Written Exam Economics summer 2021

Fixed Income Derivatives

Date 21st of August-23rd of august

This exam question consists of 9 pages in total

Answers only in English.

A take-home exam paper cannot exceed 10 pages – and one page is defined as 2400 keystrokes

The paper must be uploaded as one PDF document. The PDF document must be named with exam number only (e.g. '1234.pdf') and uploaded to Digital Exam.

Be careful not to cheat at exams!

Exam cheating is for example if you:

- Copy other people's texts without making use of quotation marks and source referencing, so that it may appear to be your own text
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- Receive help from others in contrary to the rules laid down in part 4.12 of the Faculty of Social Science's common part of the curriculum on cooperation/sparring

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Excel settings

Please make sure to download and activate the latest fidAnalytics library from Absalon. It is the one with no number attached to it: fidAnalytics.xla. For windows users, we have also uploaded a .bas file if you prefer to import fidAnalytics as a module.

To ensure that we get the same results on numerical optimization problems, please set your Excel Solver for the following settings:

- Constraint precision: 0.000001
- Automatic scaling: Yes
- Integer optimality: 5%
- Max time: 300
- Iterations: 300
- Convergence: 0.000001
- Deselect *"Make Unconstrained Variables Non-negative"* in the main solver-window, as we will be working with negative interest rates.

As written in the beginning of this document, you need to upload a single PDF document. This is the document from which your grade will be determined – and only this. You are also welcome to upload your Excel calculations. We might take a look at these if we suspect you are on the right track but have the wrong answer. In that sense, uploading the Excel calculations only has a positive upside for you. The easier they are to understand the better.

Question 1: Interest rate swap basics and intuition (25%)

In this question we assume a single –curve setup.

1.1. On Monday, you enter into a 14Y payer swap. This is the only trade you did during the day. On Tuesday, the 14Y swap rate drops 5 basis points in response to a central bank meeting. Before this, rates were unchanged compared to when you did the swap. The forward curve is upward sloping. Did you make or lose money on your Monday trade after the central bank meeting?

Answer:

You lost money on this trade since you are paying fixed. Recall that

*PV_Payer = Annuity * (SwapRate – K),*

where SwapRate is the current swap rate and K is the swap rate of your trade

1.2. Would you change your answer had the forward curve been downward sloping? If so, please explain why.

Answer:

No. You would lose money regardless of the shape of the forward curve.

1.3. Your Monday swap had a notional 52.000.000 DKK. For the following question, you may ignore discounting, day count conventions and day rules. Please approximate your profit/loss of the 5 basis point drop in the 14Y swap rate on Tuesday.

Answer:

Since we are ignoring discounting, day counts, day rules and are asked to approximate, we may assume that the annuity of the 14Y swap is equal to 14. The basis point value of the swap can under these assumptions be approximated as

*Bpv = Trade Duration in years * Notional * 0.0001 = 72.800 DKK*

Since you are positioned for higher rates, your profit/loss is (approximately)

5-72.800 DKK = -364.000*

Deviations from this number in the range of +/- 2.000 is OK.

1.4. A client of yours with little knowledge of interest rate derivatives asks you, if it is possible to enter into a 10Y payer swap with optionality to cancel the swap in 3 years if the interest rate market has moved against her. With your knowledge of non-linear interest rate derivatives, what structure would you (conceptually) offer her? Please provide a short explanation of your rationale on directions, expiries and maturities.

Hint: you need to enter into a swaption combined with a swap. Think about who has the optionality here in order to determine the direction.

The client can enter into a cancellable swap. You can structure this by letting the client enter into a 10Y payer swap and sell her a 3Y7Y receiver swaption with strike equal to the current swap rate. If rates increase before expiry, the receiver swaption will expire worthless but she will have gained on the swap. If rates fall, the receiver swaption becomes valuable, as she will receive a higher swap rate than the prevailing fair swap rate, thus counteracting the loss he will incur on the 10Y swap. If exercised, the 10Y payer swap and the exercised swaptions cashflows will cancel out.

1.5. Will the client be paying a higher or lower fixed rate in the structure of question 1.4, compared to the fixed rate she will be paying in comparable plain vanilla 10Y swap?

Hint: who sells optionality and who is buying?

Answer:

The client will be paying a higher fixed rate in the cancellable swap compared to the plain vanilla swap because of the optionality she has in the cancellable swap.

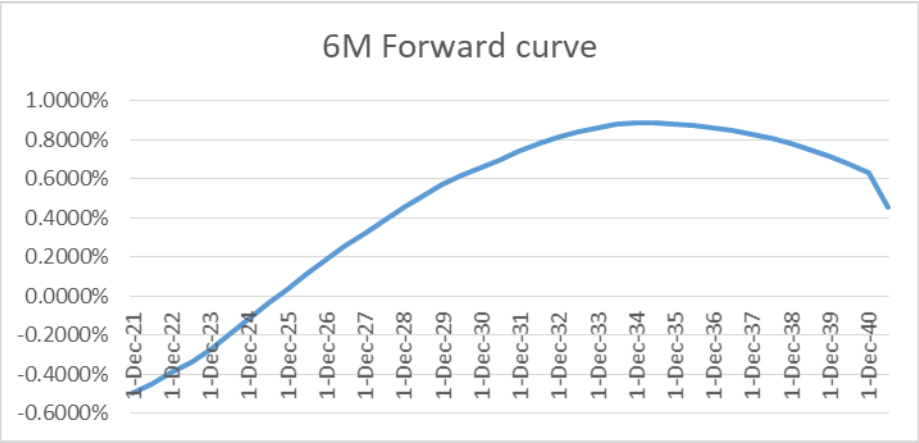
This question can be answered without answering question 1.4 correctly since it would introduce a clear arbitrage in the market if the premium of any form of added optionality to a product were zero or negative.

Full points is given if student argues that swaption should/could be paid upfront but that this effectively means paying a higher rate. In practice you would probably bake the swap rate into the fixed rate. To do this, you would need to solve for the fixed that makes the whole structure have a PV equal to the premium. Note 10Y payer should have same fixed rate as swaption, so you will need to solve for the value simultaneously in the plain vanilla and receiver swaption. It is OK if students does not mention this.

1.6. Using the zero-coupon curve given in the exam data for this question, please calculate the implied 6-month forward curve using Hermite-interpolation from two business days forward and 20 years into the future. To do this, please create a schedule of adjusted dates using the floating IRS conventions (6M with ACT/360 day count and the modified following convention). Please include the actual numbers with four decimals along with dates in your answer. Also, please add a plot of the curve.

Answer:

There were some confusing about the anchor date of this question. Full points have been given if the schedule has been rolled correctly and forward rates calculated correctly given assumed anchor!



Answer for question 1.6

Start	End	Forward rate
27-Dec-21	27-Jun-22	-0.4989%
27-Jun-22	27-Dec-22	-0.4545%
27-Dec-22	27-Jun-23	-0.3922%
27-Jun-23	27-Dec-23	-0.3376%
27-Dec-23	27-Jun-24	-0.2719%
27-Jun-24	27-Dec-24	-0.1972%
27-Dec-24	27-Jun-25	-0.1206%
27-Jun-25	29-Dec-25	-0.0412%
29-Dec-25	29-Jun-26	0.0362%
29-Jun-26	28-Dec-26	0.1094%
28-Dec-26	28-Jun-27	0.1851%
28-Jun-27	27-Dec-27	0.2560%
27-Dec-27	27-Jun-28	0.3204%
27-Jun-28	27-Dec-28	0.3854%
27-Dec-28	27-Jun-29	0.4532%
27-Jun-29	27-Dec-29	0.5156%
27-Dec-29	27-Jun-30	0.5717%
27-Jun-30	27-Dec-30	0.6201%
27-Dec-30	27-Jun-31	0.6598%
27-Jun-31	29-Dec-31	0.7001%
29-Dec-31	28-Jun-32	0.7437%
28-Jun-32	27-Dec-32	0.7822%
27-Dec-32	27-Jun-33	0.8154%
27-Jun-33	27-Dec-33	0.8431%
27-Dec-33	27-Jun-34	0.8646%
27-Jun-34	27-Dec-34	0.8797%
27-Dec-34	27-Jun-35	0.8877%
27-Jun-35	27-Dec-35	0.8884%
27-Dec-35	27-Jun-36	0.8813%
27-Jun-36	29-Dec-36	0.8718%
29-Dec-36	29-Jun-37	0.8625%
29-Jun-37	28-Dec-37	0.8489%
28-Dec-37	28-Jun-38	0.8312%
28-Jun-38	27-Dec-38	0.8091%
27-Dec-38	27-Jun-39	0.7829%
27-Jun-39	27-Dec-39	0.7522%
27-Dec-39	27-Jun-40	0.7173%
27-Jun-40	27-Dec-40	0.6780%
27-Dec-40	27-Jun-41	0.6328%
27-Jun-41	27-Dec-41	0.4572%

1.7. Below, you are given a risk calculation in terms of market instruments based on the curve given in the exam data. This is risk on a 100m 2Y3Y receiver swap with standard conventions.

Risk in instrument terms			
			EUR pr. bp
FIXING (DEPOSIT)	2B	6M	51
FRA	6M	6M	54
IRS	2B	2Y	20,123
IRS	2B	3Y	-121
IRS	2B	4Y	-240
IRS	2B	5Y	-50,392
IRS	2B	7Y	46
IRS	2B	10Y	-0
IRS	2B	15Y	-0
IRS	2B	20Y	-0
Total (outright) risk			-30,479

To neutralize the bucket risk of the 2Y and 5Y point, and assuming you can only trade spot starting swaps, what would you trade? Please provide direction, notional and maturity of your hedges.

Answer:

A two year receiver swap with notional 100m EUR.
A five year payer swap with notional 100m EUR.

If the students rationalize the notional size through an approximate basis point calculation such as

*Risk pr. basis points = Notional * Annuity / 10.000 ~ Notional * T / 10.000*
*<=> Notional = Risk pr. basis points / Annuity * 10.000*

Instead of "remembering" that the notional would have to be equal to the original trade, this would be good, although this not required.

1.8: As discussed throughout the lectures, it is convenient to view swap-risk in terms of what you need to trade. So far, we have only considered the problem of translating the zero-coupon risk into risk against the market instruments used as input for the curve calibration. However, there is nothing that prevents us from translating the zero-coupon risk into a whole set of different instruments. We refer to risk in terms of certain instruments as a "risk view".

Below we see a risk calculation on the 2Y3Y swap from question 1.7 but translated into *forward rate risk*. That is, the zero-coupon risk projected onto a strip of *forward rate agreements*. This risk view tells you how much the present value of your 2Y3Y swap changes with each forward rate in the risk output. For instance, we see that if the forward rate from 25-DEC-2023 on EURIBOR 6M increases 1 basis point, the swaps present value changes EUR -5.216.

Risk in terms of 6M EURIUBOR forward rates			
	Start date	End date	EUR pr. bp
FORWARD RATE	25-Jun-21	27-Dec-21	13
FORWARD RATE	27-Dec-21	27-Jun-22	13
FORWARD RATE	27-Jun-22	26-Dec-22	14
FORWARD RATE	26-Dec-22	26-Jun-23	-45
FORWARD RATE	26-Jun-23	25-Dec-23	-5,131
FORWARD RATE	25-Dec-23	25-Jun-24	-5,126
FORWARD RATE	25-Jun-24	25-Dec-24	-5,132
FORWARD RATE	25-Dec-24	25-Jun-25	-5,104
FORWARD RATE	25-Jun-25	25-Dec-25	-5,173
FORWARD RATE	25-Dec-25	25-Jun-26	-5,021
FORWARD RATE	25-Jun-26	25-Dec-26	0
FORWARD RATE	25-Dec-26	25-Jun-27	0
FORWARD RATE	25-Jun-27	27-Dec-27	0
FORWARD RATE	27-Dec-27	26-Jun-28	0
FORWARD RATE	26-Jun-28	25-Dec-28	0
FORWARD RATE	25-Dec-28	25-Jun-29	0
FORWARD RATE	25-Jun-29	25-Dec-29	0
FORWARD RATE	25-Dec-29	25-Jun-30	0
FORWARD RATE	25-Jun-30	25-Dec-30	0
FORWARD RATE	25-Dec-30	25-Jun-31	0
Total (outright) risk			-30,691

Please put some intuition on the following points:

- The size of the forward bucket risk from 26-june-2023 until the 25-dec-2025.
- Why are these buckets roughly equal in size? Why negative?
- Why is the risk roughly flat in terms of the four first forward rates?

Hint: how is the swap a function of forward rates?

Answer:

The students have not themselves tried to project the zero-coupon risk on a set of instruments that are not input to the calibration. However, this question is designed to test their general understand of swap risk and should be considered difficult. There are many acceptable answers, but the ideal one should contain the following reflections, although not all of them are required:

- *The size of the bucket risk is roughly -5.000 EUR. A 2Y forward starting swap running for three years is equivalent to a position in a 2Y and 5Y swap as seen from the risk view in question 1.8. As only the 5Y swap hedge is sensitive to forward rates beyond 23-june-2023, this number is only related to the 5Y trade. Since the floating leg annually pays roughly*

  *Fwd(t,T,T+1) * Notional * 0.5*

  (up to day roll, discounting etc.), we see that the derivative of this payment with respect to the forward rate equals notional times a half. Translated into basis points this would give

  *Risk = 0.5 * 100.000.000 * 0.0001 = 5000*

  Students can deduce this (tenor ~ 0.5), since they are told we are looking at standard conventions (6M EURIBOR).

  Since the 2Y3Y is a receiver swap, an increase in the forward rates beyond 3Y would mean that we would be paying a higher rate. Therefore the risk is negative and equal to roughly -5.000 EUR up to day count conventions etc.

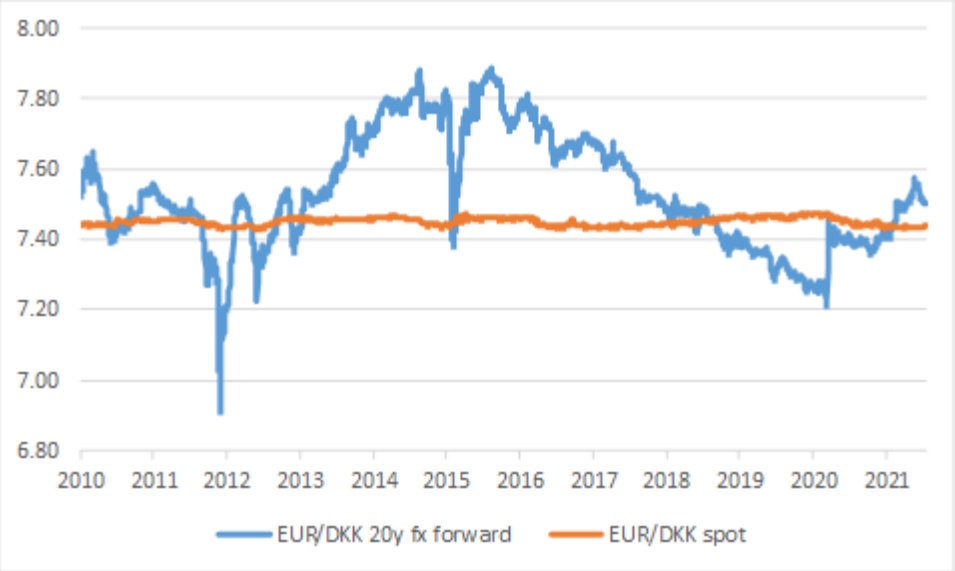
- *Since the notional of the swap is fixed, each floating rate payment has the same sensitivity to the forward rates (up to some discounting and day counts etc.). Therefore, the buckets are roughly equal in size.*
- *On the short-end segment of the curve, the 2Y3Y swap is equivalent to a short position in the 2Y swap (for rates up) and a long position in the 5Y swap (for rates down) with the same notional. Since the notionals are equal, the 2Y and 5Y has the same nominal sensitivity to the forward curve given the arguments in the first bullet but with opposing directions. Hence, the cashflows cancels out. A simpler argument would be to say, that since the 2Y3Y swap is forward starting, there are no payments the first two years, and for this reason it has no sensitivity to the first four forward rates.*

A correct variation of the points mentioned above is considered acceptable. The student needs to show an understanding that the risk view presented here is risk directed specifically at the forward rates of the swap.

Full points have only been given is all three points have been mentioned. This includes the size 5.000 of the bucket risk. Again, variations of the point discussed above is acceptable. For instance, and argument that there are six forward rates and that 1/6 of the outright risk of ~-30.000 is contained in each bucket.

Question 2: FX forwards and a fixed rate regime (25%)

In this exercise you are going to act as a market maker on the FX swaps desk responding to a client's wish to take advantage of a very stable EUR/DKK spot exchange rate. The Danish central bank is mandated only to maintain the EUR/DKK within a band of +/- 2.25% from the central parity of 7.46038 within the framework of the ERMII vis-à-vis the European central bank (ECB). In practice, however, the bank maintains a much tighter grip on the currency as shown in the chart below. As also shown, FX forward levels can diverge quite a bit from the spot rate. This is sometimes interesting to exploit for especially the life and pension sector.



Before beginning calculations, we will work a bit on intuition on some topics, which, as a market maker, is good to know in order to prepare for potential client interests.

2.1. Danish households hold very large pension savings and Denmark as a country is a large creditor nation (net foreign assets) of which most are invested through pension funds. Are Danish pension funds structural buyers or sellers of EUR/DKK and USD/DKK in FX forward markets?

Answer:

They are structural sellers (buyers of DKK) as they need to hedge future DKK payments to clients.

2.2. Given your knowledge on how to hedge a FX forward, will the above structural position give rise to a downward or an upward pressure on DKK interest rate all else equal?

Hint: First note that the market maker's position will be opposite to that of the pension funds. Next, consider what discounting risk the market maker obtains in DKK when doing the FX forward with the pension funds, and in what direction we would need to trade swaps in order to mitigate that.

Answer:

Selling of EUR/DKK and USD/DKK forward from pension funds leaves the market marker long and thereby negatively affected if DKK interest rates fall. In order to hedge, market makers will receive DKK rates. Alternatively, in order to replicate a short EUR/DKK or short USD/DKK forward this requires to be receiving DKK rates.

2.3. If DKK interest rates are higher than is the case in EUR, what does that imply for the forward rate X(t,T)? Is it higher or lower than the spot rate S(t)?

Answer:

Higher.

2.4. If DKK interest rates are higher than is the case in EUR, is there a positive or negative carry associated by being short EUR/DKK forward?

Answer:

We can write carry in a short EUR/DKK as $\frac{X(t,T)-S(t)}{S(t)}\left(\frac{1}{\tau(t,T)}\right) \approx ln\left(\frac{X(t,T)}{S(t)}\right)\left(\frac{1}{\tau(t,T)}\right) = r_{DKK} - r_{€}$ *. This quantity is positive if DKK rates are larger than in EUR.*

2.5. Given the answers to the above questions do you think it is possible to maintain a general high interest rate level in Denmark relatively to EUR?

Hint: Think of the carry associated with selling EUR/DKK forward in this case.

Answer:

It will be difficult since high DKK interest rates will result in positive carry in short EUR/DKK positions and thereby induce more sellers of EUR/DKK – ie. implicitly receiving DKK rates.

2.6. If a client of yours sells EUR/DKK forward what spot risk would that leave you (the market maker) with? Long or short EUR/DKK?

Answer:

The market maker would be long EUR/DKK forward and thus long EUR/DKK spot as well.

2.7. Assume you try to hedge your trade with the pension funds in interbank markets. However, here only FX swaps trade. You can create a FX forward using two transactions/trades. Which are they and what direction would you trade?

Answer:

I would trade a FX swap plus a spot both in EUR/DKK. I would buy-sell EUR/DKK FX swap and sell EUR/DKK spot.

2.8. Given the relative stability of EUR/DKK do you think pension funds hedge a relatively large or small share of the FX risk as compared to USD/DKK? The latter is more volatile.

Answer:

A small share.

2.9. All else equal should the pension fund buy or sell more or less USD/DKK forward in order to maintain a fixed hedge ratio if US equity markets rally (perform)?

Hint: What happens to the USD notional it needs to hedge?

Answer:

They would need to sell more USD/DKK forward as the PV of their USD assets have increased.

2.10. Assume that US equity markets perform strongly. What does that imply for the USD/DKK spot rate all else equal? Will there be a downward or upward pressure?

Hint: First think about what the pension funds would do as in 2.9. Next think about what spot risk the market maker obtains on his books reacting to the pension funds' demand and how he could get rid of that. No specific trades required.

Answer:

This will leave the market maker longer USD/DKK. Thus, he would need to hedge his risks by selling more USD/DKK spot.

The above questions should have put you in the "mood" in order to solve the rest of the exercise where we will focus a bit more on numbers.

2.11. Use the data in the 'data' sheet in order to calibrate the forward and discounting curves in EUR and DKK. Use the knot points matching the maturity dates of the input trades. Report your results in percent with two decimal places (eg. 1.21%).

	EUR		DKK	
Maturity	Forward	Discount	Forward	Discount
16-03-2022	-0.45%	-0.68%	-0.42%	-0.91%
17-03-2025	-0.35%	-0.58%	-0.31%	-0.75%
16-03-2027	-0.27%	-0.49%	-0.23%	-0.64%
18-03-2030	-0.16%	-0.38%	-0.14%	-0.53%
16-03-2035	0.00%	-0.20%	-0.01%	-0.36%
16-03-2040	0.04%	-0.11%	0.00%	-0.29%

2.12. Given the EUR/DKK spot rate and calibrated discount rates compute the 20y EUR/DKK FX forward rate and report with four decimal places.

Given the implied level and comparing to the stability of the EUR/DKK spot, what direction do you think the client will trade? Buy or sell EUR/DKK?

Even if you get this question wrong full points will still be given for the remaining questions, as long as you answer correctly based on the direction chosen here.

Hint: Think of the carry associated by being long or short EUR/DKK forward at the calculated level.

Answer:

7.2079.

He will buy in order to take advantage of a low implied level of the EUR/DKK.

2.13. Why are FX forwards/swaps only liquidly traded/quoted with below 2y maturities?

Answer:

FX forwards are primarily traded in order to hedge FX risk. Longer maturities has significant interest rate risk which can disturb your hedge.

2.14. The EUR/DKK spot rate is only 6 pips below the historical maximum seen over the period from 2010 (ie. the EUR is currently historically strong versus the DKK). Do you think this changes anything for the client's wish to trade the direction mentioned in 2.12?

Hint: What spot risk does the client take on by trading the direction in 2.12?

Answer:

Since the client is asking for a long EUR/DKK forward he will also become long spot. As we are in the high end of the range the client might think twice about being long EUR/DKK spot.

Assume now that the client trades a notional of DKK 100m in a EUR/DKK FX forward with a direction as indicated in question 2.12.

2.15. Calculate the PV from the client's perspective 12m ahead under the assumption that the spot rate in 12m has dropped to 7.4360 and that discount curves are unchanged (note now that the trade has a remaining maturity of 19 years). Report the result in EUR.

Answer:

The PV will be EUR -36,244.

2.16. Calculate model and market rate delta vectors of the FX forward from your perspective (the market maker's) with respect to your calibration instruments: cross currency swaps and interest rate swaps. Report your vectors in EUR.

	EUR		DKK	
Knot points	Forward	Discount	Forward	Discount
16-03-2022	0	0	0	0
17-03-2025	0	0	0	0
16-03-2027	0	0	0	0
18-03-2030	0	0	0	0
16-03-2035	0	0	0	0
16-03-2040	0	28,424	0	-28,367

Start	Maturity	Currency	Instrumer	FX forward ri
2b	2y	EUR	IRS	20
2b	5y	EUR	IRS	20
2b	7y	EUR	IRS	23
2b	10y	EUR	IRS	64
2b	15y	EUR	IRS	142
2b	20y	EUR	IRS	28,648
2b	2y	EUR	CCS	20
2b	5y	EUR	CCS	21
2b	7y	EUR	CCS	23
2b	10y	EUR	CCS	65
2b	15y	EUR	CCS	144
2b	20y	EUR	CCS	29,055
2b	2y	DKK	IRS	-34
2b	5y	DKK	IRS	-53
2b	7y	DKK	IRS	-59
2b	10y	DKK	IRS	-168
2b	15y	DKK	IRS	-370
2b	20y	DKK	IRS	-28,167
2b	2y	DKK	CCS	-34
2b	5y	DKK	CCS	-54
2b	7y	DKK	CCS	-60
2b	10y	DKK	CCS	-170
2b	15y	DKK	CCS	-375
2b	20y	DKK	CCS	-28,547

2.17. What instruments and in what directions would you trade in order to hedge the FX forward position taken on? No exact notionals required.

Answer:

As I am short EUR/DKK forward I will in order to hedge this: Receive EUR/USD CCS, receive EUR irs, pay USD/DKK CCS and pay DKK irs. In order to remove the spot transactions I will also buy EUR/DKK spot.

Since I am short EUR/DKK forward I will be negatively exposed towards an increase in EUR/DKK spot, higher DKK discounting rates and lower EUR discounting rates.

Through my hedge I will on a forward basis be receiving EUR and paying out USD thus hedging FX risk. By adding interest rate swaps I will be hedging interest rate risk as well. More specifically I will in fact be hedging discounting risk since if for example the USD/DKK CCS spread increases (less negative) all else equal this will manifest itself in a higher DKK discounting curve. However, since I am a payer of USD/DKK CCS I would have hedged that risk.

2.18. USD/DKK CCS can be somewhat illiquid. Assume that you are not able to trade cross-currency swaps at all (also not EUR/USD). Is there a way for you to approximately hedge the long-dated FX forward anyways? What instruments and what directions? When does this hedge not work?

Hint: The hedge involves trading a EUR/DKK FX forward.

Answer:

Since I am short EUR/DKK forward I would still be paying DKK irs and receiving EUR irs. Then I would add a sell/buy EUR/DKK fx swap and buy EUR/DKK spot as well in order to create a FX forward where I am long. The FX swap would need to be rolled on an ongoing basis.

I am not hedging the risk of an increase in the USD/DKK CCS basis (higher DKK discounting curve) all else equal as well as a decrease in EUR/USD CCS (lower EUR discounting curve) all else equal.

Question 3: Pricing a capped floating rate bond (25%)

In Denmark capped floating rate bonds (from now on 'CF') trade quite frequently. CFs are constructed such that the buyer of the CF is entitled to periodic cash-flows consisting of a money market fixing L plus a fixed spread A^{CF}. The fixing is fixed-in-advance and paid-in-arrears as standard. However, the buyer has also sold a cap with a preset strike level, K, such that the total cash-flow received at each payment date is:

$$Payment(t_i) = Max[L(t_{i-1}, t_i) + A^{CF}; K] \cdot \delta_{t_i}$$

where δ_{t_i} is the day count fraction.

In this exercise we are going to work with a 6M CIBOR CF with maturity 1/7/2026 (1 July 2026) and $K = 0.5\%$.

We assume that there are no redemptions/repayments and hence at maturity of the CF we will receive back the entire notional of the bond (100).

Note that:

$$Payment(t_i) = Max[L(t_{i-1}, t_i) + A^{CF}; K] \cdot \delta_{t_i} = \{Max[L(t_{i-1}, t_i); K - A^{CF}] + A^{CF}\} \cdot \delta_{t_i}$$

ie. we have modified the strike level by the size of the fixed spread.

Discount curve and forward curves are equal for this assignment.

A CF can be priced as the value of an ordinary floating rate bond minus the value of the cap. By an ordinary floating rate bond we mean a floating rate bond which is not capped.

3.1. First up we need to find the fixed spread on an ordinary floating rate bond such that a floating rate bond trading with the same maturity as the CF has a price of par. It is not always the case that floating rate bonds with the same maturity trade in the market, so we need to replicate, a floating rate bond by using a fixed rate bond, which typically trade liquidly in all maturities.

Explain how you can find the fixed spread A^{ORD} in an ordinary floating rate bond from a fixed rate bond of the same maturity, such that the floating rate bond has a price of par. In other words: what instrument can you use in order to transform a fixed rate bond into a floating rate bond? No calculations required.

Answer:

The par-par ASW spread defines exactly such a situation namely where an investors pays 100 up front while receiving a fixed spread and a money market fixing.

3.2. In the data sheet you can find the specification of a fixed rate bond with a similar maturity as the CF as well as zero rates. Use this data in combination with the fidAswSpread formula in order to compute A^{ORD}. Report A^{ORD} in per cent with two decimal places.

Answer:

-0.12%.

3.3. Next you are to calibrate a SABR model to the three caplet maturities listed in the sheet. For each expiry there is three different caplets.

First you will need to find the at-the-money (ATM) forward rates to generate relevant strikes for each expiry. These are ATM, ATM-25bp and ATM+25bp.

Next use the function fidNormSabrAlphaZero in order to calibrate SABR parameters for each expiry. This function has been given to you in the exam library. The function implements formula (A.70a) in the 'Managing smile risk' paper of Hagan et al. That is, given parameter values it returns the normal volatility for a chosen strike level K, time-to-expiry T and at-the-money forward rate F, to be input into the normal (Bachelier) model. The normal (Bachelier) option pricing formula has been implemented into fidSwaptionNormPv. However, for now only make use of the fidNormSabrAlphaZero formula.

OBS: We only need to calibrate $(\sigma_0, \epsilon, \rho)$ since α is fixed at zero. Hence, α does not enter into the calibration procedure. This is in order to allow for negative interest rates. Start with initial guesses $(\sigma_0, \epsilon, \rho) = (0.20\%, 50\%, 20\%)$ as given in the data sheet. Don't be surprised if ρ doesn't move too much.

Report your calibrated parameters for each expiry in per cent with two decimal places.

Answer:

Expiry	Tenor	Expiry	Maturity	Sigma_0	Epsilon	Rho
6M	6M	4-Feb-22	4-Aug-22	0.20%	118.15%	2.19%
3Y	6M	5-Aug-24	5-Feb-25	0.33%	88.79%	39.62%
5Y	6M	4-Aug-26	4-Feb-27	0.47%	51.30%	48.68%

3.4. Why do you think it is a good idea to employ the SABR model for this question?

Hint: Compare the strike level of the CF with the strike level of the caplets that are actually traded.

Answer:

The SABR model is known to be good for interpolation especially valuing correctly options deeply in- or out-of-the-money.

3.5. Next you will need to interpolate the SABR parameters for all the relevant caplet expiries using the calibrated SABR parameters. Use Hermite interpolation.

The first caplet expiry is at 1/1/2022 and the last expires on 1/1/2026 (unadjusted). Thus, we need to interpolate parameters for <u>nine</u> caplets with expiries (unadjusted) 1/1/2022, 1/7/2022, etc. As the first caplet with expiry 1/1/2022 expires before the expiry of the first traded caplet, simply use flat extrapolation (ie. use the same SABR parameters for 1/1/2022 as for the 6Mx6M caplet).

Before you interpolate, adjust the unadjusted expiry dates listed above using the modified following day rule.

Report your interpolated parameter values for each adjusted expiry date in per cent with two decimal places.

Hint: It can be an advantage to make use of the fidGenerateSchedule for this question as well as for the next. Use Act/360 day count basis.

Answer:

Adj start	Adj end	Cvg	Sigma_0	Epsilon	Rho
03-01-2022	01-07-2022	0.49722	**0.20%**	**118.15%**	**2.19%**
01-07-2022	02-01-2023	0.51389	**0.22%**	**114.75%**	**10.17%**
02-01-2023	03-07-2023	0.50556	**0.24%**	**109.74%**	**19.15%**
03-07-2023	01-01-2024	0.50556	**0.27%**	**104.03%**	**26.83%**
01-01-2024	01-07-2024	0.50556	**0.30%**	**97.54%**	**33.35%**
01-07-2024	01-01-2025	0.51111	**0.32%**	**90.28%**	**38.72%**
01-01-2025	01-07-2025	0.50278	**0.36%**	**82.14%**	**42.97%**
01-07-2025	01-01-2026	0.51111	**0.39%**	**73.37%**	**46.01%**
01-01-2026	01-07-2026	0.50278	**0.43%**	**63.65%**	**47.93%**

3.6. Next find the implied normal volatility for each expiry, again using the function fidNormSabrAlphaZero. In order to do so first calculate at-the-money forward rates and time to

expiry for each of the nine caplets. The strike level for each expiry should be $\mathrm{K} - \mathrm{A}^{\mathrm{CF}}$. Put $\mathrm{A}^{\mathrm{CF}} = \mathrm{A}^{\mathrm{ORD}}$ for now which you found in question 3.2.

Report your normal volatilities in per cent with two decimal places.

Answer:

Adj start	Adj end	Cvg	Sigma_0	Epsilon	Rho	Forward rate	Time to expiry	NormVol
03-01-2022	01-07-2022	0.49722	0.20%	118.15%	2.19%	-0.15%	0.43	**0.43%**
01-07-2022	02-01-2023	0.51389	0.22%	114.75%	10.17%	-0.15%	0.93	**0.48%**
02-01-2023	03-07-2023	0.50556	0.24%	109.74%	19.15%	-0.13%	1.44	**0.51%**
03-07-2023	01-01-2024	0.50556	0.27%	104.03%	26.83%	-0.11%	1.94	**0.54%**
01-01-2024	01-07-2024	0.50556	0.30%	97.54%	33.35%	-0.07%	2.45	**0.56%**
01-07-2024	01-01-2025	0.51111	0.32%	90.28%	38.72%	-0.03%	2.96	**0.57%**
01-01-2025	01-07-2025	0.50278	0.36%	82.14%	42.97%	0.02%	3.47	**0.57%**
01-07-2025	01-01-2026	0.51111	0.39%	73.37%	46.01%	0.07%	3.97	**0.57%**
01-01-2026	01-07-2026	0.50278	0.43%	63.65%	47.93%	0.12%	4.48	**0.57%**

3.7. Finally price each caplet using the fidSwaptionNormPV and sum them to get the cap value. Use the conventions provided. Remember each caplet has a notional of 100. Use Act/360 day count basis. Report your results with four decimal places.

Answer:

Adj start	Adj end	Cvg	Sigma_0	Epsilon	Rho	Forward rate	Time to expiry	NormVol	Premium
03-01-2022	01-07-2022	0.49722	0.20%	118.15%	2.19%	-0.15%	0.43	0.434%	**0.0001**
01-07-2022	02-01-2023	0.51389	0.22%	114.75%	10.17%	-0.15%	0.93	0.479%	**0.0043**
02-01-2023	03-07-2023	0.50556	0.24%	109.74%	19.15%	-0.13%	1.44	0.513%	**0.0168**
03-07-2023	01-01-2024	0.50556	0.27%	104.03%	26.83%	-0.11%	1.94	0.542%	**0.0332**
01-01-2024	01-07-2024	0.50556	0.30%	97.54%	33.35%	-0.07%	2.45	0.558%	**0.0531**
01-07-2024	01-01-2025	0.51111	0.32%	90.28%	38.72%	-0.03%	2.96	0.566%	**0.0733**
01-01-2025	01-07-2025	0.50278	0.36%	82.14%	42.97%	0.02%	3.47	0.568%	**0.0939**
01-07-2025	01-01-2026	0.51111	0.39%	73.37%	46.01%	0.07%	3.97	0.568%	**0.1142**
01-01-2026	01-07-2026	0.50278	0.43%	63.65%	47.93%	0.12%	4.48	0.567%	**0.1353**
Sum									**0.5242**

What we have found out now is that a 1/7/2026 CF trades at a price of $100 - \mathrm{PV}_{\mathrm{cap}}$, where the buyer at each payment date receives a fixing plus a fixed spread, where we have so far assumed

$\mathrm{A}^{\mathrm{CF}} = \mathrm{A}^{\mathrm{ORD}}$. Sometimes, however, we are interested in what ASW spread, A^{CF}, makes the CF price at par value.

3.8. We will now try and do so. In order to solve this you need to increase A^{CF}. The higher A^{CF} lowers the strike level and thereby increases the PV of the cap, but at the same time the higher fixed spread increases the PV of the fixed payments received. The latter effect dominates. Thus, you need to increase A^{CF} until the sum of these two effects are large enough in order to generate a PV of 100. You can use either the solver or goal seek for this in combination with the formula below. Report your results using four decimals.

$$\mathrm{PV}_{\mathrm{CF}} = 100 - \mathrm{PV}_{\mathrm{cap}} + \mathrm{Annuity}^{\mathrm{ORD}} \cdot \left(\mathrm{A}^{\mathrm{CF}} - \mathrm{A}^{\mathrm{ORD}}\right) \cdot 100$$

Answer:

-0.0022%

Question 4: Pricing CVA as a strip of options (25%)

Introduction

The purpose of this exercise is to test your knowledge of swap exposure by combining the theory on general counterparty risk exposure, swap theory and volatility. As discussed in the lectures, xVAs depends on counterparty exposure which is generally computed using complicated simulation models. The reason is that CVA can be regarded as a short option which means that even for simple (linear products) such as the interest rate swap, calculating swap exposure requires a volatility model. Also it turns out, that counterparty exposure on an interest rate swap can be calculated as a strip of sold options. As such, the exposure calculation itself is independent of the credit quality of your counterpart, but only depends on market observables such (forward, discounting and volatility surfaces/curves)

For the purpose of this exam question, we consider a single curve setup.

4.1. In the exam material for this question, you will find market quotes based on 3M-EURIBOR and some swap conventions. Calibrate a zero-coupon curve from this market data and calculate the ATM rate of a 5Y EUR swap against 3M-EURIBOR. Please present a table with your zero quotes and dates along with the 5Y ATM swap rate as the written answer to this question along with your calibration setup in the Excel-attachment.

Answer:

The fair swap rate is 1.5270% and the zero-coupon curve is given by. The clever solution to this question would note that we are actually given the 5Y swap rate as market input. However, the students need to calibrate a zero-coupon curve to answer the following questions.

	ZC curve
18-Mar-21	0.908%
18-Mar-22	1.080%
20-Mar-23	1.191%
18-Mar-25	1.524%
18-Mar-30	2.262%
19-Mar-35	2.614%
19-Mar-40	2.660%
18-Mar-50	2.464%

4.2. In the following questions we are looking at a 5Y receiver swap. Given the current forward curve, what do we expect the value of this 5Y swap is in 6M given that the current forward curve is realized? Can you put some (short) intuition on why the sign of the expected value? You are most welcome to back your answer with an illustration although this is not required.

Answer:

The value of the 5Y swap is expected to be -155.949 EUR in 6M given that the current forward curve is realized.

This can be shown by considering the present value of a 6M forward starting swap ending in 5Y with the fixed rate set as the fair swap rate of the 5Y swap. That is, 1.5270% as calculated in question 3.1.

Partial credit has been given if student correctly deduce that the swap is expected to have a negative value, but full points have only been given if an actual number on the PV is presented. +/- 2.000 deviation from answer above is acceptable.

4.3. Construct a 3M schedule running from today to 5Y (that is in 3M increments from t=2b to T=5Y). Please use the modified following convention and day count convention “ACT/365” for this schedule. As in question 2, please calculate how the expected PV of the 5Y EUR swap changes over the lifetime of the swaps given that the current forward curve is realised, and please use dates of the schedule. We might refer to this profile as the "expected exposure" of the swap.

Answer:

The expected exposure profile on the schedule of grids evolves according to the fidSwapPv column:

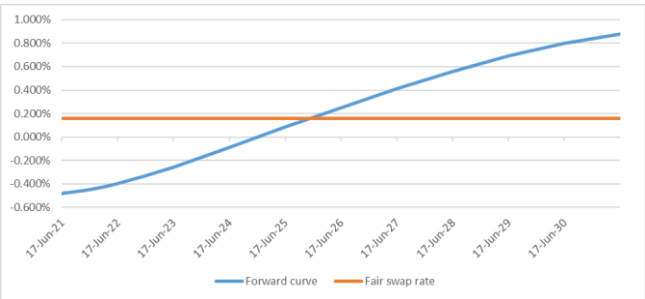
Swap start	Swap End	Fair swap rate	Actual swap rate	fidSwapPv (EUR)
18-Mar-20	18-Mar-25	1.527%	1.5270%	0
18-Jun-20	18-Mar-25	1.560%	1.5270%	-77,839
18-Sep-20	18-Mar-25	1.597%	1.5270%	-155,949
18-Dec-20	18-Mar-25	1.639%	1.5270%	-235,615
18-Mar-21	18-Mar-25	1.687%	1.5270%	-316,828
18-Jun-21	18-Mar-25	1.722%	1.5270%	-361,414
20-Sep-21	18-Mar-25	1.757%	1.5270%	-397,522
20-Dec-21	18-Mar-25	1.794%	1.5270%	-426,920
18-Mar-22	18-Mar-25	1.833%	1.5270%	-451,814
20-Jun-22	18-Mar-25	1.875%	1.5270%	-469,580
19-Sep-22	18-Mar-25	1.924%	1.5270%	-486,226
19-Dec-22	18-Mar-25	1.982%	1.5270%	-500,157
20-Mar-23	18-Mar-25	2.046%	1.5270%	-504,729
19-Jun-23	18-Mar-25	2.099%	1.5270%	-485,700
18-Sep-23	18-Mar-25	2.148%	1.5270%	-451,965
18-Dec-23	18-Mar-25	2.198%	1.5270%	-406,196
18-Mar-24	18-Mar-25	2.248%	1.5270%	-347,376
18-Jun-24	18-Mar-25	2.274%	1.5270%	-270,032
18-Sep-24	18-Mar-25	2.287%	1.5270%	-183,035
18-Dec-24	18-Mar-25	2.291%	1.5270%	-91,994

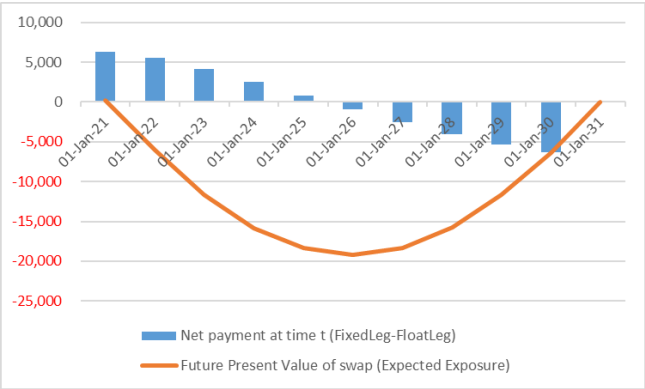
How to construct the grid should be clear given the question formulation, but small variations in the grid construction does not matter – the expected exposure at a certain date can be calculated on any date and not just the cash-flow dates. Small variations in the profile compared to the above is there OK.

4.4. Please discuss how the relationship of "who is expected to owe who" (e.g. the expected exposure profile) of a receiver swap changes with the shape of the forward curve (upward-, downward-sloping or flat?). As before, illustrations are most welcome but not required.

Answer:

What is expected from the student here is an answer that relates the shape of the forward curve to the expected exposure curve. If the forward curve is upward-sloping, the fixed rate will be higher than the floating rates in the beginning of the swap, but this relationship will turn around at the exact point where floating rates are expected to be higher than the fair swap rate given the current forward curve. The students can illustrate this using the following illustrations:





For downward sloping forward curve this is reversed. For a flat curve no one is expected to owe the other (up to some discounting etc.)

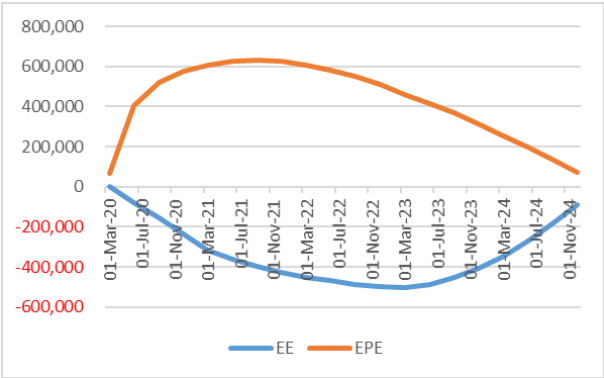
4.5. Next, we want to calculate the expected positive exposure of the swap as a strip of options on the underlying swap. For the purpose of this question, we will be using the Black-Scholes-Merton model with a (flat) volatility of 60%. Please re-use the 5Y grid in 3M increments to calculate the expected positive exposure from t=2B to t=5Y. Also, please use the start dates as expiry. Present a plot and table with the expected exposure and the positive exposure.

Answer:

The students can provide an answer like the one below. What is important is that they correctly calculate that the EPE profile is strictly positive, as we can only have positive credit exposure towards a client (and since options premiums are strictly positive). For a correct answer to this question, the profile should be roughly equal to the below, but if the grid is slightly different the numbers will be slightly different. This is OK as long as the differences are small.

Expiry	Swap end	EPE (EUR)	EE (EUR)
18-Mar-20	18-Mar-25	67,644	0
18-Jun-20	18-Mar-25	405,059	-77,839
18-Sep-20	18-Mar-25	519,132	-155,949
18-Dec-20	18-Mar-25	578,099	-235,615
18-Mar-21	18-Mar-25	605,717	-316,828
18-Jun-21	18-Mar-25	626,378	-361,414
20-Sep-21	18-Mar-25	632,548	-397,522
20-Dec-21	18-Mar-25	625,490	-426,920
18-Mar-22	18-Mar-25	607,777	-451,814
20-Jun-22	18-Mar-25	582,906	-469,580
19-Sep-22	18-Mar-25	549,948	-486,226
19-Dec-22	18-Mar-25	508,940	-500,157
20-Mar-23	18-Mar-25	461,983	-504,729
19-Jun-23	18-Mar-25	416,178	-485,700
18-Sep-23	18-Mar-25	366,921	-451,965
18-Dec-23	18-Mar-25	313,017	-406,196
18-Mar-24	18-Mar-25	255,687	-347,376
18-Jun-24	18-Mar-25	197,950	-270,032
18-Sep-24	18-Mar-25	136,501	-183,035
18-Dec-24	18-Mar-25	70,582	-91,994

A plot of the EPE and EE profile could look like the one below



4.6. Please comment on the moneyness of the swaptions used to approximate the expected positive exposure: are they in-the-money, out-the-money or at-the-money? Please provide a short explanation.

Answer:

As discussed in relation to question five, the strip of swaptions should be regarded as receiver swaptions entered with a strike of K = 1.5270%. Since the forward starting fair swap rates are clearly increasing in maturity (since the forward curve is increasing), the swaptions are struck out-of-the-money across the whole time-grid from the point of view of the bank. This is also evident from the fact, that the expected exposure is negative.

And argument along the lines of the following is also acceptable. These are receiver swaptions we are looking at. Since we are receiving the spot rate for the full duration, swaptions struck at the spot rate – and not the at-the-money forward rate – is OTM because we receive a lower rate compared to the at-the-money forward rates. In that sense, client is expected to pay a lower fixed rate compare to the forward par swap rate.

Note, that the first swaption is done ATM. If the student does not mention this, but notes that the swaptions are OTM – this is OK!

4.7. In the exam-data for this question, you have been given a credit curve in spot terms as well as a recovery rate. The interpretation of credit spreads is that they represent the market-implied probability of default for a corporate based on market observable CDS spreads. Using the 3M grid created above, calculate the implied 3M forward CDS spreads. That is, the market implied probability of default of the corporate between three and six months, six and nine months, nine and twelve months and so forth. Please use the modified following and ACT/365 conventions along with Hermite interpolation.

Hint: the same no-arbitrage relation between spot and forward curves holds for CDS as it holds for zero-coupons so you can use your existing *fidForwardRate* implementation for this question.

Answer:

Using the same grid as before and applying the fidForwardRate function with start and end dates given below yields the following:

Start date	End date	Forward credit spread
18-Mar-20	18-Jun-20	0.387%
18-Jun-20	18-Sep-20	0.389%
18-Sep-20	18-Dec-20	0.565%
18-Dec-20	18-Mar-21	0.676%
18-Mar-21	18-Jun-21	0.778%
18-Jun-21	20-Sep-21	0.878%
20-Sep-21	20-Dec-21	0.994%
20-Dec-21	18-Mar-22	1.136%
18-Mar-22	20-Jun-22	1.287%
20-Jun-22	19-Sep-22	1.442%
19-Sep-22	19-Dec-22	1.623%
19-Dec-22	20-Mar-23	1.843%
20-Mar-23	19-Jun-23	2.149%
19-Jun-23	18-Sep-23	2.447%
18-Sep-23	18-Dec-23	2.633%
18-Dec-23	18-Mar-24	2.670%
18-Mar-24	18-Jun-24	2.605%
18-Jun-24	18-Sep-24	2.600%
18-Sep-24	18-Dec-24	2.680%
18-Dec-24	18-Mar-25	2.867%

4.8. The following convenient approximation of the CVA formula allows us to discretize the integral:

$$\begin{aligned} CVA(t) &= -(1-R)\int_0^T EPE(t)dPD(t) \\ &\approx -(1-R)\sum_{i=1}^{n} EPE(t,T_i)PD(t,T_{i-1},T_i)\tau(T_{i-1},T_i) \\ &= -\sum_{i=1}^{n} EPE \cdot CS(t,T_{i-1},T_i)\tau(T_{i-1},T_i) \end{aligned}$$

Use this approximation to calculate the CVA for the 5Y receiver swap considered in this set of questions. For the purpose of this exercise (to simplify things) we assume that the probability of default is independent of the expected positive exposure of the swap. In practice, this might not be the case. Can you think of a reason for why this is intuitively?

Answer:

CVA = - 36.609 EUR

Deviations in the size of +/- 500 is acceptable. This might be due to small calibration errors and/or small timing errors.

Using the input below

Start	End	Tenor	Fwd Credit	EPE
18-Mar-20	18-Jun-20	0.256	0.39%	67,644
18-Jun-20	18-Sep-20	0.256	0.39%	405,059
18-Sep-20	18-Dec-20	0.253	0.56%	519,132
18-Dec-20	18-Mar-21	0.250	0.68%	578,099
18-Mar-21	18-Jun-21	0.256	0.78%	605,717
18-Jun-21	20-Sep-21	0.261	0.88%	626,378
20-Sep-21	20-Dec-21	0.253	0.99%	632,548
20-Dec-21	18-Mar-22	0.244	1.14%	625,490
18-Mar-22	20-Jun-22	0.261	1.29%	607,777
20-Jun-22	19-Sep-22	0.253	1.44%	582,906
19-Sep-22	19-Dec-22	0.253	1.62%	549,948
19-Dec-22	20-Mar-23	0.253	1.84%	508,940
20-Mar-23	19-Jun-23	0.253	2.15%	461,983
19-Jun-23	18-Sep-23	0.253	2.45%	416,178
18-Sep-23	18-Dec-23	0.253	2.63%	366,921
18-Dec-23	18-Mar-24	0.253	2.67%	313,017
18-Mar-24	18-Jun-24	0.256	2.61%	255,687
18-Jun-24	18-Sep-24	0.256	2.60%	197,950
18-Sep-24	18-Dec-24	0.253	2.68%	136,501
18-Dec-24	18-Mar-25	0.250	2.87%	70,582

Reason why default probability of default and swap market value might not be independent is because the swap market value might compromise the clients credit quality (think cooperative housing associations "andelsboligforeninger").

4.9. Calculate the CVA sensitivity of the 5Y swap moving 1 basis point entered with the corporate with respect to the 5Y swap rate. Can you explain the sign of the risk-number? How would you expect the CVA of the swap vs the corporate to change with the credit spread?

Answer:

The sensitivity dCVA/d(Swap5Y) equals +382 EUR.

The student needs to calibrate a new zero-coupon curve with the 5Y input swap rate bumped 1 basis point and then repeat the entire exercise of calculating CVA. The sensitivity is then given by subtracting the initial CVA number of -36.609 from the previous question from the bumped CVA number -30.228. That is, this is a bump-and-run exercise such as the one we do for market instrument risk. The easiest way to do this is to record the initial CVA number, and replace the bumped curve by the one used for the previous questions.

A great answer would set up the Jacobian for the 5Y point and multiply with the model rate delta (a single point), but this is somewhat cumbersome for a single risk point.

Full points will be awarded if the student bumps the 5Y zero coupon rate and mentions that this is roughly equivalent to bumping the 5Y swap rate. That is, they calculate the model rate delta. Partial credit (almost full points) will be given if risk is correctly calculated and interpreted using the model rate delta vector, but no mention of the equivalence has been given, although we specifically asks for the market rate delta since we ask for the sensitivity to the 5Y swap rate.

The sign of the number can be explained as follows. Since we are receiving fixed, and increase in the 5Y swap rate will make the present value of the swap more negative for us. Since we owe the client more, the counterparty credit exposure falls and hence the CVA. Hence, an increase in rates will lower the CVA for fixed rate receiver swap.

The CVA risk towards the credit spread is negative: a higher credit spread would imply a higher probability of default (as seen by the market), which should give higher credit risk and hence higher CVA in absolute terms (that is, a more negative number).

dCVA/dCS < 0, CS as credit spread

The good answer to this question mentions this point.

4.10. Assume that you are at trader on an xVA desk and your sales team are about to enter into this swap with the corporate. Your swap trader will handle the outright exposure to the 5Y swap rate, but you yourself are concerned about a flattening of the swap-curve in the 5Y point in relation to your CVA-number. What swap would you enter to neutralize this 5Y-swaprate risk?

Answer:

In this question we are concerned with 5Y swap risk and in the previous question we established that our CVA-risk towards this point is +382 EUR pr. Basis point. Since we are short interest rates (for interest rates up) on the CVA versus this counterparty, we need to receive fixed in the hedge.

*To calculate the notional, we recall the formula Risk in basis points = Notional * Annuity / 10.000. Inverting this to isolate the notional gives Notional = Risk in basis points / Annuity * 10.000*

The annuity for this market and the 5Y swap is 4.906, so the notional of the hedge is EUR 777.988. An approximate notional (e.g. 800.000) is also OK.

The outstanding answer to this question would comment on the size of the CVA hedge vs. the market risk hedge. The CVA hedge is much smaller compared to the market hedge that the trading desk needs to put on the books. However, it is fine to avoid commenting on this.

4.11. Finally, the corporate enters into the 5Y swap. For this question, no calculations are required.

- How will the swap trader hedge the receiver swap ideally?
- Do you think it would make sense for the swap-desk and your xVA desk to exchange interest rate risk internally in the bank before hedging any residual risk – if any – in the market?

Answer:

The banks swap trade gets a receiver swap on the books. He will hedge this with a payer swap of similar size (same notional/maturity of 52.000.000 ideally).

Since we are the other way around on the CVA (fixed rate receivers), it makes sense for us to exchange interest rate risk in-house at a mid-price, as both of us would likely pay a bid/offer spread in the interbank market.