CVA and CCR:

Approaches, Similarities, Contrasts, Implementation

Part 4. Implementation and daily operations. Comparisons and contasts.

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Outline

CVA as exotic portfolio derivative

CVA pricing steps and infrastructure design

- Introduction
- Pricing CVA as an FTD
- Application of collateral and netting
- FMTM generation
- Preprocessing and model calibration

CCR infrastructure design

Comparisons and contrasts

Operational issues

- Centralized team setup
- Operations

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CVA as exotic portfolio derivative

Why?

- As we will figure out, netting set does posses features that allow treating it as an exotic (portfolio derivative).
- The key advantage of this is ability to plug it into the existing front office frameworks.
- The main challenges will come from the fact that such trade
  - references a portfolio of other trades
  - such portfolio can be large
  - such portfolio can be (quite) dynamic

Approach to exotic derivatives

Building blocks

- Exotic derivative typically has the following properties, supported by the quant libraries and systems.
  - Payoff; typically implemented using a script
  - Selection of pricing models.
  - Local model calibration linked to a typical hedging strategy per model.
  - Preferred numerical method per model.
- All those are either elements of the product type or elements of booking.

Approach to exotic derivatives

Use cases and limitations

- The typical use cases for the derivative calculator are
  - Single name pricing
  - Bump and recalc individual risks
  - Typically overnight batch for PV and Risk
  - Ad hoc PV
- Structured credit pricers were sometimes optimized for fast calculations of greeks, but the methods used were very much specific to credit, the models used and payoffs in scope.

Netting set as exotic derivative

Use cases

- Use cases for computing CVA on a netting set are a superset of those of a typical derivative.
  - Spot portfolio valuation
  - Pre-deal valuation/scenario analysis
  - Greeks and overnight batch
- Pre deal valuation is the key difference, which imposes restrictions on the system design and caching.
- We may want to cache the whole model object with paths of relevant variables to speed up pricing new trades, entering the netting set.

Netting set as exotic derivative

Use cases

- The fact that we are actually dealing with portfolios, also requires incorporation of various parallelization capabilities in the design.
  - E.g. traditional systems are optimized simply for pricing on a grid. In case of CVA one may have to introduce aggregation across grid results before final pricing steps can be done.

Netting set as exotic derivative

"Product" features: payoff.

- Netting set *has* a payoff. And such payoff may be somewhat exotic and require scripting.
  - The payoff is netting and collateral logic. In the most trivial cases, there will be no collateralization and perhaps only mandatory break clauses.
  - However there may be various triggers, plus collateral assets themselves may require pricing (if bonds, for example).
  - This is somewhat similar to the waterfall logic of a cash CDO.
- To qualify for (at least regulatory) netting treatment, netting rules must be contractually enforceable. So there is even a contract behind the payoff.
- Thus such payoff is really a booking element, as it would be for an exotic derivative

Netting set as exotic derivative

"Product" features: model local calibration.

- Netting set will typically have a (slowly changing) hedging strategy, based on the experience of the CVA desk with the counterparty.
- Such hedging strategy will imply local model calibration strategy.
- The model will invariably require marking several non-observed parameters
  - correlations
  - jump parameters (for FX contingent on default)
  - proxy credit curves
  - proxy discount/funding curves
- This is similar to model overrides that may be booked with exotic derivatives, but it is also clearly a superset of the typical per trade booking model customizations.

Netting set as exotic derivative

Underlying trades: duality

- Underlying trades are perhaps the biggest challenge for the traditional approach to exotic derivatives
  - The portfolio is dynamic.
  - How often to revise hedging approach?
- Are underlying trades part of payoff, or rather part of "augmented" model?
  - Their payoffs are not really relevant for CVA pricing itself, only their FMTMs.
- Perhaps an indication of a natural "split" in the architecture.
- In our approach we will treat them as part of "augmented" model.
- It is an ingredient of which CVA "underlying" is constructed.

Netting set as exotic derivative

Recap

- Netting set definitely possesses the properties of an exotic derivative.
    1. Collateral and netting logic is the payoff.
    2. Calibration strategy is trade specific.
    3. Underlying trade portfolio is "underlying".
- With this in mind, one can plug netting set into the existing library, treating it as another exotic derivative type.

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  - Factor simulation and caching
  - Model calibration
  - Trade preprocessing
- We will actually consider these steps in the reverse order, to build on earlier discussions.

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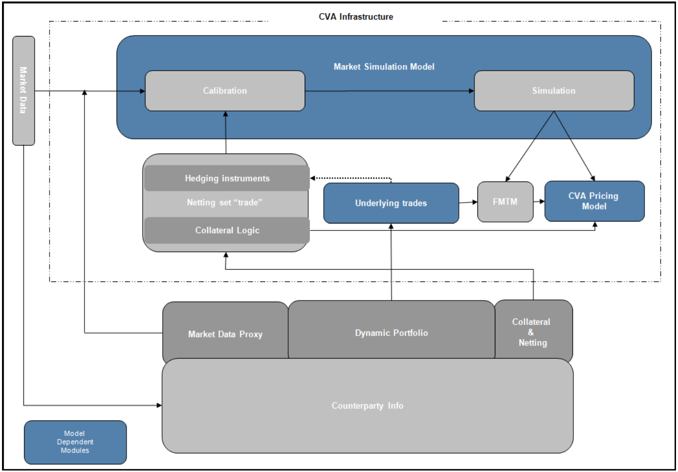
Introduction

Infrastructure diagram



Outline

Pricing CVA as a FTD

Why this step?

- Recall CVA pricing equation:

$$CVA = Ccy^R \mathbb{E}^Q \left(\int_0^T V_t (1 - R_t^c) \lambda_t^c e^{-\int_0^t (\lambda_u^c + \lambda_u^s) du} D_t dt \right).$$

- It implies the "CVA model" has to provide the following:

1. counterparty and self credit curves (dynamics)
2. recovery rate
3. discount factor
4. future MtM distribution, which will go into the receivable V_t.

Pricing CVA as a FTD

CVA pricing model as augmented evolution model

- The key observation is that should the model provide all those ingredients consistently for all paths, it will be trivial to valuate per path values and expectations in

$$\sum_{i=1}^{N} \mathbb{E}^{Q}\left(V_t\left(1 - R^{c}_{t_i}\right) D_{t_i} e^{-\int_0^{t_i} \lambda^s_u \mathrm{d}u} \left[\begin{array}{l} e^{-\int_0^{t_{i+1}} \left(\lambda^c_u + \lambda^s_u\right) \mathrm{d}u} \\ -e^{-\int_0^{t_i} \left(\lambda^c_u + \lambda^s_u\right) \mathrm{d}u} \end{array} \right] \right)$$

- Most importantly, the way of computing MtM_t (or all other ingredients) is totally irrelevant at this stage.
- All of them are just "matrices" (of same shape) of numbers.

Pricing CVA as a FTD

Pricing currency

- Importantly, all cashflows in the above formula are assumed to be expressed in the termination currency of the Master Agreement of the netting set.
- The key implication is for hedging.
- To avoid currency basis, credit risk in CVA must be hedged in the termination currency, which, if necessary, should be co-diffused with all other model variables and made available by the model at this step.
- If the reporting currency is different, the whole CVA can be translated into this currency using spot FX.

Pricing CVA as a FTD

Mechanics

This is mostly the "expectation" step of pricing.

1. Denote the value under expectation in the above, corresponding to $i-$th time for path k as $V_{i,k}$.
2. This value should include relevant pathwise "survival probability" integrals.
3. Take expectations for all times and add up across times.

- DVA can be computed similarly, but swapping the survival curves
- Clearly the above formula can trivially be simplified to account for the unilateral CVA case.

Pricing CVA as a FTD

Other considerations

- As this step considers all model ingredients in the opaque way, it opens wide opportunities for proxying.
  - For example, some counterparty portfolios can be proxies as a whole and only plugged into the above formula.
- The biggest question is how to select the discretization dates?
  - Important dates of underlying trades?
  - Equidistant grid for collateral?
  - How to allow for the pre-deal analysis (new trades adding extra important dates)?

Outline

Application of collateral and netting

Why this step?

- This is really the "payoff" stage of calculation, which transforms the individual FMTMs in their relevant currencies into a single netted FMTM in the termination currency of the netting set as per Master agreement.
- There may be more currencies involved:
  - underlying trade currencies
  - different CSA currencies
  - termination currency
- Some assumption needs to be made about which trades will be collateralized with which assets in which currencies.
- Collateral itself is just another asset in the portfolio, only its notional is stochastic.

Application of collateral and netting

Mechanics: two passes

- If single trade FMTMs were computed on different nodes of a grid, bringing them together for collateral modelling is clearly a bottleneck.
- There are two passes
  - Pass to determine the dynamic notional of each collateral type.
  - Pass to net and aggregate FMTMs of the underlying trades with that of collateral.
- We assume that the value of the collateral assets have already been computed (as any other FMTM).

Application of collateral and netting

Mechanics

- In the worst case, determining collateral notional path will require another rollback step (See Brigo et at 2011)
  - Effectively collateral is an option with strike equalling to the netted FMTM expressed in the termination currency
  - Depending on sophistication of the collateral model, the optionality may either be localized and handled for each step individually, or not.
  - E.g. if bid/offer spreads are introduced, the problem is surely one of dynamic programming
- Aggregate and net
  - Now treating collateral as another asset with its notional computed, net it per time per path with the relevant netted FMTMs of the underlying trades.
  - Multiply aggregated values by the local FX rate to translate into the termination currency, if necessary and aggregate again.

Outline

FMTM generation

Why this step?

- This the step that will compute the key ingredient of the CVA pricing model.
- From the infrastructure perspective it is better viewed as part of the model, not payoff, as discussed before.
- It is indeed the case: MtM_t are just paths of random numbers, consistent with evolution of other model outputs.
- In particular, various correction techniques, i.e. moment matching and martingale resampling can be applied to FTMT distribution as a whole, which are typically applied to model variables.

FMTM generation

Mechanics

- This step will typically have up to 3 passes through all dates

1. A forward pass, accumulating the model variables. This may be necessary for some path dependent products. Also, if given the model certain *MtM* can be evaluated analytically, this can be done at this pass.
2. Projection pass. This is essentially an American MC pass.
3. Postprocessing pass, which will apply exchange rules, including mandatory break clauses.

- Note that this will produce FMTM in the relevant pricing currency, i.e. foreign currency rollback is to be performed in the foreign measure.

FMTM generation

Challenges

- Using AMC for FMTM generation makes it impossible to parallelize computations by path.
- Convergence properties for AMC for the in the future pricing is not well understood (widely).
- Projection polynomials must be selected for all payoffs in scope of the CVA system, which is going to use AMC.
- Polynomials must be optimized for particular payoffs depending on the state. This is not a common feature in the scripting frameworks, which typically operate on the time slices.
- Selection of the dates on which to compute EE is not trivial. Clearly all important dates of all underlying trades (and collateral) cannot be included. It may be necessary to interpolate MtMs for relevant dates.

FMTM generation

Opportunities

- This step is the key source of parallelization opportunity.
- It is best to parallelize the projection pass, if we are not dealing with any additional payoffs, because this will not introduce branching in the code and can be done on a GPU.
- In any case, one can generally parallelize generation of FMTMs corresponding to different risk scenarios, if the netting set contains many trades.
- In terms of the AMC core design, it may be possible to split different aspects of the rollback between the generic model core and scripts.
  - For example, projection step can be implemented on the core side, while MtMs and projection basis can be tracked as script variables.
  - This allows huge generality in specifying projection basis.

Outline

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Preprocessing and model calibration

Why this step?

- This is perhaps the least trivial step, which cannot be entirely automated.
- User input, or at least frequent review is necessary to ensure adequate calibration of the model and sufficiency of the hedging strategy.

Preprocessing and model calibration

Trade/portfolio preprocessing

- Portfolio needs to be preprocessed to
  - establish or verify hedging/calibration strategy
  - to potentially group trades for simultaneous processing (like portfolios of delta one products in the same currency)
  - to modify certain aspects of trades on the fly
- At least three time grids may have to need to be established at this stage:
  - model evolution grid
  - AMC grid
  - time integration grid (ideally should be dealt at least at the short end to minimize problems with calculations of theta).

Preprocessing and model calibration

Trades on the fly modifications

- However existing trades, booked using existing systems, will not necessarily be AMC friendly, or CVA AMC friendly, or CVA friendly at all. Trades may not have any scripts associated with them at all, or can be coming from legacy systems.
  - Think booking of an IRS
- This means that some trades attributes, like pricing scripts, will have to be modified on the fly, once the trade objects are being constructed.
- Writing CVA-specific pricing scripts is perhaps the most time consuming and tedious job of the respective quant team.
- Strategically, each new trade type should also have CVA script associated with it.

Preprocessing and model calibration

Model calibration and caching

- Once the set of hedging instruments is determined, model calibration can proceed.
- Importantly, it is not, strictly speaking, necessary to know how this set has been obtained.
- Therefore as setup where the hedging strategy is reviewed less frequently is possible.
  - In this case guards need to be designed to provide early warnings in case portfolio has deviated too much from the one for which the current calibration strategy has been selected.
- Note that once the model is calibrated, rerunning MC to generate paths, especially if only a subset of factors is necessary, is relatively cheap.

Recap

All steps once again

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CCR infrastructure design

Differences to CVA

- Model calibration is substituted for model estimation. Model estimation is always global.
- CCR simulation will typically involve larger number of globally estimated factors, but much lower number of factors if CVA models are calibrated per netting set
- FMTMs are produced mostly by at the point pricing, hence exotic incur the biggest hit
  - In CVA vanillas get the biggest hit compared to valuation
- Focus of collateral model is on modeling over margin period of risk (MPR): the time between the default event and settlement
  - Structure of netting sets can be quite different for CCR, because IMM waivers are provided per trade type.

CCR Infrastructure Design

Data vs compute requirement

- CVA is mostly the computationally intensive problem, mostly due to sensitivity calculation and higher required accuracy
  - A simple IRS can easily be subject to 1000 factors (because of the volatility exposure)
  - Number of MC runs for CVA can easily be ~100x than that for CCR
  - Due to usage of AMC parallelization per path is problematic
  - Computed only for actively managed cptys
- CCR is more data hungry
  - FMTMs need to be computed for all trades that are subject to the IMM treatment, independently of the CVA desk's approach to hedging the netting set
  - MPR doubles the compute requirement
  - Can be parallelized per path, which can result in a much higher hardware utilization rates.

CCR Infrastructure Design

Synergies with CVA

Synergies appear in the most tedious parts of the infrastructures, hence they better be realized

- Single trade representation across a firm is a rarity Implementing it for CVA/EPE is a nice motivation. Otherwise a complex validation layer will be necessary, perhaps, involving the trades round tripping to the booking systems to validate correctness of representation.
- Single ageing logic, ideally shared among booking system, CVA and CCR risk engines. Also can be reused for backtesting, hedge performance testing and other similar exercises.
- Market data, both T0 (for CVA and CCR) and historical (for CCR), and both for real and proxied data. There should be unique set of global market data and a single centre for market data validation.

Outline

Comparisons and contrasts

Rates, Inflation and FX

- As we will show CVA and EPE analysis can be complementary, in particular
  - to benchmark one model against the other,
  - to identify the risk-neutral model's shortcuts.
- We consider a realistic setup of running CVA and EPE kind of calculations for
  - 10 year IRS,
  - 10 year RPI swap,
  - 10 year FX option.
- Limit outputs to EPE, ENE produced by CVA and EPE models
- Initial data for IR and Inflation models as of January 24, 2011

Comparisons and contrasts

CVA Model for IR/Inflation

- Hybrid Rates-Inflation risk-neutral model (HW/HW/BS):

$$
\begin{aligned}
dr &= (f_r - a \cdot r(t))\,\mathrm{d}t + \sigma_r(t)\mathrm{d}W_t^r, \\
di &= (f_i - a \cdot i(t))\,\mathrm{d}t + \sigma_i(t)\mathrm{d}W_t^i, \\
dY/Y &= i(t)\mathrm{d}t + \sigma^Y \mathrm{d}W_t^Y.
\end{aligned}
$$

- Calibrated to ATM IR caplets and YOY Inflation options
- Projection curve = discount curve (LIBOR)
- IR/Break even correlation marked
- Other correlations set to zero (for this exercise)

Comparisons

EPE Model: specification

- Rates and break-even curves: 3 factor Nelson-Siegel.
- Inflation index:

$$dI_t = (\alpha + \beta X(t,1))\,\mathrm{d}t + \sigma \mathrm{d}W_t,$$

where $X(t,1)$ is the one-year tenor point of the inflation break even curve

- All estimated from history:
  - 5 year history,
  - daily returns where available,
  - monthly data for inflation index.
- Each marginal model is estimated first. Correlations between the diffusion terms are then determined.

Comparisons and contrasts

Inflation models: calibration/Estimation

CVA Model

Tenor	31/12/2012	01/01/2013	31/12/2013	01/01/2014	31/12/2014	01/01/2015	31/12/2015	01/01/2016 +
Rate vol, bp	56	84	**84**	**109**	**109**	**119**	119	116
BE vol, bp	179	179	**179**	**179**	**179**	**179**	202	202
Index vol	1.00%	1.00%	1.00%	1.00%	1.00%	1.00%	1.00%	1.00%

MR Speeds:	Rate	0.05	BE	0.12		Rate/BE corr	0.25

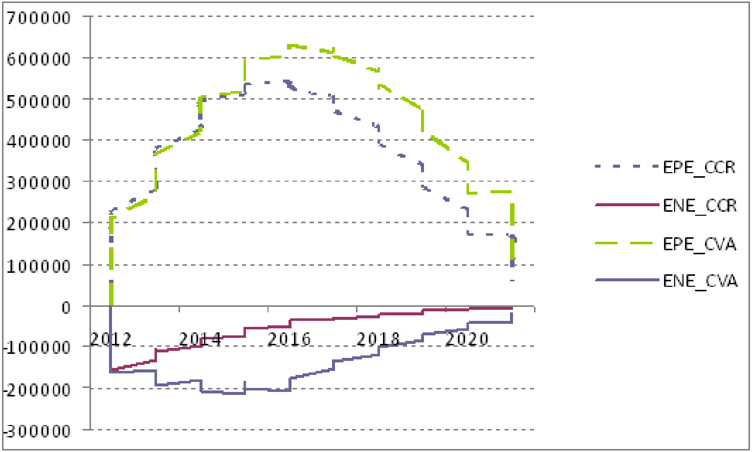
EPE Model

Rate				**Break even**			**Index**
Parameter	Level	Curvature	Tilt	Level	Curvature	Tilt	
LT level, bp	460	-110	40	332	-65	-35	
MR speed	0.250	0.250	0.250	0.445	0.730	1.224	
Sigma (ann), bp	**89**	**113**	260	***45***	**180**	277	2.906%

Correlations	
Rate Level/Curvature	-0.70
Rate Level/Titl	-0.50
Rate/BE	-0.20…+0.20
BE Level/Curvature	0.10

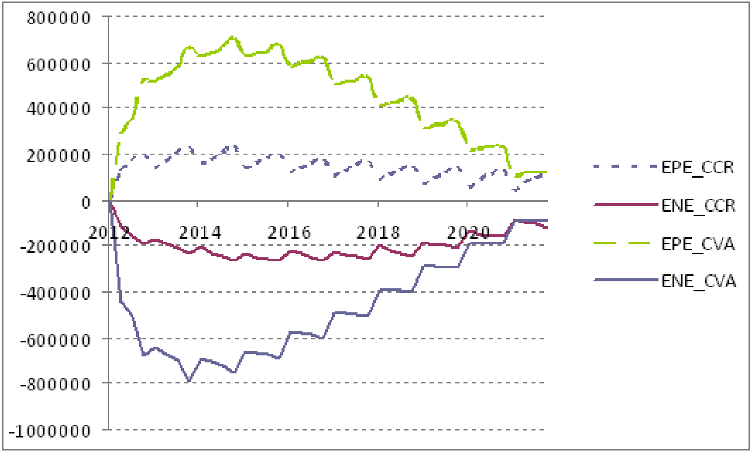
Comparisons and contrasts

10 year IRS: broadly same



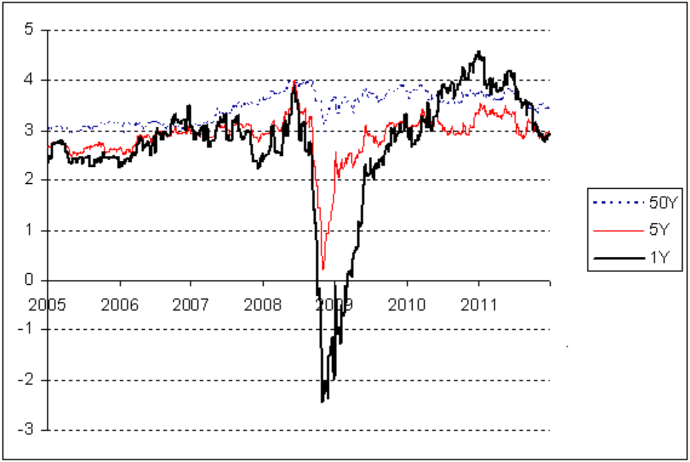
Comparisons and contrasts

10 year RPI: CVA riskier?



Comparisons and contrasts

RPI swap history: curve titling in 2008



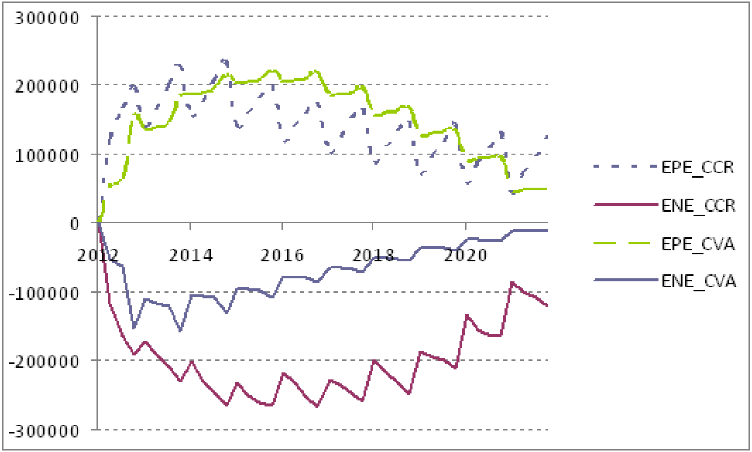
Comparisons

RPI models

- NS-based EPE model correctly picks up 2008 curve tilting by assigning higher vol to the second factor and making its long-term level negative.
- CVA model we chose cannot reproduce this dynamics, as 1-factor HW essentially produces parallel shifts.
- Thus future evolution of CVA model will move the whole curve in parallel, resulting in higher exposure.
- NS model will mostly tilt the curve, by moving the short end.
- That’s why CCR EPE graph is so flat: shortening maturity is offset by higher short term volatility induced by NS dynamics.
- Raising vol of the first NS factor to the level of second NS factor, makes NS model much more similar to HW.

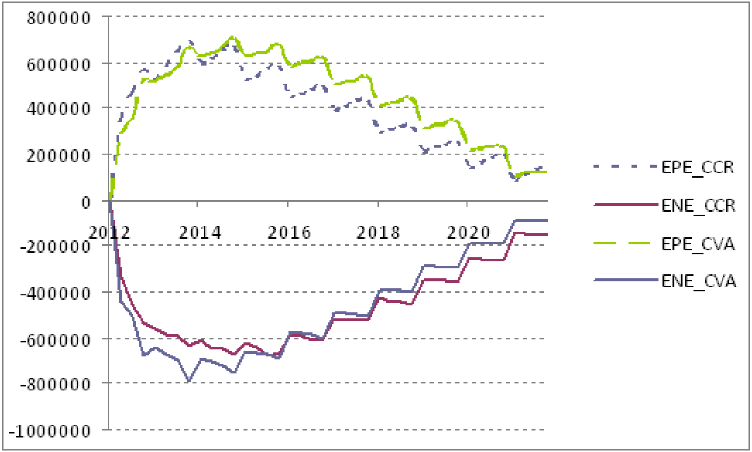
Comparisons and contrasts

10 year RPI: CVA vol brought to EPE level



Comparisons and contrasts

10 year RPI: NS first factor vol = NS second factor vol



Comparisons and contrasts

FX option models

- CVA
  - Black' 76 setup, rates set to zero

$$F = F_0 \exp\left(-\frac{\sigma_F^2 t}{2} + \sigma_F W_F\right),\ \sigma_{BS} = \sigma_F$$

- EPE
  - In addition to the above

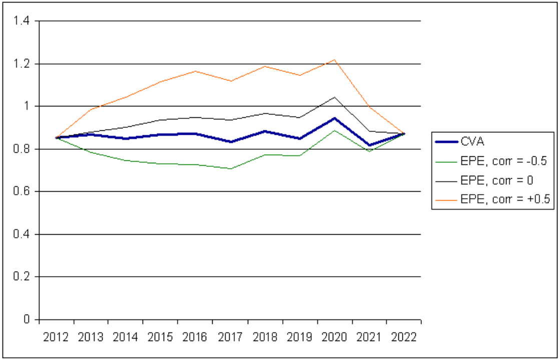
$$\sigma_{BS} = \sigma_F \exp\left(-\frac{\sigma_\sigma^2 t}{2} + \sigma_\sigma\left(W_F \rho + W_\sigma \sqrt{1-\rho^2}\right)\right)$$

  - Correlation kept constant through EPE evolution
  - 3 cases of correlation: $\rho \in \{-0.5, 0, 0.5\}$.

Comparisons and contrasts

FX option: WWR in EPE

More variance in the model implies higher variance in EPE.



$F_0 =$ 10

Strike= 15

$\sigma_F =$ 0.3

$\sigma_\sigma =$ 0.3

Comparisons and contrasts

Summary

- Difference may be material.
- Differences to be more pronounced for non-linear products, where WWR can be present because of correlations not present in the CVA model.
- EPE model can be a useful tool to identify pitfalls of risk neutral models, trying to just fit the market.

Outline

Centralized team setup

Why?

- Centralized CVA hedging team is typically a transformed risk team, powered with the FO tools.
- This setup was the only possible in the past, and it still makes sense.
- *Pros*
  - It allows hedging on portfolio basis.
  - It resolves the issues of "market clearance" in the presence of CVA/DVA.
  - The operation can be (and usually is) integrated with funding.
- *Cons*
  - Mega model is necessary to truly hedge the whole book.
  - This model will not exactly reproduce FO prices.
  - The team will not have expertise to hedge residual risks.

Outline

Operations

Charging: like CCDS

- To hedge CVA of a single deal, the perfect product would be Contingent CDS (CCDS).
  - Emerged around 2006 with the goal to exactly hedge some "stochastic notional" exposures.
  - CCDS is essentially the protection leg of a CDS.
  - Paid for upfront, like an option, no funding leg, mostly because the prices use to be very small.
- The issue CVA desk has is that not only notional is stochastic, but also maturity: the underlying portfolio is dynamic.
- Therefore CVA desk typically charges the internal clients upfront for the incremental CVA costs and then uses the proceeds to buy credit protection.
- Theoretically, negative incremental charges are possible.

Operations

Hedging

- *Credit deltas*. This is the biggest first order hedge, which follows from the fact that CVA is first to default. Although the biggest exposure would be not to the maturity, but roughly to the point of the largest expected exposure. Must be actively managed.
- *Factor deltas.* They come via MtM_t^+ If not for the crosses these deltas would be pretty much stable, as long as MtM_t is not oscillating around 0.
- *Crosses*. Correlation risks between factors and defaults. The contribute mostly to the instability of factor deltas.
- Correlation credit analogy with upfront deltas?

Operations

Credit hedging

- Credit deltas computed using standard bump and recalc.
- Singe name hedging for CVA purposes may not be optimal, so index hedges may be used.
- The cost savings limit is somewhat governed by CVA VAR, which will still require single names to go into the VAR model.
- Illiquid names must be proxied.
  - Better be proxied by other single names than indices to better explain volatility.

Operations

Reserving

- What cannot be hedged must be reserved against.
- *Recovery.* This is the main credit related risk which has to be reserved.
- *Wrong way risk.* As discussed earlier, parameters of the WWR model are hard to estimate, while this risk may be significant. Hence it must be reserved against.
- *Other unobserved risks,* mostly factor correlations. Also need to be reserved, in principle. Concentrations must be identified via scenario analysis.

Operations

Default compensation

- Upon counterparty default, CVA desk should compensate (the bank) for the losses.
- Given stochasticity of notionals and maturities, this hedge will never be perfect.
- It will typically be necessary to split the compensation burden between the CVA payment and reserves.
- The worst situation is proxy hedging of distressed names. Proxy hedge may not be performing well enough for DV01, it will not perform for the event, while the name exposure will produce have negative PNL.

Operations

Challenges for Quants

- If integral part of the quant team, CVA quant team is dependent on developments of all other teams.
  - It is a plus because many other developments can be leveraged (models and their implementation, risk engine, upstream and downstream feeds)
  - However changes introduced by any other team can affect CVA team and CVA desk: a very tight daily regression test must be in place and a process around resolving the issues.
- Amount of daily support is potentially huge (simply due to the global coverage).
  - Cooperation with other quant teams is essential

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