Systemic Risk and the Open Source Risk Engine

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21/01/2017

Introduction

- Nikolai Nowaczyk
  - Consultant at Quaternion Risk Managment
  - currently staffed on projects in London
  - 2015-2016: Academic Visitor at Imperial College London
  - 2011-2014: PhD in maths at Uni Regensburg
  - 2005-2011: studied maths at Uni Bonn
- Quaternion Risk Managment
  - Risk Managment company (consulting and software)
  - offices in Dublin, London, New York and Düsseldorf
  - core areas of expertise include Dynamic Initial Margin and CVA
  - about 30 people and rapidly growing

Key Points today

1. A financial derivative is a contract between two counterparties that transfers a financial risk from one counterparty to another.
2. The counterparties in a derivative trade are exposed to each others default risk.
3. This risk can be drastically reduced by collateralizing the derivative trade.
4. This reduction of risk comes at a significant cost - in money and overhead.
5. ORE is free and open source software that can be used to quantify and simulate the counterparty credit risk in derivatives trades.

1. Financial Derivatives
   - FX risk: A practical example
   - Terminology, Jargon, Basics
2. Counterparty Credit Risk (CCR)
   - The problem of "too big to fail"
   - Collateralization of Derivative Trades
   - (Dynamic) Initial Margin
3. Open Source Risk Engine
   - The technical side
   - Purpose of ORE
   - What ORE does
4. A vision for the Capstone project

Outline

Case study: The great British bake off

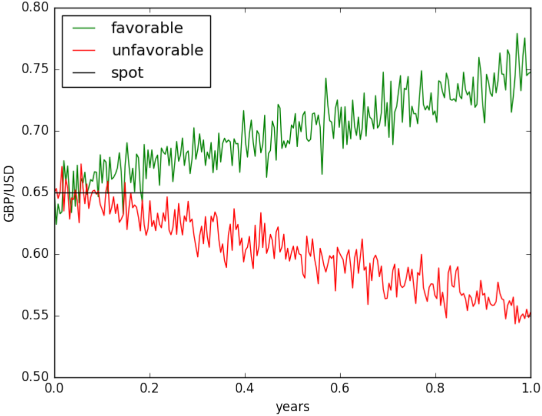
- Your grandmother from Yorkshire runs a small bakery business in the UK.
- The CEO of a large US firm is on holiday in Lake District and passes by your grandmother's bakery.
- He is so impressed with the cake that he buys a huge order for his entire company and offers her **USD 1mn** to be paid on delivery in **1Y**.
- Granny has dreamed of running an international business for all her life and wants to enter into the deal. But when the runs the books, she realizes that she would first have to make an investment to expand the business so it can handle the big order. This expansion would incur quite some costs first and of course she runs her business in **GBP**.

Can she close the deal?

A back of the envelope calculation (1)

- The current FX rate is $\mathbf{FX_{spot} = 0.65}$, so **USD 1mn** is equal to **GBP 650k**.
- She needs to invest **GBP 550k** to deliver the order. That's a profit of **GBP 100k**.
- But then she studies the FX rate and realizes: The FX rate can change by about **15%** over a year. If it moves into the wrong direction, she would only get **GBP 552.5k**. That is dangerously close to a loss!
- She doesn't want to loose this once-in-a-lifetime business opportunity, but she also doesn't want to risk her pension.

A back of the envelope calculation (2)



FX Forward

Definition (FX Forward)

An *FX Forward* is a financial contract between two counterparties consisting of

- a *domestic currency* (for instance GBP) and a *foreign currency* (for instance USD),
- a *notional* N (for instance $N = 1mn$ in foreign currency),
- a *strike rate* K (for instance $K = 0.60$),
- a *maturity* T (for instance $T = 1Y$),

which if incepted today at $t = 0$ pays out

$$N(K - FX_T)$$

at $t = T$ (in domestic currency), where FX_T is the FX rate at time T.

Hedging a future transaction

- A cashflow at T in the amount of N in foreign currency will be worth $N\ FX_T$ in domestic currency, i.e. this cashflow is *exposed* to an FX risk.

- A portfolio consisting of this future cashflow and an FX Forward with the same notional has a combined payoff of

$$N(K - FX_T) + N\ FX_T = NK$$

  and is completely determined today.

- In practice the strike K of an FX Forward is often chosen in a way such that its current market price is 0.

Assuming this strike is **K=0.6** and granny enters into the FX Forward at, she will have **GBP 600k** and therefore a profit of **GBP 50k** for sure!

Deal done!

Some comments, features and terminology

- The FX Foward is a *derivative*, the future cashflow is the *underlying*, and the FX rate is the *risk factor*.
- A derivative can be used to *hedge* the *market risk* in an *underlying*.
- A derivative works like an insurance against adverse market movements.
- A derivative may be bought without the underlying - for speculative reasons.
- The risk of changing future FX rates does not vanish via the derivative. It gets transferred from the buyer of the derivative (for instance a small business) to the issuer (for instance a big bank).
- A derivative like an FX Forward can in theory be created at any time and for any notional - it is not a ressource like gold. (In practice this creation requires quite some banking infrastructure though.)

Other products and features

- An *FX Option* is a derivative similar to an FX Forward, but the payoff is $N(K - FX_T)^+ \geq 0$ (that one always costs a premium to buy).

- There are many more derivatives, but a common theme is that something is agreed on in advance and that something is either mandatory (Forward) or optional (Option).

- There are many more asset classes that have derivatives:
  - IR (Interest Rates)
  - FX (Foreign Exchange)
  - CDS (Credit Default Swap)
  - EQ (Equities)
  - CO (Commodities).

- Derivatives are financial goods themselves and can be traded. As a result their prices change just like the underlyings.

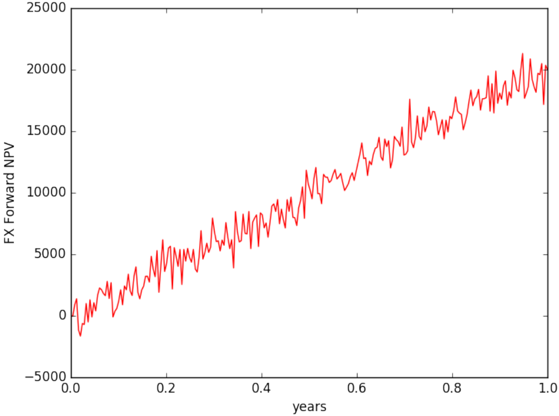
Summary

- A financial derivative is a contract between two counterparties that transfers a financial risk from one counterparty to another.
- Derivatives themselves are traded and change in value.

Outline

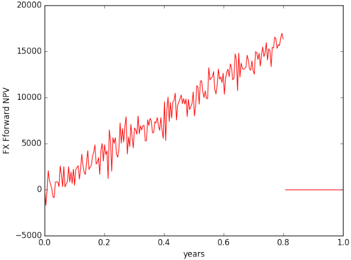
Coming back to our example: Good old times

- Granny has closed the deal. Everything goes well. The FX rate dropped by 15%, so she is really happy about the FX Forward, which is now worth a lot of money.



Coming back to our example: Financial crisis

- Suddenly she reads in the news that the bank she bought the Forward from went bust.
- The bank failure causes a major market turmoil and the FX rate goes down another 10%.
- When she receives the USD transaction, the GBP equivalent is not nearly enough to cover her costs. She suffers a huge loss and her business goes bust too.



Derivatives and CCR

- *Counterparty Credit Risk* is the risk that a counterparty does not satisfy its contractual obligations to you, because it goes bankrupt before the end of the contract.
- CCR has a long history in finance, in particular in credit! Loans are the oldest example where this risk component is very well encorporated into the business.
- During the crisis in 2007/08 people realized that derivatives have a credit risk component too. A derivative issued by a bank that goes bust is worth nothing.
- Since derivatives transfer risk from one counterparty to another, a bank failure transfers it back in an unpredictable way, which has a knock-on effect.

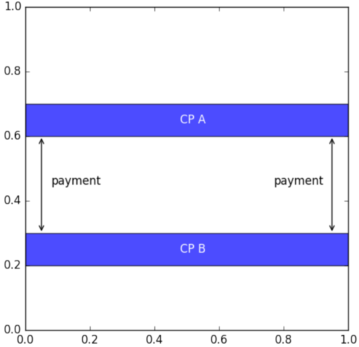
What has happened since the crisis

- People realized that certain banks and financial institutions are *too big to fail*, i.e. their failure would cause knock-on effects on other banks that are so disastrous that they would fail too. This chain reaction endangers the world's finance system as a whole, hence the term *systemic risk*.
- If such an institution would crumble, the government could save it using tax payers money (hugely unpopular).
- Tighter regulation, higher capital requirements and stress testing have been introduced.

The rules of the game for derivative trading have changed to mitigate counterparty credit risk via the introduction of *margining*!

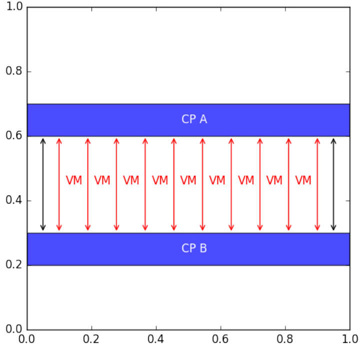
Uncollateralized derivative trades

- "Old world" style of trading.
- Payments between counterparties are only exchanged at the payment dates (for the FX Forward only at inception and maturity).
- Between those dates, the counterparties are fully exposed to each other's credit risk.



VM collateralized trades

- At inception CPs A and B exchange payments.
- The day after, the value of the derivative has changed by some Δ. If this is positive for A, then A pays Δ to B. If it is negative B pays Δ to A. These payments are called *variation margin* (VM).
- This procedure is repeated every day after inception till maturity.



Features of a VM collateralized derivative trade

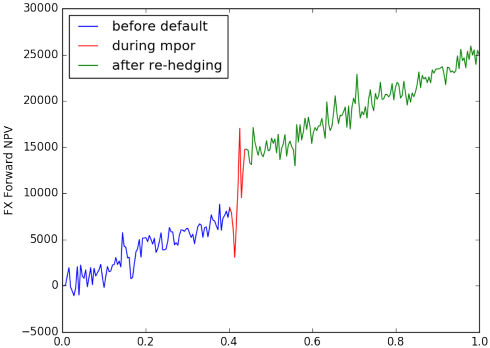
- The sum of all payments exchanged in an uncollateralized trade is the same as the sum of all payments exchanged in the VM collateralized trade.

- Both CPs are no longer exposed to each others credit risk assuming:
  - Defaults only happen instantanously after VM payments.
  - CPs notify each other instantanously after a default.
  - The surviving CP is able to instantanously buy the exact trade it has lost from another CP for exactly the amount of VM it has collected.

In reality, none of these assumptions is satisfied!

The MPOR

- In reality there is a gap between the *default date* and the *close out date*, i.e. the date at which the surviving counterparty has been able to replace all trades from the defaulting counterparty with trades with some other counterparty.
- This gap is called the MPOR (Margin Period of Risk) and in practice is assumed to be between 5d to 20d.



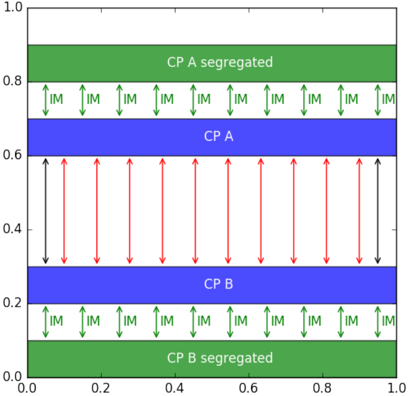
The role of Initial Margin

- It is assumed that during the MPOR the markets will be in an extremely stressed regime, since the default of a major bank will cause an enormous turmoil.

- At worst the markets will move massively against the surviving CPs favor still resulting in a big loss, since the received VM does not suffice to replace the trades at the closeout date.

Solution: Banks have to post *Initial Margin* (IM) in addition to VM to each other to cover for potential losses during the MPOR.

Cashflows in a VM & IM collateralized trade



The administrative overhead of trading VM and IM collateralized derivatives is much higher for secured trades than for uncollateralized trades.

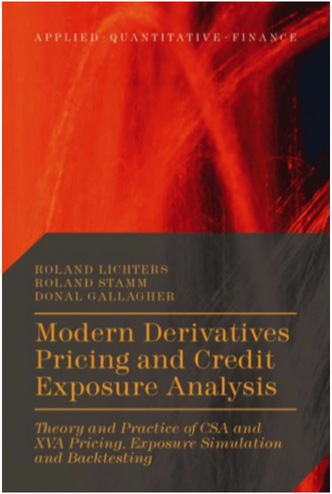
Features of a VM & IM collateralized trade

- The overall CCR in derivatives trading is reduced drastically.
- VM may be *rehypothicated*, i.e. you may use the VM you received from CP A to post your VM to CP B. IM may not be rehypothicated, which makes this very expensive.
- Pricing an uncollateralized derivative and simulating its future value is already a very complex modelling challange and considered as the holy grail of mathematical finance.
- The overwhelming majority of literature on derivative pricing does not (yet) account for VM and IM and therefore, most of these models do no longer reflect the reality of trading.

Dynamic Initial Margin

- The term *Initial Margin* is misleading: At inception it is paid initially based on a model and the current market conditions.
- If the market conditions change after the initial Initial Margin is posted and before the trade matures, a *margin call* is initiated to re-adjust the IM based on the updated market conditions.
- Therefore, the introduction of Initial Margin, which was designed to mitigate risk, actually introduces a new risk.
- In presence of IM banks need to plan ahead for future margin calls.
- This planning ahead is called DIM (Dynamic Initial Margin) and is one of Quaternions' core business areas.

With one notable exception...



Summary

- The counterparties in a derivative trade are exposed to each others default risk.
- This risk can be drastically reduced by collateralizing the derivative trade.
- This reduction of risk comes at a significant cost - in money and overhead.

Outline

Risk Managment Systems

Banks have had risk managment systems for decades. These systems are

- massive! They typically involve
  - large databank systems to store information about clients, trades and the markets.
  - computer clusters to perform a massive amount of computations in parallel.
  - complex reporting systems.
  - many desktop clients to be used by the banks staff.
- top secret, proprietary, closed source and a mixture of bought black-box software and in-house developments.
- constantly in need of updating, maintainance, bugfixing, refurbishment, extension etc.
- **intransparent**.

Practical problems

- If such a risk managment system computes some number that sounds reasonable, how can we be sure it is actually correct? (**validation**)
- If bank A issues a margin call to bank B based on their risk managment system and bank B claims that according to their system bank A is not right about this, what can they do? (**Margin dispute**)
- How can a regulator know what a bank is actually calculating and how can a bank explain its reported numbers? (**control**)
- How can the regulator make sure two banks with comparable trades are actually treated comparably? (**fairness in competition**)

Open Source Risk Engine

- ORE is a free and open source software that can perform complex risk managment computations like a production system in a bank.
- Based on QuantLib - a free and open source library for pricing derivatives.
- Developed and released on github by Quaternion Risk Managment.
- Its purpose is to
  - serve as an independent reference implementation of risk.
  - be useful for banks to validate an implementation of a model.
  - be serious about transparency in banking.
  - better connect academics and practitioners.
  - inspire new ideas on what can be done with open source software in finance.

What does ORE compute?

ORE computes the *collateralized exposure*

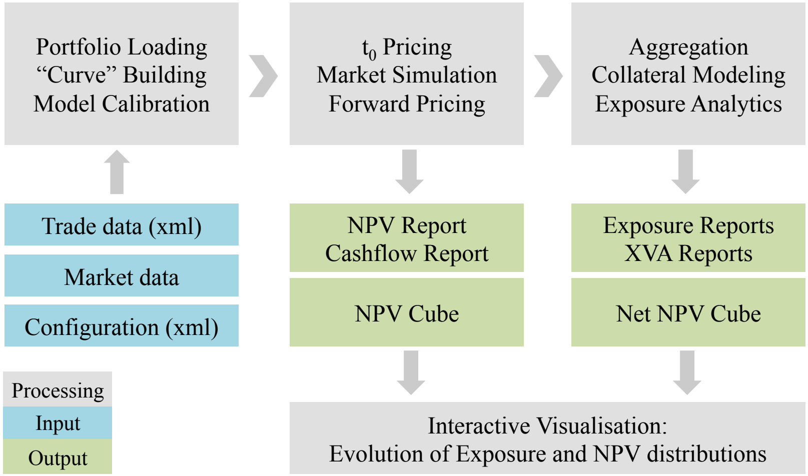
$$EPE(t) := (V(t) - VM(t) - IM(t))^{+}$$

of a derivatives portfolio (among other things, greatly simplified). Here

- $V(t)$ is the simulated value of the portfolio at time t,
- $VM(t)$ is the simulated VM collateral at time t,
- $IM(t)$ is the simulated IM collateral at time t and
- $EPE(t)$ is the *expected positive exposure* at time t.

The $EPE(t)$ is the amount of money you would lose if the counterparty defaults at t. It is a quantitative measure of the counterparty credit risk.

ORE Data Flow



Trade Portfolio XML Input

```xml
<?xml version="1.0"?>
<Portfolio>
  <Trade id="FXFWD_EURUSD_10Y">
    <TradeType>FxForward</TradeType>
    <Envelope>
      <CounterParty>CPTY_A</CounterParty>
      <NettingSetId>CPTY_A</NettingSetId>
      <AdditionalFields/>
    </Envelope>
    <FxForwardData>
      <ValueDate>2026-03-01</ValueDate>
      <BoughtCurrency>EUR</BoughtCurrency>
      <BoughtAmount>1000000</BoughtAmount>
      <SoldCurrency>USD</SoldCurrency>
      <SoldAmount>1100000</SoldAmount>
    </FxForwardData>
  </Trade>
```

Kicking off a run

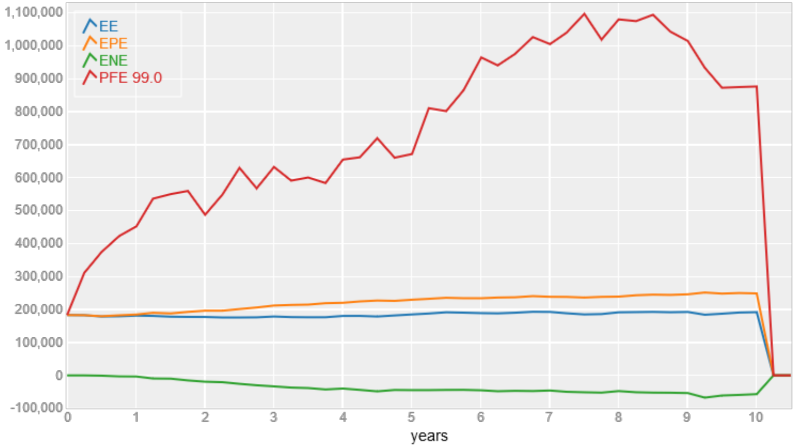
```
C:\github\ore\Examples\Example_7>..\..\App\bin\x64\Release\ore.exe Input\ore.xml
ORE starting
Market data loader...                   OK
Conventions...                          OK
Curve configuration...                  OK
Market...                               OK
Engine factory...                       OK
Portfolio...                            OK
Curve Report...                         OK
NPV Report...                           OK
Cashflow Report...                      OK
Simulation Setup...                     OK
Aggregation Scenario Data 42 x 5000...  OK
Build Cube 3 x 42 x 5000...             OK
Write Cube...                           OK
Write Aggregation Scenario Data...      OK
Aggregation and XVA Reports...          OK
run time: 77 sec
ORE done.

C:\github\ore\Examples\Example_7>
```

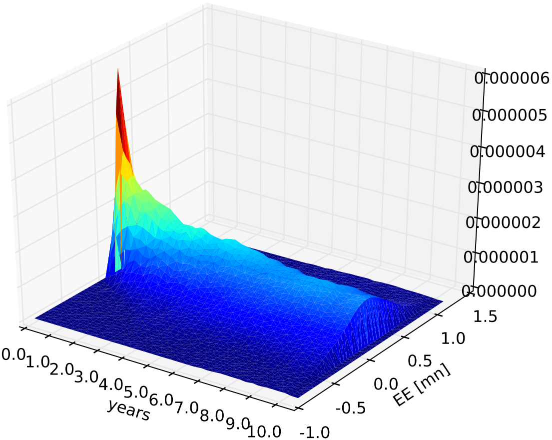
NPV Cube as a CSV Output

Id	NettingSet	DateIndex	Date	Sample	Value
FXFWD_EURUSD_10Y	CPTY_A	39	05/11/2025	4986	-835286.19
FXFWD_EURUSD_10Y	CPTY_A	39	05/11/2025	4987	190497.02
FXFWD_EURUSD_10Y	CPTY_A	39	05/11/2025	4988	563065.06
FXFWD_EURUSD_10Y	CPTY_A	39	05/11/2025	4989	214321.09
FXFWD_EURUSD_10Y	CPTY_A	39	05/11/2025	4990	-96431.227
FXFWD_EURUSD_10Y	CPTY_A	39	05/11/2025	4991	756491.75
FXFWD_EURUSD_10Y	CPTY_A	39	05/11/2025	4992	695232
FXFWD_EURUSD_10Y	CPTY_A	39	05/11/2025	4993	325480.66
FXFWD_EURUSD_10Y	CPTY_A	39	05/11/2025	4994	-33990.871
FXFWD_EURUSD_10Y	CPTY_A	39	05/11/2025	4995	79392.102
FXFWD_EURUSD_10Y	CPTY_A	39	05/11/2025	4996	157414.58
FXFWD_EURUSD_10Y	CPTY_A	39	05/11/2025	4997	430111.38
FXFWD_EURUSD_10Y	CPTY_A	39	05/11/2025	4998	246089.81
FXFWD_EURUSD_10Y	CPTY_A	39	05/11/2025	4999	81753.703
FXFWD_EURUSD_10Y	CPTY_A	39	05/11/2025	5000	-1207201
FXFWD_EURUSD_10Y	CPTY_A	40	05/02/2026	1	216319.77
FXFWD_EURUSD_10Y	CPTY_A	40	05/02/2026	2	-307775.13
FXFWD_EURUSD_10Y	CPTY_A	40	05/02/2026	3	680287.13
FXFWD_EURUSD_10Y	CPTY_A	40	05/02/2026	4	551766.56
FXFWD_EURUSD_10Y	CPTY_A	40	05/02/2026	5	163719.16
FXFWD_EURUSD_10Y	CPTY_A	40	05/02/2026	6	-498192.25
FXFWD_EURUSD_10Y	CPTY_A	40	05/02/2026	7	479456.47
FXFWD_EURUSD_10Y	CPTY_A	40	05/02/2026	8	318041.22
FXFWD_EURUSD_10Y	CPTY_A	40	05/02/2026	9	-26598.15

Exposure Metrics



Exposure Surface



Summary

- Risk managment systems of banks are inaccessible to academics.
- ORE is free and open source and a realistic simulation of a banks risk managment system.
- ORE can be used to quantify and simulate the counterparty credit risk in derivatives trades.

Outline

A vision for this project

ORE provides a unique opportunity for a collaboration between academia and practice. We are among the first group of people with access to a free and open source software that realistically simulates a bank in (almost) all its complexities (ORE and QuantLib have about 400k lines of C++ code).

- Learn how to use ORE to simulate a trade, a portfolio, a bank.
  - Start with the examples supplied with ORE.
  - Modify these examples and play around with them.
  - (Define your own examples.)

- Coding project: Simulate a consortium of banks and study quantitatively the systemic risk in that system.
  - Define a toy problem to study systemic risk using ORE.
  - Define portfolios for a handful of banks (2-5) and run all their portfolios through ORE.
  - Develop a systemic risk dashboard that visualizes the systemic risk.

Further Deliverables

- Use these tools to write a project report that studies systemic risk based on the quantitative evidence gathered via the coding project. More concretely, the following points could be addressed:
  - Define exposure metrics for a single counterparty in that system. Define exposure metrics for a system of counterparties.
  - Summarize existing measures of systemic risk (as described for instance in *Systemic Risk, Crises, and Macroprudential Regulation by Freixas et al.*) Define alternative measures of systemic risk as found in the literature and explore the strengths, opportunities and robustness of these measures.
  - What is the total Initial Margin that is posted in that system? How does the total Initial Margin in the system change over time? (Think about the interplay between Initial Margin and Liquidity.) Can one reduce the Initial Margin in the system without substantially increasing the risk in the system?

- Write a summary of the project report that can be published as a paper.