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Mnuchin makes life harder for quants

The add-on to a derivatives contract's fair value to account for the cost of capital, known as the capital valuation adjustment (KVA), is already arguably the most complex of the suite of adjustments out there. But US Treasury secretary Steven Mnuchin's review of bank regulation, released on June 13, looks set to send quants further down the rabbit hole.

The review recommends that the US Federal Reserve Board's annual stress test – the Comprehensive Capital Analysis and Review (CCAR) – be amended so that, if a bank fails the qualitative element, it cannot be the 'sole basis' for the Fed to object to dividend payments.

The dividend question is already vexing US banks that are trying to work out how much KVA to charge for a trade. In a world without CCAR, a bank can set, for example, a 10% return on equity (ROE) hurdle for a new trade, and if it misses, there's an implicit assumption it can hand back the capital it didn't allocate to the trade to shareholders through buybacks or dividends.

Under CCAR though, some banks take into account the likelihood they may fail the test and be unable to hand back that unused capital, trapping it in the bank and earning no return for shareholders. In this situation, a dealer may respond by lowering its ROE hurdles to guarantee it will win more trades, ensuring it can generate at least some returns for shareholders, and lowering the risk of having trapped capital lying around.

"These are all embedded assumptions that could be critical to the KVA calculations. So any change in affecting the assumption would move the numbers, such as the capital release and distribution to shareholders in dividends," says a derivatives quant at a US bank.

This activity, along with similar reductions in ROE hurdles by some European banks, is said to have contributed to the increased competition for corporate derivatives trades since the beginning of the year.

But, if the US Treasury's recommendation that a CCAR qualitative fail does not automatically trigger a ban on capital distribution to shareholders is implemented, this calculation gets even more complicated. If a model showed that the bank is headed for a CCAR fail, there is now uncertainty about whether ROE hurdles should be amended, and therefore how much KVA should be priced into a trade.

For some, this could be a step too far. KVA has always been more art than science, so trying to incorporate the probability that the regulator will allow a capital distribution, even if the bank fails its CCAR qualitative test, may be taking perfectionism to the extreme.

In 2016, quants were confident KVA would follow in the footsteps of the funding valuation adjustment and require accounting fair values of derivatives portfolios to be amended. But, given the difference in practice between banks and the ever-evolving nature of the calculation methodology, that may be some time away.

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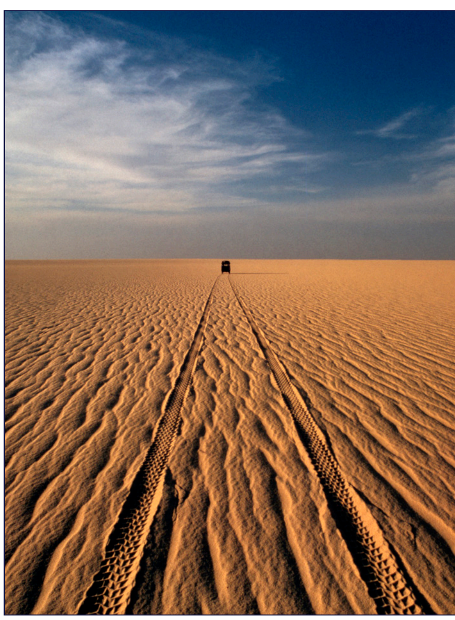

Margin settlement risk and its effect on CVA

Alexander Sokol, head of quant research at CompatibL, explains how the risk of non-payment of reciprocal margin after a trade payment leads to significantly higher credit valuation adjustment for collateralised portfolios with and without initial margin

Until recently, the discourse on XVA had focused on new valuation adjustments: funding valuation adjustment (FVA), margin valuation adjustment (MVA) and capital valuation adjustment (KVA). Plain old credit valuation adjustment (CVA) seemed boring and devoid of surprises by comparison. This has changed with a series of recent publications from quants at Bank of America Merrill Lynch, the US Federal Reserve Board and CompatibL[1,2,3] and two influential editorials authored by Nazneen Sherif in *Risk* magazine.[4,5] These publications highlight the importance of margin settlement risk and its major influence on CVA, especially when initial margin (IM) is also present.

Alexander Sokol

What is margin settlement risk and why is it so important for CVA?

Under a zero-threshold credit support annex (CSA) mandated by recent regulations, the parties in a bilateral trading relationship exchange variation margin (VM) to offset the exposure to each other. If they are also subject to the Basel Committee on Banking Supervision and International Organization of Securities Commissions IM regulation, IM is posted in addition to VM. The stated objective of adding IM to VM is to eliminate exposure and CVA almost completely.

As it turns out, the mechanics of CSA only work well away from trade payments. In their vicinity, it grinds to a halt in the face of new risk that CSA is ill-suited to handle in its current form: margin settlement risk. This new type of risk arises because of the peculiar way trade and margin payments are exchanged. Each trade payment changes portfolio value, instantly creating exposure. Due to the time needed to perform valuation and issue a call for collateral, the reciprocal margin payment that reduces exposure back to its baseline level is scheduled to arrive only a day or two later. If this date falls within the margin period of risk (MPR), the margin payment never arrives, resulting in counterparty credit loss in the amount of trade payment, an amount that is one or two orders of magnitude greater than baseline exposure.

The exposure spikes that appear because of this effect are very tall, but also narrow, extending only for the length of MPR – usually 10 business days – around each trade payment. For a large portfolio, the aggregate effect of a large number of exposure spikes is a significant increase in exposure on almost every business day, with the amount varying from one day to the next. Andersen, Pykhtin and Sokol estimated that margin settlement risk is responsible for 15–25% of exposure without IM, and for up to 90–95% of the exposure with IM.[2,3] Without margin settlement risk, CVA under IM would be suppressed to such an extent that it would be reasonable to ignore it; with margin settlement risk, it is only suppressed by a factor of around 5–10: certainly a significant reduction, but not sufficient to disregard the residual CVA completely. Exposure spikes are responsible for the majority of CVA that remains under IM.

The increase of CVA due to margin settlement risk is undesirable, but is it possible to avoid it?

Andersen, Pykhtin and Sokol proposed a mechanism for eliminating exposure spikes and excess CVA under the traditional CSA framework.[2] They proposed a minor change to how portfolios are valued for the purposes of CSA. This makes the trade payment and the reciprocal margin payment fall on the same day, so they can be settled via a payment-versus-payment service such as CLS. An alternative way to eliminate margin settlement risk is the new SwapAgent service by LCH, which nets trade and margin payments. Unlike the former method, the LCH service can only be used for certain types of bilateral trades, however.

Until exposure spikes near trade payments can be eliminated, their contribution to CVA must be calculated. It may seem that such calculation would require valuing the portfolio on a daily grid, making it too slow for practical use. Fortunately, Andersen, Pykhtin and Sokol developed a fast and accurate numerical technique for calculating exposure spikes with daily resolution without daily portfolio revaluation.[1] Source code for implementation of this technique is available free of charge from *ModVal.org* [6] for model validation purposes, and commercially as part of CompatibL Risk software.[7] ■

1 *Andersen L, M Pykhtin and A Sokol 2016,* Rethinking margin period of risk, *SSRN Working Paper, January, https://ssrn.com/abstract=2719964*
2 *Andersen L, M Pykhtin and A Sokol 2017,* Does initial margin eliminate counterparty risk, Risk *May, p.74, www.risk.net/5209111*
3 *Andersen L, M Pykhtin and A Sokol 2016,* Credit exposure in the presence of initial margin, *SSRN Working Paper, July, https://ssrn.com/abstract=2806156*
4 *Sherif N 2017,* Time to talk about settlement risk, Risk *May, p.73, www.risk.net/5208901*
5 *Sherif N 2017,* Time trial: the big risks that lurk in OTC margin gaps, Risk *June, pp.26–29, www.risk.net/5274526*
6 *Andersen L, M Pykhtin and A Sokol 2016, www.modval.org/papers/aps2016*
7 *CompatibL Risk, www.compatibl.com/software/compatibl-risk*

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Quants head for the shop floor

From banks to buy-side firms, and from XVA pricing to data science, today's quants have a dizzying array of opportunities available to them – but employers are looking for specific skills and, as Louie Woodall reports, some schools are not keeping up

Need to know

- The role of a bank quant has changed almost beyond recognition following the global financial crisis.
- While quant numbers have gone up on the sell side, traditional roles have declined. One-time pricing specialists are now employed across a host of bank functions, such as analytics, risk management and model validation.
- The market for quant graduates is also splintering: asset managers, insurance companies and tech firms alike have ramped up their recruitment efforts, in direct competition with the banks.
- Today's recruiters place a premium on quants trained as data scientists, familiar with artificial intelligence, machine learning and natural language processing.
- Academia is racing to keep up with the pace of change. A number of universities have updated their syllabuses to reflect the new world, though graduates may still be surprised by the differences between learning and practising quantitative finance.

Illustration: Lon Chan, nbillustration.co.uk

In the old days, there were banks and there were quants. The banks were making a fortune trading complex derivatives, and the quants were there to show them how.

The banks are still around, of course, but they're now making money in very different ways, and the quants aren't just quants; there are more of them, and they're doing a lot of new things. There are library quants, 'full-stack' quants, XVA quants, compliance quants, analytics quants – more varieties than you can shake a stick at.

Three senior quants at top-tier banks who spoke to *Risk.net* for this article claimed to have more staff than in the pre-crisis years, but also said their front-office pricing and modelling teams – the traditional home of the quant – have been decimated. The roles that have taken their place challenge the way the profession defines itself.

"The term 'quant' doesn't mean much these days – it's a word that should be disposed of," says Lorenzo Bergomi, head of quantitative research at Societe Generale Corporate & Investment Banking in Paris.

Today, quants are less likely to be maverick mathematicians, and more likely to be managerial and collaborative; the one-time pricing specialists are scattered across a range of functions, from risk management and model validation, to data science, algorithmic trading and regulatory compliance.

Essentially, the structural changes wrought on banks by post-crisis regulation and increased market complexity have forced quants to leave behind the lab, and join the hurly-burly of the shop floor.

"Back in the day, a quant could be sitting in their office all day cranking out models and not interacting with anybody. Today they need to be a lot more open in terms of tools, data, and with other members of the business. Quants need to constantly improve themselves and work to be active participants in the market," says Andrew Chin, chief risk officer and head of quantitative research at fund manager AB.

These "full-stack quants", as Linda Kreitzman, executive director at Haas School of Business's master of financial engineering programme dubs them, are expected to be proficient in more than pure mathematics: familiarity with esoteric subjects such as machine learning and natural language processing – a methodology that enables computers to derive data from human language – are increasingly expected, but so too is a working familiarity with programming and the post-crisis regulatory landscape. They are also in greater demand outside the banking industry, where buy-side firms, high-frequency traders, exchanges, regulators and others are adding to their technical muscle (see box: *Case study 1: The view from CME*).

Hiring managers are divided, though, over whether this shift is being reflected in academia. Some worry tomorrow's quants are being groomed for a future that may not exist.

"There remain well-founded concerns over both the quality of candidates seeking to study on specialist master's programmes, and the relevance of the course material to the industry's rapidly changing needs. Over the years, I've encountered many graduates from these courses who can tell me all about martingales and risk-neutral measures, but only a few who can tell me why they are used and how they relate to a bank's trading business," writes Gordon Lee, part of the quant analytics group at UBS in London, in an introduction to *Risk*'s inaugural guide to the world's top quant finance courses (see *Risk* special report, *Quant Finance programme guide 2017 www.risk.net/ 5291711*).

"It's more and more difficult, not to say absurd, to make courses based on theory only" Jean-Philippe Bouchaud, Capital Fund Management

Jean-Philippe Bouchaud, chairman and head of research at France's largest quantitative hedge fund manager, Capital Fund Management, agrees some schools are struggling to keep up with the market's shifting needs: "It's more and more difficult, not to say absurd, to make courses based on theory only. Yet it's highly non-uniform. Some universities have done more practical courses already for a long time, others are resisting. It's a question of country culture, university culture, and so on."

Plenty of universities – particularly in the US – cite the importance of engaging with industry practitioners to keep their syllabus on point. Rutgers University in New Jersey, for example, has introduced dedicated modules on data mining, machine learning and advanced statistics in a bid to move beyond a "pure quant" syllabus and equip graduates with the skills needed to thrive in the transformed business environment.

The University of Toronto, meanwhile, offers an introductory module on the financial industry to bring enrolees up to speed with current applications of quantitative finance, and incorporates a four-month internship as part of its winter session.

Some unis are also adjusting their programmes to suit the tastes of non-bank recruiters, particularly hedge funds and asset managers. The Cass Business School at City University, London, for instance, is adding a quantitative trading module that aims to teach students the intricacies of market microstructure as well as in-vogue trading strategies.

The programme a student enrols in can go a long way to determining how smooth they find the transition to industry. It could also create a yawning gulf between graduates' expectations and reality. "Many end up with this idea that they'll have this exciting life. Compensation for quants has gone up in the last five years, but I think that is driven by the incredible impact of model risk rules on the banking system. The amount of energy and resource that has been poured into the model validation effort has been staggering – but it's not the same thing as building a trading model," says Nicholas Silitch, chief risk officer at Prudential Financial.

Changing role

So, does the average bank employ more quants now than in 2007? The simple answer, say most banks, is yes – with the caveat that it depends on what each bank now defines as a quant.

One chief front-office quant at a major US bank says his team has roughly doubled in size since 2007, but that is partly down to an internal reorganisation. The bank has combined its front-office and risk analytics functions into one large "global analytics" group, whose task is to churn out the risk numbers the front office, the risk department – and regulators – demand on a daily basis.

As a result, his team is composed of far fewer pricing specialists now, he says, with headcount in those roles replaced by four broad new functions: regulatory calculations; model governance, validation and monitoring; margining and funding requirements; and computer technology (see box: *Case study 2: The view from SG CIB*).

Outside his team – which he says makes up one-third of the bank's total quant workforce of over 1,000 – there is a "very substantial" number engaged in the risk function, dealing with regulations such as the Fundamental Review of the Trading Book and other Basel III updates; another third works in the bank's consumer banking and wealth management unit.

For other banks, the numbers differ, but the shift in roles is broadly similar: the head of quant analytics at one large European bank his team's size at 400; a similarly sized peer says closer to 300 – though he currently feels under-resourced – while a major dealer with a smaller markets business puts the total closer to 200.

The under-resourced banker says two-thirds of his 300 roles are front-office positions – a roughly 15% increase on front-office headcount pre-crisis, he estimates. But whereas before, virtually all such roles would have been pricing-focused, now he estimates the number of such specialists in the front office at no more than 100, most of whom focus on XVAs and credit exposure. The rest of the front-office roles are overwhelmingly working in the bank's algorithmic trading businesses, he says.

"Most of these would be new blood; a lot of our old pricing specialists have gone to the buy side," he says.

XVA teams are identified by most banks as the front-office group that has enjoyed the biggest increase in resources. While most sizable banks have been calculating credit valuation adjustments (CVAs) since the early 2000s, most only did so as a way of monitoring the capital impact of counterparty credit exposure at a trade level. Post-crisis, the metric has evolved into a regulatory requirement, and a source of potential competitive advantage for dealers.

On top of that is a newer battery of adjustments, for own-credit risk, capital, funding and – in theory, at least – margin. Getting these numbers correct at the inception of a trade should ensure tomorrow's banks are not left with huge back-books of value-destroying positions, but the theoretical basis for some of the adjustments is still being debated, and the computational power required to get anywhere close to real-time XVA pricing is huge – itself opening up new fields for quants to explore.

The end result is that the pricing of vanilla products has become astonishingly complex – helping offset the drop-off in exotics trading, and safeguarding jobs for a cohort of front-office quants. The size of these teams varies according to the size of each bank's markets business.

The second bank's senior quant points to one big US dealer as an example, claiming its XVA team – at roughly 300 staff – is "larger than our entire stock of quants". It was not possible to confirm that claim before *Risk* went to press.

Across all functions, there is increased demand for quants who can fill the role of trouble-shooting technologists – capable of melding theoretical knowledge with computer programming skills to build out their host firm's various tech projects. So-called library quants – who code a bank's pricing models library, as well as its risk-analytics engine and, depending on the bank, sometimes its CVA engine – are one example.

"The average quant these days is less technical than in the past, but with better IT and roll-up-your-sleeves skills," says the first bank's senior quant. "A majority of junior hires come from master's programmes in computational finance, rather than PhD programmes in physics or maths."

Outside the front office, arguably the biggest recent need has been for model validation experts: those responsible for assessing their bank's regulatory capital and stress testing models, hunting for faults and ultimately ensuring they are fit for purpose.

US prudential regulators have been the biggest drivers of demand, with their 2011 Supervisory guidance on model risk management, commonly known as SR 11-7. The largest US banks estimate the size of their model validation teams has grown tenfold since the statute was enforced, with the average number of models that need validating annually trebling. The rules also forced organisational changes on banks, requiring the validation teams to be separated from those who build and use the

"The trend has been away from models that are heavily parameterised and over-fitted towards those that are explainable and intuitive"
Neville O'Reilly, Rutgers University

models. Banks have also had to set up a consolidated firm-wide model risk function, maintain an inventory of all models, and fully document their design and use.

Regulators' rationale – curbing the modelling freedom of traders and front office and formally transferring oversight to second-line risk managers – is pretty clear, and has helped push the industry towards models that are easier to validate. "The trend has been away from models that are heavily parameterised and over-fitted towards those that are explainable and intuitive," says Neville O'Reilly, director of the risk management programme at Rutgers University.

With regulators in Europe looking to ape the regime, some banks have begun to explore the potential for machine-learning techniques to help with labour-intensive exercises such as data cleansing, for instance to help identify trouble spots and lighten the load – making model validation just one of the functions where data scientists are increasingly in demand by banks.

Competition

It is here, however, that banks face stiff competition from the buy side, where demand for data scientists is, proportionally, rising still faster: AB's Chin, for example, says around 20% of his firm's current quant workforce is focused on big data and related fields, compared with 0% just five years ago. This number will only rise in the coming years, he adds.

Academia has recognised the trend, he says: "Looking at the quant finance programmes out there, it's interesting how many of them are adding a data science or big data component. The reason? Because we are looking for more of those types of skill sets. In asset management, everyone is looking at how we can apply big data and data science to our investing strategy, interactions with clients, and also in terms of how we simply run our organisations," he says.

The battle for talent is driving some novel approaches to grad recruitment: Chicago-based Citadel, which has separate asset management and market-making divisions, is hosting no fewer than 18 'datathon' competitions at universities in the US, UK and Ireland this year, inviting competing teams of students to analyse large, unstructured datasets, and come up with a working, modellable hypothesis that can form the basis of a technical paper presented to judges.

These changes demand a different skill set from today's graduates. Quentin Litzner, executive director in cross-asset trading at Crédit Agricole Corporate

CASE STUDY 1: THE VIEW FROM CME

Futures giant CME Group employs 45 quants full-time across its offices in Asia, Europe and the US, with more than 30 consulting staff adding to the workforce – a total that has grown "significantly" over the past five years, according to Udesh Jha, the London-based chief risk officer for CME Clearing Europe.

The team develops and supports various aspects of CME's risk methodologies – from pricing algorithms and margining models to stress testing and the development of capital-efficiency solutions for the clearing house's members.

Jha says exchanges and clearing houses are on the hunt for quant recruits not only with impeccable quantitative abilities, but a variety of soft skills too. Quants are becoming increasingly outward-facing, meaning they are expected to provide insights into the clearing house's risk management practices to regulators and customers alike. Such tasks demand tip-top presentational capabilities and a talent for explaining complex risk methodologies in simple terms to non-professionals.

"While subject matter expertise in financial mathematics and programming is very important, equally important is the need for skill sets to articulate complex models to other internal and external stakeholders," says Jha.

The models themselves have also changed – or, at least, the way they are used: "The most important need in today's times is that risk models must not be black boxes – they should be seamless in terms of explaining fast-changing risk patterns, prudently capturing all pertinent risk factors, and also allowing for the seamless injection of qualitative factors and expert risk judgement into the models," he says.

and Investment Bank agrees data-handling abilities are in demand, and that students would do better to spend time working with large datasets than grappling with model theory. Other practitioners say quant graduates adept at finding, cleaning, storing and utilising data are highly sought-after.

Proficiency in computer coding is a must, as recruits are expected to be able to interact with firms' existing back-office systems, databases and pricing libraries from day one. Familiarity with Python, R, C++, Java and SQL, among others, is especially prized.

However, this doesn't mean students must be fluent in every language under the sun.

"The foundation stones need to be there – because from there you can pick up whatever language you need to. If that understanding of data structure isn't there, you're going to struggle. If you don't know what a table structure is, or how a particular syntax is structured, how on earth are you going to find what you're looking for?" says a quant finance expert at a regulatory body.

For regulators, this rattles because recruits will be paying site visits to firms using their own proprietary version of these languages, he adds; an understanding of the building blocks is more important than mastering each in full.

Prudential Financial's Silitch adds another must-have to the growing list of quant qualifications: interpersonal skills.

"I'm interested in ensuring the people we bring on are quants that have the ability to take complex ideas and synthesise them into plain English. We spend a lot of our time having to dumb down what our quants want to do. Often a quant in the second line of defence will tell a quant in the first line that they can build a better model than them, and we have to explain to them: that's not your job – your job is to assess whether the model is reasonable," he says.

Empathy is a virtue especially welcome in regulatory circles, where the recruitment of quants is

"If you are a mathematician, you need to back up your thesis, but also write it down in a way that the enforcement officer can understand" Marcello Minenna, Consob

picking up pace. Marcello Minenna, head of quants at the Italian financial regulator Consob and adjunct professor of quantitative finance at Bocconi University in Milan, explains that though additions to the financial rulebook must be grounded in science, articulating them to an inexpert audience of lawyers, traders and fellow regulators is an art all of its own.

"This is the most difficult aspect. If you are a mathematician, you need to back up your thesis, but also write it down in a way that the enforcement officer can understand. If you're proposing inflicting sanctions on a bank, you reduce the freedom of the individual trader. I sign off on all the acts of course, but I need a first draft that supports the final result. Not every regulator has quants who can do this," he adds.

So, is this a good time to be a quant? When *Risk.net* looked at the future of quant finance five years ago, the mood among practitioners was grim. One said they were doing "worse work for worse money" – another lamented the passing of the "heroic age" for the profession. In the years since, others have wistfully recalled a time of campus-style problem-solving, or dismissed the latest generation of recruits as "muppets" with no idea how to apply their limited technical skills. These were principally veteran front-office quants and leading researchers.

Among the academics, practitioners and recent graduates interviewed for this feature and the accompanying course guide, the mood is mixed. It is probably the case that today's quants have less chance of making a spectacular solo breakthrough that changes the way markets work. It may also be true that today's quants are less isolated within their firms, have more career paths to follow, a wider range of problems to tackle.

Is it a good time to be a quant? Well, that depends what type of quant you are. ■

Additional reporting by Alina Haritonova, Sebastian Day and Tom Osborn

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CASE STUDY 2: THE VIEW FROM SG CIB

Today, the functions carried out by "quants" have multiplied and transformed far beyond those originally defined under this label.

Lorenzo Bergomi, head of quantitative research at Societe Generale Corporate & Investment Banking, points to three classes of employees typically called "quants" in the modern bank. The first are modelling quants, charged with developing models and algorithms for assessing product risks. Then there are the library quants, responsible for coding pricing models designed by the modelling quants or from open source archives. These quants also code the risk analytics and valuation adjustment "engines" used by the risk management and pricing functions.

Finally, there are the analytics quants, who deploy the models coded by the library quants to calculate valuation adjustments for portfolios of trades and the resulting funding cost of initial margin payments.

"Nowadays [quant] mostly means the third kind. In quite a few banks, the front-office and risk analytics functions have been merged into one large 'global analytics' group whose task is to churn out all risk numbers that front office, risk department and regulators want," says Bergomi.

NEX TriOptima

Accelerated MVA in triCalculate

The choice between building or buying an XVA system has recently been extended with the option to use a service to calculate valuation adjustments. Users supply their trade, credit curve and collateral data to the triCalculate service, and interact with the centrally hosted calculation engine through a web interface. Martin Engblom, business development manager at NEX TriOptima, explains how – by utilising the *Probability Matrix Method* and state-of-the-art graphics processing unit hardware – triCalculate can cater for a large number of customers simultaneously

The phased introduction of bilateral initial margin is affecting institutions with gradually decreasing size. Institutions that stand to benefit the most from a central analytics service are coming into scope and, as a response, triCalculate has added margin valuation adjustment (MVA) to the catalogue of risk metrics.

Consistent global modelling

Traditional XVA systems separate the tasks of generating market factor paths and pricing netting set values. Paths for each market factor are generated using a simulation model, which is calibrated to traded instruments. The netting set value for each path and time step is obtained by feeding the simulated market state into separate independent pricing models. The pricing models generally imply a different dynamic behaviour of the underlying to the dynamics assumed by the simulation model in the path generation phase. This mismatch ultimately leads to XVA inaccuracies as well as mismatching hedging strategies.

The *Probability Matrix Method* – as introduced by Albanese *et al* [1] – is more consistent. The modelling framework is based on common transition probability matrices for generating scenarios and pricing netting sets. Provided with calibrated models, the first step is to generate transition probability matrices on a predefined discrete time-and-space grid. The second step involves using the generated matrices to price all derivatives contracts to obtain valuation tables expressing the value of every netting set in every discrete state of the world. The transition probability matrices are again used in the third step to generate simulation paths for the underlying market factors. Market factors are correlated using a Gaussian copula, which is typically calibrated to historical time series. Finally, in the fourth step, XVA is calculated by stepping through simulation paths, looking up the netting set values in the valuation tables and evaluating the XVA contributions.

The clear separation of computation tasks into the steps described above has proven to be extremely effective – from the point of view of performance as well as development. Pre-computing transition probability matrices and valuation tables, using graphics processing unit (GPU) technology, allows for a simplified simulation procedure that significantly cuts overall computation time by orders of magnitude. This raw power facilitates a simple and uncompromising implementation of MVA. Where many authors advocate approximations for evaluating the initial margin formula, the sheer speed of the triCalculate engine allows for full valuation in every time step, along every path.

MVA calculation

The standard credit valuation adjustment (CVA) and funding valuation adjustment (FVA) calculations are trivial exercises once we have generated scenarios and valuation tables as described above. In every step along the path, we simply need to look up the netting set value from a table rather than firing up an external pricing engine. MVA presents a further challenge, however. As in Green and Kenyon,[2] we define MVA as an expectation of an integral according to:

$$E\left[\int_0^T s_t e^{-\int_0^t \left(r_s+\lambda_s^C+\lambda_s^B\right)ds} M_t dt\right]$$

where s_t is the funding spread over the initial margin collateral rate, λ_s^C and λ_s^B are the (dynamic) default intensities of the counterparty and the bank respectively, and M_t is the initial margin amount.

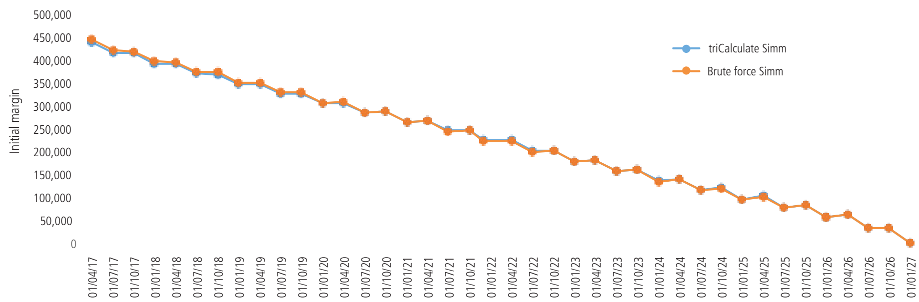
This expression is very similar to the expressions for the traditional XVA measures CVA and FVA. The complicating factor is that the initial margin is a rather complex quantity to calculate along the path. The standard initial margin model (Simm) bilateral initial margin formula takes bucketed netting set sensitivities as input, and value-at-risk or expected shortfall-based clearing house initial margin can be simplified using delta/gamma type expansions also requiring bucketed netting set sensitivities to be calculated (see figure 1).

Fortunately, the valuation table generation in the *Probability Matrix Method* responds very well to bucketed netting set sensitivity calculations. Experience has shown that clever chain-rule applications – or adjoint algorimithic differentiation – is only needed for the simulation step when calculating regular XVA sensitivities. For MVA we may rely on standard perturbation techniques to generate the bucketed netting set sensitivities we need. The reason netting set sensitivity calculation scales so well with the number of sensitivities is down to the use of GPU hardware. The operation of transferring memory to the GPU device is the bottleneck that constrains GPU performance. This means there is often spare capacity to be used on the GPU while memory

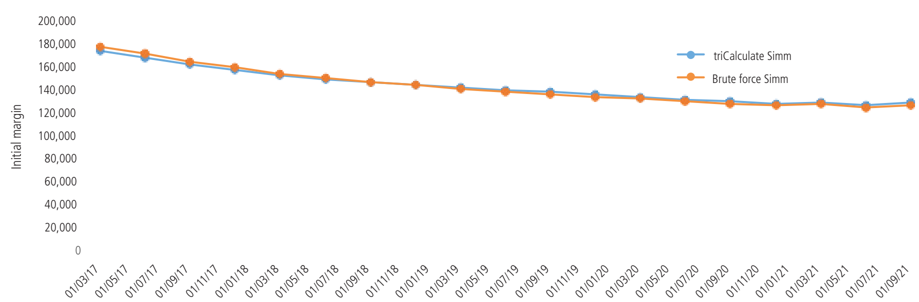
[1] *Claudio Albanese and Giacomo Pietronero,* Coherent global market simulations and securitization measures for counterparty credit risk, *2010, http://ssrn.com/abstract=1844711*

[2] *Andrew Green and Chris Kenyon,* MVA by replication and regression, *Risk, 28 (5), 2015, http://www.risk.net/derivatives/2405264/mva-replication-and-regression*

1 Expected Simm initial margin for a 10-year Euribor swap. Comparing triCalculate Simm with brute force Simm using industry-standard sensitivities and initial margin implementations



2 Expected Simm initial margin for a five-into-five-year Euribor swaption. Comparing triCalculate Simm with brute force Simm using industry-standard sensitivities and initial margin implementations



3 Calculation time

Example of calculation time when running MVA on a diversified portfolio on a standard laptop computer using the *Probability Matrix Method*

- 100,000 paths
- Quarterly time steps
- 50 counterparties
- 20,000 trades
- Intel i7 2.6GHz
- 8GB RAM
- NVIDIA GTX 950M
- Valuation: 132 seconds
- Simulation: 65 seconds
- Total time: 197 seconds

is being copied back and forth during execution. Sensitivity calculations are efficiently utilising this spare capacity as more computations can be performed on each batch of data.

For the MVA calculation we generate not only the valuation tables containing netting set values during the valuation step, but also tables containing the bucketed netting set sensitivities for every future state of the world. Despite the minor complexity of the Simm formula, the simulation step is still a simple exercise of simulating the market factors forward, looking up the bucketed netting set sensitivities and evaluating the initial margin formula.

Test results and performance

To benchmark the MVA calculation we turn to two initial margin-related services actively used by the industry today: The Acadia IM Exposure Manager, powered by TriOptima, and the triBalance initial margin optimisation service. First, we generate and export 1,000 paths with quarterly time steps from triCalculate. Simm sensitivities are generated for every path and every time step using the infrastructure and models used to generate triBalance initial margin optimisation proposals. The sensitivities are then fed to the IM Exposure Manager Simm implementation, which produces an initial margin number for every simulation date in every path.

The end-result of this exercise is essentially a brute force MVA calculator, which we use to benchmark the triCalculate expected initial margin curves. Results can be observed in figures 1 and 2, where we compare the expected Simm initial margin for a standalone swap and a standalone swaption, respectively.

The naive brute force MVA implementation takes hours to run while the triCalculate initial margin profile is generated in minutes. To further highlight the performance of the *Probability Matrix Method*, figure 3 provides an example of calculation times when calculating MVA on a realistic portfolio using a standard laptop computer. ■

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Article 104

A looming headache for corporates

When the European Banking Authority announced it was shelving efforts to impose a regulatory capital charge for corporate credit valuation adjustment, it seemed like a decisive reprieve for corporates. But regulators are poised to drop a new bombshell in the form of rules that would clear away legal barriers frustrating previous efforts. By Catherine Contiguglia and Nazneen Sherif

Need to know

- The European Banking Authority (EBA) has abandoned projects to impose capital requirements for credit valuation adjustment (CVA) risk on corporate exposures via Pillar 1 or Pillar 2.
- Guidelines for a Pillar 2 charge faced legal challenge because it isn't clear if capital can be required against risks exempt under Pillar 1 of the Capital Requirements Regulation.
- No national regulators contacted by *Risk.net* have a set Pillar 2 approach to calculating capital against exempt CVA, partly because of this legal question.
- However, a change proposed in CRD V could clear the way for national regulators and the EBA to pursue a Pillar 2 charge, and will also mandate the EBA to write a draft regulatory technical standard harmonising how to measure the risk.
- The situation confuses derivatives pricing for banks, which had started to price in the assumed repeal of the CVA exemption as well as Pillar 2 charges.

The duelling adversaries in children's cartoons never give up, and their attacks become ever-more creative. If the frying-pan ambush fails, then the dangling anvil will surely do the trick. Europe's regulators are hoping the latter approach will now bring them a final, decisive victory in their repeated attempts to wipe out a controversial capital exemption enjoyed by the region's non-financial corporates.

So far, corporates have been one step ahead. Because the Pillar 1 capital exemption for credit valuation adjustment (CVA) is granted in Europe's Capital Requirements Regulation (CRR), national supervisors have balked at applying a Pillar 2 add-on – the usual remedy when capital rules leave an exposure uncovered. The fear among the watchdogs is that it might be illegal to ignore the wishes of the legislators. But new wording in Article 104 of the revised Capital Requirements Directive (CRD V), issued in draft form last November, will for the first time explicitly allow national authorities to apply specific add-ons for risks exempt under the CRR.

The rope is taut, the anvil is in position, and banks are already worrying about the mess it will make of their derivatives prices.

"Not only do we not have clarity now, if we have [the amendment] as well, it just makes it worse. It is an even stronger statement within the directive that the competent authorities at their discretion can decide to give you Pillar 2 capital for something that has been exempted from Pillar 1. I don't see how that helps if the whole nature of this is to allow comparability between firms," says a regulatory expert at a European bank.

Comparability isn't the principal aim for the regulators though. The goal is finding a legally sound way to capitalise risk.

In an exclusive interview with *Risk.net* in April, the European Banking Authority's (EBA) head of regulation Isabelle Vaillant said the agency had dropped efforts to repeal an exemption in CRR for the CVA risk capital charge on exposures to corporates. This followed a decision by members of the international standard-setter, the Basel Committee on Banking Supervision, to rule out more risk-sensitive internal modelling of CVA risk capital requirements in revised rules. She also revealed the EBA was forced to abandon planned guidance for national regulators on how to include CVA capital in additional buffers because of questions about whether, legally, Pillar 2 capital add-ons could be imposed on exposures exempt under Pillar 1 in the EU regulation.

"We are in a legal setting where you can't have this. This is why we interpreted there could be room for a Pillar 2 solution, even though this was disputed by some – in particular, members of the European Parliament. We never issued the guidelines, so in the end it means it's only for the bank to decide," Vaillant said.

Any perceived legal risk would disappear if the passage of the newly drafted Article 104 of CRD V were passed into law, freeing national regulators to pursue charges as they see fit, and in turn allowing the EBA to revive its guidelines. And even if national regulators decline to take action, the revised Article 104 also mandates the EBA to write a draft regulatory technical standard (RTS) specifying how certain Pillar 2 risks – encompassing the exempt CVA exposures – would be measured. An RTS would be binding across the EU.

The Pillar 2 guidance and the exemption itself can be seen as part of a two-step plan envisaged by the EBA. The exemption from Pillar 1 regulatory capital was written into European regulations implementing Basel III in 2013, and was originally meant to be repealed as new market risk rules were implemented in the review of the CRR and fourth CRD. As those changes would not go online for several years, the EBA had suggested in the meantime putting in place a harmonised approach for national regulators to apply capital charges to excess CVA risk via Pillar 2. But the long-term goal of repealing the exemption has now almost certainly been nixed after Basel negotiations yielded a CVA methodology that European regulators say is not what they bargained for.

"This is a case where the recommendations we had were contingent on Basel developments that did not happen, so we have to reconsider the situation – so, that's life," said Vaillant.

Imperfect harmony

That puts all eyes on Pillar 2. A harmonised approach for national regulators to apply a Pillar 2 charge was first suggested in 2015 in draft guidelines on the treatment of CVA in the supervisory review and evaluation process (Srep). It was part of a broader move launched in 2014 by regulators to harmonise the Pillar 2 process via Srep.

The idea was immediately slammed by the European Parliament and corporate treasurers as a case of the EBA overstepping its mandate. In its consultation response, the European Association of Corporate Treasurers said Article 104 in CRD could not be interpreted to allow authorities to impose charges that circumvent "clear policy decisions adopted by the legislator".

Although experts in regulatory bodies are said to have interpreted the article otherwise, it's clear that fear of the legal risk was enough to freeze plans to define a Pillar 2 charge for the exempt exposures. And it's not just the EBA that is caught.

"We are still in the meantime under CRD IV, so if competent authorities are applying an add-on for CVA risk, they are potentially exposed to this legal risk," says one European regulatory source.

Back in 2013, when the Pillar 1 exemption was first implemented, several regulators including Germany's Bafin and the UK Prudential Regulation Authority (PRA) expressed a desire to impose a Pillar 2 charge unilaterally, and Bafin told *Risk.net* it was hoping for further harmonised guidance from EU regulators on how to impose a Pillar 2 charge.

However, fresh responses from six national regulators reveal none has imposed a defined Pillar 2 CVA charge for exempt exposure, though some indirectly require capital as part of larger market risk requirements. In addition, regulators are split on how to read the existing version of Article 104 that is contained in CRD IV, with some implying they would be unable to apply a charge under the current working, while others assert there are no limitations (see box: *Regulators divided*).

One spokesperson for an EU national regulator says they support the EBA's decision to put the harmonised Pillar 2 guidelines on hold because of the "legal and commercial risks", but note that "language in Article 104a(2) of CRD V now explicitly allows competent authorities to disregard the capital impact of the CVA exemptions in assessing Pillar 2 capital requirements".


Stéphane Boivin, EBA

Others argue the current wording of Article 104 is already sufficient for them to impose a charge on excessive CVA risk from exempt exposures. "A Pillar 2 capital charge requirement can in our view be set if the supervisor considers the CVA risk generated by counterparties exempted from the calculation of minimum own-funds requirements to be excessive," says a spokesperson for the National Bank of Belgium.

"A revised wording of Article 104 would in this respect not make a difference as the possibility of imposing a Pillar 2 capital charge for this risk is already included in the CRD IV text," he adds.

A lot of this opacity would be wiped out by the new Article 104. The CRD IV version doesn't explicitly say a national regulator can impose additional funds for risks that are exempt in the CRR. However, in a change proposed in November 2016, the new Article 104a(2) says additional own-funds requirements imposed by national regulators should cover all material risks or elements of that risk "not subject to a specific own-funds requirement", including "risks or elements of risks that are explicitly excluded from own funds requirements" in CRR (see box: *Article 104: wider implications*). This would formalise a long-standing view among some supervisors.

"If you asked the UK regulators at any time over the last 20 years, they would have told you they can do pretty much anything they like under Pillar 2 because that is what Pillar 2 is for. However this isn't what CRD says, and many EU authorities believed the Pillar 2 charge was tightly constrained to the specified items set out in the directive," says Simon Gleeson, a partner at law firm Clifford Chance in London.

"Many authorities take the view that an over-legalistic adherence to the question of what can be included in Pillar 2 results in bank capital charges being set too low, and these changes are an explicit attempt to address that," he adds.

Next steps

There are a few possibilities for how Pillar 2 charges might unfold. The EBA could push ahead with its guidelines based on a broader interpretation of the existing CRD. However, it would be hard to imagine harmonisation guidelines if national regulators have not yet implemented their own approaches.

More likely is that the new Article 104 will play a key role in creating a specific measure to tackle exempt CVA risk. National regulators, freed from overhanging legal risk, could push ahead with their own charges, prompting the EBA to expedite its guidelines project. Alternatively, the EBA will define a binding measure for CVA in its RTS on Pillar 2.

The EBA will soon be discussing the future of the guidelines internally, and its policy expert Stéphane Boivin says it will likely give more information on the status of potential guidance in the second half of the year when it releases a report on CVA risk data collected in 2015 and 2016. "This work has been a bit delayed also due to the discussion at Basel and other priorities for the EBA. We will be discussing them internally again soon, and may communicate further detail publicly at the same time we initiate the yearly CVA monitoring exercise," says Boivin.

Guidelines would result in exactly the kind of harmonised capital requirements not intended for corporate exposures, argue critics. While before, some regulators might have chosen unilaterally to impose charges, now all will necessarily do so, and in the same way.

"We understand some national supervisors were already applying some charge for excess CVA, even for exempted entities, and one of the EBA's objectives was to harmonise this at the EU level. If the EBA issues official guidelines on this, national supervisors who weren't applying charges would have to comply with the guidelines, or they might be asked to give a good reason to the EBA why they were not complying. This would have removed most of the benefits of having an exemption in the first place," says Anni Mykkänen, a policy expert at the European Association of Corporate Treasurers.

The purpose of the CVA exemption, she argues, is for small corporates to be able to benefit from their exemption from central clearing, which was legislated in order to spare the real economy from regulatory burden.

"Applying CVA charges to non-cleared derivatives in

CRD IV would have taken away a lot of that advantage by assigning a punitive capital treatment to non-cleared derivatives. That is the main reason why we have fought to keep this exemption," says Mykkänen.

But critics will have more than guidelines to worry about now. The EBA is mandated in the proposed Article 104a(6) to issue an RTS on how to measure the risks in 104a(2). This would be going a step further, as regulators are expected to follow guidelines and provide explanations when they don't, but RTSs are instructions on how to actually follow the law.

This is part of a larger initiative under the proposed CRR II and CRD V where efforts to harmonise Pillar 2 have gone from a system of guidelines to one where the measurement of Pillar 2 risks will be enshrined in law. Not everyone is a fan of this approach, and the chair of the supervisory board of the European Central Bank Danièle Nouy has repeatedly criticised it, saying it would increase risk in the system.

"Some of the current proposals would limit the discretion of the supervisor, for example with regard to the details of the Pillar 2 capital requirements for banks. I don't imagine we can and should decide how many basis points of additional capital should be allocated for each risk category. If there is one thing we learned from the financial crisis, it is that risks are interrelated and affect each other," she said in a recent interview with the German newspaper *Handelsblatt*.

At present, the ECB does not disclose the exact composition of Pillar 2 capital charges, and applies them flexibly to reflect, for example, the difference between repeated or one-off failures of risk management.

A repealing approach

The repeal of the exemption isn't necessarily completely off the table, either. The European CVA framework has been dubbed non-compliant with international standards by the Basel Committee in a 2014 peer review, putting pressure on the EU to tackle the errant exemption. The EBA published a study in 2015 that found aggregate capital requirements for CVA value-at-risk for the 26 respondent banks would rise by more than 150% without the exemption, which to the authority was a flashing warning sign that banks are undercapitalised. Although a repeal is not suggested in the November draft of CRR II, it could theoretically be introduced during tripartite discussions before being passed, or in a later review of CRR and CRD.

That scenario seems increasingly unlikely, unless there is a major about-face by the Basel Committee. The EBA says repealing the exemption is contingent on Basel allowing internal modelling in its approach to calculating CVA risk capital. This hope was dashed in March last year, and the Basel Committee now seems intent on just the basic and standardised approaches which are said to yield capital requirements two times higher than current internal models outputs.

"We wanted a better calibration of the CVA risk framework, and yet the calibration from the quantitative impact studies made it look like the new framework was coming out with roughly similar numbers to the existing requirement. Then you go out and drop the most risk-sensitive part of it. Basel seems to be moving in the opposite direction to what the EBA wanted, so it's hard to see how Europe can then change its mind," says the regulatory expert at the European bank.

The EBA says it will make its final decision on the recommendation when the Basel framework is released. If the Basel approach is not in line with EBA thinking, the idea of revoking the exemption will be dropped.

"We said previously that, provided Basel would review the CVA framework according to our policy recommendations, we would consider recommending the removal of the EU exemption to the Parliament and Council. The revised Basel CVA report framework is still pending, but when it is finalised and the legislative process to adopt it in Europe is initiated, this debate about the exemption will resume," says the EBA's Boivin.

REGULATORS DIVIDED: HOW AUTHORITIES ARE APPLYING ARTICLE 104

EU national financial regulator

This EU regulator says it does not have a "mechanistic approach using thresholds to determine eligibility and/or capital consequences", and instead uses a "judgement-based approach" to decide whether CVA capital is sufficient. It acknowledges "legal and commercial risks" under the current CRD Article 104, and says the new wording in CRD V "now explicitly allows competent authorities to disregard the capital impact of the CVA exemptions in assessing Pillar 2 capital requirements".

Germany's Bafin

The German regulator does not have an explicit requirement in the form of a standardised Pillar 2 capital add-on, which it says is included in market risk in a bank's internal capital assessment. If that amount is greater than the market risk calculated under Pillar I, an add-on would be required. The regulator did not comment on Article 104.

Bank of Greece

The Greek central bank does not require banks to hold Pillar 2 capital for CVA on exempt exposures, and applies charges based on a "holistic approach" looking at "overall risk assessment", according to a spokesperson, who added that new wording of Article 104 allows Pillar 2 charges on risks "not covered or not sufficiently covered by Pillar 1", giving more flexibility to scope.

Bank of Italy

The Bank of Italy is unable to share Pillar 2 information publicly, but says it is "willing to comply with the [EBA] guidelines on the treatment of CVA risk under Srep once they are finalised and approved by the EBA", and "welcomes" the slated changes to Article 104.

National Bank of Belgium

The Belgian national bank does not impose any Pillar 2 charge for CVA risk because it is not considered a "material risk". However, according to a spokesperson, under the current Article 104, "a Pillar 2 capital charge requirement can in our view be set". As a result, the "revised wording of Article 104 would in this respect not make a difference", as the ability to apply a charge is "already included in the CRD IV text".

Finnish Financial Supervisory Authority

The Finnish financial authority does not require a separate charge for corporate CVA, and a spokesperson says the Pillar 2 requirement is derived using both "risk-by-risk approach and holistic approach to risks", adding that a materiality threshold "plays a key role" in requirements for derivatives activities.

European Central Bank

ECB single supervisory mechanism representatives declined to comment.

Pricing repeal risks

One particularly awkward aspect about any rolling back of plans to impose capital charges on exempt CVA exposures is that some parts of the market are said to be pricing it in already. Practices range widely and pricing for valuation adjustments – known collectively as XVAs – is notoriously opaque, but market participants say they have seen CVA capital charges on exempt exposures being included in one way or another.

CVA is the cost of counterparty credit risk reflected in the market value of derivatives. The adjustment reflects both the credit quality of the counterparty and the market risk factors of the underlying trades. Regulatory capital requirements aim to capture the sensitivity of CVA to these risk factors – called CVA risk. Current Basel III capital rules require capital to be held against the sensitivity of CVA to credit spreads, though the yet-to-be-finalised revised CVA framework attempts to go a step further by capturing the sensitivity of CVA to market risk factors.

The regulatory capital for CVA is a key component of the capital valuation adjustment (KVA), which sources say is being priced in more rigorously following Basel III reforms. Following the EBA's push for the removal of corporate exemption for CVA in Europe, some dealers started pricing the additional capital cost into their trades under the assumption that the exemption would be removed at some point in the future.

Jon Gregory, a London-based XVA consultant, says the CVA risk capital charge, assuming no exemption, would often be at least half of KVA calculated by banks. In a paper by experts from corporate consultancy JC Rathbone Associates, the CVA part of KVA for a £10 million seven-year swap with a three-month Libor floating leg is 3.1 basis points out of 7.1bp total KVA (see figure 1).

The way this cost is priced, however, has been more of an art than science – especially because as opposed to counterparty credit risk, CVA capital is calculated on a portfolio level, and must then be allocated back down to individual clients.

"I don't think there is any kind of real scientific way to do it per se, because what you are doing is you are trying to predict the way a legislator might think," says the regulatory expert at the European bank.

One rule of thumb has been to price in the cost only on longer-dated trades, usually those beyond five years, though the decision on whether to pass the charge on to corporate clients depends on competition and the bank's relationship with the client.

"I would say in general for corporate counterparties for relatively short-dated trades, say within five years, there is a good chance they might not price it in at all. For a trade beyond five years I'd say they will price some of it in," says Gregory.

"For relatively uncompetitive situations, a bank may aim to price in most of the CVA capital charge. However, in more competitive situations, the clearing price will be lower and reflect little or no CVA capital charge," he adds.

In some cases, dealers are said to be pricing in full repeal of the exemption for a portion of longer-dated trades, especially those initiated when it seemed more likely that the new CVA approach in revised market rules would herald its repeal.

"Some banks say they don't price it in because the exemption is in the law. Others say they price it in for a certain period of time – for example, on a 10-year swap, they would assume on year three, the exemption would be taken away, so it is priced in for seven years. But everyone uses a different point in time," says one head of treasury at a large European corporate. Although XVA surcharges aren't usually itemised, he describes seeing differences between the highest and lowest charges of as much as 300bp.

Or, in the same spirit, some dealers might incorporate break clauses into trades that would trigger if the exemption gets repealed in the future – allowing the bank to either reprice or close out unprofitable trades where the capital cost was initially not priced in. For example, on a 10-year trade, the bank could choose to break the trade if the CVA exemption were repealed.

"A break clause would allow a bank to charge more or exit a trade in the event that the CVA capital charge materialises at some point in the future," says Gregory.

ARTICLE 104: WIDER IMPLICATIONS

The additions to Article 104 could affect exemptions elsewhere in the EU Capital Requirements Regulation (CRR), opening up the possibility of significant increases in Pillar 2 capital, and of more standardisation in how that capital is assigned. But at first glance, the wording may still leave one of the main exemptions up for debate.

In addition to the CVA exemption, Europe was identified as materially non-compliant by the Basel Committee for extending a rule that ultimately results in a zero risk weight for most sovereign exposures. The Basel credit risk framework allows a bank that already has internal credit risk model approval to apply the standardised approach for non-significant business units and asset classes, instead of the internal ratings-based (IRB) approach. The CRR in Europe extends this allowance to cover sovereigns, member state central banks and regional governments. This has by and large translated into a zero risk weight for central government exposures, even though in theory national supervisors can set a higher risk weight – and even though sovereign risk is a highly significant asset class for most banks.

The zero risk weight has been hugely controversial. A 2014 report published by the Basel Committee as part of its Regulatory Consistency Assessment Programme showed that zero risk weights for sovereign exposures could lead to a "material overstatement" of the Common Equity Tier 1 ratio when compared against capital calculated using the IRB approach for the sample of EU banks considered.

So it wouldn't be surprising if this rule is viewed as the perfect candidate for a revamped Pillar 2.

However, the new wording may not go that far. Article 104a(2) says Pillar 2 shall cover all material risks or elements "not subject to a specific own-funds requirement", including those that are "explicitly excluded". Sovereign exposures are neither of those; they are subject to a specific requirement, and they are not explicitly excluded.

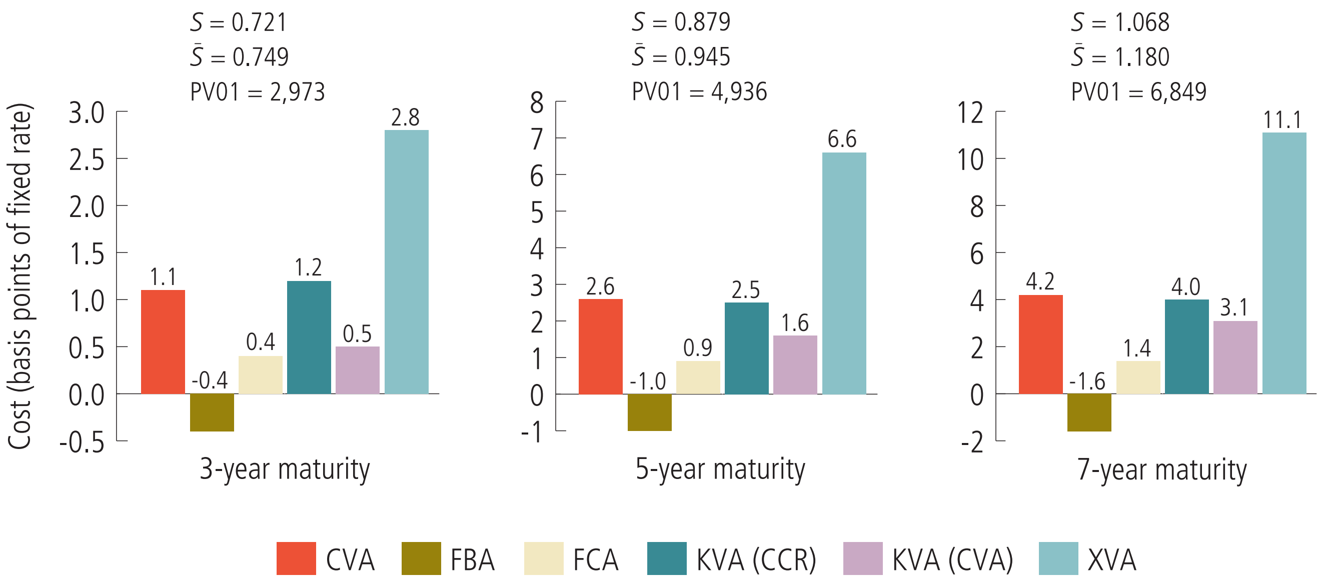
"There has always been a spectrum of risks that are relatively easy to capitalise, and those which are harder to capitalise for various reasons. There are risks like interest rate risk and pension risk where there is a lot of debate around measurement, but it is generally clear these risks can be capitalised in Pillar 2," says Alan Adkins, senior director of credit policy at rating agency Fitch.

"Where the debate is more nuanced is for areas already covered in Pillar 1, like sovereign risk. There is a treatment in Pillar 1 – it is a 0% risk weight under the standardised approach – but it is still a treatment. So to what extent is Pillar 2 a legitimate vehicle for essentially unwinding the Pillar 1 treatment and substituting the supervisors' preferred treatment? That has always been a difficult debate," he adds.

But experts also point out that higher up, in Article 104a(1)a, a sweeping condition for imposing Pillar 2 could encompass sovereign risk. It says Pillar 2 can be imposed when an institution "is exposed to risks or elements of risks that are not covered or not sufficiently covered by the own-funds requirements".

Overall, how much of an impact the change of wording to Article 104 will have on Pillar 2 is very difficult to discern, largely because how Pillar 2 capital is assigned is very specific to each firm. That will change as EU regulators work towards harmonising the approach to a number of risks under Pillar 2.

1 Breakdown of XVAs for £10 million client payer swap at different maturities



Breakdown of XVAs for £10m notional payer swap with floating rate of 3-month Libor and quarterly payment for three different maturities. PV01 is the sensitivity of the price of the swap to one basis point change in the underlying interest rate. S is the fixed swap rate priced under risk-free assumptions, without accounting for XVA costs. S-bar is the fixed swap rate that includes XVA charges. The XVA cost actually passed on to clients – obtained by taking the difference between the two swap rates – depends on the client and nature of the business. As a result, average XVA costs calculated for each of these trades – represented by the coloured bars in the chart – do not add up to the spread actually priced into the trade. That is, the swap may trade above or below that level.

Source: *JCRA, Uncollateralised Interest Rate Swap XVA*; https://ssrn.com/abstract=2807803

Pricing Pillar 2 charges

Pillar 2 capital costs might also be priced in, though details around that are far more difficult to find. *Risk.net* reported in March last year that banks had started to price in Pillar 2 costs, though sources have been hard-pressed to define any examples, largely because even banks aren't entirely clear on how Pillar 2 capital is charged by regulators.

"The Pillar 2 process is not transparent, and therefore you don't know what's going on. The idea is that you as a firm identify additional pieces of risk that may not be part of the Pillar 1 framework and you then go through this with the competent authorities. This is very specific to every firm and there is no way of knowing what is there in each firm," says the regulatory expert at the European bank.

Beyond whether a bank is actively being charged regulatory capital or not, either via Pillar 1 or Pillar 2, a bank may end up holding the capital anyway because of investor expectations, say sources. For instance, bank analysts might adjust the required capital level of a bank because they view the bank as less safe because of the existence of exemptions. This adds a new dimension to pricing in the form of additional capital cost.

"They make a guesstimate of how much that should be, saying 'well, your capital level compared to a peer in terms of your safety should be discounted a little bit and you may have to adjust your own capital levels and capital planning to take into account investor expectations as well'. So it's not just a pure regulator-driven thing in terms of how a particular divergence is treated relating to pricing and capital supply," says a regulatory expert at a US bank with EU-regulated subsidiaries.

Overall, corporate treasurers say whether CVA regulatory capital is being included in the trade price can be opaque, as they will receive an overall XVA cost that often will not be broken down. Treasurers say they can only speculate on what explains the price differences, which can range from the tens to hundreds of basis points, but that they suspect CVA regulatory capital plays a role.

"Yes we see it with certain banks. It is pushing the burden on corporate prices for banks. So for the moment we are not talking about a huge number of basis points, but we have the feeling that the banks are using this to increase credit charges, which is something that is detrimental to the hedging activity," says Jacques Molgo, head of treasury at gas company Air Liquide.

"We trade derivatives to hedge risks, so I think there is a big misconception here. The reasoning should not be the same for entities using derivatives for trading and those using it for hedging. It would cause major pain to have everyone in the same basket," he adds.

One corporate treasurer says all the uncertainty about the future of regulatory capital costs for corporate exposures prompted the firm to switch to credit support annexes (CSAs) – the agreements that govern derivatives transactions between counterparties – that match those between banks. Moving to an interbank CSA meant getting rid of an exposure threshold below which collateral is not posted. Without that threshold, the trade would be perfectly collateralised, drastically reducing CVA. ■

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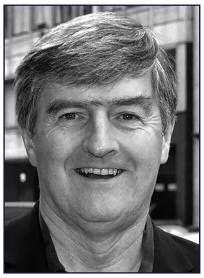
XVA reaches far and wide

Practices range widely across the family of valuation adjustments – collectively known as XVAs – which are typically calculated by taking the expected positive exposures of a derivative at future points in time and then applying the relevant costs to that exposure. In a forum sponsored by CompatibL, Murex and Numerix, a panel of market practitioners examine some of the key issues, including the lack of standardisation and consistency, and how technological developments look to address some of them



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What are the greatest challenges facing the industry in the world of XVA?

Nick Haining, CompatibL: The greatest risk in the world of XVA right now is the lack of standardisation in how valuation adjustments – such as funding valuation adjustment (FVA), margin valuation adjustment (MVA) and capital valuation adjustment (KVA) – are computed, reported and charged to clients. In a recent paper, Leif Andersen, Michael Pykhtin and Alexander Sokol argue that even the plain credit valuation adjustment (CVA) is not always properly evaluated because of previously unrecognised margin settlement risk – a view supported in recent *Risk.net* editorials by Nazneen Sherif. When a variety of disparate ways of computing valuation adjustments are combined with limited disclosure of calculation methodology options for financial reporting purposes, it is difficult to assess the significance of the reported XVA figures in bank financials. The lack of a standard approach in charging these valuation adjustments to clients is also problematic as it may cause firms that fail to properly calculate one of the XVAs to suffer from a 'winner's curse' in taking trades with major hidden costs they fail to appreciate.

Marwan Tabet, Murex: The industry is facing several challenges in the XVA domain. Banks recognise the need to move to the next stage by industrialising the process of pricing and managing XVA, but many lack the technology and the right organisation.

While most trading desks have implemented CVA and FVA solutions, they have often relied on tactical solutions, focusing primarily on their pricing engines. They are now facing significant limitations in terms of scaling and integrating new and complex valuation adjustments, as well as implementing central desk capabilities.

The inability to scale is one of the major impediments to streamlining the XVA process across an organisation. Banks need to include existing and nascent XVAs in their entire derivatives portfolio, while sales desks require real-time pricing of XVA for any new transaction or trade amendment. Central desks need to calculate a constantly growing number of first- and second-order sensitivities, in addition to stress testing and running XVA profit-and-loss (P&L) attribution. Banks looking to deploy such capabilities are facing major challenges, which increasingly require new architecture and a redesign of their software solutions landscape.

Setting up central desks is another challenge facing the industry. The portfolio nature of XVA, encompassing a wide range of 'cross-desk' risks – such as credit, capital, funding and collateral – has led to the emergence of XVA desks, along with the introduction of new business and decision-making processes within capital markets organisations. The set-up of central desks poses substantial operational and technological challenges, as it requires the integration of processes and systems across the entire trading value chain.

Dennis Sadak, Numerix: Drawing from our own experience, the greatest challenge facing the industry right now related to XVA is the constantly evolving landscape. As regulations are constantly changing, adjustments like KVA have to be updated and revised according to those regulatory changes. For example, when the Fundamental Review of the Trading Book (FRTB) was introduced, there was a rush to understand it so XVA measures could properly reflect the new regulation.

Regulations forcing industry participants to account for the cost of clearing and post increased amounts of collateral have also given rise to MVA. So as the regulatory landscape is constantly changing, practitioners responsible for XVA must be ready to adjust with it.

Another challenge is the compute aspect of XVA. In the front office, real-time pre-trade XVA measures are extremely complex. They require an enormous amount of compute power to handle the data being generated.

So we're dealing with business challenges as a result of the regulatory landscape, and technological challenges where speed and data management are the top concerns.

MUREX™

Marwan Tabet, Head of Enterprise Risk Management Practice, Murex
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Banks have so far been unwilling to price MVA into non-cleared trades since the initial margin (IM) rules were introduced, as no single approach has won consensus support. Are there signs of this changing?

Marwan Tabet: Pressure to include MVA in pricing is likely to grow in the coming months as we draw closer to phase III of the IM regime, which is currently scheduled for September 2018. At this time, only a minority of banks – which aggregate notional amounts exceeding the threshold of \$2.52 trillion – are posting IM on their non-cleared over-the-counter (OTC) derivatives; and many banks have optimised their portfolios via compression and other means to reduce their notional amounts. These banks are likely to be eligible during the next phase.

While all agree that both cleared and non-cleared IM need to be accounted for when measuring MVA, there are no best practices for modelling the expectation of IM over the lifetime of transactions. For example, the model may need to forecast standard initial margin model (Simm) for non-cleared derivatives and value-at-risk (VAR) for centrally cleared derivatives. Several methods exist, but most of them have either performance or precision limitations. Therefore, implementing MVA is mostly about finding the right trade-off that allows the integration of MVA in real-time pricing by adopting the right approximations without compromising accuracy. In any case, several methods can co-exist and, depending on the actual usage, banks can use the method that best matches their particular needs or portfolio mix. This will certainly be the case when banks are calculating sensitivities or performing stress testing on MVA. Having the flexibility and the right architecture to achieve this is going to be fundamental.

Nick Haining: Because MVA represents a major cost compared with other valuation adjustments, we expect the industry to quickly converge around a standard way of pricing MVA – at least on a standalone basis. Accurate pricing of incremental MVA may take longer, as dealers may be initially unwilling to pass on cost savings from MVA offset on risk-reducing new trades to their clients.

Dennis Sadak
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Which valuation adjustments are set to cause the most headaches for the industry, and what specific regulation is likely to introduce new challenges for pricing XVA?
Dennis Sadak: Overall, uncertainty in regulations can leave a big question mark over what methodology to use to calculate some of these valuation adjustments.

Practically every valuation adjustment requires the simulation of different risk measures into the future, spanning the entire lifespan of those trades under consideration. Consequently, computational complexity is immense. Many, for example, are finding MVA to be a challenge. The reasoning is that, for MVA, the risk measure to be simulated into the future is a VAR-like measure. So, in other words, daily portfolio VAR must be simulated into the future for the entire lifespan of the trades. This is the case for trades cleared through central counterparties such as LCH or Eurex, as well as for OTC transactions that will be governed by the International Swaps and Derivatives Association's (Isda's) Simm.

Marwan Tabet: KVA is likely to pose serious challenges to the industry. The rules for calculating capital are quite complex and can be computationally intensive – in particular, when banks are using internal models. Integrating these calculations in a Monte Carlo engine requires a non-trivial mix of optimisation and approximation. In addition, a KVA model may need to account for future changes in regulations over the lifetime of the transaction. In that context, XVA frameworks need to accommodate a regulatory backdrop that is expected to continue in a state of flux over the next few years. Thus, the ability to manage configurability and variability of regulations is essential.

Nick Haining: This year's prize for the most problematic valuation adjustment, as well as for the valuation adjustment most affected by the ongoing changes in regulation, goes to KVA. Not only does KVA depend on multiple regulatory capital methods – each contributing its share of the capital and each with its own calculation challenges – but the regulations also change over time. This leads to the possibility of calculation of KVA to portfolio maturity based on today's regulations proving inaccurate because they may change in ways we cannot anticipate. On top of that, recent publications by Duffie *et al* challenge the established way of calculating KVA based on the hurdle rate (expected return on capital) and propose a new approach based on the analysis of the entire balance sheet of the bank and the concept of 'debt overhang'.

Are there new valuation adjustments on the horizon, or has the industry reached its limit?
Dennis Sadak: The industry hasn't quite reached its limits. In fact, a new industry term – additional valuation adjustment (AVA) – has been introduced as part of prudent valuations, a regulation that has emerged somewhere between pricing and risk management. AVA categories can vary widely and take into account such things as operational and administrative costs.

Banks must consider the total cost of ownership of their pricing to understand the impact on their business and profitability. With a clear picture of operations – everything pre-deal and post-trade – banks will have a clear path to allocating these costs back to the individual trade level. Only at this point will they be able to determine if that particular area of business or trade type is profitable enough to stay operational, or if it should be automated or even shut down.

Nick Haining: As the industry endeavours to model the costs of derivatives trading with ever-increasing precision, it is almost certain that other derivatives trading costs will be reflected in new valuation adjustments. We also see a trend toward splintering well-known valuation adjustments into multiple variations, depending on the assumptions used in their calculation and the way the total valuation adjustment is split into its component parts.

Is it becoming easier for banks to price in XVA as technology improves, and rules affecting them become more widely enforced?
Nick Haining: Definitely. As XVA calculation methodology becomes more standardised and more widely available, most financial institutions are able to compute XVA properly via Monte Carlo calculation, instead of relying on crude approximations or XVA calculations provided by their dealers. This trend leads to lower trading costs as more market participants are able to challenge

XVA numbers provided by their counterparties and demand fair and accurate valuation of the XVAs charged to them.

Dennis Sadak: As technology improves, XVA will become more cost-effective to compute.

For example, new quantitative methods – such as new approaches to algorithmic differentiation to calculate XVA sensitivities – will help to reduce computational expenses. Less arduous computational methods can reduce the IT cost of XVA – while not easier, they will perhaps be less expensive.

Also – as seen with Isda and the introduction of standardised credit support annexes (CSAs) – by removing collateral optionality from CSAs, the complexity of calculating these measures is also reduced.

As technology improves, speed and performance will also be impacted. From our perspective, performance of XVA solutions have as much to do with the speed of the calculations as it does with the way these calculations are linked together in a real-time framework. For example, with trades and analytics that are up-and-running leveraging new graph technologies, intraday changes are feeding in on a real-time, event-driven basis – so new trades, market data, CSAs and counterparties are effecting changes quickly and efficiently, focusing on the minimal recompute path. We see this as a very powerful technology.

How great a concern is figuring out how to price XVA for options compared with swaps?

Nick Haining: At this stage, accurate calculation of XVA – not only for swaps but also for more complex trade types such as options, callables and barriers – is routine and widely available within internal and vendor XVA solutions. Only after every trade in the portfolio is modelled properly on a standalone basis can the calculation accurately capture the portfolio-level effect of netting, CSA and IM on XVA.

How are new tech solutions evolving to help price XVA?

Marwan Tabet: Recent evolutions in technology have significantly helped to develop new capabilities around XVA. Graphics processing units (GPUs) are shifting into the mainstream as they become critical for a variety of domains, such as deep learning. At Murex, we started using GPUs more than a decade ago for pricing complex derivatives. This experience was instrumental in designing an architecture that leverages GPUs for delivering advanced XVA functionalities, including sensitivities calculation, CVA attribution and CVA stress testing.

Cloud computing is another area that brings major benefits to banks. For XVA, banks will typically have a steady load on their systems throughout the day, and will run huge numbers of intensive calculations at specific times over that time. Additional calculations may also be needed: for example, for end-of-month reporting leading to even higher resource usage peaks. Cloud services can solve this problem by offering rapid elasticity at an optimised cost. However, for a cloud solution to be truly beneficial, it must satisfy two key criteria: first, to leverage the cloud technologies for scalability across the entire calculation chain; and second, to be fully integrated into the bank's processes across the entire trading value chain. We are committed to achieving both.

Dennis Sadak: New technology solutions are evolving in many new and interesting ways for XVA.

Because of constant progress in fields such as gaming, this market is adopting technologies such as GPUs, which are changing the way hardware is designed to specifically support operations that could in turn be used for XVA calculations. Though not related to XVA or risk calculation today, Google has also introduced its first tensor processing unit, which multiplies matrices and could be applied to artificial intelligence and machine learning. In the future there could be specific application in this area of finance.

In terms of software, market-standard domain scripting languages such as Python and open-source offerings provide interfaces and allow end-users to interact with analytics in very specific, bespoke ways. This has been central to building out light, flexible front-end environments for XVA, where users can rapidly incorporate new features and address complex requirements.

The world of XVA is evolving not only because of advances in hardware, but also software technologies that are helping to manage the complexity of the data issue imposed by XVA. Technologies such as Cassandra, MongoDB and Hadoop are helping to price XVA as well as evolve banks' entire IT infrastructures, making it possible to manage incredible amounts of unstructured data.

Today, solutions must be flexible and robust enough to adapt. Therefore, cloud solutions have also become mainstream deployment strategies, especially for managing the compute needs of XVA and other risk management tasks. Whether a private, public, hybrid or managed service, a cloud computing infrastructure can help to produce pricing and risk reports for even the largest and most complex derivatives portfolios.

Nick Haining: The most important recent technology development in XVA is the introduction of adjoint algorithmic differentiation (AAD) as a method of calculating XVA sensitivities. The task of computing these sensitivities is a perfect match for the performance characteristics of AAD, because AAD works best when a large number of sensitivities must be computed. Because XVA depends on tens or hundreds of curves, each XVA figure has hundreds and sometimes thousands of bucket sensitivities in total. With AAD, all of these sensitivities can be calculated at the computational effort of around five times the effort required to compute the XVA number once, irrespective of the number of sensitivities. For bucket XVA sensitivities, this leads to around two orders of magnitude acceleration compared with the standard bump and re-price approach.

Since the variation margin rules came into force on March 1, has ground been made on a standardised approach to pricing MVA?

Nick Haining: At this time, the core mathematical principles of computing MVA are clear for both the schedule-based approach and the risk-sensitive Simm. However, effective numerical techniques for performing this calculation in practice at a reasonable computational effort are still being developed. In a presentation at the sixth annual WBS Initial Margin & XVA conference, Alexander Sokol, chief executive officer and head of quant research at CompatibL, proposed a fast and accurate method of computing MVA without crude approximations, using AAD. ■

A sound modelling and backtesting framework for forecasting initial margin requirements

The introduction of mandatory margining for bilateral over-the-counter transactions is significantly affecting the derivatives market, particularly in light of the additional funding costs financial institutions could face. In the following, Fabrizio Anfuso, Daniel Aziz, Klearchos Loukopoulos and Paul Giltinan propose a consistent framework, equally applicable to cleared and non-cleared portfolios, to develop and backtest forecasting models for initial margin

Since the publication of the new Basel Committee on Banking Supervision and International Organization of Securities Commissions (BCBS-Iosco) guidance on mandatory margining for non-cleared over-the-counter derivatives (Basel Committee on Banking Supervision 2015), there has been growing interest in the industry regarding the development of dynamic initial margin (DIM) models (see, for example, Andersen *et al* 2014; Green & Kenyon 2015); by 'DIM model', we are referring to any model that can be used to forecast future portfolio initial margin requirements (IMR).

The business case for such a development is at least twofold.

- The BCBS-Iosco IMR (B-IMR) are supposed to protect against potential future exposure at a high level of confidence (99%) and will substantially affect funding costs, XVA and capital.
- The B-IMR set a clear incentive for clearing; extensive margining, in the form of variation margin (VM) and initial margin (IM), is the main element of the central counterparty (CCP) risk management model as well.

Therefore, for both bilateral and cleared derivatives, current and future IMR significantly affects the profitability and risk profile of a given trade.

In the present article, we consider B-IMR as a case study, and we show how to include a suitably parsimonious DIM model in the exposure calculation. We propose an end-to-end framework and define a methodology to backtest the model's performance.

This paper is organised as follows. First, the DIM model for the forecasting of future IMR is presented. We then discuss methodologies for two distinct levels of backtesting analysis. Finally, we draw conclusions.

How to construct a DIM model

A DIM model can be used for various purposes. In the computation of counterparty credit risk (CCR), capital exposure or credit valuation adjustment (CVA), the DIM model should forecast, on a path-by-path basis, the amount of posted and received IM at any revaluation point. For this specific application, the key ability of the model is to associate a realistic IMR to any simulated market scenario based on a mapping that makes use of a set of characteristics of the path.

The DIM model is *a priori* agnostic to the underlying risk factor evolution (RFE) models used to generate the exposure paths (as we will see, dependencies may arise if, for example, the DIM is computed based on the same paths that are generated for the exposure).

It is a different story if the goal is to forecast the IMR distribution (IMRD) at future horizons, either in real-world P or market-implied Q measures. In this context, the key feature of the model is to associate the right probability weight with a given IMR scenario; hence, the forecasted IMRD also becomes a measure of the accuracy of the RFE models (which ultimately determine the likelihood of the different market scenarios). The distinction between the two cases will become clearer later on, when we discuss how to assess model performance.

In the remainder of this paper, we consider BCBS-Iosco IM as a case study. For B-IMR, the current industry proposal is the International Swaps and Derivatives Association standard initial margin model (Simm), a static aggregation methodology to compute IMR based on first-order delta-vega trade sensitivities (International Swaps and Derivatives Association 2016). The exact replication of Simm in a capital exposure or XVA Monte Carlo framework requires in-simulation portfolio sensitivities to a large set of underlying risk factors, which is very challenging in most production implementations.

Since the exposure simulation provides portfolio mark-to-market (MtM) values on the default (time t) and closeout (time $t+\text{MPOR}$, where 'MPOR' is 'margin period of risk') grids, Andersen *et al* (2014) have proposed using this information to infer pathwise the size of any percentile of the local $\Delta\text{MtM}(t, t+\text{MPOR}, \text{path}_i)$ distribution,[1] based on a regression that uses the simulated portfolio $\text{MtM}(t)$ as the independent variable. This methodology can be further improved by adding more descriptive variables to the regression, eg, the values at the default time t of selected risk factors of the portfolio.

For our DIM model, the following features are desirable.

- (f1) The DIM model should consume the same paths as those generated for the exposure simulation, in order to minimise the computational burden.
- (f2) The output of the DIM model should reconcile with the known B-IMR value for $t = 0$, ie, $\text{IM}(\text{path}_i, 0) = \text{IMR}_{\text{Simm}}(0)$ for all i.

Before proceeding, we note some of the key aspects of the BCBS-Iosco margining guidelines and, consequently, of the Isda Simm model (International Swaps and Derivatives Association 2016).

[1] *The* $\Delta\text{MtM}(t, t+\text{MPOR}) = \text{MtM}(t+\text{MPOR}) - \text{MtM}(t)$ *distribution is constructed assuming no cashflows take place between default and closeout. For a critical review of this assumption, see Andersen* et al *(2016).*

■ (a1) The MPOR for the IM calculation of a daily margined counterparty is equal to 10 days. This may differ from the capital exposure calculation, in which, for example, MPOR $= 20$ days if the number of trades in the portfolio exceeds 5,000.
■ (a2) The B-IMR in Basel Committee on Banking Supervision (2015) prescribe the calculation of IM by segregating trades from different asset classes. This feature is coherently reflected in the Simm model design.
■ (a3) The Simm methodology consumes trade sensitivities as its only input and has a static calibration that is not sensitive to market volatility.

These features, together with the requirements (f1) and (f2) stated previously, are addressed by our model proposal, as we will see.

For the IM calculation, the starting point is similar to that of Andersen *et al* (2014), ie, (i) we use a regression methodology based on the paths $\mathrm{MtM}(t)$ to compute the moments of the local $\Delta\mathrm{MtM}(t, t+\mathrm{MPOR}, \mathrm{path}_i)$ distribution, and (ii) we assume the $\Delta\mathrm{MtM}(t, t+\mathrm{MPOR}, \mathrm{path}_i)$ is a given probability distribution that can be fully characterised by its first two moments: drift and volatility. Additionally, since the drift is generally immaterial over the MPOR horizon, we do not compute it and set it to 0.

There are multiple regression schemes that can be used to determine the local volatility $\sigma(i,t)$. In the present analysis, we follow the standard American Monte Carlo literature (Longstaff & Schwartz 2001) and use a least-squares method (LSM) with a polynomial basis:

$$\sigma^2(i,t) = \langle(\Delta\mathrm{MtM}(i,t))^2 \mid \mathrm{MtM}(i,t)\rangle = \sum_{k=0}^{n} a_{\sigma,k}\,\mathrm{MtM}(i,t)^k \tag{1}$$

$$\mathrm{IM}^{\mathrm{U}}_{\mathrm{R/P}}(i,t) = \Phi^{-1}(0.99/0.01, \mu = 0, \sigma = \sigma(i,t)) \tag{2}$$

where R/P indicates received and posted, respectively. In our implementation, n in (1) is set equal to 2, ie, a polynomial regression of order 2 is used. We observe that LSM performs well compared with more sophisticated kernel methods (such as Nadaraya-Watson, which is used in Andersen *et al* (2014)), and it has the advantage of being parameter free and cheaper from a computational standpoint.

The unnormalised posted and received $\mathrm{IM}^{\mathrm{U}}_{\mathrm{R/P}}(i,t)$ are calculated analytically in (1) and (2) by applying the inverse of the cumulative distribution function $\Phi^{-1}(x,\mu,\sigma)$ to the appropriate quantiles; $\Phi(x,\mu,\sigma)$ being the probability distribution that models the local $\Delta\mathrm{MtM}(t, t+\mathrm{MPOR}, \mathrm{path}_i)$. The precise choice of Φ does not play a crucial role, since the difference in quantiles among different distributional assumptions can be compensated in calibration by the scaling factors applied (see the $\alpha_{\mathrm{R/P}}(t)$ functions in (4)). For simplicity, in the below we assume Φ is normal.

As a next step, we should account for the $t = 0$ reconciliation as well as the mismatch between the Simm and exposure model calibrations (see, respectively, items (f2), (a1) and (a3) above). These points can be tackled by scaling $\mathrm{IM}^{\mathrm{U}}_{\mathrm{R/P}}(i,t)$ with suitable normalisation functions $\alpha_{\mathrm{R/P}}(t)$:

$$\mathrm{IM}_{\mathrm{R/P}}(i,t) = \alpha_{\mathrm{R/P}}(t) \times \mathrm{IM}^{\mathrm{U}}_{\mathrm{R/P}}(i,t) \tag{3}$$

$$\alpha_{\mathrm{R/P}}(t) = (1 - h_{\mathrm{R/P}}(t))\sqrt{\frac{10\ \text{days}}{\mathrm{MPOR}}} \times (\alpha^{\infty}_{\mathrm{R/P}} + (\alpha^{0}_{\mathrm{R/P}} - \alpha^{\infty}_{\mathrm{R/P}})\mathrm{e}^{-\beta_{\mathrm{R/P}}(t)t}) \tag{4}$$

$$\alpha^{0}_{\mathrm{R/P}} = \sqrt{\frac{\mathrm{MPOR}}{10\ \text{days}}} \cdot \frac{\mathrm{IMR}^{\mathrm{Simm}}_{\mathrm{R/P}}(t=0)}{q(0.99/0.01, \Delta\mathrm{MtM}(0,\mathrm{MPOR}))} \tag{5}$$

■ In (4), $\beta_{\mathrm{R/P}}(t) > 0$ and $h_{\mathrm{R/P}}(t) < 1$, with $h_{\mathrm{R/P}}(t = 0) = 0$, are four functions to be calibrated (two for received and two for posted IMs). As will become clearer later in this paper, the model calibration generally differs for received and posted DIM models.
■ In (4) and (5), MPOR indicates the MPOR relevant for Basel III exposure. The ratio of MPOR to 10 days accounts for item (a1), and it is taken as a square root because the underlying RFE models are typically Brownian, at least for short horizons.
■ In (5), $\mathrm{IMR}^{\mathrm{Simm}}_{\mathrm{R/P}}(t = 0)$ are the $\mathrm{IM}_{\mathrm{R/P}}$ computed at $t = 0$ using Simm; $\Delta\mathrm{MtM}(0,\mathrm{MPOR})$ is the distribution of mark-to-market variations over the first MPOR; and $q(x,y)$ is a function that gives the quantile x for the distribution y.

The values of the normalisation functions $\alpha_{\mathrm{R/P}}(t)$ at $t = 0$ are chosen in order to reconcile the $\mathrm{IM}_{\mathrm{R/P}}(i,t)$ with the starting Simm IMR. Instead, the functional form of $\alpha_{\mathrm{R/P}}(t)$ at $t > 0$ is dictated by what is shown in panel (a) of figure 1: accurate RFE models, in both the P and Q measures, have either a volatility term structure or an underlying stochastic volatility process that accounts for the mean-reverting behaviour to normal market conditions generally observed from extremely low or high volatility. Since the Simm calibration is static (see item (a3) above), the $t = 0$ reconciliation factor is inversely proportional to the current market volatility, and not necessarily adequate for the long-term mean level. Hence, $\alpha_{\mathrm{R/P}}(t)$ interpolate between the $t = 0$ scaling driven by $\alpha^{0}_{\mathrm{R/P}}$ and the long-term scaling driven by $\alpha^{\infty}_{\mathrm{R/P}}$, where the functions $\beta_{\mathrm{R/P}}(t)$ are the mean-reversion speeds. The value of $\alpha^{\infty}_{\mathrm{R/P}}$ can be inferred from a historical analysis of a group of representative portfolios, or it can be *ad hoc* calibrated, eg, by computing a different $\Delta\mathrm{MtM}(0,\mathrm{MPOR})$ distribution in (5) using the long end of the risk factor-implied volatility curves and solving the equivalent scaling equation for $\alpha^{\infty}_{\mathrm{R/P}}$.

As we will see, the interpretation of $h_{\mathrm{R/P}}(t)$ can vary depending on the intended application of the model.
■ For capital and risk models, $h_{\mathrm{R/P}}(t)$ are two haircut functions that can be used to reduce the number of backtesting exceptions (see below) and ensure the DIM model is conservatively calibrated.
■ For XVA pricing, $h_{\mathrm{R/P}}(t)$ can be fine-tuned (together with $\beta_{\mathrm{R/P}}(t)$) in order to maximise the accuracy of the forecast based on historical performance.

Note that, regarding item (a2) above, the $\mathrm{IM}^{x}_{\mathrm{R/P}}(i,t)$ can be computed on a standalone basis for every asset class x defined by Simm (interest rate (IR)/foreign exchange, equity, qualified and not qualified credit, commodity) without any additional exposure runs. The total $\mathrm{IM}_{\mathrm{R/P}}(i,t)$ is then given by the sum of the $\mathrm{IM}^{x}_{\mathrm{R/P}}(i,t)$ values.

A comparison between the forecasts of the DIM model defined in (1)–(5) and the historical IMR realisations computed with the Simm methodology is shown in panel (b) of figure 1, where alternative scaling approaches are also considered. This comparison is performed at different forecasting horizons using seven years of historical data, monthly sampling and averaging among a wide representative selection of single-trade portfolios for the posted and received IM cases. For a given portfolio/horizon, the chosen error metric is given by:

$$\langle |F_{\mathrm{R/P}}(t_k + h) - G_{\mathrm{R/P}}(t_k + h)|\rangle_{t_k} / \langle G_{\mathrm{R/P}}(t_k + h)\rangle_{t_k}$$

where $\langle\cdots\rangle_{t_k}$ indicates an average across historical sampling dates[2] (for $F_{\mathrm{R/P}}$ and $G_{\mathrm{R/P}}$, see definitions below). The tested universe is made up of

[2] *Here and throughout the paper, t_k is used in place of t whenever the same quantity is computed at multiple sampling dates.*

102 single-trade portfolios. The products considered, always at-the-money and of different maturities, include cross-currency swaps, IR swaps, forex options and forex forwards (approximately 75% of the population is made up of $\Delta = 1$ trades).

As is evident from figure 1, the proposed term structure of $\alpha_{R/P}(t)$ improves the accuracy of the forecasts by a significant amount. The calibration used for this analysis is provided in the caption of figure 1. Below, we will further discuss the range of values that haircut functions $h_{R/P}(t)$ are expected to take for a conservative calibration of DIM to be used for regulatory capital exposure.

Finally, as an outlook, in panel (c) of figure 1 we show the error metrics for the case of CCP IMR, where the DIM forecasts are now compared with Portfolio Approach to Interest Rate Scenarios (Pairs; LCH.Clearnet) and historical value-at-risk (HVaR; Chicago Mercantile Exchange) realisations.[3] The forecasting capability of the model is tested separately for Pairs and HVaR IMR as well as for 22 single-trade portfolios (interest rate swap (IRS) trades of different maturities and currencies). The error at any given horizon is obtained by averaging among the 22×2 cases.

Without fine-tuning the calibration any further, the time-dependent scaling $\alpha_{R/P}(t)$ drives a major improvement in the accuracy of the forecasts with respect to the alternative approaches.

How to backtest a DIM model

So far, we have discussed a DIM model for B-IMR without being too specific about how to assess model performance for different applications, such as CVA and margin valuation adjustment (MVA) pricing, liquidity coverage ratio/net stable funding ratio (LCR/NSFR) monitoring (Basel Committee on Banking Supervision 2013) and capital exposure. As mentioned above, depending on which application one considers, it may or may not be important to have an accurate assessment of the distribution of the simulated IM requirements' values (the IMRD).

We introduce two distinct levels of backtesting that can measure the DIM model performance in two topical cases: (i) DIM applications that do not directly depend on the IMRD (such as capital exposure and CVA), and (ii) DIM applications that directly depend on the IMRD (such as MVA calculation and LCR/NSFR monitoring). The two corresponding methodologies are presented below, with a focus on P measure applications.

■ **Backtesting the DIM mapping functions (for capital exposure and CVA).** In a Monte Carlo simulation framework, the exposure is computed by determining the future mark-to-market values of a given portfolio on a large number of forward-looking risk factor scenarios. To ensure a DIM model is sound, one should verify that the IM forecasts associated with future simulated scenarios are adequate for a sensible variety of forecasting horizons as well as initial and terminal market conditions. We should introduce a suitable historical backtesting framework so as to statistically assess the performance of the model by comparing the DIM forecasts with the realised exact IMR (eg, in the case of B-IMR, calculated according to the Simm methodology) for a representative sample of historical dates as well as market conditions and portfolios.

Let us define generic IMR for a portfolio p as:

$$\text{IMR} = g_{R/P}(t = t_\alpha, \Pi = \Pi(p(t_\alpha)), \vec{M}_g = \vec{M}_g(t_\alpha)) \quad (6)$$

[3] *The realisations are based on prototype replications of the market risk components of the CCP IM methodologies.*

In (6), the following hold.

■ The functions g_R and g_P represent the exact algorithm used to compute the IMR for received and posted IMs, respectively (eg, Simm for B-IMR or, in the case of CCPs, IM methodologies, such as Standard Portfolio Analysis of Risk (Span), Pairs or HVaR).

■ $t = t_\alpha$ is the time at which the IMR for the portfolio p are determined.

■ $\Pi(p(t_\alpha))$ is the trade population of the portfolio p at time t_α.

■ $\vec{M}_g(t_\alpha)$ is a generic state variable that characterises all of the $T \leqslant t_\alpha$ market information required for the computation of the IMR.

Similarly, we define the DIM forecast for the future IMR of a portfolio p as:

$$\text{DIM} = f_{R/P}(t_0 = t_k, t = t_k + h, \vec{r}, \Pi = \Pi(p(t_k)), \vec{M}_{\text{DIM}} = \vec{M}_{\text{DIM}}(t_k)) \quad (7)$$

In (7), the following hold.

■ The functions f_R and f_P represent the DIM forecast for received and posted IMs, respectively.

■ $t_0 = t_k$ is the time at which the DIM forecast is computed.

■ $t = t_k + h$ is the time for which the IMR are forecasted (over a forecasting horizon $h = t - t_0$).

■ $\vec{r}$ (the 'predictor') is a set of market variables whose forecasted values on a given scenario are consumed by the DIM model as input to infer the IMR. The exact choice of $\vec{r}$ depends on the DIM model. For the one considered previously, $\vec{r}$ is simply given by the simulated mark-to-market of the portfolio.

■ $\vec{M}_{\text{DIM}}(t_k)$ is a generic state variable characterising all the $T \leqslant t_k$ market information required for the computation of the DIM forecast.

■ $\Pi(\cdot)$ is defined as for (6).

Despite being computed using stochastic RFE models, f_R and f_P are not probability distributions, as they do not carry any information regarding the probability weight of a given received/posted IM value. $f_{R/P}$ are instead mapping functions between the set $\vec{r}$ chosen as a predictor and the forecasted value for the IM.

In terms of $g_{R/P}$ and $f_{R/P}$, one can define exception counting tests. The underlying assumption is that the DIM model is calibrated at a given confidence level (CL); therefore, it can be tested as a VaR(CL) model. This comes naturally in the context of real-world P applications, such as capital exposure or liquidity monitoring, where a notion of model conservatism (and, hence, of exception) is applicable, since the DIM model will be conservative whenever it understates (overstates) received (posted) IM.

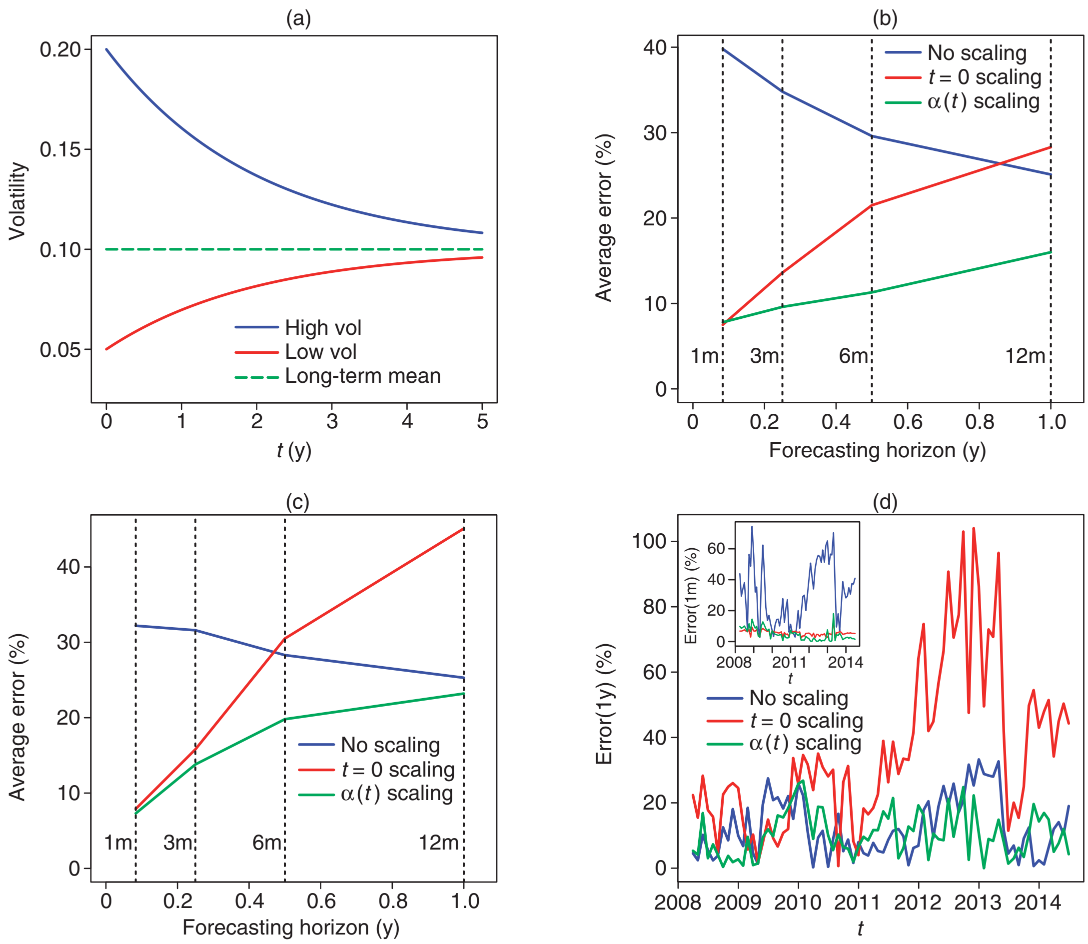
For a portfolio p, a single forecasting day t_k and a forecasting horizon h, one can proceed as follows.

■ (1) The forecast functions $f_{R/P}$ are computed at time t_k as $f_{R/P}(t_0 = t_k, t = t_k + h, \vec{r}, \Pi = \Pi(p(t_k)), \vec{M}_{\text{DIM}} = \vec{M}_{\text{DIM}}(t_k))$. Note that $f_{R/P}$ depends explicitly on the predictor $\vec{r}$ ($\vec{r} = \text{MtM}$ for the model considered above).

■ (2) The realised value of the predictor $\vec{r} = \vec{R}$ is determined. For the model considered above, $\vec{R}$ is given by the portfolio value $p(t_k + h)$, where the trade population $\Pi(p(t_k + h))$ at $t_k + h$ differs from t_k only because of portfolio ageing. Aside from ageing, no other portfolio adjustments are made.

■ (3) The forecasted values for the received and posted IMs are computed as $F_{R/P}(t_k + h) = f_{R/P}(t_0 = t_k, t = t_k + h, \vec{r} = \vec{R}, \Pi = \Pi(p(t_k)), \vec{M}_{\text{DIM}} = \vec{M}_{\text{DIM}}(t_k))$.

1 Model forecasting performance versus historical realisations



(a) Market-implied volatility term structure. Sketch of the term structure of the RF volatility in the case of low (red line) and high (blue line) volatility markets. The dashed green line indicates long-term asymptotic behaviour. (b) Historical comparison of DIM forecasts versus Simm realisations. The accuracy of the DIM forecasts is measured versus historical Simm realisations for three choices of scaling (no scaling: $\alpha(t) = 1$; $t = 0$ scaling: $\alpha(t) = \alpha^0_{R/P}$, as for (4), with $\beta_{R/P}(t) = 0$ and $h_{R/P}(t) = 0$; $\alpha(t)$ scaling: as for (4), with $\beta_{R/P}(t) = 1$, $\alpha^\infty_{R/P} = 1$ and $h_{R/P}(t) = 0$). (c) Historical comparison of DIM forecasts versus CCP IM realisations. The accuracy of the DIM forecasts is measured for CCP IMR with an equivalent error metric. (d) DIM forecasts versus Simm realisations: 20-year USD IRS. The realised error of the Simm DIM for received IM is shown versus time for a 20-year USD IRS payer in the case of one-month (inset graph) and one-year (main graph) forecasting horizons

■ (4) The realised values for the received and posted IMs are computed as $G_{R/P}(t_k + h) = g_{R/P}(t_0 = t_k + h, \Pi = \Pi(p(t_k + h)), \vec{M} = \vec{M}_g(t_k + h))$.

■ (5) The forecasted and realised values are compared. The received and posted DIM models are considered independently, and a backtesting exception occurs whenever F_R (F_P) is larger (smaller) than G_R (G_P). As discussed above, this definition of exception follows from the applicability of a notion of model conservatism.

Applying the 1–5 programme to multiple sampling points t_k, one can detect backtesting exceptions for the considered history. The key step is 3, where the dimensionality of the forecast is reduced (from a function to a value), making use of the realised value of the predictor and, hence, allowing for a comparison with the realised IMR.

The determination of the test p-value requires the additional knowledge of the test value statistics (TVS), which can be derived numerically if the forecasting horizons are overlapping (see Anfuso *et al* 2014). In the latter situation, it can happen that a single change from one volatility regime to another may trigger multiple correlated exceptions; hence, the TVS should adjust the backtesting assessment for the presence of false positives.

The single-trade portfolios of figure 1 have been backtested with the above-described methodology, using Simm DIM models with the three choices of scaling discussed in the same figure. The results shown in table A confirm the greater accuracy of the term-structure scaling $\alpha_{R/P}(t)$. In fact, for the same level of haircut function $h_{R/P}(t > 0) = \pm 0.25$ (positive/negative for received/posted), a much lower number of exceptions is detected. We observe in this regard that, for realistic diversified portfolios and for a calibration target of CL = 95%, the functions $h_{R/P}(t)$ take values typically in the range 10–40%.[4]

[4] *This range of values for* $h_{R/P}(t)$ *has been calibrated using* $\beta_{R/P}(t) = 1$ *and* $\alpha^\infty_{R/P} = 1$*. Both assumptions are broadly consistent with the historical data.*

A. Simm backtesting: R/P DIM VaR(95%) exceptions/tests					
Scaling type	**1m**	**3m**	**6m**	**12m**	**Total**
$\alpha(t)$ scaling	0/200	2/184	14/152	35/120	51/656
$t = 0$ scaling	0/200	4/184	32/152	42/120	78/656
No scaling	106/200	97/184	79/152	47/120	329/656

Historical backtesting for the Simm DIM model defined in equations (1)–(5), where $h_{R/P}(t > 0) = \pm 0.25$. VaR(95%) exception counting tests are performed for the same single-trade portfolios of figure 1, and in accordance with the first backtesting methodology described. The results are shown in the format (x/y), where y is the number of portfolios tested at a given horizon and x is the observed number of backtesting failures for a p-value acceptance threshold of 5% (received and posted IM cases are considered in aggregate). The backtesting analysis is performed using seven years of historical data and a monthly sampling frequency.

Note also that the goal of the BCBS-Iosco regulations is to ensure netting sets are largely overcollateralised (as a consequence of (i) the high confidence level at which the IM is computed and (ii) the separate requirements for daily VM and IM). Hence, the exposure-generating scenarios are tail events, and the effect on capital exposure of a conservative haircut applied to the received IM is rather limited in absolute terms. See, in this regard, panel (b) of figure 2, where the expected exposure (EE) at a given horizon t is shown as a function of $h_R(t)$ (haircut to be applied to the received IM collateral) for different distributional assumptions on $\Delta\text{MtM}(t, t + \text{MPOR})$.

In panel (b) of figure 2, $h_R(t) = 0$ and $h_R(t) = 1$ indicate full IM collateral benefit or no benefit, respectively, and the unscaled IM is taken as the ninety-ninth percentile of the corresponding distribution. For different choices of the ΔMtM distribution, the exposure reduction is practically unaffected up to haircuts of order $\approx 50\%$.

■ **Backtesting the IMRD (for MVA and LCR/NSFR).** The same Monte Carlo framework can be used in combination with a DIM model to forecast the IMRD at any future horizon (here, we implicitly refer to models in which the DIM is not always constant across scenarios). The applications of the IMRD are multiple. The following are two examples that apply equally to the cases of B-IMR and CCP IMR: (i) future IM funding costs in the Q measure, ie, MVA, and (ii) future IM funding costs in the P measure, eg, in relation to LCR or NSFR regulations (Basel Committee on Banking Supervision 2013).

Our focus is on forecasts in the P measure (tackling the case of the Q measure may require a suitable generalisation of Jackson (2013)). The main difference with the backtesting approach discussed above is that now the model forecasts are the numerical distributions of simulated IMR values. These can be obtained for a given horizon by associating every simulated scenario with its correspondent IMR forecast, computed according to the given DIM model. Using the notation introduced previously, the numerical representations of the received/posted IMRD cumulative density functions (CDFs) of a portfolio p for a given forecasting day t_k and horizon h are given by:

$$\text{CDF}_{R/P}(x, t_k, h) = \#\{v \in V \mid v \leqslant x\}/N_V \quad (8)$$

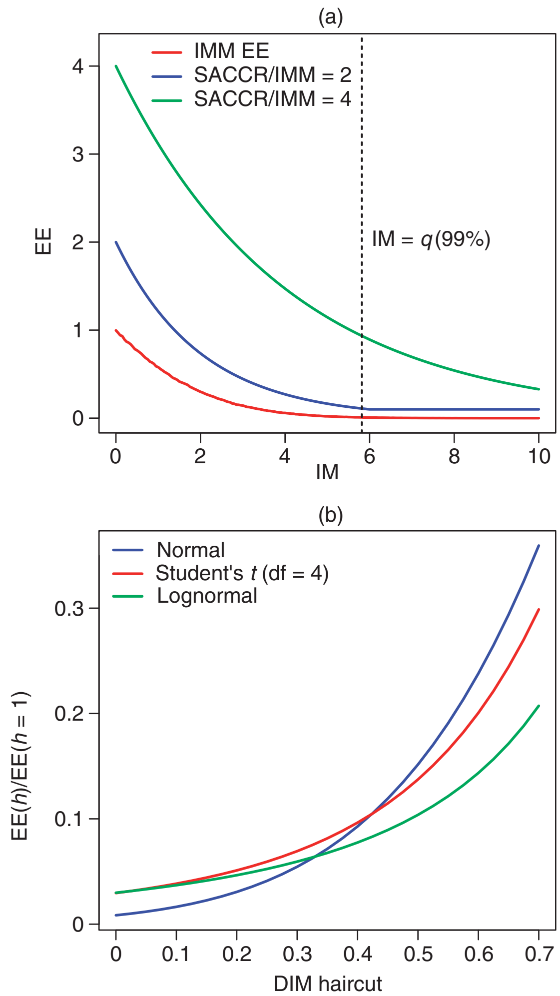
$$V = \{f_{R/C}(t_0 = t_k, t = t_k + h, \vec{r}_\omega, \Pi = \Pi(p(t_k)), \vec{M}_{\text{DIM}} = \vec{M}_{\text{DIM}}(t_k)),\ \forall \vec{r}_\omega \in \Omega\} \quad (9)$$

In (8), N_V is the total number of scenarios. In (9), $f_{R/P}$ are the functions computed using the DIM model; $\vec{r}_\omega$ are the scenarios for the predictor (the portfolio mark-to-market values in the case originally discussed); and Ω is the ensemble of the $\vec{r}_\omega$, spanned by the Monte Carlo simulation.

The IMRD in this form is directly suited for historical backtesting using the probability integral transformation (PIT) framework (Diebold *et al* 1998). Referring to the formalism described in Anfuso *et al* (2014), one can derive the PIT time series $\tau_{R/P}$ of a portfolio p for a given forecasting horizon h and backtesting history $\mathcal{H}_{\text{BT}}$ as follows:

$$\tau_{R/P} = \{\text{CDF}(g_{R/P}(t_k + h, \Pi(p(t_k + h)), \vec{M}_g(t_k + h)), t_k, h),\ \forall t_k \in \mathcal{H}_{\text{BT}}\}. \quad (10)$$

2 IMM DIM versus SA-CCR IM and exposure versus DIM haircut



(a) Back-of-the-envelope model: IMM versus SA-CCR. The EE(t) of a daily VM margined counterparty versus the received IM for a simplified IMM model (continuous red line) and SA-CCR (continuous blue and green lines) is shown. The IMM EE(t) is calculated assuming ΔMtM(t, t + MPOR) is normal. Since the SA-CCR EE(t) depends on the size of the trade's add-ons, the SA-CCR exposure is computed for the stylised cases of SA-CCR add-ons being two (blue line) or four (green line) times larger than the correspondent IMM level. (b) EE(t) versus $h_R(t)$ for different distributional assumptions on ΔMtM(t, t + MPOR): normal (blue line), Student's t (red line) and lognormal (green line)

In (10), $g_{\mathrm{R/P}}$ is the exact IMR algorithm for the IMR methodology we intend to forecast (defined as for (6)), and t_k are the sampling points in $\mathcal{H}_{\mathrm{BT}}$. Every element in the PIT time series $\tau_{\mathrm{R/P}}$ corresponds to the probability of the realised IMR at time $t_k + h$ according to the DIM forecast built at t_k.

As discussed extensively in Anfuso *et al* (2014), one can backtest the $\tau_{\mathrm{R/P}}$ using uniformity tests. In particular, analogously to what is shown in Anfuso *et al* (2014) for portfolio backtesting in the context of capital exposure models, one can also use test metrics that do not penalise conservative modelling (ie, models overstating/understating posted/received IM). In all cases, the appropriate TVS can be derived using numerical Monte Carlo simulations.

In this setup, the performance of a DIM model is not tested in isolation. The backtesting results will be mostly affected by the following.

- (1) The choice of $\vec{r}$. As discussed earlier, $\vec{r}$ is the predictor used to associate an IMR to a given scenario/valuation time point. If $\vec{r}$ is a poor indicator for the IMR, the DIM forecast will consequently be poor.
- (2) The mapping $\vec{r} \to$ IMR. If the mapping model is not accurate, the IMR associated with a given scenario will be inaccurate. For example, the model defined in (1)–(5) includes scaling functions to calibrate the calculated DIM to the observed $t = 0$ IMR. The performance of the model is therefore dependent on the robustness of this calibration at future points in time.
- (3) The RFE models used for $\vec{r}$. These models ultimately determine the probability of a given IMR scenario. It may so happen that the mapping functions $f_{\mathrm{R/C}}$ are accurate but the probabilities of the underlying scenarios for $\vec{r}$ are misstated and, hence, cause backtesting failures.

Note that items (1) and (2) are also relevant for the backtesting methodology discussed earlier in this paper. Item (3), however, is particular to this backtesting variance, since it concerns the probability weights of the IMRD.

Conclusion

We have presented a complete framework to develop and backtest DIM models. Our focus has been on B-IMR and Simm, and we have shown how to obtain forward-looking IMs from simulated exposure paths using simple aggregation methods.

The proposed DIM model is suitable both for XVA pricing and capital exposure calculation: the haircut functions $h_{\mathrm{R/P}}(t)$ in (4) can be used either to improve the accuracy (pricing) or to ensure the conservatism of the forecast (capital).

If a financial institution were to compute CCR exposure using internal model methods (IMM), the employment of a DIM model could reduce CCR capital significantly, even after the application of a conservative haircut. This should be compared with the regulatory alternative SA-CCR, where the benefit from overcollateralisation is largely curbed (see panel (a) of figure 2 and Anfuso & Karyampas (2015)).

As part of the proposed framework, we have introduced a backtesting methodology that is able to measure model performance for different applications of DIM. The DIM model and the backtesting methodology presented above are agnostic to the underlying IMR algorithm, and they can be directly applied in other contexts, such as CCP IM methodologies, as shown in panel (c) of figure 1. ■

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