.3%	0.3%	0.4%	0.4%	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%	0.2%	0.2%	0.2%	0.2%	0.2%																				
4		2.1%		0.0%	0.2%	0.5%	0.7%	0.8%	0.8%	0.8%	0.8%	0.8%	0.7%	0.7%	0.7%	0.6%	0.6%	0.5%	0.5%	0.5%	0.4%	0.4%	0.4%																				
5		2.4%		0.3%	1.3%	1.8%	2.0%	2.0%	1.9%	1.8%	1.6%	1.5%	1.4%	1.3%	1.2%	1.1%	1.0%	0.9%	0.8%	0.7%	0.7%	0.6%	0.6%																				
6		2.8%		3.4%	5.0%	4.9%	4.6%	4.1%	3.7%	3.3%	3.0%	2.7%	2.4%	2.2%	1.9%	1.8%	1.6%	1.4%	1.3%	1.2%	1.1%	1.0%	0.9%																				
7		3.1%		15.9%	12.8%	10.4%	8.7%	7.4%	6.3%	5.5%	4.8%	4.3%	3.8%	3.4%	3.0%	2.7%	2.4%	2.2%	2.0%	1.8%	1.6%	1.5%	1.3%																				
8		3.4%	100.0%	33.3%	21.9%	16.7%	13.4%	11.2%	9.5%	8.2%	7.1%	6.3%	5.5%	4.9%	4.4%	3.9%	3.5%	3.2%	2.8%	2.6%	2.3%	2.1%	1.9%																				
9		3.8%		31.3%	25.2%	20.5%	17.1%	14.5%	12.5%	10.9%	9.5%	8.4%	7.5%	6.6%	5.9%	5.3%	4.8%	4.3%	3.9%	3.5%	3.2%	2.9%	2.6%																				
10		4.1%		13.1%	19.3%	19.2%	17.7%	16.0%	14.3%	12.8%	11.5%	10.3%	9.3%	8.4%	7.5%	6.8%	6.2%	5.6%	5.1%	4.6%	4.2%	3.8%	3.5%																				
11		4.5%		2.5%	9.9%	13.8%	15.1%	15.0%	14.4%	13.5%	12.6%	11.6%	10.7%	9.8%	9.0%	8.2%	7.5%	6.9%	6.3%	5.8%	5.3%	4.8%	4.4%																				
12		4.8%		0.2%	3.4%	7.6%	10.4%	12.0%	12.6%	12.7%	12.4%	11.9%	11.3%	10.6%	10.0%	9.3%	8.6%	8.0%	7.4%	6.8%	6.3%	5.8%	5.4%																				
13		5.1%		0.0%	0.8%	3.2%	5.9%	8.2%	9.7%	10.6%	11.1%	11.2%	11.0%	10.7%	10.3%	9.9%	9.3%	8.8%	8.3%	7.8%	7.3%	6.8%	6.3%																				
14		5.5%			0.1%	1.0%	2.7%	4.7%	6.5%	7.9%	8.9%	9.6%	10.0%	10.1%	10.0%	9.9%	9.6%	9.2%	8.8%	8.4%	8.0%	7.5%	7.1%																				
15		5.8%			0.0%	0.2%	1.0%	2.3%	3.8%	5.3%	6.5%	7.5%	8.3%	8.8%	9.1%	9.2%	9.2%	9.1%	8.9%	8.7%	8.4%	8.0%	7.7%																				
16		6.2%			0.0%	0.0%	0.3%	1.0%	2.0%	3.1%	4.3%	5.4%	6.4%	7.1%	7.7%	8.2%	8.4%	8.6%	8.6%	8.5%	8.4%	8.2%	8.0%																				
17		6.5%			0.0%	0.0%	0.1%	0.3%	0.9%	1.6%	2.6%	3.6%	4.5%	5.4%	6.1%	6.8%	7.3%	7.6%	7.9%	8.0%	8.1%	8.0%	8.0%																				
18		6.9%			0.0%	0.0%	0.0%	0.1%	0.3%	0.8%	1.4%	2.1%	2.9%	3.8%	4.6%	5.3%	5.9%	6.4%	6.9%	7.2%	7.4%	7.6%	7.6%																				
19		7.2%				0.0%	0.0%	0.0%	0.1%	0.3%	0.7%	1.2%	1.8%	2.5%	3.2%	3.9%	4.5%	5.1%	5.7%	6.1%	6.5%	6.8%	7.0%																				
20		7.5%				0.0%	0.0%	0.0%	0.0%	0.1%	0.3%	0.6%	1.0%	1.5%	2.1%	2.7%	3.3%	3.9%	4.5%	5.0%	5.5%	5.9%	6.2%																				
21		7.9%				0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.3%	0.5%	0.8%	1.2%	1.7%	2.2%	2.8%	3.3%	3.9%	4.4%	4.8%	5.3%																				
22		8.2%				0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.2%	0.4%	0.7%	1.0%	1.5%	1.9%	2.4%	2.9%	3.4%	3.8%	4.3%																				
23		8.6%				0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.2%	0.4%	0.6%	0.9%	1.2%	1.6%	2.0%	2.5%	2.9%	3.4%																				
24		8.9%					0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.2%	0.3%	0.5%	0.7%	1.0%	1.4%	1.7%	2.1%	2.5%																				
25		9.2%					0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.2%	0.3%	0.4%	0.6%	0.9%	1.2%	1.5%	1.8%																				
26		9.6%					0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.1%	0.2%	0.4%	0.5%	0.8%	1.0%	1.3%																				
27		9.9%					0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.1%	0.2%	0.3%	0.5%	0.7%	0.9%																				
28		10.3%					0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.1%	0.2%	0.3%	0.4%	0.5%																				
29		10.6%						0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.1%	0.2%	0.3%																				
30		10.9%						0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.1%	0.2%	0.3%	0.5%																				
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TAB: THEORETICAL VALUES

Parameters

Model	Vasicek	Hull-White, extended Vasicek	Hull-White, extended CIR
Credit rating	BB-	BB-	BB-
Maturity term	5.00	5.00	5.00
yield rate at t=0 (y_0)	3.44%	3.44%	3.44%
yield rate equilibrium ($y^* = \beta = \vartheta/\alpha$)		574596.48%	574596.48%
Drift parameter (ϑ)	0.575%	0.575%	0.575%
Mean reversion parameter (α)		0.000	0.000
yield rate volatility (σ)	0.76%	0.76%	0.76%
Index of y_0 in the tree	8		
$a^2\beta - \sigma^2/2 = -\sigma^2/2 \mid_{a=0}$		0.00	
$\gamma = (a^2 + 2\,\sigma^2)^{0.5} = 2^{0.5}\,\sigma \mid_{a=0}$			0.01
$2\alpha\beta / \sigma^2 = 0 \mid_{a=0}$			199.55

Results

Distribution mean	**6.32%**	**6.32%**	**6.32%**
Distribution stdev	**1.70%**	**1.70%**	
Bond bullet value	**99.68**	**99.66**	**99.59**
The yield rate that generates bullet par value			**3.444%**

Cash flows

#	time	Cash flow	Zero-coupon bond bullet value												
	years	$	Vasicek	Hull-White, extended Vasicek						Hull-White, extended CIR					
				α - any		α = 0				α - any		α = 0			
				A	B	A	B	$P=Ae^{-By}$		A	B	A	B	$P=Ae^{-By}$	
0	0.00	0.00	1.00	1.00	0.00	1.00	0.00	1.00		1.00	0.00			1.00	
1	0.25	0.00	0.99	1.00	0.25	1.00	0.25	0.99		1.00	0.25			0.99	
2	0.50	2.39	0.98	1.00	0.50	1.00	0.50	0.98		1.00	0.50			0.98	
3	0.75	0.00	0.97	1.00	0.75	1.00	0.75	0.97		1.00	0.75			0.97	
4	1.00	2.39	0.96	1.00	1.00	1.00	1.00	0.96		1.00	1.00			0.96	
5	1.25	0.00	0.95	0.99	1.25	1.00	1.25	0.95		1.00	1.25			0.95	
6	1.50	2.39	0.94	0.99	1.50	0.99	1.50	0.94		0.99	1.50			0.94	
7	1.75	0.00	0.93	0.99	1.75	0.99	1.75	0.93		0.99	1.75			0.93	
8	2.00	2.39	0.92	0.99	2.00	0.99	2.00	0.92		0.99	2.00			0.92	
9	2.25	0.00	0.91	0.98	2.25	0.99	2.25	0.91		0.99	2.25			0.91	
10	2.50	2.39	0.90	0.98	2.50	0.98	2.50	0.90		0.98	2.50			0.90	
11	2.75	0.00	0.89	0.98	2.75	0.98	2.75	0.89		0.98	2.75			0.89	
12	3.00	2.39	0.88	0.97	3.00	0.97	3.00	0.88		0.97	3.00			0.88	
13	3.25	0.00	0.87	0.97	3.25	0.97	3.25	0.87		0.97	3.25			0.87	
14	3.50	2.39	0.86	0.96	3.50	0.97	3.50	0.85		0.97	3.50			0.86	
15	3.75	0.00	0.84	0.96	3.75	0.96	3.75	0.85		0.96	3.75			0.84	
16	4.00	2.39	0.83	0.96	4.00	0.96	4.00	0.83		0.96	4.00			0.83	
17	4.25	0.00	0.82	0.95	4.25	0.95	4.25	0.82		0.95	4.25			0.82	
18	4.50	2.39	0.81	0.94	4.50	0.94	4.50	0.81		0.94	4.50			0.81	
19	4.75	0.00	0.80	0.94	4.75	0.94	4.75	0.80		0.94	4.75			0.80	
20	5.00	102.39	0.78	0.93	5.00	0.93	5.00	0.78		0.93	5.00			0.78	

TAB: CHARTS

State distribution at maturity

number of periods 21
number of observations 30

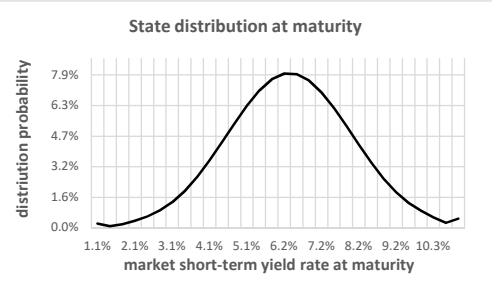
Mean: 6.316%
StDev: 1.690%

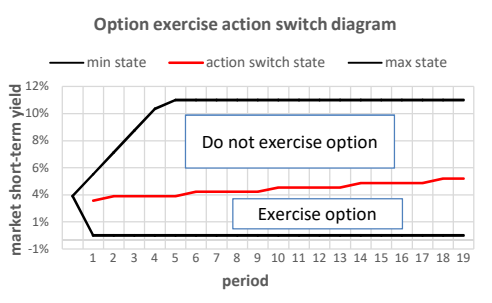
#	state	prob
1	1.1%	0.208%
2	1.4%	0.073%
3	1.7%	0.178%
4	2.1%	0.356%
5	2.4%	0.575%
6	2.8%	0.893%
7	3.1%	1.333%
8	3.4%	1.911%
9	3.8%	2.630%
10	4.1%	3.478%
11	4.5%	4.418%
12	4.8%	5.389%
13	5.1%	6.315%
14	5.5%	7.107%
15	5.8%	7.683%
16	6.2%	7.978%
17	6.5%	7.957%
18	6.9%	7.622%
19	7.2%	7.014%
20	7.5%	6.199%
21	7.9%	5.262%
22	8.2%	4.291%
23	8.6%	3.361%
24	8.9%	2.529%
25	9.2%	1.832%
26	9.6%	1.284%
27	9.9%	0.880%
28	10.3%	0.530%
29	10.6%	0.252%
30	10.9%	0.464%

Option exercise action switch state

period	action switch state	min state	max state
		3.44%	3.44%
1	3.10%	0.38%	5.15%
2	3.44%	0.38%	6.85%
3	3.44%	0.38%	8.55%
4	3.44%	0.38%	10.26%
5	3.44%	0.38%	10.94%
6	3.79%	0.38%	10.94%
7	3.79%	0.38%	10.94%
8	3.79%	0.38%	10.94%
9	3.79%	0.38%	10.94%
10	4.13%	0.38%	10.94%
11	4.13%	0.38%	10.94%
12	4.13%	0.38%	10.94%
13	4.13%	0.38%	10.94%
14	4.47%	0.38%	10.94%
15	4.47%	0.38%	10.94%
16	4.47%	0.38%	10.94%
17	4.47%	0.38%	10.94%
18	4.81%	0.38%	10.94%
19	4.81%	0.38%	10.94%
20		0.38%	10.94%

Charts





TAB: TESTING OUTPUT

Cash Flows Test

last period 20

dt 0.25

Function Test

java.lang.IndexOutOfBoundsException: Inde:

period	time	principal outstanding	principal paid	interest accrued	interest paid	**Total amount paid**	**Redemption value**	t	x	drift	volatility
0	0.00	oundsExcepti	oundsExcepti	oundsExcepti	oundsExcepti	**oundsExcepti**	**BoundsExceptio**	0	0	0.57%	0.76%
1	0.25	oundsExcepti	oundsExcepti	oundsExcepti	oundsExcepti	**oundsExcepti**	**BoundsExceptio**	0	1	0.57%	0.76%
2	0.50	oundsExcepti	oundsExcepti	oundsExcepti	oundsExcepti	**oundsExcepti**	**BoundsException: Index: 10, Size: 10**				
3	0.75	oundsExcepti	oundsExcepti	oundsExcepti	oundsExcepti	**oundsExcepti**	**BoundsExceptio**	java.util.ArrayList@Sun, 24 Jun 2018			
4	1.00	oundsExcepti	oundsExcepti	oundsExcepti	oundsExcepti	**oundsExcepti**	**BoundsExceptio**	java.util.ArrayList@Sun, 2		2	
5	1.25	oundsExcepti	oundsExcepti	oundsExcepti	oundsExcepti	**oundsExcepti**	**BoundsExceptio**	java.util.ArrayList@Sun, 2		2	
6	1.50	oundsExcepti	oundsExcepti	oundsExcepti	oundsExcepti	**oundsExcepti**	**BoundsException: Index: 10, Size: 10**				
7	1.75	oundsExcepti	oundsExcepti	oundsExcepti	oundsExcepti	**oundsExcepti**	**BoundsException: Index: 10, Size: 10**				
8	2.00	oundsExcepti	oundsExcepti	oundsExcepti	oundsExcepti	**oundsExcepti**	**BoundsException: Index: 10, Size: 10**				
9	2.25	oundsExcepti	oundsExcepti	oundsExcepti	oundsExcepti	**oundsExcepti**	**BoundsException: Index: 10, Size: 10**				
10	2.50	oundsExcepti	oundsExcepti	oundsExcepti	oundsExcepti	**oundsExcepti**	**BoundsException: Index: 10, Size: 10**				
11	2.75	oundsExcepti	oundsExcepti	oundsExcepti	oundsExcepti	**oundsExcepti**	**BoundsException: Index: 10, Size: 10**				
12	3.00	oundsExcepti	oundsExcepti	oundsExcepti	oundsExcepti	**oundsExcepti**	**BoundsException: Index: 10, Size: 10**				
13	3.25	oundsExcepti	oundsExcepti	oundsExcepti	oundsExcepti	**oundsExcepti**	**BoundsException: Index: 10, Size: 10**				
14	3.50	oundsExcepti	oundsExcepti	oundsExcepti	oundsExcepti	**oundsExcepti**	**BoundsException: Index: 10, Size: 10**				
15	3.75	oundsExcepti	oundsExcepti	oundsExcepti	oundsExcepti	**oundsExcepti**	**BoundsException: Index: 10, Size: 10**				
16	4.00	oundsExcepti	oundsExcepti	oundsExcepti	oundsExcepti	**oundsExcepti**	**BoundsException: Index: 10, Size: 10**				
17	4.25	oundsExcepti	oundsExcepti	oundsExcepti	oundsExcepti	**oundsExcepti**	**BoundsException: Index: 10, Size: 10**				
18	4.50	oundsExcepti	oundsExcepti	oundsExcepti	oundsExcepti	**oundsExcepti**	**BoundsException: Index: 10, Size: 10**				
19	4.75	oundsExcepti	oundsExcepti	oundsExcepti	oundsExcepti	**oundsExcepti**	**BoundsException: Index: 10, Size: 10**				
20	5.00	oundsExcepti	oundsExcepti	oundsExcepti	oundsExcepti	**oundsExcepti**	**BoundsException: Index: 10, Size: 10**				

TAB: CONFIGURATION FILE **Calculation enabled** **TRUE** Test connecti host: home-pc; user: Konstantin Rybakov; key: null

Implemented models and default parameters

Model	dx-down	dx-up
Vasicek	3.00	3.00
Cox-Ingersoll-Ross (CIR)	2.00	2.00
Hull-White, extended Vasicek	3.00	3.00
Hull-White, extended CIR	2.00	2.00
Other	3.00	3.00

T (Covered Transaction)	5.00
dt	0.25
n_T	21
X-count	30

Output keys

Key	Description
principal	Bond principal amount
dt	Tree time increment value (in years)
tenor-remaining	Sample bond remaning tenor
coupon-rate	Sample bond coupon rate
coupon-frequency	Sample bond coupon frequency
make-whole-duration	Sample bond remaining duration of make-whole provision
redemption-premium-post-make-whole	Sample bond redemption premium after make-whole provision termination
redemption-premium-schedule	Customized redemption premium schedule
amortization-rate-annual	Annual rate of principal amortization
amortization schedule	Customized principal amortization schedule
interest-deferral-period-last	Last interest deferral period
is-interest-compounded	Indicator of whether edefrred interest is compounded or not
sample-prices	Sample bullet and actual prices estimated by calculator

Output array sizes

Array formula cell address	number of rows	number of cols	Description
'value'!$E$6	30	21	Bond value in the presence of the option
'value'!$D$6	30	1	Bond collection of states
'bullet'!$E$6	30	21	Bond bullet value
'action'!$E$6	30	21	Option exercise action value
'D'!$E$6	30	21	Tree state distribution
'cf'!$I$9	21	6	Bond cash flows
'sample'!$Q$13	10	2	Sample bond prices
'charts'!$C$12	30	2	Terminal state distribution
'charts'!$F$12	21	2	State at which action switches from non-exercise to exercise
'charts'!$H$12	21	2	Tree bounds
'test'!$D$8	21	6	Sample bond cash flows

Graph configuration

Parameter	Value	Description
Line	yes	Set to yes/no to set line visible or non-visible
Line size	1.5	Set line size
Marker	no	Set to yes/no to set markers visible or non-visible
Marker size	4	Set markers size

Package: SRM

Interest rate process modelling

The objective of the model is to analyze fixed income securities, specifically bonds. The template allows to set generic parameters for the interest rate tree but generally assumes specific inputs for the calculated bond prices and related interest rate options.

Modelling bond prices

The bond prices are modelled as follows:

1. **The bond terminal value**. The terminal value is generally assumed to be equal to the sum of the outstanding principal value and the accrued interest. The outstanding principal value depends on the (i) time period; (ii) applied amortization schedule; (iii) and exercised options. The accrued interest depends on the (i) time period; (ii) interest payment schedule; and (iii) outstanding balances used as a base for interest calculations.

2. **The bond coupon payments**. The bond coupon payments depend on time period and interest payment terms. Fixed interest payments are assumed (will be extended to variable interest rate).

3. **Redemption price**. The redemption price models the penalty that is applied in the case of bond option exercise. Generally, both call (early prepayment) and put (pay-on-demand) options nvolve a penalty that determines the bond redemption price.

4. **Amortization schedule**. The schedule determines the timing of bond principal repayments. Based on the amortization schedule, the outstanding principal balances are calculated.

Notes:

A. **Steady state**. The mean reversion process is assumed to converge to current yield rate: $\vartheta = \alpha \times y_0$;
B. **Par value**. If the bond at t=0 is priced at par, the initial value y0 must be calibrated to generate par value (y_0 = coupon will not produce par value because the underlying yield rate process is modelled for zero-coupon bonds and has an increasing / decreasing term structure);

Package: SRM

Note: to resize the output arrays, press Ctrl+R

Markov tree objects and output

IMarkovTreeR1 tree = Markov.tree(int T, double x_0, Map states, Object Q);

Construct Markov tree object using the following paarmeters:
T - number of periods
x_0 - initial state,
states - Map: *X-min* - minimum state value, *X-max* - maximum state value; *X-count* - number of states; and *X-type* which is set either to *uniform* or *log-uniform* to describe how the states are generated within the range;
Q - object that describes transition probabilities (typically in the form of a function: (t, x) => {xi => pi} that mapps given period and state (t, x) into a mapping {xi => pi} between next period states and probabilities;

Object[][] out = Markov.get(IMarkovTreeR1 tree, String key, Map<String, Object> params);

Return the value of a given field (referred to bya given key) of the Markov tree using the given set of parameters (if necessary). Keys include:
state-values - an array[][] that describes tree structure (contains a state value in a given cell if the cell belong to the tree or zero otherwise);
Q - returns an array of transition probabilities $Q(x_t, x_{t+1})$ for a given period t;
P - return an array of tree state probabilites