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From our financial risk analytics experts

In recent years, a greater focus has been placed on the inclusion of a broader range of valuation adjustments into the pricing of OTC derivatives. This applies not only to established measures, such as CVA, DVA and FVA, but also to a new breed of xVAs, which are challenging banks' legacy systems.

Driven by the application of fair value accounting practices under IFRS 13, measures such as CVA, DVA and FVA have all become key components of banks' disclosure requirements for accounting purposes. In addition, the Basel Committee on Banking Supervision has increased its focus on CVA as a source of risk to a bank and evolved its CVA risk framework to incorporate a new SA-CVA capital requirement under post Basel III reforms*, which is to be implemented by 2022.

On top of these reporting requirements, a bank's infrastructure is now required to also support this new breed of xVAs. Margin value adjustment (MVA), collateral valuation adjustment (ColVA) and capital value adjustment (KVA), among others, all need to be priced at trade inception. Today's traders require a single platform that can assess the incremental impact of a deal across all of these valuation adjustments; measures that may be calculated at counterparty, funding set, or enterprise levels, yet allocated to a single trade.

These developments create methodological, data and technological challenges for firms. In this booklet, we shine a light on some of these challenges and offer insights on possible approaches to address them.

Dr. Andrew Aziz

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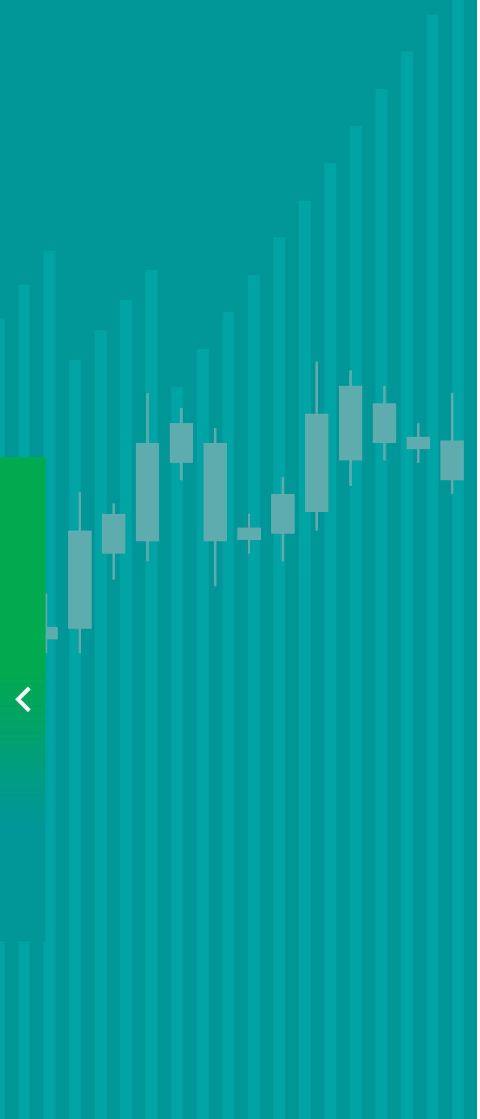
**Commonly referred to as Basel IV*



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Managing xVAs:
Why legacy technology systems are feeling the strain

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Derivatives pricing has changed dramatically over the past decade. Once seen as a task in pricing cash flows – albeit often for complex payoffs – it is now commonplace to consider the impact the trade has on the bank's balance sheet when coming up with a price. This entails pricing in the costs of credit risk, funding, collateral/initial margin, and capital. To do this properly, banks' derivative pricing engines must be expanded to capture not only the market risk factors affecting the payoff but also the credit quality of the parties, the banks' funding structure, types of collateral posted and capital requirements. Many seemingly separate issues need to be considered holistically and consistently.

The CVA losses banks experienced during the credit crisis of 2007/2008 illustrated the need for banks to price in these credit losses and properly manage them by hedging. In addition, the liquidity squeeze experienced at the time drastically increased the funding costs for banks. This resulted in the birth of a Funding Valuation Adjustment (FVA) - the cost of funding the unsecured exposure. It soon became apparent that there can be a significant cost of holding a derivatives portfolio, and it should be recognized and managed upfront in order for the bank to manage liquidity.

Another consequence of the credit crisis was that regulators vowed to do more to strengthen the banking system to avoid another crisis. A new CVA capital charge and leverage ratio charge was introduced as were updates to Counterparty Credit Risk capital and Market Risk capital. The capital requirements for banks are increasing due to these reforms and as such banks' appetite to price in the cost of capital and manage the return on capital has grown. The cost of this capital, known as Capital Valuation Adjustment (KVA), has thus become a key ingredient in derivatives pricing.

Another reform was to promote the use of Central Counterparties (CCPs) as clearing agents for derivatives. One method used by CCPs to reduce bilateral risk is to collect Initial Margin from all members, which is then available to cover losses upon member default. To level the costs between cleared and non-cleared trades, regulators have introduced a bilateral Initial Margin charge between counterparties, which is currently being phased in. As such, most derivative trades (cleared or not) are now subject to the costs of funding Initial Margin. The cost of funding Initial Margin has become known as Margin Valuation Adjustment (MVA).

Collectively these Valuation Adjustments are known as xVAs. While the drivers for these xVAs are clear, the task of accurately calculating and managing them can be more challenging. Once calculated, the goal of xVA or resource management desks is to optimize them in order to reduce the balance sheet costs of the derivatives business. This drives more complexity and requires analysis of the connection between these adjustments.

A recent webinar we held with Dr. Jon Gregory discussed the issues of xVA calculation and optimization. One particular challenge is that xVA is no longer a trade level valuation but, in the most general sense, must consider the bank's entire balance sheet. While some measures like CVA can be computed at the netting set level, measures like asymmetric FVA require a calculation that spans the entire derivatives portfolio, while the KVA incorporating the leverage ratio would need to take into account the full balance sheet.

Calculating xVAs at the portfolio or balance sheet level requires a robust enterprise-level system that can efficiently simulate all risk factors and price all trades of the portfolio in a consistent manner. The aggregation of these simulated trade valuations also pushes the memory and performance requirements of hardware being used. Some banks' xVA systems may be designed to work counterparty by counterparty, as historically that was the area of focus for CVA. With the portfolio-wide requirement of some of the newer xVAs, some banks are looking to big data technologies to complete the task.

An additional looming cost for banks is the new CVA capital charge under FRTB (Fundamental Review of the Trading Book). As discussed in an earlier article, the incremental impact of moving from the standard Basel 3 CVA charge with EAD computed with CEM to the new basic approach using the SA-CCR EAD can be significant (a factor of 2 to 4). This is motivating many banks to set up an appropriate CVA desk in order to qualify for the SA-CVA approach under FRTB. Even if a bank qualifies for SA-CVA, the capital requirements of this regulation are still expected to be higher than what banks have currently. As such, the question many xVA traders are asking is: How can I optimize SA-CVA capital?

Some xVA system requirements needed for SA-CVA optimization are discussed in the webinar. A granular breakdown of the risk factors driving the capital provides insight into how to optimize. But an additional critical component is a system that allows banks to compute the pre-trade incremental change in SA-CVA. This allows for traders to do pre-trade what-if checks on the impact of a given trade or hedge before it is executed. Such deal-time decision tools enable deal-time optimization of the capital along with other xVAs.

Incorporating xVAs into the pricing of derivative portfolios has pushed complexity from the pricing of exotics to the incorporation of portfolio and balance sheet wide effects. The industry must adapt its processes and systems to accommodate these calculations. Our webinar serves to illustrate the issues and offers some solutions to dealing with these new xVAs.■

CVA Wrong Way Risk:
What does the CDS data tell us?

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The wrong way risk (WWR) modelling of valuation adjustments (xVAs) is known to be a challenging problem, if not intractable. This is due to the lack of relevant historical data and potential for misspecification in the joint modelling of discrete default event and continuous risk factor movement (Aziz et. al, 2014). In this article, we revisit WWR modelling by using information from the credit default swap (CDS) market. In particular, we analyze the market prices of Quanto CDS contracts, which are designed to provide credit protection against the default of a reference entity and are settled in a non-domestic currency. The contingent payoff of the Quanto CDS contract naturally reflects the market-implied interaction of FX risk and credit default event, and hence, sheds light on the level of WWR for FX-sensitive trades and portfolios.

Figure 1 shows the Japan sovereign CDS premium (5-year par spread) which represents the cost of buying credit protection for a Japan sovereign default. The USD spread and JPY spread correspond to the CDS contracts in which the settlement currencies are in USD and JPY, respectively. One can find an intriguing persistent basis between the two CDS spreads, despite the fact that they are referencing the same entity. Indeed, the persistent Quanto basis reflects a strong devaluation jump of the JPY against USD upon a Japan sovereign default – and those who bought the CDS contract settled in USD will have to pay a higher premium in order to shield themselves from the FX devaluation risk. This illustrates that the CDS market has been pricing in WWR ***consistently***, that is, the FX-credit interaction as a devaluation jump upon a counterparty default.

According to the no-arbitrage argument, one can long a CDS contract in JPY and short a Quanto CDS contract in USD, and since the underlying credit events are identical, what is left behind in the portfolio is the FX risk of the dollar-yen exchange rates at default. This insight leads to the rule-of-thumb:

$$s_{JPY} = (1+\gamma)s_{USD}$$

where γ is the jump size of the FX risk factor at the counterparty default, s_{JPY} and s_{USD} are the CDS spreads denominated in JPY and USD respectively. The estimated FX jump size can be readily used as the input parameters for the FX jump-at-default xVA WWR model implemented within the IHS Markit xVA solution.

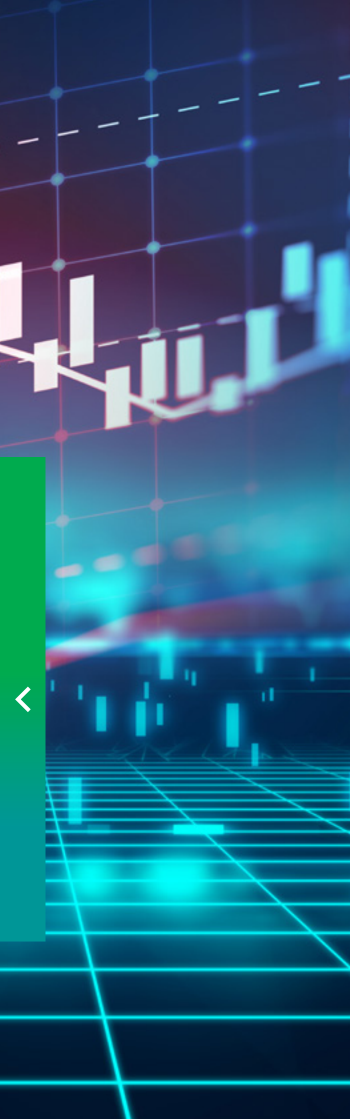
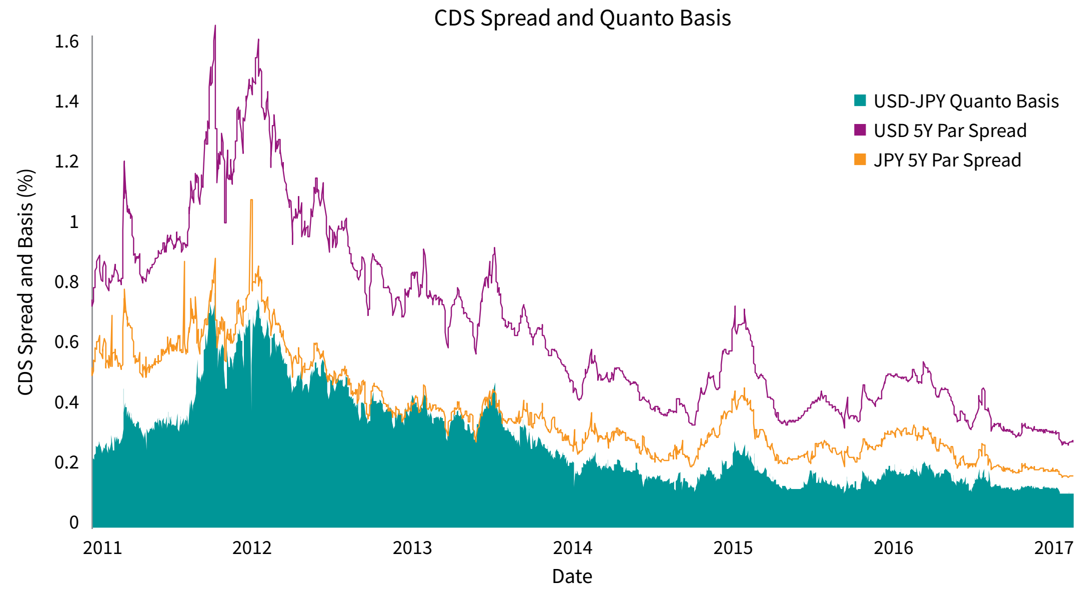
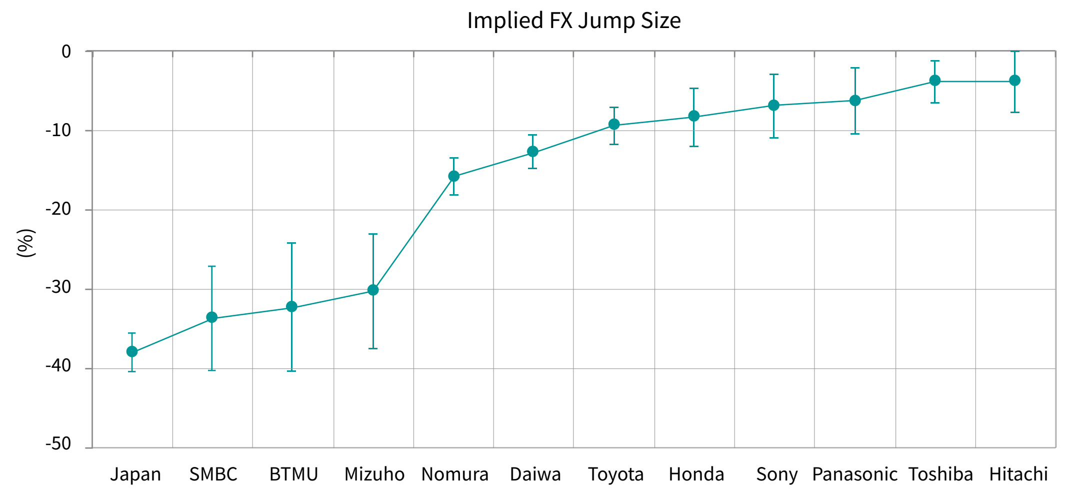


Figure 1: Japan sovereign CDS spreads denominated in USD and JPY



In Figure 2, we plot the historical mean and standard deviation of the implied FX jump size for different counterparties. A number of interesting implications can be drawn. Firstly, all of the implied FX jump sizes are significantly negative (i.e., JPY devaluation), suggesting that the CDS market has been consistently pricing in WWR between FX rate and credit default for these systemically large counterparties. Secondly, the implied FX jump size is strongly related to the systemic importance of the reference entity and we observe a decreasing impact of FX rate down the spectrum, confirming the anecdotal evidence that the Quanto CDS implied jump size is related to systemic importance (Pykhtin and Sokol, 2013). The similar level of FX jump sizes across industry groups also points to the possibility of building a “sector basis curve”, hence allowing one to estimate the FX-WWR for a wider range of counterparties. For a more detailed analysis, we will shortly be publishing a technical white paper on the calibration of WWR models to the Quanto basis.

Figure 2: Implied FX jump sizes across different Japanese names



The FRTB-CVA regulation requires banks to apply WWR modelling when the dependence between exposure and counterparty credit quality is significant. To make this judgment, one can be complemented by market-implied information from the Quanto CDS data – a significant Quanto basis indicates the counterparty is exposed to FX- WWR which requires monitoring and active management. Our analysis shows that for these counterparties the CVA WWR add-on could be 50% higher against the no-WWR baseline, and therefore choosing a proper jump-at-default WWR model is critical to capture the impact.■

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MVA: The next challenge for derivatives pricing

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Staying competitive in the derivatives markets today requires participants to price in the total cost of the trade to the bank. The total cost must include the potential for credit losses (CVA), funding costs (FVA/ColVA) and capital (KVA), together known as xVAs (or 'x' valuation adjustments). Central clearing of derivatives, and the related introduction of bilateral Initial Margin rules, can reduce CVA and KVA costs, but the net effect is to shuffle costs into funding the Initial Margin (IM) on the positions. This cost, known as MVA (Margin Valuation Adjustment), is the latest xVA to be added to the list. In an effort to stay profitable, banks are increasingly looking to optimize their xVA costs by constructing net xVA reducing trading strategies. However, effective optimization requires computing all xVAs consistently and this is a formidable financial engineering challenge, particularly with the onset of MVA.

The introduction of IM posting for non-centrally cleared derivatives aims to promote the central clearing of derivatives and reduce systemic risk by ensuing enough excess collateral is available to cover the shortfall experienced at times of default. This collateral is posted up-front and segregated to a third party to ensure its availability. Promotion of central clearing is achieved by ensuring the costs of bilateral trading reflect those of trading with CCPs that already require the posting of IM.

The CVA of a collateralized portfolio is driven by the gap risk at default. IM is to be calculated as the 99% VaR over this period of risk meaning CVA is reduced to only the expected 99% shortfall over this margin period of risk. While this essentially eliminates CVA on these fully collateralized portfolios, the trade-off is the new cost of funding the IM or MVA as it has become known.

ISDA's SIMM has emerged as the global standard for computing IM. Calibrated to 99% VaR, the model leverages trade-level sensitivities in an FRTB-style Sensitivity Based Approach aggregation. IM is rebalanced frequently and computed on portfolios of non-centrally cleared products, including options. As a result, IM is highly path dependent, varying by portfolio composition and market conditions.

Accurate approaches to computing MVA therefore require projecting the forward IM within a Monte Carlo simulation.

While CVA with IM may be essentially zero, CCR capital under the presence of IM can still be significant. Under the rules of SA-CCR, the benefit of over collateralization is progressively scaled in and capped at 95% reduction in PFE through the PFE multiplier. Banks that price in KVA on SA-CCR must therefore also accurately model the future IM in order to capture the IM relief in their KVA. This again involves projection of IM within the KVA Monte Carlo simulation.

Projecting IM within Monte Carlo simulations raises a number of challenges for xVA systems. Firstly, the calculation of trade level sensitivities per path and time step in the simulation poses computational challenges. Secondly, IM can have significant contribution from Vega and Basis risk in addition to Delta risk. Capturing the trade level Vega and Basis risk would require the xVA models to treat basis spreads and volatility as risk factors, which is beyond the means of many xVA engines. The dominate Vega risk for CVA is the volatility of the risk factors driving the exposure, whereas the Vega risk of interest for the forward IM projection is the Vega of each trade, and how that Vega varies with underlying market levels.

Additionally, the low number of risk factors (i.e. 1 or 2-factor short rate models) typically used in xVA models may map poorly to the high number of dimensions (ten distinct tenor buckets on each yield curve) used in SIMM, further missing the granular risk factor weighting and correlation offsets built into SIMM. Finally, as SIMM may be recalibrated from time to time, a lifetime projection of IM would ideally account for this calibration impact.

Standard approaches to projecting IM are yet to emerge in the industry. The above challenges have motivated the proposal to bypass SIMM and revert to the 99% VaR definition of IM. This can be relatively easily computed within the Monte Carlo simulation using regression techniques. A scaling to the time zero SIMM can be used to account for – at least crudely – the components of SIMM missed in the MVA model. Algorithmic Differentiation (AD) is another possible

approach, but it can still suffer from the challenges of Vega and Basis risk mentioned above, as well as the adaptability of AD to compute forward sensitivities per trade to forward market factors.

Figure 1 below shows a comparison of a SIMM within Monte Carlo approach to one implementation of a regression based approach. The choice of regression variables, regression techniques and scaling all impact the accuracy of these approximation approaches. As evidenced in the plot, the average IM required for MVA and the shape of the distribution can be well approximated with these approaches, at least for small portfolios. However, when more risk factors drive the portfolio exposure, the approximations can deteriorate as the set of required regression variables grows. In particular, accurately modelling the path-wise IM required to capture correlation (Wrong-way or Right-way) between IM and exposure (such correlation could impact the KVA benefit of IM) is likely beyond the scope of these approaches.

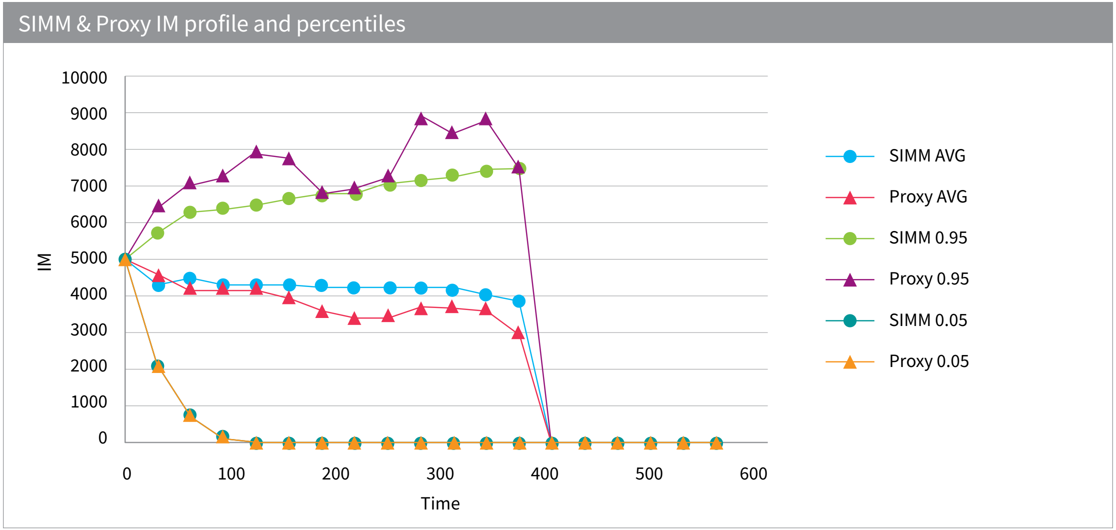

Figure 1: Expected IM profile, 5th and 95th percentiles of IM distribution for a SIMM within Monte Carlo approach (circles) and regression proxy (triangles) for an ATM swaption

As more banks and the size of the portfolios subject to IM grow, traders will start to feel the squeeze from the IM funding cost. Those prepared to accurately price it into trades and optimize it along with other xVAs will ensure no undue costs are taken on, providing a competitive edge in the derivatives markets. ■

CCR KVA with Least Squares Monte Carlo

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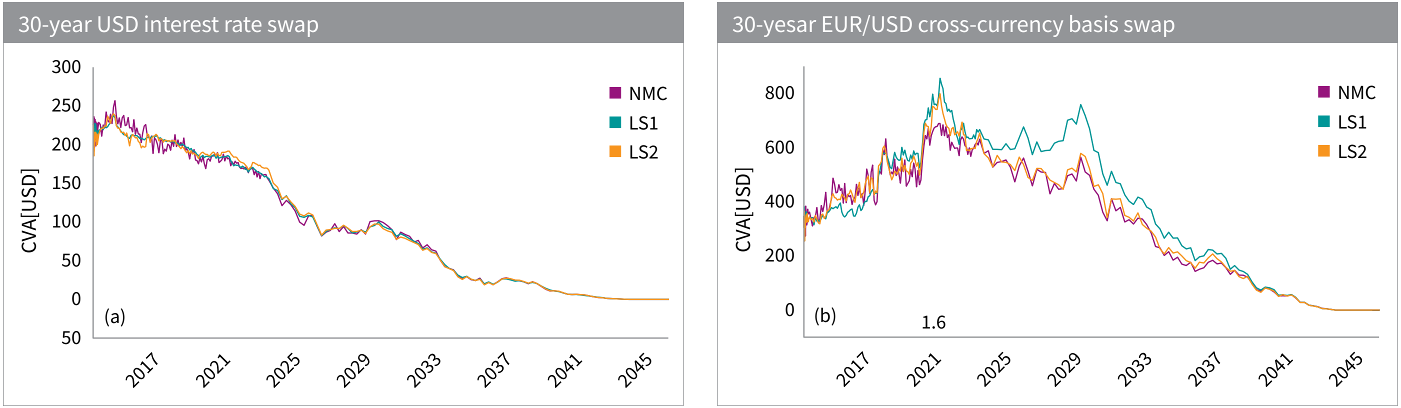
The Basel III/IV framework contains a number of new and updated measures to increase bank liquidity, decrease bank leverage, and to strengthen risk management and regulation in the banking and financial sector. The latest amendments were just finalized in December 2017, and all features are expected to be implemented or phased in by 2022. The framework increases capital charges substantially and makes banking activities more capital intensive. The cost of holding regulatory capital over the lifetime of a portfolio to buffer and control counterparty losses therefore is finding its way into derivatives pricing in the form of the capital valuation adjustment (KVA). It supplements other upfront adjustments such as credit, debit, funding, and collateral/margin valuation adjustments (CVA, DVA, FVA, and ColVA/MVA, respectively).

Estimating the lifetime cost of capital, or KVA, is a non-trivial task. The capitalization of counterparty credit risk under Basel III/IV builds on frameworks for counterparty default (CCR) risk and credit valuation adjustment (CVA) risk and is reinforced by the leverage ratio and the (risk-weighted) capital floor as backstops. But even without considering the impact of these backstops, pricing capital requirements can be challenging, as it requires fast and accurate numerical estimation of exposures over potentially long time horizons and high-dimensional risk factor spaces.

Both CCR and CVA capital use as one of the inputs the exposure-at- default (EAD), whose non-internal model method (non-IMM) alternatives were updated in Basel III/IV to the standardized approach for measuring counterparty credit risk (SA-CCR). With the new SA-CCR methodology, EADs are more risk-sensitive generally, but also tend to be more conservatively calibrated than the previous non-IMM methods, in particular in the absence of collateral. The Basel III/IV CCR capital framework, however, opens the door to adjusting the EAD for incurred CVA as a capital-lowering measure. This follows from the fact that the upfront CVA already realizes the expected cost of counterparty credit default. Its impact therefore is recognized in Basel III/IV by the introduction of the outstanding EAD, i.e. the maximum of zero and the EAD less the incurred CVA, in lieu of solely the EAD (this applies to CCR capital calculations only).

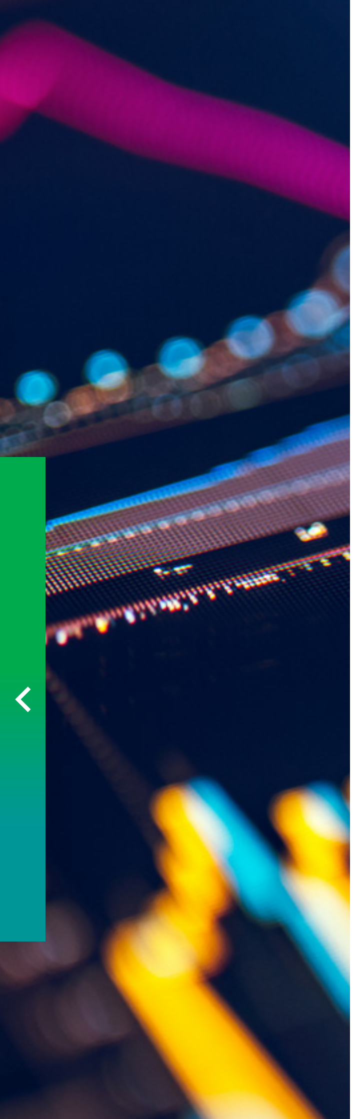
Under SA-CCR, estimating the EAD over the lifetime of a transaction or portfolio is relatively straightforward. The SA-CCR formulae can be embedded within a single Monte Carlo pass and evaluated for each path and time step. Factoring in the incurred CVA on the other hand is computationally more elaborate and, taking the brute force route, requires lengthy nested Monte Carlo simulations. To avoid this bottleneck, one may resort to least squares Monte Carlo where the incurred (or forward evaluated) CVA is approximated efficiently over the entire time horizon by regression-based proxies (see Figure 1).



30-year USD interest rate swap

30-yesar EUR/USD cross-currency basis swap

Figure 1: One-path incurred/forward CVA projections for (a) a 30-year USD interest rate swap and (b) a 30-year EUR/USD cross-currency basis swap, based on nested Monte Carlo (NMC) and two types of least squares Monte Carlo (LS1 and LS2). In the present case, approach LS2 utilizes more explanatory variables than LS1 and tends to agree better with the nested Monte Carlo benchmark.



The success and accuracy of the regression approach, of course, depends on a number of different factors, chiefly among them the choice of regression basis functions and explanatory variables, but also, to equally important extent, the way the regression-based proxies are used in subsequent computations. For CCR capital and CCR KVA calculations, the incurred/forward CVA enters the outstanding EAD, which in turn makes up part of the risk-weighted asset (RWA) that the CCR risk framework relies on. The outstanding EAD thus has to be manipulated accordingly to keep estimator bias at bay. This is akin to the Longstaff-Schwartz approach to Bermudan option pricing[1]. Hence, as with the Bermudan option exercise boundary, the overall accuracy for CCR KVA computations therefore ultimately comes down to accurately approximating the trigger boundary of the max-operator of the outstanding EAD.

Some questions that arise naturally in this context are the following: What is the actual impact of the incurred CVA on CCR capital and/or CCR KVA? How accurate is the regression approach typically? And, under what circumstances do the approximations become increasingly challenging for CCR capital and CCR KVA? These questions are hard to answer in general terms as portfolios and netting sets can have complicated exposures and the time structure of the CCR KVA integrand (partially determined, for example, by the counterparty survival probability and/or the dynamics of the internal ratings based (IRB) CCR risk weights) can sensitively impact the final CCR KVA result.

The regression approach obviously also becomes more challenging the larger the number of underlying risk factors. Simple instruments, however, such as an interest rate swap or a cross-currency basis swap (both without collateral) indicate that the SA-CCR EAD tends to outsize the incurred/forward CVA, typically by up to a few multiples. The reduction of CCR KVA due to upfront CVA therefore is tangible, and even rough incurred/forward CVA proxies can lead to good results.

In very rare circumstances, SA-CCR EAD and incurred CVA can be made of roughly equal size, giving rise to relatively small CCR KVA. In these cases, higher accuracy of the forward CVA estimate may be desirable and can be achieved through further refinement of the regression approach. Compared with other valuation adjustments, CCR KVA appears to be smaller overall than the corresponding CVA KVA (excluding CVA hedging) or the upfront CVA.

In a nutshell, even though the updates for counterparty credit risk put in place by the Basel III/IV regulation have made counterparty credit risk capital and the cost of capital more severe – to encourage collateralization, hedging, and central clearing –

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[1] Longstaff, F. A. and Schwartz, E. S. (2001) Valuing American Options by Simulation: A Simple Least-Squares Approach. The Review of Financial Studies, 14, 113

upfront CVA has a real, mitigating impact on CCR capital and CCR KVA. The impact can be computed efficiently with exposure simulations, and the accuracy can be reasonably well controlled by utilizing a regression based proxy for incurred/forward CVA. ■

More details are available at
http://ssrn.com/abstract=3127856

SA-CVA Capital: Are you ready for the next regulatory hurdle?

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Regulatory reform over the past decade – driven to a large extent by the Basel Committee – has made managing regulatory capital a priority for banks around the world. The introduction of the Fundamental Review of the Trading Book (FRTB) and the potentially significant capital implications of key decisions banks must make around issues such as non-modellable risk factors, P&L attribution and desk level reporting, further underlines its importance.

While much attention has been focused on the implications of the new regulation on market risk, the landscape for credit valuation adjustment (CVA) regulatory capital is undergoing its own transformation. As such, banks are trying to assess the potential impact of the CVA capital requirements and how they can best be mitigated.

Back in 2015, the Basel Committee on Banking Supervision (BCBS) launched its review of the CVA risk framework. Its objective was to take into account the market risk exposure component of CVA along with its associated hedges, as well as ensuring consistency with the proposed revisions to the market risk framework under FRTB. The review would enhance the current Basel III CVA risk framework, which was implemented in 2010 to respond to the significant CVA losses suffered by banks on their OTC derivatives portfolios during the financial crisis.

The proposed CVA risk framework introduces two new types of risk models: i) the Basic Approach (BA-CVA) and ii) the Standardised Approach (SA-CVA). Consistent with the typical regulatory approach, banks can choose to implement either basic regulatory models or the SA-CVA, which requires regulatory approval and is based upon meeting certain prescribed criteria.

In order to better understand – and minimise – the impact of SA-CVA, and other regulatory changes, four large banks commissioned IHS Markit to conduct Quantitative Impact Studies (QIS) at the end of 2015. These studies were based on the draft regulatory parameters and were run on representative portfolios[1]. Although some of the parameters within the regulations have since changed, we found that by moving from BA-CVA (SA-CCR[2]) to SA-CVA, banks could potentially reduce CVA risk capital by 71%. To read the full findings, you can download the paper here.

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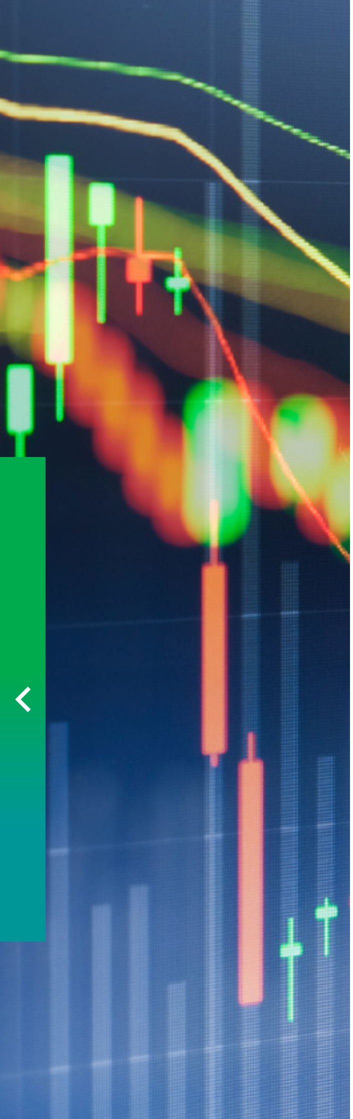
*This article was written in May 2017

[1] The studies were conducted on representative portfolios containing 1,000 to 100,000 actual trades with 50 to 2,000 collateralised and uncollateralised counterparties, with the majority being uncollateralised corporates. The portfolio did not include CVA hedging trades



Since then, the BCBS has made a number of updates to the draft regulatory parameters[3]. Taking these latest changes into account*, our updated research shows us that banks that are currently on the Basel III Standardised CVA (Basel III Std CVA) charge using the Current Exposure Method (CEM) as the input for exposure-at-default could face a CVA risk capital increase of 3.5 times (from a ratio of 1.0 to 3.5) when moving to the new framework.

This increase is due to the combined impact of having to move from CEM to the new SA-CCR, and from Basel III Std CVA to the new BA-CVA. See Figure 1 below for more details.

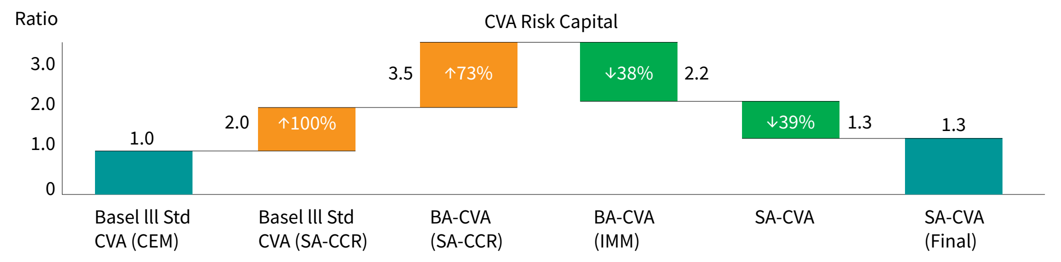


Figure 1: Capital comparison across regulatory models, March 2016

In order to mitigate the impact of this capital increase, banks can instead choose to adopt the new SA-CVA, which could reduce the capital charge by 2.7 times (from a ratio of 3.5 to 1.3).

However, as mentioned earlier, in order to adopt the SA-CVA approach, banks will need to meet certain prescribed criteria. One of the key pre-requisites is that banks that do not already have an active CVA desk in place, will need to set one up for the 'risk management and hedging of CVA'. This will require non-trivial investment in software systems and skilled CVA expertise, to name just two considerations.

The review of the CVA risk capital regulation is expected to be finalised soon at which stage we will update our original paper and calculations. However, suffice to say that banks that have yet to embark on an analysis of the impact of the new regulations could find a huge capital increase looming in the horizon.

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[2] SA-CCR is the Standardised Approach which replaces the Current Exposure Method (CEM) and the Standardised Method (SM) in Basel's capital adequacy framework http://www.bis.org/publ/bcbs279.htm

[3] Basel Committee on Banking Supervision, Instructions: CVA QIS, February 2016

Accelerating CVA calculations using Quasi Monte Carlo Methods

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One of the most important counterparty credit risk measures is the credit valuation adjustment (CVA), defined as the present value of the potential loss due to a counterparty failing to meet their contractual obligations. Risk neutral pricing states that the present value is equal to the expected value of the payoff using risk adjusted probabilities. The payoff in this case is the netted portfolio value less collateral (floored at zero) at the time of counterparty default, multiplied by one minus the recovery rate. The payoff is at counterparty level, potentially path dependent (collateral, early exercise conditions, lags between fixings and cash flows), and subject to change. The expectation of high dimensional, fluid payoffs of this sort must be estimated with Monte Carlo (MC) simulation (see Gregory 2015 [7]).

Monte-Carlo estimation of an expectation involves randomly sampling the payoff n times according to the risk neutral probabilities and averaging the results. The estimate approaches the true expectation with probability 1 with a normally distributed error with zero mean and standard deviation equal to the standard deviation of the payoff (a constant) divided by the square root of the number of replications n used [6]. Requiring the error to be on average 100 times smaller than the standard deviation of the CVA payoff requires 10,000 replications, a number typically used. This highlights the main disadvantage of MC: its computational expense.

This is of particular importance in the context of CVA where each evaluation of the payoff is also computationally expensive. Consider a bank with 100,000 trades that uses 200 exposure dates in the time discretization. One replication of the CVA payoffs across all counterparties requires roughly 10,000,000 trade prices (assuming trade maturities are evenly distributed) and thus one MC CVA estimate using 10,000 paths requires of the order of 100,000,000,000 trade price evaluations. Furthermore, many banks risk manage these credit adjustments, and to do so requires the calculation of the derivatives of the CVA with respect to the market prices of the instruments used to hedge it. Bump and run techniques require at least one full MC CVA calculation per derivative. 200 derivatives bring the computational load up to 20,000,000,000,000 trade price evaluations per day.

Not surprisingly, quants have been searching for ways to accelerate this massive calculation. One successful line of research uses algorithmic adjoint differentiation (AAD) to compute the derivatives, reducing the computational burden to a fixed multiple

(5 to 10 times depending on the problem and memory handling) of the baseline CVA calculation, no matter how many derivatives are required (see Capriotti et al. 2011 [4] for more information).

Assuming a conservative fixed multiple of 10, this would reduce the total number of calculations by a factor of 20, requiring 1,000,000,000,000 trade price evaluations. This dramatic improvement, however, does not come for free. The implementation of an AAD enabled system requires large changes to existing code libraries, requiring a significant upfront investment to implement. As a consequence, many still compute the derivatives using bump and run techniques.

In another line of research, Ghamami and Zhang 2014 [5] highlight that direct and independent simulation of the portfolio value to each time step diversifies the errors in each time bucket, leading to a significant reduction of the standard error of the final sum across time. The benefit of the direct simulation approach is reduced if simulating to each time step independently is more computationally expensive than simulating to each step sequentially using a common simulation path. Highly path dependent portfolios containing collateral may not benefit as a result, but the technique looks quite promising for portfolios of uncollateralized vanillas.

In a similar line of research, Burnett, O'Callaghan and Hulme 2016 [2] note that the computational expense of calculating valuation adjustment risks (derivatives) vary significantly across different counterparties, and that the computational expense is uncorrelated with the size of the adjustment error. This opens up the possibility to optimally allocate computational resources where they are needed most, using a different number of paths and/or time steps for different counterparties and risks. They formalize this idea by setting up and minimizing the expected unexplained PnL by varying the number of paths and frequency of time steps allocated to each counterparty and risk, subject to a computational time constraint. The acceleration they report computing FVA on a sample Barclays portfolio is impressive, roughly in line with the acceleration provided by AAD.

In a forthcoming IHS Markit research paper, we explore yet another acceleration technique used to price payoffs called quasi Monte Carlo (QMC). The mechanics are identical to classical Monte Carlo simulation with the exception that the pseudo random numbers (PRN) are replaced with carefully selected low discrepancy (number) sequences (LDS) that are more evenly distributed, with the hope of improving the convergence rate closer to the optimal $O(n^{-1})$. In the paper, we estimate CVA and CVA sensitivities of several portfolios of vanilla interest rate swaps, ranging from single currency single trade portfolios, to nettings sets containing eleven different currencies, all with a multi-currency, multi-curve extension to the Hull-White model [8] with deterministic hazard rates.

We find that QMC with Sobol' sequences [9], Broda's 65,536 direction numbers [1], and the Brownian bridge discretization [3], with on average 1,197 paths produces errors roughly equivalent in size to classical MC with 10,000 simulations, a factor of 8 acceleration.

The number of paths needed to match classical MC with 10,000 paths varies significantly between portfolios and calculation type, however, increasing as the portfolio becomes more out of the money (291 paths for far in the money, 538 paths for at the money, and 2,763 for far out of the money). The gains are most impressive when the CVA, the CVA sensitivities, and the corresponding standard errors are the largest (in the money portfolios) and more modest when the standard errors are the smallest (out of the money portfolios). For all but the far out of the money portfolio, the equivalent number of paths increase as more factors are added to the portfolio (208 paths for single trade single currency, 463 paths for six trade six currency portfolio, and 573 paths for the eleven trade eleven currency portfolio), and for more complex calculations (242 for CVA MTM, 282 for CR delta, 431 for IR and FX delta, and 702 for IR and FX vega). Illustrative results for in the money and at the money portfolios are presented in tables 1 and 2. Far out of the money portfolios are the most difficult and erratic, as indicated by the numbers in table 3.

Table 1: Approximate number of QMC + BB paths needed to produce CVA and CVA sensitivities with errors roughly equivalent to classical MC with 10,000 paths for far in the money portfolios of various sizes (one 10 year fixed rate payer swap in each currency). Fixed rates set to par – 300 basis points.

Type	1 CCY	6 CCY	11 CCY	Average
CVA	168	238	242	216
CR Delta	178	256	261	232
IR, FX Delta	198	313	432	314
IR, FX Vega	247	397	565	403
Average	198	301	375	291

Table 2: Approximate number of QMC + BB paths needed to produce CVA and CVA sensitivities with errors roughly equivalent to classical MC with 10,000 paths for at the money portfolios of various sizes (one 10 year fixed rate payer swap in each currency). Fixed rates set to par.

Type	1 CCY	6 CCY	11 CCY	Average
CVA	177	308	319	268
CR Delta	228	405	365	333
IR, FX Delta	227	651	766	548
IR, FX Vega	240	1,131	1,633	1,001
Average	218	624	771	538

Table 3: Approximate number of QMC + BB paths needed to produce CVA and CVA sensitivities with errors roughly equivalent to classical MC with 10,000 paths for far out of the money portfolios of various sizes (one 10 year fixed rate payer swap in each currency). Fixed rates set to par + 300 basis points.

Type	1 CCY	6 CCY	11 CCY	Average
CVA	360	7,880	1,733	3,324
CR Delta	415	3,139	1,903	1,819
IR, FX Delta	438	2,847	2,506	1,930
IR, FX Vega	411	6,506	5,022	3,980
Average	406	5,093	2,791	2,763

The various acceleration approaches presented above are not mutually exclusive: they can be used together to compound the computational savings. One potentially interesting combination we have just started to explore is to combine the direct simulation methods proposed by Ghamami 2014 [5] for non-collateralized CVA calculations with QMC and the Brownian Bridge mechanism, allowing us to first reduce the effective dimension of each term of the summed CVA, and second, when combined with a randomization method such as digital shift ([6]), diversify the errors across the time axis. We provide some early convergence results in table 4. The results are very promising indeed.

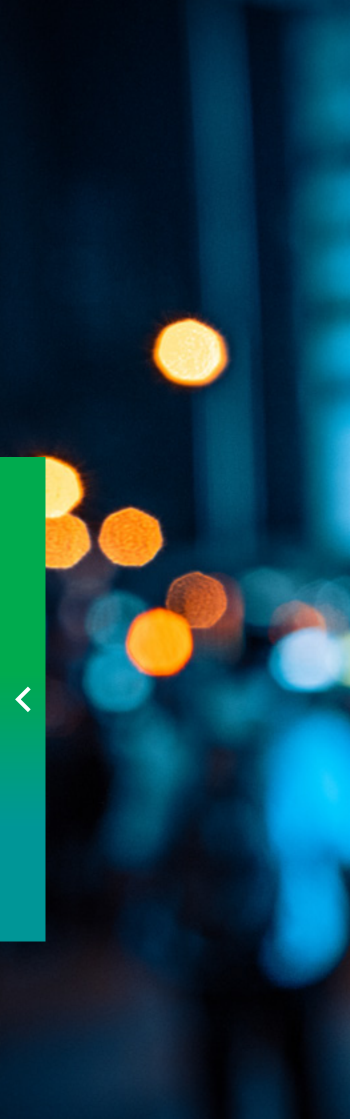

Table 4: CVA error for an at the money 10 year USD fixed for float swap with $10,000 notional for various numbers of simulation paths. Three methodologies are presented. Classical MC, randomized QMC + BB (RQMCBB) with regular pathwise simulation, and randomized QMC + BB (RQMCBB) with direct and independent simulation of the risk factors to each time step. ■

Paths	Pseudo Pathwise	RQMCBB Pathwise	RQMCBB Direct
32	2.7898	0.7904	0.1957
64	1.9505	0.4156	0.0759
128	1.6297	0.2383	0.0440
256	1.0343	0.1347	0.0247
512	0.7116	0.0695	0.0133
1,024	0.5221	0.0328	0.0059
2,048	0.3384	0.0176	0.0032
4,096	0.2281	0.0109	0.0017
8,192	0.1716	0.0064	0.0010
16,384	0.1248	0.0038	0.0006
32,768	0.0992	0.0020	0.0003

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The impact of region on FVA submissions

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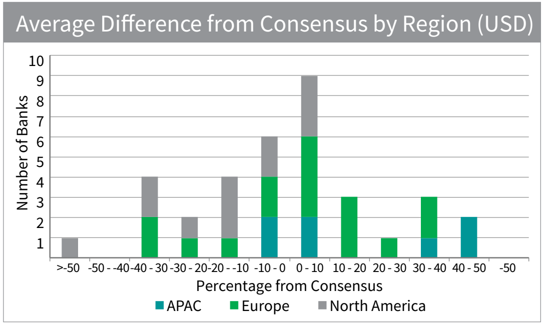
Funding valuation adjustment, or FVA, has long been the subject of heated debate within the industry. Intended to ensure banks account properly for the cost of funding unsecured derivatives transactions, it is one of the concepts covered by XVA. However, questions persist around how FVA should be applied and calculated. As part of the Totem XVA service, we collect a range of submissions from clients – including on FVA – which gives us unique insight into patterns and trends. Banks are interested in comparing submissions to their peers and so we have sought to review the significance of various factors and how they affect submissions. FVA is where we often see larger differences in pricing between participants and so our analysis is focused specifically on this concept.

In this analysis, the FVA submissions are reviewed in absolute terms. The term 'above the consensus' refers to a larger negative adjustment and 'below consensus' refers to a smaller negative adjustment, as compared to the consensus data. One of the significant variables in banks that submit to the XVA service is the region where they are based. The question therefore arises: does region have a significant impact on the adjustments that are submitted?

Our analysis shows that there does appear to be some relationship between region and USD adjustment. This relationship is similar across the different scenarios, so we have chosen the 10Y swap as the sample scenario against the IG Sovereign counterparty.

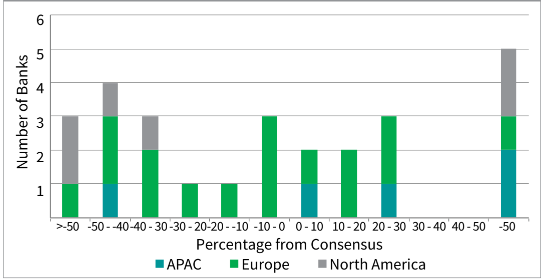


Average Difference from Consensus by Region (USD)

The USD swap shows that all North American banks submit 110% of consensus or below whilst all APAC banks submit 90% of consensus or above. The European banks show the most dispersion and submit data across the range.

These findings indicate that region can play a factor in submissions, although European banks appear to have the least consistency. The picture is slightly different when looking at the 10Y EUR swap which shows a different spread. Although the European banks are still spread across the range, there are a number of banks from different regions submitting large adjustments. Both APAC and North American banks show a much wider distribution, varying from one of the smaller adjustments to one of the largest.

The data indicates that for a EUR swap, the bank's domicile is not a significant factor affecting its FVA, Average Difference from Consensus by Region (EUR)

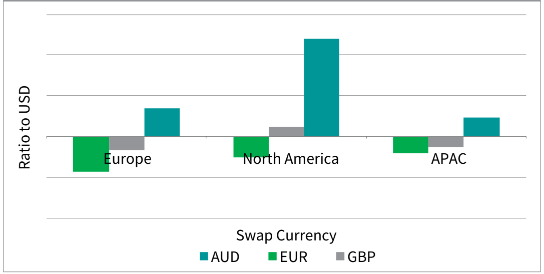


but there does appear to be greater influence of domicile when looking at FVA on USD trades. This is most apparent for North American and APAC banks. The dispersion in European banks – when compared to other regions – may be in part due to the differing local currencies. Not all European banks have EUR as their local currency and this may cause some dispersion in the results. A similar dispersion to the EUR trades was observed in the GBP trade, where domicile was not a significant factor.

Reviewing the internal relationship between currencies for banks based in three regions and using the USD FVA adjustments as the base, the average basis between GBP and USD trades is smallest and the basis between AUD and USD is the largest. This demonstrates that in all regions GBP FVA is, on average, closer to the USD FVA than either AUD or EUR to USD. The AUD basis is positive, signifying larger AUD FVA adjustments and the EUR basis is negative representing a smaller EUR adjustment. The GBP basis is not consistent across regions.

The domicile of a bank appears to affect the relationship between currencies only with GBP to USD, which is likely influenced by the relationship of region indicated in the USD trades previously, as the North American banks' FVA was smaller on the USD trades when compared to other regions, while there was no relationship present in the GBP trade.

10Y YYY Counterparty Swaps



Of all of the factors we reviewed, region appears to have the most significant effect on FVA with the other factors (credit spread, rating and bank structure) having less impact. Data was reviewed over a number of months and a variety of scenarios analysed and no relationship was found between these three additional factors. Therefore, it is highly possible that if there is a relationship observed in these factors, then region may be affecting them. ■

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We offer a Counterparty Credit Risk (CCR)/xVA Solution Suite that supports regulatory capital calculations and an extensive range of pricing valuation adjustments on a single, modular platform. It allows firms to mitigate the impact of capital requirements and delivers flexible pre-trade analytics to the front office.

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