

# Counterparty Credit Risk and CVA under Basel III

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The

- latest version of this document
- additional resources
- examples

may be found on

<https://github.com/haenerconsulting/basel3cva>

# Outline

- 1 Credit Risk Measures
- 2 Credit Risk Mitigation
- 3 Model Implementation
- 4 Back Testing
- 5 Regulatory Requirements and Basel III

# Motivation

## Definition (Credit Risk)

Risk to incur a loss due to counterparty's default or loss of creditworthiness.

Credit risk measures are introduced to

- Quantify the credit risk
- Help Mitigating that risk

# Motivation

Risk measures are estimated by **Credit Risk Models**

## Impact of Credit Risk Model

Trading activity limits set by *PE*

Capital charges regularity capital dependent of *EEPE*

P&L *EE* enters CVA/DVA

# Motivation

## Challenges

**Measure** Asking the right question

**Model** Picking right model to estimate measure

**Act** Make decisions based on measurements

# Overview

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# Likelihood vs Severity of Credit Events

## Categories

Which dimensions to consider?

**Severity** How much will we lose?

**Likelihood** What's the chance that we lose?

**Granularity** What does the measure refer to?



# Granularity of Measure

## Based on Defaults

- All Counterparties
- Single Counterparty

## Other Aggregations

- Global/macro economic
- Sector, country
- Trade

## Exposure and Recovery

How to measure severity? Need to value trade:

### Definition (Exposure at Default)

$$\text{EAD}(t) = \max 0, p(t) | \tau = t$$

$\tau$  : time at which CP defaults

### Definition (Loss Given Default)

$$\text{Loss at time } t = \text{LGD}(t) \text{EAD}(t)$$

### Definition (Recovery)

$$R(t) = 1 - \text{LGD}(t)$$

# Severity

## Valuation Approaches

**Accrual** Banking book; rarely adjust; illiquid assets

**Mark to market** Trading book; frequently adjusted; traded assets

**Mark to model** Trading book; frequently adjusted; complex structures

## Example

CreditRiskMeasures.xlsx 

# Severity

## Accrual

Loan to Acme Ltd

- value is face value
- maximal loss is notional of loan

## Mark to market

Buy bond of Acme Ltd; assume liquid market

- value is mark to market of bond
- value lower than in risk-free valuation

# Severity

## Mark to model

Exotic interest rate swap with Acme Ltd. What is the value

- risk free: assuming Acme may never default
- risky: Acme may default
- risky with own risk: Acme and we may default

# Forward Looking Measures

Assess exposure in future → model how state of the world evolves

**Deterministic Evolution** Scenario Analysis, Stress testing

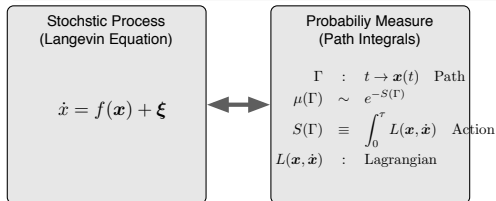
**Stochastic Evolution** Model for risk factors

# Scenario Analysis/Stress Test

## Meanings of Stress

- change model parameters  $\rightarrow$
- pick a single path  $\rightarrow$  degenerate measure (Dirac measure)

Unified handling by **Measure Transforms**



Dual Model Representations

# Types of Stress Tests

## Approaches

- give economic scenario
- given loss (inverse stress)

Inverse stresses



# Statistical Measures

## Single Netting Set

### Definition (Potential Future Exposure)

$$\text{PFE}(t) = \max 0, p(t) | \tau = t$$

$\tau$  : time at which CP defaults

### Definition (Expected Exposure (EE))

$$\text{EE}(t) = \mathbb{E}[\text{PFE}]$$

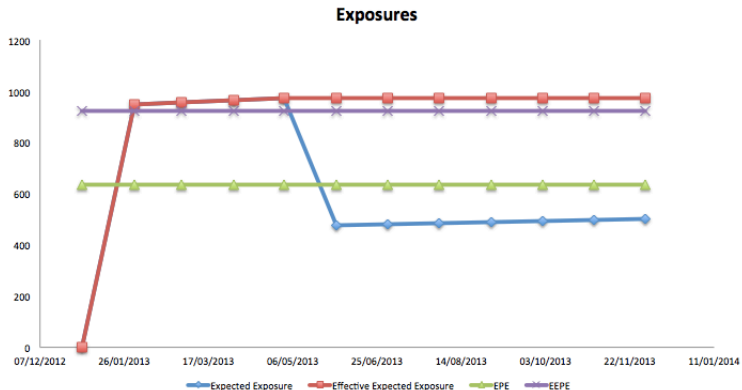
### Definition (Expected Positive Exposure)

$$\text{EPE}(T) = \frac{1}{T} \int_0^T \text{EE}(t) dt$$

# Regulatory Measures

## Definition (Effective Expected Exposure (EEE))

Maximum of EPE and past EEE: never decreasing.



# Statistical Measures

## Multiple Netting Set

### Definition (Losses across Netting Sets)

$$L(t) = \sum_a \chi_{\tau_a \leq t} \text{LGD}_a \max 0, p_a(\tau_a)$$

$a$  : Identifier of netting set

# Portfolio Measures

Meaningful risk measures for portfolios

## Definition (Coherent Risk Measure)

Risk measure  $\rho$ : for portfolio  $X$ :

**Normalization**  $\rho(\emptyset) = 0$  empty portfolio has no risk

**Monotonicity**  $X_1 \leq X_2 \rightarrow \rho(X_1) \geq \rho(X_2)$

**Sub-additivity**  $\rho(X_1 + X_2) \leq \rho(X_1) + \rho(X_2)$  diversification/netting

**Homogeneity**  $\rho(\alpha X) = \alpha \rho(X) \quad \alpha > 0$

**Translation invariance**  $\rho(X + a) = \rho(X) - a$  adding cash  $a$  reduces risk

# Portfolio Measures


## Quantile

$q\%$  quantile: value, for which  $q\%$  of outcomes are smaller/larger.  
Quantiles are **not** coherent measures.

## Expected Shortfall


Expected loss conditioned on the loss being larger than  $X$ . The Expected Shortfall (Mean Excess Loss) is a coherent measure.

## Example

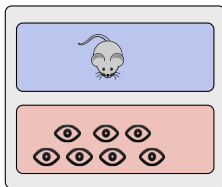
PortfolioMeasure.xlsx 

# Likelihood of Default

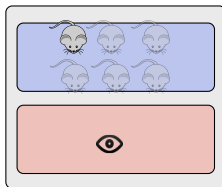
## Example

LikelihoodExperiment.xlsx 

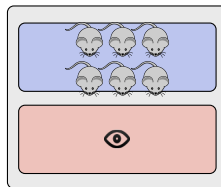
# What does probability mean?



Average observers



Implied ensemble



Genuine ensemble

## Probability and Measurement

Need to define

- Ensemble
- Measurement process

# Examples

## Genuine Ensemble

- Mathematics
- Physics: Identically prepared experiment

## Average observers

Consensus of observers:

- Market prices
- Betting quota

## Implied Ensemble

Equivalence classes:

- Names with same rating
- Price returns in different time windows



# Measures for Probability of Default

## Definition (Survival/Default Probability, Default Intensity)

Let  $\tau$  be time of default

$$S(t) = p(\tau > t)$$

$S$  : survival probability

$$S(t) = e^{-\lambda(t)t}$$

$\lambda$  : term default intensity

$$D(t) = 1 - S(t)$$

$D$  : default probability

Note:  $D$  is a CDF!

# Forward Intensity

## Forward default intensity

Probability  $d(t)$  of defaulting between  $t$  and  $dt$ :

$$d(t) = \frac{dD(t)}{dt} \quad (1)$$

# Estimating Probability of Default

Estimating  $\lambda$

**Credit Rating** Typically using historical data

**Market Prices** Current credit spreads from bonds or CDS

## Implied Default Intensity

Let  $s(t)$  be a credit spread

$$s(t) = (1 - R)\lambda(t)$$

$R$  : recovery rate

# Unifying Severity and Frequency Measures

## High Severity/Low Frequency vs. Low Severity High Frequency

How to compare

- Single large deal with good counterparty
- Set of small deals with bad counterparties

Answer

Pricing including credit risk allows comparing!

# Approaches

## Top-down vs Bottom-up

**Top-down** Pricing from first principles

**Bottom-up** Calculate **price correction** from building blocks:  
Exposure (EE) and PE, LGD

# Bottom-Up approach

## Assumptions

- Risk-free prices known
- Calculate EE
- Estimate PE, LGD
- Calculate correction to risk-free price

# Measuring the Corrections

Riskiness of counterparty reduces the price:

## Definition (CVA)

Risky price  $p_A^*$  as seen from counterparty  $A$  with counterparty  $B$ :

$$p^* = p - CVA_B$$

$p$  : risk-free price

$CVA_B$  : Credit Valuation Adjustment for counterparty  $B$

## Measuring the Corrections

Does credit risk of counterparty  $A$  also affect price?

### Definition (DVA)

Price  $p_A$  as seen from counterparty  $A$  with counterparty  $B$ :

$$p^* = p - CVA_B + DVA_A$$

$p$  : risk-free price

$DVA_A$  : Debit Valuation Adjustment for counterparty  $A$

DVA increases the price.

### Accounting vs. Regulatory

DVA must be used for P&L but not for regulatory capital.



# Regulatory CVA

BCBS 189, paragraph 89:

$$CVA = (LGD_{MKT}) \cdot \sum_{i=1}^T \text{Max} \left( 0; \exp \left( -\frac{s_{i-1} \cdot t_{i-1}}{LGD_{MKT}} \right) - \exp \left( -\frac{s_i \cdot t_i}{LGD_{MKT}} \right) \right) \cdot \left( \frac{EE_{i-1} \cdot D_{i-1} + EE_i \cdot D_i}{2} \right)$$

## Regulatory CVA

Similar to regulatory capital charge for default:


Assumes independence of exposure and default process.

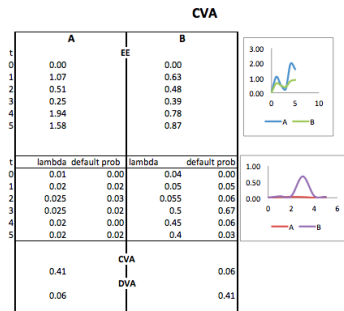
$$CVA = \int_0^T (1 - R) Df(t) EE(t) d(t) dt$$

where  $d$  is the default probability from equation (1),  $Df$  discount factor

# CVA

## Example

CVA.xlsx 



# Regulatory CVA

## Regulatory vs Trading CVA

**Regulatory** Historic measure for EE, implied for PD

**Trading** Both EE and PD in implied measure

## Pricing for Portfolio of Netting Sets

As for single netting sets: pricing combines severity and likeliness.  
Requires knowing

- prices of individual netting sets at default
- probability of default  $P(\chi_{\tau_1} \leq t_1, \chi_{\tau_2} \leq t_2, \dots, \chi_{\tau_N} \leq t_N)$

Additional useful quantity: in terms of total losses:

Definition (Loss distribution)

$$\mathcal{L}(l, t) = P(L(t) \geq l)$$

# Granularity of Measure in Regulatory Context

## Metrics used for Regulatory Purposes

Focus on measures for individual counterparties. No proper modelling of collective losses required.

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# Mitigate

- realized losses from default of counterparty
- P&L fluctuation from change in credit spreads of counterparty

# Netting Agreement

## Definition (Netting Set)

For all trades within a netting set long and short positions may be netted. The exposure is reduced due to

$$\max \sum_i p_i, 0 \leq \sum_i \max p_i, 0$$

## Example

A short and a long position worth 10 Mios with counterparty acme yield an exposure of 10 Mio w/o netting agreement and 0 with.



# CSA

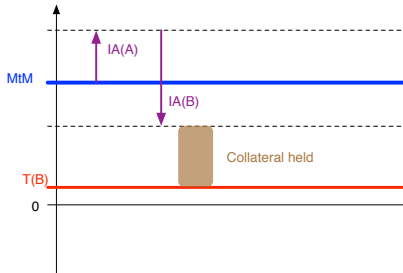
ISDA Credit Support Annex (CSA) : collateral that must be delivered between the parties

## Definition

- the Secured Party's Exposure plus
- the aggregate of all Independent Amounts applicable to the Pledgor, minus
- all Independent Amounts applicable to the Secured Party, if any, minus
- the Pledgor's Threshold

The Secured Party is the party that is holding collateral; the Pledgor is the party that has delivered collateral

# CSA



- At default losses offset by collateral
- Rebalancing needed
- Collateral price may move

# Re-hypothecation

By Ruby Lian and Fayen Wong

SHANGHAI | Sun Sep 16, 2012 3:07pm EDT

(Reuters) - Chinese banks and companies looking to seize steel pledged as collateral by firms that have defaulted on loans are making an uncomfortable discovery: the metal was never in the warehouses in the first place.

- Counterparty may repo the collateral → when defaulting collateral gone
- Forbidding may increase costs
- Transferring collateral management to central counterparty

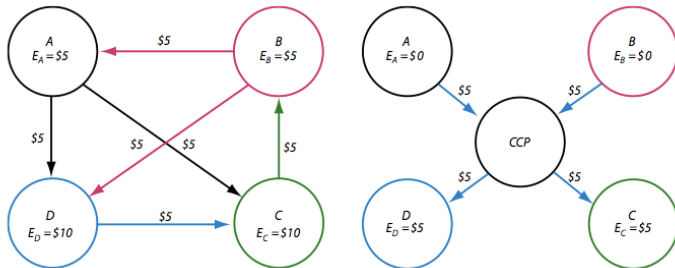
# Gap Risk

Collateral process is discreet, e.g. daily.

- position value
- collateral value

may move

# Central Counterparties



- Counterparty to every trade
- Multilateral netting → reducing risk
- Potentially mutualizing credit losses among participants
- Increased transparency

# Spread vs Default Risk

## Definition (Default Risk)

Risk of changes in price  $p$  induced by hitting default time  $\tau$ :

$$\begin{aligned} t &\rightarrow \tau \\ p &\rightarrow p + \Delta_{\tau}p \\ \Delta_{\tau}p &= (R - 1)p \end{aligned}$$

## Definition (Spread Risk)

Risk of changes in price  $p$  induced by changes of counterparty credit spread  $s$ :

$$\begin{aligned} s &\rightarrow s + \Delta s \\ p &\rightarrow p + \Delta_s p \end{aligned}$$

# Spread vs Default Risk

## Hedging

### Loans

**Default Risk** Single name CDS or short bond

**Spread Risk** **MtM accounting** Single name CDS/bond, index or proxy

**Accrual accounting** N/A

# Hedging Instruments and Strategies

## Static Hedges

Insurance for replacement of some asset on default:

Bond hedged by Credit Default Swap

Swap, CCYSwap Contingent Credit Default Swap (CCDS)

Netting sets insurance from CVA desk

## Dynamic Hedges

Hedging default or spread risk: use instruments with price  $q$ . First order:

Default  $\Delta_{\tau} q = -\Delta_{\tau} p$

Spread  $\Delta_s q = -\Delta_s p$



# Cross Counterparty Hedges

## Analogy Hedging Credit Risk for Bonds

<i>Granularity</i>	<i>Underlying</i>	<i>Hedge</i>
Single	Bond Netting Set	CDS CCDS
Portfolio	Bonds Netting Set	CDO "CCDO"

# Securitisation

Hedging losses across netting sets:

## CDO on CVA

- bond ↔ exposure of netting set
- tranches like CDO

## Issues

- notional of "bond"s fluctuating
- "bond" not transparent
- who rates the "bond"s and the CDO?

# Systemic Risks

In distressed market environment correlations increase → less diversification.

- Macro hedges
- Buying insurance won't work (→ Monolines)

# Limit Monitoring

## Limits

Manage size of exposure per

- counterparty
- industry
- region

Limits may typically expressed in terms of

**Quantiles** E.g. 95% quantile: 5% of losses are larger than that quantile

**Mean Express Loss** E.g. Average of the 5% biggest losses

A term structure of limits may be reflect risk appetite.

# Mutualization

## Central Counterparties

Losses distributed among participants → diversification  
Systemic risks?

# Internal CVA Desk

## Trading CVA

Trading desk within the firm:

- Sells default protection to other desks
- Hedges counterparty credit spread risk

## Costs/Benefits

- ⊖ High build and run costs
- ⊕ More accurate metrics for credit risk
- ⊕ Increased transparency on costs
- ! Hedged bought from CVA desk yield **no regulatory capital relief**

# Internal CVA Desk Operating Model

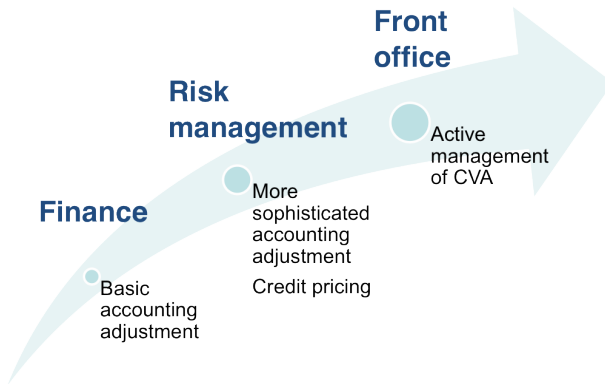
## Mandate

Depends on rationale for setting up

## Risk management or front office function?

Responsibility often changes with sophistication . . .

# Internal CVA Desk Responsibility





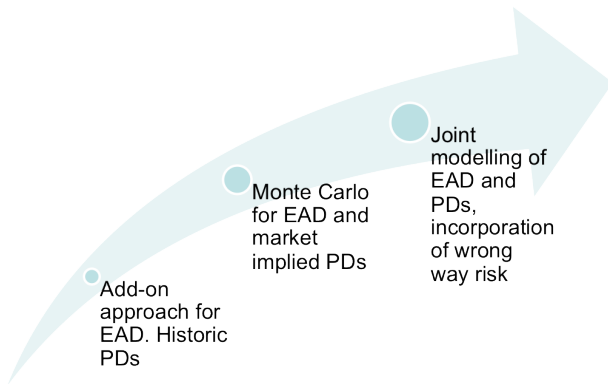
# Internal CVA Desk

## Profit Centre vs Service Centre

Approach	Advantages	Disadvantages
<i>Profit Centre</i>	<ul style="list-style-type: none"> <li>• P&amp;L enable performance to be measured</li> <li>• Easy to align remuneration with success and design incentives</li> </ul>	<ul style="list-style-type: none"> <li>• Potential conflicts of interest</li> <li>• May lead to overactive position taking</li> <li>• Requires more infrastructure</li> </ul>
<i>Service Centre</i>	<ul style="list-style-type: none"> <li>• Requires less infrastructure</li> <li>• Less market activity</li> <li>• Less internal politics</li> <li>• Qualitative focus can lead to broader focus</li> </ul>	<ul style="list-style-type: none"> <li>• Difficult to measure performance</li> <li>• Harder to retain and incentivise appropriate staff</li> </ul>

# Internal CVA Desk

## Methodology

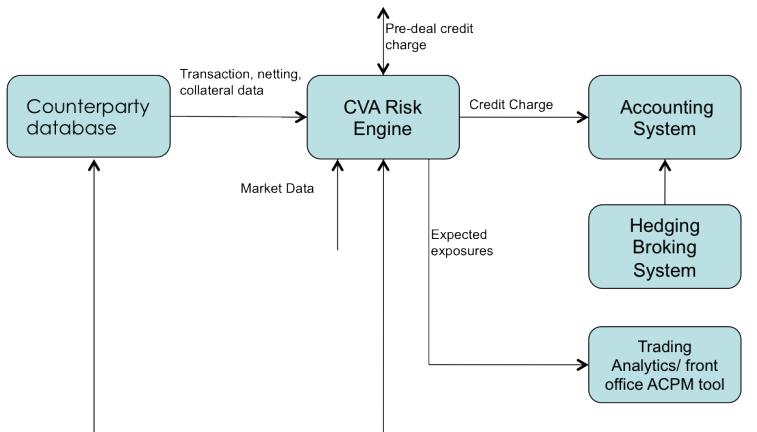


# Internal CVA Desk

## Methodology

- Risk vs pricing models: Use same models?
  - Pricing model **Fit** market prices
  - Risk model **Predict** future outcomes
- Bilateral vs unilateral calculation: Include products w/o PFE (e.g. notes)
- Define proxy spreads when no liquid CDS market
- Wrong way risk

# Internal CVA Desk Infrastructure



# Internal CVA Desk

## System Requirements

Basic requirements same as Monte Carlo Credit Risk system for Risk/Regulatory capital

### Additional Requirements

- Calculation of sensitivities
- Include wrong way risk in price
- Simulate in risk neutral calibration
- Integration with FO infrastructure and processes
- Attribution ability

# Internal CVA Desk

## Infrastructure

Pre-trade approval/marginal CVA/DVA calculation:

- Needs to be fast
- Avoid recalculating whole portfolio: add new trades in scenario-consistent manner

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# Building Blocks

## Model Building Process

Business Analysis Materiality, specification

Model choice Find adequate model

Software implementation Develop and roll out



# Materiality

## What to Model?

Which risk factors material for current portfolio?

How can we assess materiality without exposure model in place?

## Approach

Simple estimation of exposure assuming

- future portfolio prices normally distributed
- estimation of first two moments

# Gaussian Approximation

Need to estimate  $\mathbb{E}[p(T)]$ ,  $\mathbb{E}[p^2(T_i)]$  at some future times  $T$ :  
Performing Taylor expansion for price  $p$  around expected risk factor:

$$\begin{aligned} p(\mathbf{x}(T), T) &\approx p(\mathbf{x}_0(T), T) + \sum_i \frac{\partial p(\mathbf{x}_0(T), T)}{\partial x_i} \Delta x_i(T) \\ &\quad + \frac{1}{2} \sum_{ij} \frac{\partial^2 p(\mathbf{x}_0(T), T)}{\partial x_i \partial x_j} \Delta x_i(T) \Delta x_j(T) \end{aligned}$$

$$\mathbf{x}_0(T) \equiv \mathbb{E}[\mathbf{x}(T)]$$

$$\Delta x_i(T) \equiv x_i(T) - x_{0,i}(T)$$

# Gaussian Approximation

The expectation value  $M$  of the price is hence

$$M(T) \approx p(\mathbf{x}_0(T), T) + \frac{1}{2} \sum_{ij} \gamma_{ij}(T) \Omega_{ij}(T)$$

$$M(T) \equiv \mathbb{E}[p(\mathbf{x}(T), T)]$$

$$\gamma_{ij}(T) \equiv \frac{\partial^2 p(\mathbf{x}_0(T), T)}{\partial x_i \partial x_j}$$

$$\Omega_{ij}(T) \equiv \mathbb{E}[\Delta x_i(T) \Delta x_j(T)]$$

For the variance  $V$  we obtain up to second order in  $\Delta \mathbf{x}$ :

$$V(T) \approx \sum_{ij} \delta_i(T) \delta_j(T) \Omega_{ij}(T)$$

$$V(T) \equiv \mathbb{E}[(p(\mathbf{x}(T), T) - \mathbb{E}[p(\mathbf{x}(T), T)])^2]$$

$$\delta_i(T) \equiv \frac{\partial p(\mathbf{x}_0(T), T)}{\partial x_i}$$

# Gaussian Approximation

What can we learn?

## Risk factor contributions

Matrix elements  $\Psi_{ij} = \delta_i(T)\delta_j(T)\Omega_{ij}(T)$  indicate contribution of risk factors  $ij$  to total variance.

## EE, PE

Knowing mean and variance of the Gaussian distribution, any statistical quantity may be evaluated.

## Caveat

Depending on specifics of portfolio this approximation may be more or less accurate: that is why we use Monte Carlo simulations after all.

# Practical Implementation

- For  $t = 0$ :  $\delta$  and  $\gamma$  from Market risk system. **But:** need netting set level aggregation  $\rightarrow$  deal level granularity
- For  $t > 0$  estimate future  $\delta$ ,  $\gamma$  by bumping

# Trade Models

## Requirements

- Represent trades/products
- Standardize for interoperability

# Trade Models

## Trade Parameters

Product represented by parameters

### FpML

```
<?xml version="1.0" encoding="UTF-8"?>
<FpML xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance" xmlns="http://www.fpml.org"
xsi:schemaLocation="http://www.fpml.org/2003/FpML-4-0 fpml-main-4-0.xsd">
  <trade>
    <tradeHeader>
      <partyTradeIdentifier>
        <partyReference href="CHASE"/>
        <tradeId tradeIdScheme="http://www.chase.com/swaps/trade-id">921934</tradeId>
      </partyTradeIdentifier>
      <partyTradeIdentifier>
        <partyReference href="UBSW"/>
        <tradeId tradeIdScheme="http://www.ubsw.com/swaps/trade-id">204334</tradeId>
      </partyTradeIdentifier>
      <tradeDate>2000-04-03</tradeDate>
    </tradeHeader>
    <swap>
      <!--
      Chase pays the floating rate every 6 months, based on 6M EUR-EURIBOR-Telerate
      + 10 basis points, on ACT/360 basis
      -->
      <swapStream>
        <payerPartyReference href="CHASE"/>
        <receiverPartyReference href="UBSW"/>
        <calculationPeriodDates id="floatingCalcPeriodDates">
          <effectiveDate>
            <unadjustedDate>2000-04-05</unadjustedDate>
            <dateAdjustments>
              <businessDayConvention>NONE</businessDayConvention>
            </dateAdjustments>
          </effectiveDate>
          <terminationDate>
            <unadjustedDate>2005-01-05</unadjustedDate>
          </terminationDate>
        </calculationPeriodDates>
      </swapStream>
    </swap>
  </trade>
</FpML>
```

# Trade Models

## Trade Parameters

### Pro/Con

- ⊕ standardized
- ⊖ logic in client



# Trade Models

## Cashflows

Product represented by casflows

### Payoff macros

<b>Notional</b>	100
<b>DCF</b>	Act/Act

<b>Date</b>	<b>Libor fixing</b>	<b>Payoff</b>
02-Mar-13	1.34%	0.335
02-Jun-13	1.19%	0.2975
02-Sep-13	1.42%	0.355
02-Dec-13	1.39%	0.3475

# Trade Models

## Cashflows

### Pro/Con

- ⊕ simple
- ⊖ not expressive enough (just cash is exchanged)
- ⊖ single product (no interactions)

# Trade Models

## Transaction Model

### Approach

Multi agent simulation:

Time Map wall clock to simulation time

Market Events simulation time to events

Transactions events to transactions (e.g. cashflows)

Execution execute events

### Pro/Con

- ⊕ general
- ⊕ all business logic in model → easy tooling
- ⊖ expensive

# Pricing & Risk Models

## Criteria for Model Choice

### Categories

Independent of product   Relate to Mathematics or Physics

Dependent of product   Specific to product type

Dependent of portfolio and market   Context

# Pricing & Risk Models

## Independent of Product

### Coordinate Systems

From Physics we know: dynamics must not depend on choice of coordinates → dimension analysis.

### Interpolation

How to interpolate  $r$ ,  $\sigma$ . Interpolate dimension-less quantities:  $rt$  and  $\sigma^2 t$ .

# Pricing & Risk Models

## Product Dependent

### State Variables vs. Parameters

**Liquidity** Hedge frequency, transaction costs, close-out period

**Completeness** Unhedgeable risk, uniqueness of price

# Pricing & Risk Models

## State Variables and Parameters

### Indicators of Model Quality

**Parameter Dimensionality** Avoid overparameterization

**Stability of Parameters** Frequent recalibration: indicator of poor model performance

### GBM w termstructure vs Garch

	<b>TS GBM</b>	<b>Garch</b>
<i>dimension</i>	$\infty$	3
<i>recalibration</i>	frequently for short end	less frequent
<i>time-homogeneous</i>	N	Y

# Pricing & Risk Models

## Arbitrage

### Risk Model for Volatility surface

Directly modelling surface w/o arbitrage not trivial. Alternatively model option prices with HJM-like framework.



# Pricing & Risk Models

## Market

### Liquidity & Completeness

**Liquidity** Hedge frequency, transaction costs, close-out period

**Completeness** Unhedgeable risk, uniqueness of price

# Comparing Models

Assume state of the world evolves randomly:

Model as Process: Stochastic Differential Equation (Langevin Equation)

$$\frac{dx}{dt} = f(\mathbf{x}) + g(\mathbf{x})\xi(t) \quad \text{Physics Notation}$$

$$dx = f(\mathbf{x})dt + g(\mathbf{x})d\mathbf{W}(t) \quad \text{Finance Notation}$$

Wiener Process (SDE)

$$dx = dW(t)$$

$W$  : Wiener Process

# Comparing Models

## Model as Measure $\mathbb{P}$

$\mathbb{P} : \Gamma \rightarrow \mu(\Gamma)$  probability

$\Gamma : t \rightarrow \mathbf{x}(t)$  some path

## Wiener Process (SDE)

$\Gamma \equiv \{x_1, \dots, x_N\}$

$\mu(\Gamma) \sim \prod_i G(x_i, x_{i+1})$

$G : \text{Gaussian}$

# Pricing & Risk Models

## Parametric Models

### Error Analysis

Infer from parameter uncertainty price/risk uncertainty.

**Parameter Uncertainty** E.g. such that hedging instrument prices still in bid-ask

**Parameter Error** Uncertainty of price/risk due to error in parameters

### GBM with vol uncertainty

$$(\Delta p)^2 = \left( \frac{\partial p}{\partial \sigma} \Delta \sigma \right)^2$$

# Benchmarking

Pricing/risk factor models  $\mathbb{Q}, \mathbb{Q}'$ , empirical measure  $\mathbb{P}$

## Comparing

Pricing Models  $\mathbb{Q}$  vs  $\mathbb{Q}'$

Risk Models  $\mathbb{P}$  vs  $\mathbb{Q}$

# Benchmarking

## Distances

### How far apart two models?

Need to define metric:

**Expectation values** E.g. differences of prices and EEs under different measures

**Distributions** E.g. Kullback-Leibler entropy  $\int \frac{d\mathbb{P}'}{\mathbb{P}} \log \frac{d\mathbb{P}'}{\mathbb{P}} d\mathbb{P}$ .  
Independent of quantity to average.

# Model Uncertainty

Benchmarking giving limited answer:

## Calibration-Consistent Measures

Define metric  $d$  to quantify goodness of calibration:

$p_i^{\mathbb{P}}$  : model price calibration instrument  $i$

$p_i$  : market price calibration instrument  $i$

$$d^{\mathbb{P}} = \sum_i (p_i^{\mathbb{P}} - p_i)^2$$

$$\mathcal{C}_{\epsilon} = \{\mathbb{P} | d^{\mathbb{P}} \leq \epsilon\}$$

# Model Uncertainty

## Non-uniqueness

For  $d = 0$ :

- Multiple measures
- For single parametric measure, multiple solutions for calibration  $\rightarrow$  ill behaved
- Incomplete market

For  $d > 0$ :

- For single parametric measure: parameter risk



# Beyond Benchmarking

Pricing model descriptive:

- Replicates prices of hedging instruments
- Determines no-arbitrage price of illiquid product

## How to assess quality of model?

There are implied predictions:

**State variables vs parameters** Prediction: parameters are constant

**Martingale** Total price of deal and self-financing hedges should be 0 at any point in time

# State variables and parameters

**State variables** Temporal evolution or measure

**Parameters** Family of evolutions/measures

## Analysis

- Choice of state variables: qualitative assessment
- Robustness of parameters: predicted are no changes

# Hedge Performance

If perfectly hedged: pathwise replication  $\rightarrow$  P&L distribution

- Unbiased
- Sharply peaked (Dirac)

## Hedge Simulations

**Self Consistency** Use state variables simulated with pricing model

**Performance** Historical state variables

# Exposure

## Goal

Estimate Credit Risk measures → need to estimate exposure/price distributions in future.

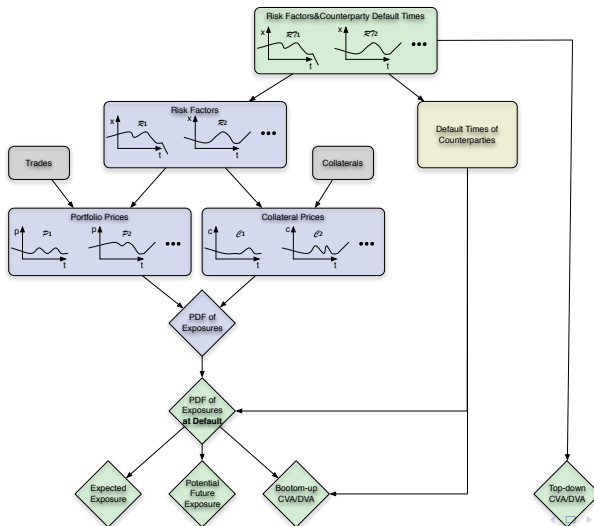
The exposure  $e(t)$  at time  $t$  of a netting set is given by

$$e(t) = \max 0, \sum_i p_i(\mathbf{x}, t) - C(t) \quad (2)$$

where

- $p_i$  price of trade  $i$
- $\mathbf{x}$  risk factors
- $C(t)$  price of collateral

# Calculating Exposure, CVA/DVA and Losses



# Building Blocks

## Components

Required for estimating risk measures for single and portfolios of netting sets:

- Pricing
- Risk-factor
- Collateral
- Netting
- Dependency

# Pricing Models

## Requirements

- Need to be fast!
- Ideally same as front office
- Perform well under stressed state variables

# Pricing Models

## Acceleration Techniques

### Dumb lookup

Approximate price as function of few variables

- define variables (e.g stock price)
- define grid
- recalculate for each gridpoint price
- interpolate



# Pricing Models

## Acceleration Techniques

### Smart lookup

Approximate price as function of few variables

- define variables (e.g stock price)
- prices on grid are **side effect** of pricing at spot; e.g. pricing on tree or AMC
- interpolate

# Risk Factor Models

## Pricing vs Risk Models

### Purpose

**Pricing Model** Fit liquid market instruments; arbitrage-free

**Risk Model** Predict

### Challenges for Risk Model

**Dependency** Simultaneously simulate all asset classes

**Calibration** Global calibration

# Risk Factor Models

## Short vs Long term prediction

Long term prediction a challenge:

- Reducing dimensionality
- Economic macro factors
- Co-integration

# Risk Factor Models

## Pricing model Dynamics

Arbitrage-free models used with risk calibration

- GBM
- HJM type of models
- ⊕ Well understood, tractable
- ⊖ Not intended for risk

# Gaussian Dependency Modelling

## Goal

Express random vector  $\xi$  with correlated  $\xi_i$  as

- linear combination of
- uncorrelated

random factors  $\eta_i$ :

$$\xi = \mathbf{M}\eta$$

$$\mathbb{E}[\xi_i \xi_j] - \mathbb{E}[\xi_i] \mathbb{E}[\xi_j] \equiv \Omega_{ij}$$

$$\mathbb{E}[\eta_i \eta_j] - \mathbb{E}[\eta_i] \mathbb{E}[\eta_j] = \lambda_i^2 \delta_{ij} \quad \text{diagonal, pos. sem. def.}$$

## What to consider?

- $\Omega$ ?
- correlation matrix?

# Principal Component Analysis

## Dimensional Analysis

Risk factors  $\xi_i$  not dimension-less!

- interest rate :  $[T^{-1}]$
- stock price : [Cash]
- volatility:  $[T^{-\frac{1}{2}}]$

→  $\Omega_{ij}$  may have different dimensions, i.e.  $\Omega$  in general not a physically meaningful quantity!

# Principal Component Analysis

## Solution

Consider instead of  $\Omega$  following matrix  $\Phi$ :

$$\Phi_{ij} \equiv \frac{\partial f(\xi)}{\partial \xi_i} \frac{\partial f(\xi)}{\partial \xi_j} \Omega_{ij}$$

$f$  : some function

For dimensionality  $[\Phi]$ :

$$[\Phi_{ij}] = \frac{[f]}{[\xi_i]} \frac{[f]}{[\xi_j]} [\xi_i][\xi_j] = [f^2] \quad \forall i, j \quad \checkmark \quad (3)$$

# GBM Risk Factor Model

## Multivariate GBM

$$X_i(t + \Delta t) = X_i e^{(\mu_i - \frac{1}{2}\sigma_i^2)\Delta t + \sigma_i \sqrt{\Delta t} \xi_i(t)}$$

$\mu$  : drift

$\sigma$  volatility

$\xi_i$  : Normal random

$$\text{Cov}(\ln X_i(t + \Delta t), \ln X_j(t + \Delta t)) = \Omega_{ij}$$



# Dependent Gaussian Random Variables

Given uncorrelated Gaussian random number vector  $\zeta$ . Need build  $\eta$ :

$$\text{Cov}(\eta_i, \eta_j) = \Omega_{ij}$$

# Calibration

## Definition

**Calibration** is the process to determine model parameters.

## Approaches

**Statistical** Using historical data

**Implied** Market implied parameters

**Economic** Macro economical relation between rates, infaltion

## Asumptions

**Statistical** Past is good predictor for future

**Implied** Information in spot market predicts future


**Economic** Some fundamental economic laws rule future

# Statistical Calibration

For simple models: ad hoc parameter estimation

- averaging
- fitting

## Example

SimpleEstimation.xls 

# Maximum Likelihood Estimation

Systematic way to calibrate

## Approach

Parametric model with parameters  $\alpha \leftrightarrow$  parametric measure  $\mu_\alpha$ :

$$\mu_\alpha(\Gamma) = e^{-S_\alpha(\Gamma)} \mathcal{D}[\Gamma]$$

Assume: historical path  $\Gamma_H$  is the most likely one. Find  $\alpha^*$  such that:

$$\mu_{\alpha^*}(\Gamma_H) = \max_{\alpha} \mu_{\alpha}(\Gamma_H)$$

# Maximum Likelihood Estimation

## Implementation

Assuming iid:

$$\begin{aligned}\mu_{\alpha}(\Gamma) &= \prod m(\mathbf{x}_i) \\ m(\mathbf{x}) &= e^{-s(\mathbf{x})} \\ \Gamma &= \{\mathbf{x}_1, \dots, \mathbf{x}_n\}\end{aligned}$$

Maximizing  $m \leftrightarrow$  minimizing

$$\sum_i s(\mathbf{x}_i) : \text{ log-likelihood}$$

# Maximum Likelihood Estimation

## Example

MLE.xls



# Implied Parameters

Apply parameters used for pricing:

## Drift and Volatility

- Drift  $\mu$  from  $T$  forward price (Covered Parity)
- Volatility  $\sigma$   $T$  years ATM implied volatility

## Assumption

Risk neutral measure yield good predictor for real-world measure

## Caveat

- Carry trades
- Supply/demand, risk premium


Perform analysis before using implied parameters!

# Economic Calibration

Parities connect for instance

- FX rates
- Inflation rates
- Real interest rates
- Nominal interest rates
- Purchasing power

## Example

Parities.xlsx 



# Parities

## Example (Relative Purchasing Power Parity)

$$p_f(t_1)(1 + i_f)X(t_2) = p_d(t_2)(1 + i_d)$$

$p_{d/f}$  : domestic/foreign price

$i_{d/f}$  : domestic/foreign 1 yr inflation rate

$X$  : Exchange rate

Yields after averaging

$$\frac{\mathbb{E}[X(t_2)]}{X(t_1)} = \frac{1 + I_d}{1 + I_f}$$

where  $I$  is the expected inflation rate.

# Parities

## Example (International Fisher Effect (Uncovered Parity))

$$(1 + r_{d/f}) = (1 + \rho_{d/f})(1 + i_{d/f})$$

$r_{d/f}$  : domestic/foreign nominal 1 yr interest rate

$\rho_{d/f}$  : real domestic/foreign 1 yr interest rate

Assuming  $\rho_d = \rho_f$  gives

$$\frac{\mathbb{E}[X(t_2)]}{X(t_1)} = \frac{1 + r_d}{1 + r_f}$$

# Issues with standard GBM model

## Issues

- rigidity: calibration short vs long horizons → term structure of parameters
- dimensionality → factor models
- underestimation of rare events and bursts (clustering) → GARCH
- not suitable where spread stationary process → cointegration
- unable to capture some behaviour like regime-switches → parametric models (Nelson-Siegel)

# GBM with Term Structure

## Interpolation Principles

Interpolate dimension-less quantities

## Forward Drift/Covariance

Dimensionality analysis  $\rightarrow$  interpolate  $T\Omega$

# Factor Models

## Issues with general covariance matrix

$N$  risk factors  $\rightarrow \propto N^2$  parameters

- over-parametrization
- for empirical parameters: problems with positive definiteness

## Idea

Split return  $r$  of riskfactors into contributions from

Indices  $f_n$  shared by multiple risk factors

Idiosyncratic factors  $\epsilon$  unique to each risk factor

$$r = \alpha + \sum_n \beta_n f_n + \epsilon$$

and assume

- indices uncorrelated to idiosyncratic

# Types of Factor Models

## Classification

**Macroeconomic** Observables like changes in inflation, interest rate, unemployment rate

**Fundamental** Portfolios associated to security attributes like industry membership, book to market ratio, dividends

**Statistical** Factor analysis of covariance matrix

# Macroeconomic Factor Model

## Fast/Slow

**Slow variables** Macro-economic state of the economy: inflation, unemployment rate, GDP

**Fast** Asset prices

## Pros and Cons


- ⊕ Designed to predict long-term evolution
- ⊕ Able to reflect systemic macro risks
- ⊖ Empirical evidence not convincing
- ⊖ Theories controversial

# Fundamental Factor Model

## Sector/Region

- 1 Define for each sector/region pair an index
- 2 Associate stock to sector/region
- 3 Regress stock return vs index return  $\rightarrow \alpha, \beta$

## Example

FactorModel.xls 

## Pros and Cons

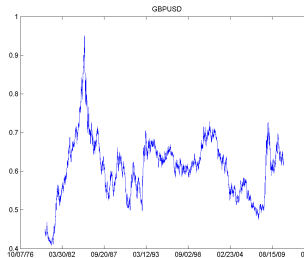
- ⊕ Designed to predict long-term evolution
- ⊕ Able to reflect systemic macro risks
- ⊖ Empirical evidence not convincing



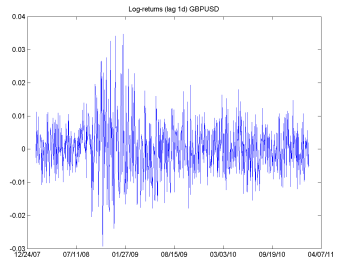
# Choice of Factors

How to know whether factors appropriate?  
Analyze variance explained by factors

# Volatility Clustering



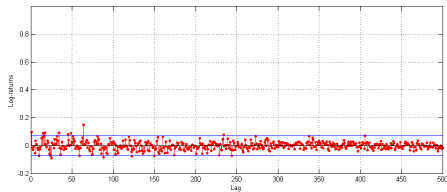
(a) Spot



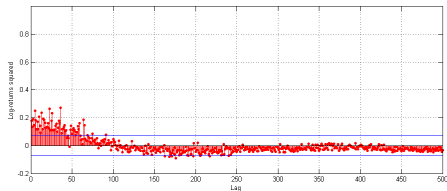
(b) Log-returns

Figure : GBPUSD spot

# Autocorrelation



(a) Autocorrelation: log-returns



(b) Autocorrelation: squared

# Garch Model

Let  $X_n$  be the log-return of some foreign exchange rate  $f$  at time  $t_n$ :

$$X_n = \ln \frac{f_n}{f_{n-1}} \quad (4)$$

we may then express the foreign exchange rate  $f_N$  at some future sampling point time  $t_N$  by the initial value  $f_0$  at  $t_0$  and a series of returns:

$$f_N = f_0 e^{\sum_{i=1}^N X_i} \quad (5)$$

The observation points  $t_i$  are typically defined in terms of number of business days  $\Delta T$  between them. For short time horizon predictions we choose  $\Delta T = 1$  for larger horizon, we may choose a less granular time grid.

# Garch Model

The dynamics of the returns is then assumed to follow a Garch(1,1) process

$$X_n = \mu + \epsilon_n \quad \epsilon_t \sim \text{iid}(0, \sigma_n^2) \quad (6)$$

$$\sigma_{n+1}^2 = \alpha + \beta \sigma_n^2 + \gamma \epsilon_n^2 \quad (7)$$

The asymptotic value  $\sigma_\infty^2 = \lim_{n \rightarrow \infty} \mathbb{E}[\sigma_n^2]$  is then obtained by equation (7) noting, that  $\mathbb{E}[\epsilon^2] = \sigma^2$  and  $\mathbb{E}[\sigma_{n+1}^2] \rightarrow \mathbb{E}[\sigma_n^2]$ :

$$\sigma_\infty = \frac{\alpha}{1 - \beta - \gamma} \quad (8)$$

# Garch Model: Limit

Weak limit:

- Stochastic variance
- Mean reverting variance

$$\begin{aligned}dX_t &= \mu X_t dt + \sqrt{v_t} X_t dW_t \\dv_t &= \alpha(v_t) dt + \beta(v_t) dZ_t\end{aligned}$$

# Copula

## Dependence under Stress

In stressed markets correlations increase between

- downward price movements → systematic risk
- implied default probabilities → contagion

## Definition (Copula)

Separate

- Marginal distributions from
- Dependency

# Cointegration

## Long-run Relationship

Variables moving together:

- Macro-economic**
- Consumption-Income
  - Prices-Wages
  - Domestic prices - foreign prices

**Exogeneous** For instance managed currencies

- How to model processes. which stay close to each other?
- GBM with  $\rho_{ij} \approx 1$  **not**? No!
- Need dynamic, where difference is stationary

## Definition


Stochastic processes  $x, y$  are cointegrated:



# Implementation

- 1 find parameters  $a$ ,  $b$  by regression
- 2 show residuals are stationary (e.g. Dickey-Fuller Test)

## Example

Cointegration.xlsx 

# Risk Factor Models

## Empirical Models

### Nelson-Siegel model

$$r(T) = r_{\infty} + a(T)r_0 + b(T)r_m$$

$r_{\infty}$  : rate for long maturities

$r_0$  : rate for short maturities

$r_m$  : rate for intermediate maturities

$a, b$  : decay functions

# Risk Factor Models

## Empirical Models

### Nelson-Siegel model

- Normal/inverted curves
- **But** not arbitrage-free

How to introduce dynamics? E.g. PCA of  $(r_\infty, r_0, r_m)$

### Example

NelsonSiegel.xlsm 

# Wrong Way Risk

## Types

**Specific** Legal connection between underlying and counterparty

**General** Dependence between prob. of default of counterparty and exposure

## SFT Transactions

Lend cash to counterparty A accepting their stock as collateral.

## Emerging Market CCY swap

We are long strong currency. Weakening of emerging market currency, increased prob default → increase exposure

# Modelling Wrong Way Risk

What is wrong with standard modelling?

$p^+$  is **not** conditioned on default.

Need to add in price function default state  $\chi$  of counterparty:


**extending state of the world**

## Approaches

Given a model for default times either

- Simulating counterparty's default
- Calculating price given default

## Example

WrongWayRisk.xls 

# Collateral Modeling

## Components

**Margin Call Process** Model margin calls with correct frequency and close-out period

**Collateral Price** E.g. model bond price if collateral is bond

### Simplification

- Margin call process: just at spot → short-cut method
- All collateral as cash → haircuts

# Collateral Modeling

## Short-Cut Method

### Definition (Basel II Short-Cut Method)

EE and PE of collateralized trades given by EE and PE for close-out period (5 days for SFT, 10d for OTC)

### Benefits/Issues

- ⊕ Computationally cheap
- ⊕ No collateral exposure spikes at expiry
- ⊖ Assumes exposures declining over time
- ⊖ Risk not accurately represented

# Dependency Modelling

## Among Risk Factors

Standard way to model dependence: Gaussian Copula.  
Gaussian Copulas are Levy copulas. Replace Gaussian with other Levy coupula and obtain Levy model.

## Between Defaults

Simulate either

Default times  $\tau$  E.g. by Marshall-Olkin Copulas

Default state at  $t$ :  $\chi_{\tau \leq t}$  E.g. structural models




# Dependency Modelling

## Between a Default and Risk Factors

To capture Wrong Way risk need to model dependence between risk factor and default state

## Example

WrongWayRisk.xls 

## Between a cross name Defaults and Risk Factors

Need modelling full state of the world  $(\mathbf{x}(t), \{\chi_{\tau_1 \leq t}, \dots, \chi_{\tau_1 \leq t}\})$ .  
→ **scenario consistency** is system

# Model Lifecycle

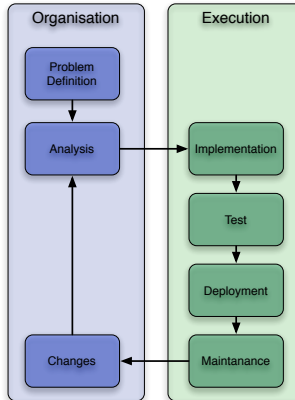


Figure : Model Development Lifecycle

# Specification

## Approaches

Human readable Business and functional specs

Machine readable Specification  $\sim$  test

# Specification Tools

## ScalaTest Code

```
class LookupSpec extends WordSpec with MustMatchers {  
  def fixture = new {  
    val i1 = Identifier[Double]("abc")  
    val i2 = Identifier[Double]("xyz")  
    val i3 = Identifier[Double]("ABC")  
    val x1 = 12.3  
    val x2 = 4.56  
    val l = Lookup(i1 -> x1, i2 -> x2)  
  }  
  
  "A Lookup" when {  
    "item exists" must {  
      "retrieve with () the item" in {  
        val f = fixture  
        val y1 = f.l(i1)  
        y1 must equal(f.x1)  
        val y2 = f.l(i2)  
        y2 must equal(f.x2)  
      }  
      "retrieve with get() an Option object containing the item" in {  
        val f = fixture  
        val y1 = f.l.get(f.i1)  
        y1 must not be Option.empty  
        y1.get must equal(f.x1)  
        val y2 = f.l.get(f.i2)  
        y2 must not be Option.empty  
        y2.get must equal(f.x2)  
      }  
    }  
  }  
}
```

# Specification Tools

## ScalaTest Output

### Part of CI:

The screenshot displays a web interface for a CI system. At the top, there's a navigation bar with links: Dashboard, Authors, Reports, and Administration. Below this, a breadcrumb trail shows 'Virtufin > Core > #13'. A status bar on the right shows four green checkmarks. The main content area is divided into a left sidebar and a main panel. The sidebar lists 'Stages & Jobs' with items: Compile, Test (highlighted), and Install. The main panel shows 'Job: Test was successful' and 'Test Results'. It indicates '21 tests in total' and '1 second taken in total'. A summary shows 'Failed Tests' (0) and 'Successful Tests (21)'. Below this, it states 'The following 21 tests have passed:' and lists 'All Successful Tests' with a table of test results.

Test
✓ ForeignExchangeRateSpec A ForeignExchangeRate should equal to a Price with the same asset <a href="#">🔗</a>
✓ ForeignExchangeRateSpec A ForeignExchangeRate should have the same hashCode as the corresponding Price <a href="#">🔗</a>
✓ ScenarioSpec A Scenario when must <a href="#">🔗</a>
✓ PortfolioHierarchyAgentSpec A PortfolioHierarchyAgent should add and subtract the correct position amounts from the source and target portfolios <a href="#">🔗</a>
✓ FeatureSpec A Feature when must <a href="#">🔗</a>
✓ PlainVanillaPayoffSpec A PlainVanillaPayoff when fixing has value must at maturity create a payment message <a href="#">🔗</a>

# Implementation

## Software

- in-house
- third-party

Require different validation strategies

# Third Party

## Strategies

- Black-box, no code review
- Reverse-engineering

# Revision Control

## Requirements

**Audit** Who changed what/when

**Resurrect** Roll-back to previous state

**Collaborate** Merge contributions from different authors

## Approaches

**Plain files** Tag files/directories with version information

**Local** Local database contains version information (e.g. RCS)

**Server** Database on server (e.g. SVN)

**Distributed** Each developer has own database with potentially central db (e.g. Git)



# Revision Control Tools

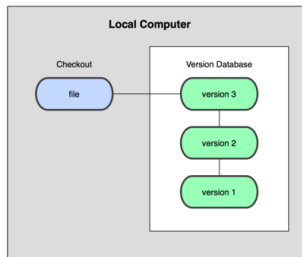
## Approaches

MyDirectoryV1.0

MyDirectoryV1.1

MyDirectoryV1.2-bugfix1

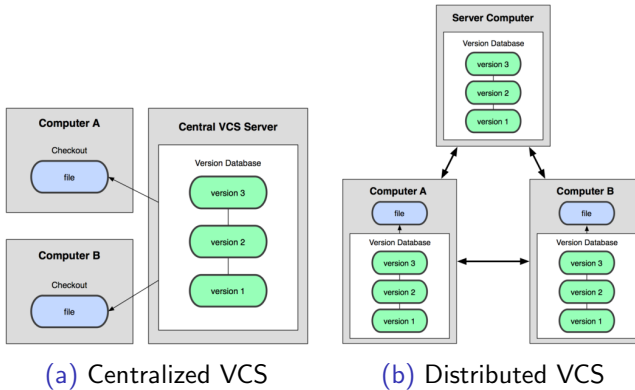
(a) File based



(b) Local VCS

# Revision Control Tools

## Approaches



# Revision Control Tools

## Git

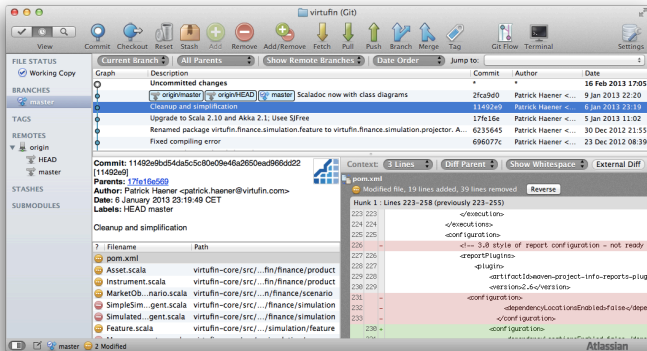


Figure : Git Gui (SourceTree)

# Documentation

## Requirement

Contain enough information to reverse-engineer.

## Tools

- Automated API doc (*Doxygen*, *ScalaDoc*, ...)
- Internal wiki (e.g. *Confluence*)

# Testing

## Test Types

Unit Library level

Integration System level

# Testing

## Unit Test

```
class BlackScholesScenarioModelTest {
  @Test
  def test() {
    val marketObservable = Price(Stock("IBM"), Currency.USD)
    val modelDate = Time(2012, 10, 1)
    val t1 = Time(2013, 10, 1)
    val t2 = Time(2015, 10, 1)
    val t3 = Time(2022, 10, 1)
    val ts = List(t1, t2, t3)
    val scenarioObservables = ts.map(t => Index(t, marketObservable))
    val x0 = 100.0
    val scenario = Scenario(marketObservable, modelDate -> x0)
    val mu = 0.01
    val sigma = 0.4
    val blackParameters = BlackParameters(mu, sigma)
    val blackParametersId = BlackParameters.identifier(marketObservable)
    val parameters = Lookup(blackParametersId -> blackParameters)
    val request = ScenarioRequest(scenarioObservables, scenario, modelDate)
    val context = ModelContext(ModelDispatcher(ModelRegistry()), parameters)
    val model = new BlackScholesScenarioModel()
    val result = model.model(request, context)
    assertTrue(result.isSuccess)
    val iterable = result.toOption.get
    val n = 1000000
    var x = 0.0
    var x2 = 0.0
    val o = scenarioObservables.last
    Timing.timing(iterable, {s: Scenario => {
      val a = s(o); x = x + a; x2 = x + a * a
    }, n)
    assertEquals(x0 * math.exp(mu * DateUtil.yearsBetween(modelDate, o.time)), x / n, 0.5)
  }
}
```

# Release

## Requirements

- Regression
- Impact analysis
- Sign-off
- Auditing
- Lock-down

# Maintenance

## Bugs/Enhancements

- Tracking system
- Failing test cases
- Metrics: severity, resolution time



# Integrated Development Process

Robust system should have

## Components

- Revision Control system
- Build System
- Bug tracking system
- Wikin

Components integrated to workflow with high degree of  
**automation**

# Overview

- 1 Credit Risk Measures
- 2 Credit Risk Mitigation
- 3 Model Implementation
- 4 Back Testing**
- 5 Regulatory Requirements and Basel III

# Motivation

## Impact of Credit risk model

Trading activity limits set by  $PE$

Capital charges regularity capital dependent of  $EEPE$

P&L  $EE$  enters CVA/DVA

## Model Risk

Back-testing should quantify model risk affecting these quantities.

# Requirements

## Back-testing Process

Should provide

Definition of measure for model risk

Monitoring of metrics

Mitigating actions for model deficiencies

# BCBS Guidance

## G1

**Guidance:** Backtesting of forecast distributions produced by EPE models and market risk factor models needs to be performed on the entire forecast distribution.

## G2

**Guidance:** The validation requirements as set out in Basel II for EPE Models should not make reference to VaR requirements and instead the qualitative standards set out in paragraph 718 (LXXIV) should be transposed into the validation requirements for EPE models and the language adapted where required.

## G3

**Guidance:** The Validation of EPE models and all the relevant models that input into the calculation of EPE must be performed separately for a number of distinct time horizons.

## BCBS Guidance

### G4

**Guidance:** The performance of market risk factor models must be validated using backtesting. The validation must be able to identify poor performance in individual risk factors.

### G5

**Guidance:** The validation of EPE models and all the relevant models that input into the calculation of EPE must be made using forecasts initialised on a number of historical dates.

### G6

**Guidance:** Historical backtesting on representative counterparty portfolios and market risk factor models must be part of the validation process. At regular intervals as directed by its supervisor, a bank must conduct backtesting on a number of representative counterparty portfolios and its market risk factor models. The representative portfolios must be chosen based on their sensitivity to the material risk factors and correlations to which the bank is exposed.

## BCBS Guidance

### G7

**Guidance:** Backtesting of EPE and all the relevant models that input into the calculation of EPE must be based on recent performance.

### G8

**Guidance:** The frequency with which the parameters of an EPE model are updated needs be assessed as part of the on-going validation process.

### G9

**Guidance:** Firms need to unambiguously define what constitutes acceptable and unacceptable performance for their EPE models and the models that input into the calculation of EPE and have a written policy in place that describes how unacceptable performance will be remediated.

# BCBS Guidance

## G10

**Guidance:** Firms need to define what constitutes a representative counterparty portfolio for the purposes of carrying out EPE model backtesting.

## G11

**Guidance:** IMM firms need to conduct hypothetical portfolio backtesting that is designed to test risk factor model assumptions, eg the relationship between tenors of the same risk factor, and the modelled relationships between risk factors.

## G12

**Guidance:** Firms need to assess whether or not the firm level and netting set level exposure calculations are appropriate.



## BCBS Guidance

### G13

**Guidance:** Firms must backtest their EPE models and all relevant models that input into the calculation of EPE out to long time horizons of at least one year.

### G14

**Guidance:** Firms must validate their EPE models and all relevant models that input into the calculation of EPE out to time horizons commensurate with the maturity of trades covered by the IMM waiver.

### G15

**Guidance:** Prior to implementation of a new EPE model or new model that inputs into the calculation of EPE a firm must carry out backtesting of its EPE model and all the relevant models that input into the calculation of EPE at a number of distinct time horizons using historical data on movements in market risk factors for a range of historical periods covering a wide range of market conditions.

# BCBS Guidance

## G16

**Guidance:** Under the internal model method, a measure that is more conservative than Effective EPE (eg a measure based on peak rather than average exposure) for every counterparty may be used in place of alpha times EEPE with the prior approval of the supervisor. The degree of relative conservatism will be assessed upon initial supervisory approval and at regular intervals in conjunction with other EPE models. The assessment needs to cover all counterparties. The firm must have an unambiguous definition of what constitutes acceptable performance for these models and a documented process in place for remediating poor performance.

# What is the Question?

## Types of Investigation

- Hypothesis testing (Answer in percentage or yes/no)
- Estimation of model uncertainty (Answer in cash terms)

Analysis at different levels: figure 7

# Domains

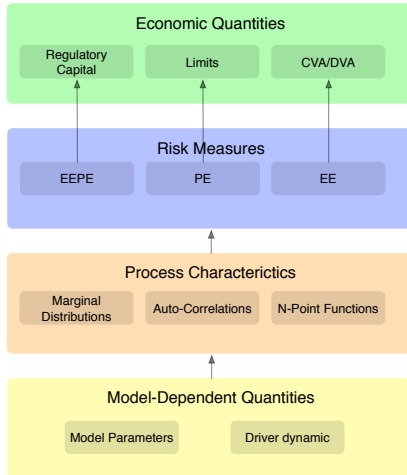


Figure : Domains

## Definition

A model is represented by a measure  $\mathbb{Q}$ .

May be generated by a stochastic process.

## Quantifying Difference of Models

- Comparing expectation values
- Comparing probability distributions

Note: PDFs and CDFs may be expressed as expectation values

# Radon-Nikodym Derivative

Distance of model  $\mathbb{Q}$  and end empirical measure  $\mathbb{P}$  in terms of  $\frac{d\mathbb{P}}{d\mathbb{Q}}$ :

$$\mathbb{E}_{\mathbb{P}}[f] = \mathbb{E}_{\mathbb{Q}}\left[\frac{d\mathbb{P}}{d\mathbb{Q}} f\right] \quad (9)$$

## Compare $\mathbb{P}$ and $\mathbb{Q}$

Direct  $\frac{d\mathbb{P}}{d\mathbb{Q}} \approx id?$

**Expectation values** Empirical expectation measures in terms of model expectations

**Relative Entropy** Kullback-Leibler entropy  $\rightarrow$  information geometry (see [?])

# Radon-Nikodym Derivative

Let  $\xi$  be a scalar stochastic variable (e.g. portfolio price  $\pi(t)$ )

## Definition

$P$  empirical,  $Q$  model CDF

$$\Psi : [0, 1] \rightarrow [0, 1] \quad (10)$$

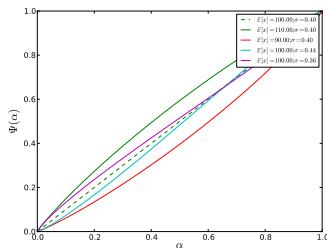
$$\Psi(\alpha) = P(Q^{-1}(\alpha)) \quad (11)$$

## Radon-Nikodym derivative $\psi$

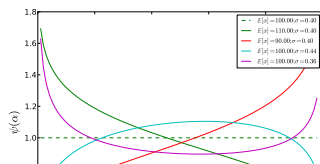
$$\mathbb{E}_P[f] = \mathbb{E}_Q[\psi(\alpha)f] \quad (12)$$

$$\psi(\alpha) = \frac{d\Psi(\alpha)}{d\alpha} \quad (13)$$

# Example



(a)





# Cumulative Distribution Functions

Cumulative distribution function (CDF) for some state variable  $\xi$  expressed as expectation:

## Definition

$$P(\xi_0) = \mathbb{E}_{\mathbb{P}}[\Theta(\xi - \xi_0)] \quad (14)$$

where  $\Theta$  is the Heaviside function.

# Estimating

Ensemble averages  $\mathbb{E}$  estimated well by time averages if

- ergodic
- stationary

CDF

$$P(\xi_0) \approx \frac{1}{N} \sum_{i=1}^N \Theta(\xi(t_i) - \xi_0) \quad (15)$$

$\Psi$

$$\Psi(\alpha) \approx \frac{1}{N} \sum_{i=1}^N \Theta(\xi(t_i) - Q^{-1}(\alpha)) \quad (16)$$

# Requirements for Estimation

Process needs to be

- ergodic
- stationary

iid price process

If empirical price process is iid, the ergodic.

iid process of underlying

Even if underlying process the price return process of the deal may not be so, if deal not time homogeneous

# Distances

## Point Distance

$$d_i = |\Psi(q_i) - q_i| \quad (17)$$

## Curve Distance

(Weighted) quadratic distance  $d$  between functions  $q \rightarrow \Psi(q)$  and  $q \rightarrow q$ :

$$d(q, \Psi(q)) = \sum_i w_i (\Psi(q_i) - q_i)^2 \quad (18)$$

$q_i$  e.g. (0.01, 0.05, 0.3, 0.5, 0.7, 0.95, 0.99)

# Hypothesis Testing

## Null-Hypothesis

- Null-Hypothesis, is that distances are 0.
- Reject Null-Hypothesis  $p$ -values smaller than some threshold

## Challenges estimating $p$ -values

- Temporal dependence: overlap of time-windows
- Ensemble dependence: returns of netting sets not independent

Good  $p$  values get bigger

Bad Estimation tricky

Need some simplifications, like effective sample sizes

# Problems using metrics for $\Psi$

## Issues using metrics for $\Psi$

**Opaque** no cash denominated measure

**Economics Product Dependent** with same distance different moments drive deviations in EE (see figure (9))

**Limited usefulness** Passes test if not enough data available

# Problems using metrics for $\Psi$

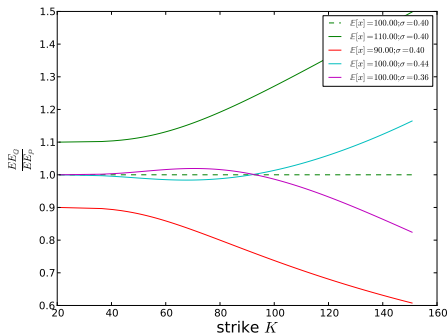


Figure : Comparing  $EEs$  for a forward using log-normal distributions with different parameters

# Comparison using Cash denominated Quantities

## Economically Relevant Model Dependent Quantities

Regulatory Capital depends on  $EE(t)$  (through EEPE)

Limits impacted by CDF

P&L impacted by  $EE(t)$

## Measure

These three quantities are functions of  $\mathbb{E}_Q$ .

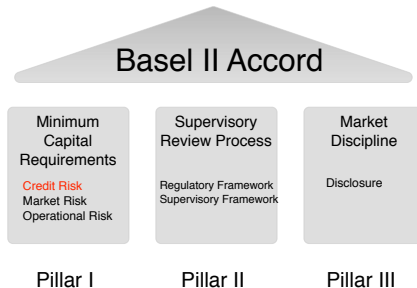
Their value under empirical measure  $\mathbb{P}$  estimated through equation (12)  $\rightarrow$  difference in cash terms



# Overview

- 1 Credit Risk Measures
- 2 Credit Risk Mitigation
- 3 Model Implementation
- 4 Back Testing
- 5 Regulatory Requirements and Basel III

# Pillars of Basel II Framework



# Basel II

## Capital Charges

- Based on Expected Exposures (EE) of netting sets
- Charge for default risk
- No charge for credit spread risk

# New in Basel III

In 2008 crisis:

- $\frac{2}{3}$  of losses **not** due to default but **MtM changes** due to credit spread widening
- Capture spread risk by VaR
- Introduction of new capital charge linked to VaR: CVA charge

## Capital Charges

Basel II Default charges

Basel III Default and **CVA charges**

# CVA charge

## Advanced CVA Charge

### VaR for credit spread for **bond** given by EE:

A. Banks with IMM approval and Specific Interest Rate Risk VaR model<sup>34</sup> approval for bonds: Advanced CVA risk capital charge

98. Banks with IMM approval for counterparty credit risk and approval to use the market risk internal models approach for the specific interest-rate risk of bonds must calculate this additional capital charge by modelling the impact of changes in the counterparties' credit spreads on the CVAs of all OTC derivative counterparties, together with eligible CVA hedges according to new paragraphs 102 and 103, using the bank's VaR model for bonds. This VaR model is restricted to changes in the counterparties' credit spreads and does not model the sensitivity of CVA to changes in other market factors, such as changes in the value of the reference asset, commodity, currency or interest rate of a derivative. Regardless of the accounting valuation method a bank uses for determining CVA, the CVA capital charge calculation must be based on the following formula for the CVA of each counterparty:

$$CVA = (LGD_{MKT}) \cdot \sum_{i=1}^T \text{Max} \left( 0; \exp \left( -\frac{s_{i-1} \cdot t_{i-1}}{LGD_{MKT}} \right) - \exp \left( -\frac{s_i \cdot t_i}{LGD_{MKT}} \right) \right) \cdot \left( \frac{EE_{i-1} \cdot D_{i-1} + EE_i \cdot D_i}{2} \right)$$

$$\text{Regulatory CS01}_i = 0.0001 \cdot t_i \cdot \exp \left( -\frac{s_i \cdot t_i}{LGD_{MKT}} \right) \cdot \left( \frac{EE_{i-1} \cdot D_{i-1} - EE_{i+1} \cdot D_{i+1}}{2} \right)$$

# CVA charge

## Standardised CVA Charge

$$K = 2.33 \cdot \sqrt{h} \cdot \sqrt{\left( \sum_i 0.5 \cdot w_i \cdot (M_i \cdot EAD_i^{\text{total}} - M_i^{\text{hedged}} B_i) - \sum_{ind} w_{ind} \cdot M_{ind} \cdot B_{ind} \right)^2 + \sum_i 0.75 \cdot w_i^2 \cdot (M_i \cdot EAD_i^{\text{total}} - M_i^{\text{hedged}} B_i)^2}$$

Where

- $h$  is the one-year risk horizon (in units of a year),  $h = 1$ .
- $w_i$  is the weight applicable to counterparty 'i'. Counterparty 'i' must be mapped to one of the seven weights  $w_i$  based on its external rating, as shown in the table of this paragraph below. When a counterparty does not have an external rating, the bank must, subject to supervisory approval, map the internal rating of the counterparty to one of the external ratings.
- $EAD_i^{\text{total}}$  is the exposure at default of counterparty 'i' (summed across its netting sets), including the effect of collateral as per the existing IMM, SM or CEM rules as applicable to the calculation of counterparty risk capital charges for such counterparty by the bank. For non-IMM banks the exposure should be discounted by applying the factor  $(1 - \exp(-0.05 \cdot M_i)) / (0.05 \cdot M_i)$ . For IMM banks, no such discount should be applied as the discount factor is already included in  $M_i$ .
- $B_i$  is the notional of purchased single name CDS hedges (summed if more than one position) referencing counterparty 'i', and used to hedge CVA risk. This notional amount should be discounted by applying the factor  $(1 - \exp(-0.05 \cdot M_i^{\text{hedged}})) / (0.05 \cdot M_i^{\text{hedged}})$ .
- $B_{ind}$  is the full notional of one or more index CDS of purchased protection, used to hedge CVA risk. This notional amount should be discounted by applying the factor  $(1 - \exp(-0.05 \cdot M_{ind})) / (0.05 \cdot M_{ind})$ .
- $w_{ind}$  is the weight applicable to index hedges. The bank must map indices to one of the seven weights  $w_i$  based on the average spread of index 'ind'.
- $M_i$  is the effective maturity of the transactions with counterparty 'i'. For IMM-banks,  $M_i$  is to be calculated as per Annex 4, paragraph 38 of the Basel Accord. For non-IMM banks,  $M_i$  is the notional weighted average maturity as defined in the third bullet point of Annex 4, paragraph 38 of the Basel Accord.

# CVA charge

## Advanced vs Standardised

	Advanced	Standardized
<i>Reflect Diversification</i>	⊕	⊖
<i>Accurate Credit Spreads</i>	⊕	⊖
<i>Regulatory Capital</i>	⊕	⊖
<i>Build/Approval Costs</i>	⊖	⊕
<i>Running Costs</i>	⊖	⊕
<i>Synergies with Market Risk</i>	⊕	⊖
<i>Integration with CVA desk</i>	⊕	⊖

# IMM

## Internal Model Method

Institutions who have IMM waiver may calculate their own regulatory capital for

**OTC transactions** Swaps, exotic deals, ...

**SFT transactions** Bond repos, stock borrow/lending, ...



# IMM

## Benefits

- Reduced capital charges
- More accurate risk measures
- Consistent risk measures for
  - Regulatory capital
  - Limit monitoring
- Improved
  - Processes
  - Quality of information

# Wrong Way Risk

## Specific Wrong Way Risk

58. A bank is exposed to “specific wrong-way risk” if future exposure to a specific counterparty is highly correlated with the counterparty’s probability of default. For example, a company writing put options on its own stock creates wrong-way exposures for the buyer that is specific to the counterparty. A bank must have procedures in place to identify, monitor and control cases of specific wrong way risk, beginning at the inception of a trade and continuing through the life of the trade. To calculate the CCR capital charge, the instruments for which there exists a legal connection between the counterparty and the underlying issuer, and for which specific wrong way risk has been identified, are not considered to be in the same netting set as other transactions with the counterparty. Furthermore, for single-name credit default swaps where there exists a legal connection between the counterparty and the underlying issuer, and where specific wrong way risk has been identified, EAD in respect of such swap counterparty exposure equals the full expected loss in the remaining fair value of the underlying instruments assuming the underlying issuer is in liquidation. The use of the full expected loss in remaining fair value of the

# Wrong Way Risk

## Stressed Calibration

### 1. ***Revised metric to better address counterparty credit risk, credit valuation adjustments and wrong-way risk***

*Effective EPE with stressed parameters to address general wrong-way risk*

98. In order to implement these changes, a new paragraph 25(i) will be inserted in Section V (Internal Model Method: measuring exposure and minimum requirements), Annex 4, of the Basel II framework and the existing paragraph 61 of Annex 4 will be revised as follows for banks with permission to use the internal models method (IMM) to calculate counterparty credit risk (CCR) regulatory capital – hereafter referred to as “IMM banks”:

25(i). To determine the default risk capital charge for counterparty credit risk as defined in paragraph 105, banks must use the greater of the portfolio-level capital charge (not including the CVA charge in paragraphs 97-104) based on Effective EPE using current market data and the portfolio-level capital charge based on Effective EPE using a stress calibration. The stress calibration should be a single consistent stress calibration for the whole portfolio of counterparties. The greater of Effective EPE using current market data and the stress calibration should not be applied on a counterparty by counterparty basis, but on a total portfolio level.

# Stressed Calibration

## Frequency of Comparison

- How often is **Effective EPE** using current market data to be compared with **Effective EPE** using a stress calibration? and
- How this requirement is to be applied to the use test in the context of credit risk management and CVA (eg can a multiplier to the **Effective EPE** be used between comparisons)?

The frequency of calculation should be discussed with your national supervisor.

The use test only applies to the **Effective EPE** calculated using current market data.

# Hedges

## CVA Charges

103. The only eligible hedges that can be included in the calculation of the CVA risk capital charge under paragraphs 98 or 104 are single-name CDSs, single-name contingent CDSs, other equivalent hedging instruments referencing the counterparty directly, and index CDSs. In case of index CDSs, the following restrictions apply:

- The basis between any individual counterparty spread and the spreads of index CDS hedges must be reflected in the VaR. This requirement also applies to cases where a proxy is used for the spread of a counterparty, since idiosyncratic basis still needs to be reflected in such situations. For all counterparties with no available spread, the bank must use reasonable basis time series out of a representative bucket of similar names for which a spread is available.
- If the basis is not reflected to the satisfaction of the supervisor, then the bank must reflect only 50% of the notional amount of index hedges in the VaR.

# Hedges

## Default Charges

### I. Default counterparty credit risk charge

1. With respect to identifying eligible hedges to the CVA risk capital charge, the Basel III provisions state that “tranching or nth-to-default CDSs are not eligible CVA hedges” (Basel III document, para 99 - inserting para 103 in Annex 4 of the Basel framework). Can the Basel Committee confirm that this does not refer to tranching CDS referencing a firm’s actual counterparty exposures and refers only to tranching index CDS hedges?

Also, can the Committee clarify that Risk Protection Agreements, credit linked notes (CLN), short bond positions as credit valuation adjustment (CVA) hedges, and First Loss on single or baskets of entities can be included as eligible hedges?

All tranching or nth-to-default credit default swaps (CDS) are not eligible. In particular, credit linked notes and first loss are also not eligible. Single name short bond positions may be eligible hedges if the basis risk is captured. When further clarifications are needed, banks should consult with supervisors.

# Collateral

## Non Cash Collateral for OTC

108. To implement the supervisory haircuts for non-cash OTC collateral, a new paragraph 61(i) would be incorporated in Annex 4 as follows:

61(i). For a bank to recognise in its EAD calculations for OTC derivatives the effect of collateral other than cash of the same currency as the exposure itself, if it is not able to model collateral jointly with the exposure then it must use either haircuts that meet the standards of the financial collateral comprehensive method with own haircut estimates or the standard supervisory haircuts.

## Other

### Proxy, Index Hedges

14. The revised CCR rules in the Basel III document include a number of areas that have not previously received regulatory scrutiny. Does the Basel Committee consider that supervisory approvals will be required for Basel III, specifically in the areas of:

- Proxy models in respect of CDS spread used where no direct CDS available;
- Applicability of index hedges to obtain the base 50% offset of the new CVA charge;
- If the basis risk requirement for index hedges is sufficient to satisfy the supervisor, will this automatically enable a 100% offset or is it intended to be a sliding scale between 50% and 100%;
- Overall system and process infrastructure to deliver the Basel III changes, even if covered by existing approved models and processes;
- Choice of stress periods to ensure industry consistency. In this regard, for VaR calculation purposes how should the one year period within the three year stress period be identified;
- The fundamental review of the Trading Book will include further analysis of the new CVA volatility charge. Is there any indication as to implementation date and, in the meantime, should CVA market risk sensitivities be included in the firm's VAR calculation.

The use of an advanced or standardised CVA risk capital charge method depends on whether banks have existing regulatory approvals for both IMM and specific risk VaR model. Supervisors will review each element of banks' CVA risk capital charge framework based on each national supervisor's normal supervisory review process.



# Elements of Application

- A High-level overview and implementation plans
- B Overview of your firm's own self assessment against relevant standards
- C Summary of your firm's approach in a number of key areas
- D Details of the IMM models being used
- E Sign-off

# Overview/Implementation Plan

- Impact Analysis
- Scope
- Rollout Plan
- Orgchart

# Self Assessment

- Description of self ssessment process
- Results: exceptions, remediation plan and status

# Firm's Approach

## Governance of Counterparty Risk

- Roles of senior management, risk functions, audit functions, legal functions, collateral management functions, and the functions of any committees
- Governance of the model, covering the organisation charts and reporting lines of the model owner, developers, and other support functions; an overview of the management committee structure which approved the model and; how external vendor models, if any, are controlled;
- ad-hoc and on going stress testing.

## Firm's Approach

### Requirement for use of IMM

- Show methodology used for the calculation of the IMM exposure is closely integrated into its day-to-day risk management processes.
- Management information where the IMM generated exposure and any other outputs from the methodology is presented
- Management information used by senior management to monitor and control counterparty and market risk including the composition / profile of the portfolios, concentration risk, wrong way risk and the results of stress testing

# Firm's Approach

## Data Management and Integrity

- Standards of data management; data architecture
- Process to ensure the accuracy, completeness and appropriateness
- Timeliness and robustness of the production systems
- Reconciliation finance and risk systems
- Business continuity

# Firm's Approach Validation

- Accountability, independence, scope, documentation and monitoring the effectiveness of the model on an ongoing basis
- Explanation of how senior management obtain comfort that the outputs from the IMM model are sufficiently robust for the business
- Summary of your approach to back testing, including the methodology and assessment of the results

# Firm's Approach Documentation

- List of all the internal documents you hold that you consider relevant to the application, including a brief description of their contents. Relevant documentation would cover documentation specific to the IMM as well as the controls surrounding it



## Details of the IMM models being used

- A description of the model coverage, in terms of businesses units, products and risk factors
- Documents relevant to the IMM, with dates when last updated. Including any pre-processing performed on transaction level information, features of the model, assumptions used, use of proxies, approximations, limitations of the output, modelling of risk factors, modelling of collateral and netting and, treatment of margins
- Use of market data
- Valuation analytics including assessment of how assumptions and approximations impact accuracy of the models

## Details of the IMM models being used

- Assessment of the model's fitness for purpose in the light of the risks presented by the portfolio (e.g. correlation between counterparties' exposures, wrong way risk)
- Analysis performed on an ad hoc or on going basis to monitor model performance
- Materiality, of any relevant risk factors not covered by the IMM
- Validation reports
- Enhancement plans