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After the Credit Crunch: The importance of Economic Capital and how to calculate it

White Paper
Credit Economic Capital
Financial Predictive Analytics

By John A Morrison, December 2008

REvolution computing

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1. Executive Summary

This is a White Paper about "Economic Capital", i.e. the amount of capital which a Financial Institution needs in order to survive in a worst case scenario. Events of recent months prove that this is no longer an academic exercise. The Credit Crunch (CC) has seen Central Governments pumping fresh capital into the banks which were clearly undercapitalized and ill-prepared to deal with the crisis.

Economic Capital is now the focus of all banks, including the Bank of International Settlements (BIS) and the Central Banks. Computation of risk capital in an holistic and comprehensive manner is the key to recovery from this crisis episode and to ensuring sustained levels of security. REvolution Computing is leading the software response to effectively meet this challenge through the development of high performance components of its product ranges in appropriate configurations.

It has taken a crisis to bring the banks and their supervisors closer together, sharing a common objective and that at the very least is one good thing to evolve from this crisis. Supervisors and senior Bankers are at least on adjacent pages in 2008 and look to remain there as the requirements of what will be by any other name a Basel 3 framework are worked out and agreed upon in the coming months.

This paper:-

- Is an exposition of how crucial both in terms of banking supervision and in terms of the individual bank's strength, economic capital has become. The paper precisely defines economic capital both at the single institution level and at the systemic level.
- Will demonstrate that best practice and supervisory requirements entail that every financial institution must calculate an appropriate quantum of economic return on an originated exposure, risk based position or portfolio.
- Reveals how such a quantum of economic return is estimated or predicted based upon quantitative techniques or statistical analytics.
- Argues that banks will now need to adopt 'financial predictive analytics' so that they can accurately estimate the amount of risk capital required to cover the true extent of risks to which they are exposed.

1.1 Lessons Learned from the Credit Crunch (CC)

In simple terms, the CC was about the mis-pricing of assets and the underassessment of risk. One of the clearest lessons of the CC is that the tactic of slicing exposures into ever smaller packages and products does not fundamentally diminish overall risk; it merely disperses risk. It is has become abundantly obvious that we now need through mathematics to be able to accurately describe and measure risk capital.

The events of recent months have politicized banking forever. Authorities worldwide have raised regulatory capital requirements to unheard of levels because economic capital modeling and quantification was not generally visible on a sufficiently robust scale. Only on an interim basis can economic capital be implemented as some fractional multiplier of regulatory capital, arbitrarily imposed across the board by the supervisory authorities in one country and thus becoming a standard for banks operating in all countries. Executive management may not like supervisory or regulatory interference. However, the reality is that supervisors will remain engaged until such time as banks can demonstrate robust risk modeling and therefore reliable economic capital values.

Hi-Performance quantitative models and better methodologies of predictive analytics will play a major part in this transition.

The ability to model and quantify risk is already the main focus of the Bank for International Settlements (BIS) and the Basel Committee for Banking Supervision (Basel II). This is further supported by the EU commission which is arguing to increase Supervision, in other words to focus efforts upon risk based approaches to Economic Capital rather than rules based approaches to Regulatory Capital.

1.2 The past does not always predict the future

Bodies such as the BIS have already raised questions concerning the packaged off-the-shelf 'black-box' solutions and simplistic management scorecards that banks have deployed over the past years. In some cases they have raised the question that models have been deployed without (the banks) having a full understanding of the underlying assumptions and techniques embedded in them.

Sometimes these black-box solutions are not amenable to subtle amendments and refinement and are not responsive to changes in the economic factors of risk that banking executives may now want to include in their model. Packaged models may also be based upon parameters and assumptions from markets (often the US) that are not relevant to local market conditions. Finally, as a result, there had been little openness of discussion between peers and counterparties to compare (and thus optimise) the value of different approaches.

In quantifying economic capital we are actually making a prediction of how much capital is necessary in the future to assure the Institution that they are not exposed to losses over the full life time of the instruments they create or hold. Predicting the future does not always come from analyzing the past and knowing which quantitative technique is best to use in each situation or for each portfolio or division is not always abundantly obvious and clear.

Openness and flexibility is not just essential for 'getting it right' but also for being able to adapt and modify as circumstances change around us. However there has been resistance to the implementation of robust financial predictive analytic toolsets in banking, despite there having been a long pedigree for this in the discipline of econometrics. Even the BIS pointed out in 2005 that the technologies being used were in effect holding back the "elaboration of … concepts and their practical implementation".

Because a great number of different methods can be used, and because what happened in the past does not always predict the future, it makes it all the more important that quantitative risk solutions are fully transparent, open, well documented and relatively easy to understand. They must increasingly be easily modified, have the ability to dig deep into the underlying data structures and to be able to integrate across the complex array of technology platforms deployed in most banks. Aggregating different solutions from different silos or depending upon solutions in little understood black-boxes are themselves risks that no board of directors can now place their trust.

1.3 The Future – Financial Predictive Analytics

There is no 'best-fit' solution and in the case of Economic Capital modelling having a toolset to be able to empirically test and validate the current model is crucial. As any Economic Capital model is a product of a forecasting process that uses an array of statistical techniques on ever-larger data sets this means that the latest 3rd generation business intelligence or predictive analytics toolsets are necessary parts of tomorrow's solution.

The development of econometrics has been accelerated rapidly in the past decade largely by financial predictive analytics, and more and more econometricians are switching to the statistical system termed **R** over and above others.

R or the R-Project is an open source programming language and software environment for statistical computing and graphics supported in the commercial domain by REvolution Computing. REvolution Computing in commercializing and industrializing the economic capital modeling process with the RPro toolset has brought a further innovative development to the technology available to support the modeling of Economic Capital.

Development of predictive analytic objects is the most efficient way to realize modern economic capital modeling requirements. REvolution Computing's commercial support for R is important for such deployment in this critical context. REvolution has expertise in delivering High Performance Computing (HPC) mission-critical solutions beyond that which anyone else has, and the REvolution tools are far easier to deploy and use than any other alternatives.

1.4 Finally

This paper may not be for everyone and we immediately apologize for the unavoidable jargon. The paper assumes an elementary understanding of the issues of the Credit Crunch and of the basics of banking supervision and regulation. A reader will benefit from a personal or professional interest in the specific issues which surround quantitative risk modeling or predictive analytics in the context of finance.

Economic Capital modeling was certainly an aspect of the risk management process which was not generally in place prior to or during the credit crunch. It has come to the fore again post credit crunch and although it is not concluded this gap is the cause of the whole 'blow up'; it is concluded that robust economic capital modeling would certainly go along way to constraining a crisis like the CC from ever happening again.

It is in the process of computation, the organization of computer systems and in the selection of quantitative techniques where challenges lie, going forward. This paper is an exposition of the considerations of executive management in preparing to go towards that future. It is also a recommendation of the REvolution Computing platforms, RPro and ParallelR, which in supporting the commercialization of the premier Open Source toolset for this requirement can support an appropriate industry response to the post credit crunch requirement to model and quantify economic capital.

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2. Economic Capital and Risk Based Pricing

Risk-Based Pricing or Quantitative Risk Analytics (focused upon Economic Capital) in a post-Basel II world is the key technique providing competitive advantage, particularly in banking today. Economic Capital is equally relevant in corporate lending (at the deal level), in retail baking (portfolio focused) and in the trading book.

It could be argued that following the CC, Economic Capital is equally important to the non-regulated sector (Private Equity and Hedge Funds) since a key current lesson is that the CC is about the mis-pricing of assets. A recent argument modeled in an academic paper proposes that that *"securitization can reduce the individual banks' economic capital requirements by transferring risks to other market participants ….. Systemic risks impact financial stability in two ways. First, if the risks are transferred to unregulated market participants there is less capital in the economy to cover these risks. And second, if the risks are transferred to other banks interbank linkages increase and therefore augment systemic risks*[1]*."*

To explain the core of the Credit Crunch in simple terms, complex structured products were mis-priced by issuers (banks) at the point of issue; they were also mis-rated by the ratings agencies and once acquired and held by investors, the buy-side of this market mis-priced them in their turn. This mis-pricing led to the spiral of asset write-downs leading to uncertainty and liquidity constraints which has characterized the CC. In short, selling and buying securitised bonds backed by retail banking assets was a process for transferring assets from high cost-of-capital banking books to low cost-of-capital trading books; with neither buyer nor seller actually computing risk based capital at any point in that market process.

Economic Capital is where all banks are now looking, led by the BIS, the Central Banks, the supervisors and the academic community. Embedding a process of not only modeling but setting parameters of economic capital which reports clearly at board level is the single most strategic decision about banking technology which a small number of very senior executives will take in a bank today.

The technology set to support economic capital modeling becomes a platform, which, once implemented may alter the manner in which business is conducted for a long time. It is important therefore that the bank (from the business requirements perspective) and the information systems implementation team consider this challenge as fully as possible. Since the end of Basel II (Pillar One, regulatory capital) implementation projects, there has been focus upon analytic techniques for the quantification of marginal risk or marginal capital (as an aspect of the focus upon 'economic capital' initiated by tackling "Pillar 2" of Basel II). Pillar 2 capital or economic capital basically subsumes regulatory capital. The UK authorities recently set a global standard by unilaterally increasing tier one regulatory requirements to "between 11 and 13 per cent. No-one can remember them being this impregnable," as the Financial Times commented[2]. This demonstrates the core nature of economic capital to financial services

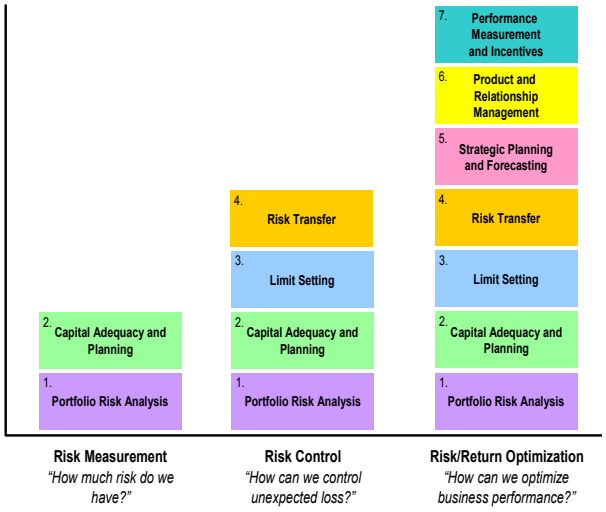
[1] The effect of credit risk transfer on financial, stability, Dirk Baury, Trinity College Dublin and Joint Research Centre, EU Commission, Ispra, Elisabeth Joossensz, , EU Commission, Ispra, 2006

[2] UK bank capital, LEX, The Financial Times, Published: October 14 2008 09:41 http://www.ft.com/cms/s/1/ccc1bcca-99cb-11dd-960e-000077b07658.html

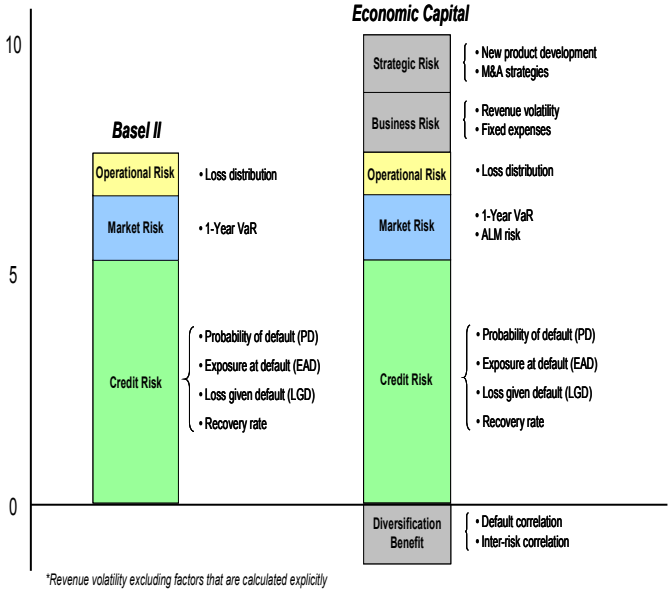
today, getting that right is arguably the key challenge of today.

Viewing capital in the economic sense as the dollar value of the risk associated with a transaction over its whole life, as far as you can see is a prediction or a forecast, thus quantitative techniques (predictive statistical analytics) are intrinsic to economic capital from a quantification or allocation perspective. Through the difficult process of implementing Basel II and thus socializing its fundamental ideas; teams of banking personnel became familiar with quantitative techniques which they may not have seen since undergraduate days. Expertise in such techniques has until very recently remained in silos in the support function to the trading desks for derivative and structured products. The Credit Crunch has driven these modeling techniques to the forefront of the focus of Boards of Directors and the general public and we can be sure that the more stringent regulation of banking being prepared now (at the end of 2008) will demand further deployment (and thus familiarity) with these types of techniques.

The Functions of Economic Capital



Comparison of Basel II Regulatory Capital and Economic Capital
SOURCE: Federal Depository Insurance Corporation (FDIC)

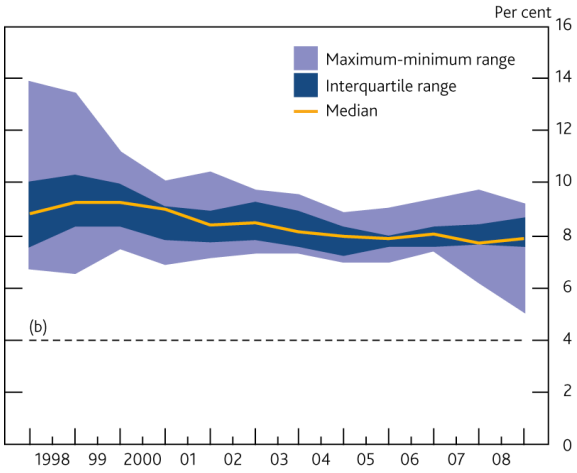


2.1 The right and wrong way to compute Economic Capital.

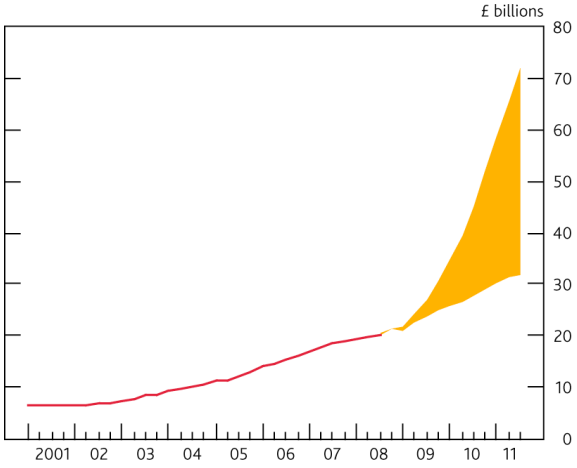
The Bank for International Settlements (BIS) leads the way out of Basel II now. Essentially the Basel Regulatory Capital formula is a single equation (analytic) for Capital which in the past had to be quantified by a large system of equations (known as a structural model). That simple single line analytic derives from the work of Michael Gordy at the US Federal Reserve[3], developed from an idea called 'Strict Loss Prioritization'[4]. Gordy then developed an analytic theory called the ASRF (the Asymptotic Single Risk Factor) analytic in 2004. Both Perraudin and Gordy were focused upon quantifying risk capital in securitised instruments (the key thing not done leading to the CC). One deploys either a strict approach to the math or an asymptotic one; an asymptotic approach is approximate; you call the shots when it is "close enough" a strict approach is just that. The Basel committee went for the asymptote for Basel II regulatory capital, in that decision economic capital was always going to be 'additional' simply from the math.

A recent Bank for International Settlements paper reviewing Economic Capital[19] refers to the Gordy ASRF model and states clearly that "*the ASRF modeling approach raises several supervisory concerns about the method used to calibrate correlations and the ways in which the bank addresses the infinite granularity and single-factor structure of the asymptotic single-risk-factor model*." This BIS paper continues *that "the single-risk-factor and infinite granularity assumptions of the ASRF model have small impacts on measurement of capital needs, especially for large, well-diversified portfolios. By contrast, the use of mis-specified or incorrectly calibrated correlations and the use of a normal distribution (which fails to replicate the tails of the distribution of asset returns) can lead to significant inaccuracies in measures of portfolio credit risk and economic capital."*

UK TIER ONE CAPITAL RATIOS (BoE FSR Oct 2008)



UK Banks' write-offs on Domestic Lending



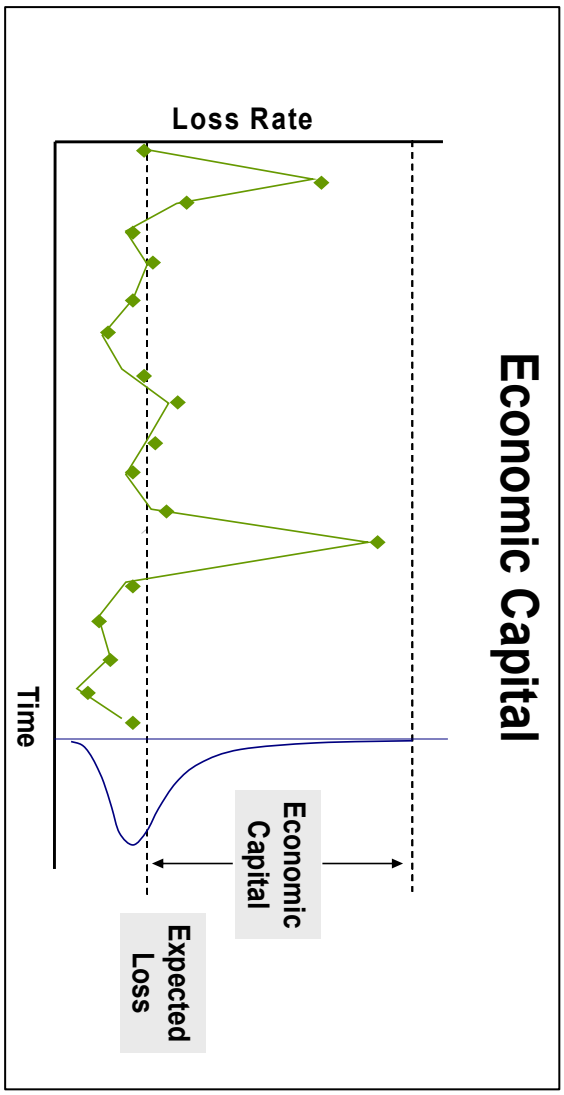
[3] Capital allocation for securitizations with uncertainty in loss prioritization, Michael Gordy and David Jones, Federal Reserve Board, December 6, 2002, http://www.bis.org/publ/bcbs_wp11gj.pdf

[4] Pykhtin, and Dev, Credit Risk in Asset Securitizations: Analytical Model," Risk, May 2002.

It is therefore clear that from a Supervisory Perspective the quality and usefulness of an Economic Capital Model is entirely dependent upon the robustness and precision of the statistical methods implemented in a Predictive Analytic approach.

This conclusion is entirely consistent with the UK authorities' decision to raise regulatory capital requirements to unheard of levels because economic capital modeling and quantification was not generally visible on a sufficiently robust scale in the UK landscape.

Only on an interim basis can economic capital be implemented as some fractional multiplier of regulatory capital, arbitrarily imposed across the board by the supervisory authorities in one country and thus becoming a standard for banks operating in all countries[5]. Executive management may not like this supervisory or regulatory interference. However the reality is that supervisors will remain engaged until such time as banks can demonstrate robust risk modeling and therefore reliable economic capital values.



5 http://www.iht.com/articles/2008/10/27/business/kbc.php

3. Economic Capital: The Holistic Approach

Risk quantification means the dollar, pound or euro value of the total risk of an exposure or position or pool of exposures (possibly structured in a product or simply a retail portfolio) over the life of that exposure expected by the holding institution. By thinking of risk in this way we can think of the process of risk quantification as applicable both off and on balance sheet; that is whether off or on balance sheet we can use the same techniques and similar data to quantify risk.

Further one can consider an originated loan exposure as only different in degree to a risk position in a market for traded securities and finally by considering risk in terms of a dollar value the immediacy of the relationship between risk and capital is embedded in the process of quantifying risk in an applied manner.

Adopting a holistic approach, the advanced analytics necessary to quantify Economic Capital in the trading room, focused upon a pool of exposures aggregated to become a trade-able structured product is all that is necessary to appropriately quantify risk capital, on balance sheet. The structured product is a microcosm of the institution; it is exposed simultaneously to credit and market risk and not to take account of the holistic nature of that risk exposure is to fail to learn the lessons of this crisis episode we have all just lived through.

3.1 Economic Capital: Lessons Learned from the Credit Crunch (CC)

The Credit Crunch (CC) has produced one basic lesson. It is folly to believe that financial innovation which slices exposures into ever more thin slices and thence packages them up into different products to disperse them across a geographic and risk appetite disparate set of counterparties does any more than distribute that risk. It does not fundamentally diminish the risk. Risk is always with us; we either learn the language to describe it (mathematics) and go some way to approximating it or we are not actually in the risk business.

3.1.1 Economic Capital is Systemic Net Worth

In an important working paper of the spring of 2008 from The Bank of England[6] the authors develop a network model of a financial system to investigate how systemic risk is affected by the structure of the financial system.

The network model allows the variance of key parameters that define the structure of the financial system, its level of capitalisation, the degree to which banks are connected, the size of interbank exposures and the degree of concentration of the system. This analysis reveals the influence of these parameters on the likelihood of contagious (knock-on) defaults. The paper provides mathematical or logical evidence for what would appear to be intuitively obvious conclusions.

[6] Bank of England, Working Paper No. 346, Network models and financial stability, Erlend Nier,, Jing Yang, Tanju Yorulmazer and Amadeo Alentorn

The network model represents the banking system as a set of nodes (banks) that are connected by directed links (interbank exposures) with a certain predefined probability. The 'weight' of these links (the size of interbank exposures) determines the capacity for losses to flow from one bank to another. Capital and deposits are introduced as the first and ultimate recipients of any losses incurred. The model simulates the extent of contagious defaults arising from losses being transmitted through interbank exposures for a wide variety of banking systems that differ in their underlying structural characteristics.

The model simulates the impact of an idiosyncratic shock hitting one of the banks in the system; the shock is to the value of a bank's external assets and can be thought of as resulting from credit risk. The concluding findings are;-

- Decreases in **"net worth"** (total system capital) increase the number of contagious defaults and that this effect is non-linear. For high levels of net worth, the system is immune to contagious defaults. But when net worth falls, once capitalisation reaches a lower threshold, a further decrease in net worth leads to sharp increases in the risk of a systemic breakdown.
- Increases in the size of interbank liabilities tend to increase the risk of knock-on default.
- Contagion is shown to be a non-monotonic function of the number of interbank connections, all else equal. When the level of connectivity is low, an increase in the number of links increases the chance of contagious defaults.
- However, when connectivity is already high, a further increase in the number of links increases the capacity of the system to withstand shocks.
- More concentrated banking systems tend to be more prone to systemic breakdown.
- The presence of liquidity effects increases the chance of systemic breakdown for any given aggregate capitalisation and any given degree of connectivity between banks.

3.1.2 Systemic Economic Capital

The first of these conclusions above is fundamental. The finding is that the total net worth of the banking system is a key variable in predicting whether system crisis will occur; where total net worth is the arithmetic sum of the capital held by each individual institution in the system. The second conclusion almost follows from this given that larger banking systems are more interconnected it entails that marginally more capital is required to be held by each institution for systemic risk insurance purposes (principally against liquidity risk, obviously) i.e. to preserve Macroprudential stability.

We can therefore conclude that Economic Capital is a systemic risk factor. In the CC, banks have been made bankrupt by other banks[7], not by business creditors or tax authorities, and generally by taking advantage of the fact that they hold their accounts with each other to seize or foreclose on each other's assets.

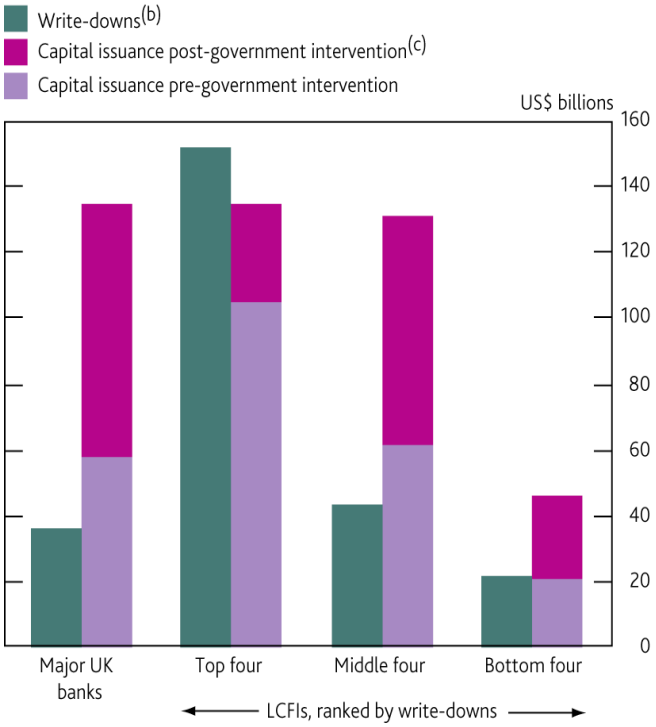
[7] Subprime puts Bear Stearns fund on brink, The Financial Times By Ben White and Saskia Scholtes in New York, Published: June 20 2007, http://www.ft.com/cms/s/0/f92171f6-1eb7-11dc-bc22-000b5df10621.html

When banks are uncertain about what claims may be raised upon them by other banks, or which other banks specifically, they inevitably lose confidence in making loans or deposits with each other[8]. This uncertainty is a function of capital held by each institution. The regulatory minimum is just that! If we have a supervisory regime which we know to be operational, then each bank knows that other banks hold sufficient risk or economic capital not to be a systemic risk. Issues of interbank confidence are thereby reduced.

3.2 Economic Capital & the politicization of banking

It has been argued (by Martin Wolf and others) that the Credit Crunch and its fall out have politicised banking forever[9]. The recent "nationalizations" and debates about socialism in the US[10] are cases in point. We are seeing the enablement of executive agencies of the state by political representation at the highest level; in the area of banking supervision, to be taking control of the banking industry. This has destructive effects on the ability of government[11] (or the central bank[12]) and the banking industry[13] to function normally. Escape from this position (or transition out of it) will entail the deepening of the requirement for Risk Quantification (measured in terms of Economic Capital) and thus higher performance quantitative models and better methodologies of predictive analysis. The democratic states can do no less than prepare the supervisors as their executives to expedite this.

UK Writedowns and Capital Issuance since Q3 2007 (Bank of England FSR Oct08)



[8] http://bankingeconomics.blogspot.com/

[9] The rescue of Bear Stearns marks liberalization's limit, By Martin Wolf, FT Published: March 25 2008 19:06 http://www.ft.com/cms/s/0/8ced5202-fa94-11dc-aa46-000077b07658.html

[10] http://www.ft.com/cms/s/0/cdfbdcb6-89a3-11dd-8371-0000779fd18c.html

[11] Professor Axel A Weber, President Deutsche Bundesbank, Financial Markets and Monetary Policy, CEPR/ESI 12th Annual Conference The Evolving Financial System and the Transmission Mechanism of Monetary Policy, Co-organised by the Bank for International Settlements in Basel, on 25/26 September 2008;http://www.bundesbank.de/download/presse/reden/2008/20080926_weber.pdf

[12] Speech by David Blanchflower, Bruce V. Rauner Professor, Dartmouth College, University of Stirling, and Member, Monetary Policy Committee, Bank of England. Inflation, Expectations and Monetary Policy, Tuesday, 29 April 2008, At the Royal Society, George Street, Edinburgh

[13] Credit markets hit by bank debt guarantee, The Financial Times, By Aline van Duyn October 27 2008 02:00, http://www.ft.com/cms/s/0/04a7006a-a3c6-11dd-942c-000077b07658.html

3.3 The Future of Banking Supervision is Economic Capital

On the basis of the supervisory reaction to the Credit Crunch it is clear that Economic Capital is fundamental to the supervision of the banking industry.

The entire focus of the two groups based around the Bank for International Settlements (BIS) i.e. the FSF (Financial Stability Forum) and the BCBS (Basel Committee for Banking Supervision) is upon Basel II Pillar 2 (B2P2) or Economic Capital, the unstructured Supervisory Review Process where the bank is expected to be able to deploy technology and personnel to quantify the risk in its exposures, that is to model economic capital.

Looking back to the collapse of Northern Rock, we can see that the FSA in the UK did not rigorously deploy the B2P2 supervisory enablement at that time. The UK House of Commons Treasury Select Committee report into Northern Rock[14] zooms in on failures in Stress Testing and Quantification of Liquidity Risk as the key failures of both Northern Rock risk management and of the UK FSA supervision of Northern Rock. In his evidence to that committee, The Governor of the Bank of the England (Mervyn King) considered aloud the under-specification of Pillar 2 with particular reference to Liquidity Risk; "*Unlike capital regulation, there is no international set of regulatory requirements for liquidity, apart from requirements under Pillar 2 of Basel II. At the time when the Basel capital regime was being negotiated the Bank of England did start an initiative to begin a parallel Basel liquidity adequacy regime, and it never got off the ground; other central banks were not so enthusiastic. It is a shame, but maybe we need to get back that.*"

What we can expect then is that the Supervisory process and regime will be strengthened and that the supervisors will act in a more coherent and coordinated way. The ECOFIN Conclusions[15] of May (08) show that the EU at ministerial level is instructing the EU Commission to increase spending in support of banking supervision and financial education throughout the EU and enhance the European dimension of Banking Supervision (note: not regulation). Although some of the conclusions seem extremely severe; "*The enhanced EU dimension would in particular allow financial supervisory authorities to consider financial stability concerns in other Member States and to apply guidelines and recommendations adopted by the EU Committees of Supervisors (level 3 committees) in line with the 'comply or explain' procedure. While guidelines and recommendations adopted by these committees are non-legally binding, those supervisors who do not comply should explain their decisions publicly.*"

The MOU (Memorandum of Understanding)[16] announcement between the Central Banks and National Supervisors of June 2008 is the first reflection of the requirements of ECOFIN and reveals that it is Supervision which will be strengthened in Europe i.e. Risk Based approaches to Economic Capital rather than rules based approaches to Regulatory Capital.

[14] "The Run on the Rock", January 24th 2008, House of Commons.

[15] COUNCIL OF THE EUROPEAN UNION, 2866th Council Meeting Economic and Financial Affairs, Brussels, 14 May 2008, http://www.consilium.europa.eu/Newsroom

[16] http://www.ecb.int/pub/pdf/other/mou-financialstability2008en.pdf

3.4 Integrated Credit and Market Risk Economic Capital

Recent experience has taught us that 'no matter what' in a financial institution today the route to the lowest possible value of retained capital will be selected, this is because the accrual of total capital in a given financial institution is a debit upon current earnings which is prior to the calculation of the payment of dividends and thus of net profit and it is either the return to shareholders or the profit figure upon which bank management will be judged (and most likely rewarded).

The incentive aspect of the post-Credit Crunch debate and the issues in the managerial economics of the banking industry which have transpired as a result of the CC are not a focus of this paper, however; our interest is economic capital.

So, abstracting from this incentive issue, the authors of the paper summarized above argue from the perspective of an institution which would truly wish to understand and quantify its integrated risk exposure (indeed which maybe required to do so by its supervisor in the future), they suggest that the incentive does exist for institutions to develop these highly complex integrated credit and market risk models since there exists a possibility that they could yield lower total capital requirements for a well diversified institution.

The proposition that optimally Credit and Market Risk need to be modeled in an integrated manner is by no means new. In fact it has been championed principally by Mathias Drehmann of the Bank of England for a number of years who has developed his ideas with co-authors in a number of papers over recent years of a modeling approach to such a challenge. Once one considers this type of challenge it is worth pointing out two aspects; a) one is by definition leaving the realms of regulatory capital and entering exclusively an economic capital domain and as with all aspects of economic capital b) one is entering a mathematical domain since it is sometimes difficult to express concepts of economic capital without using the language of the modeling technique one is considering to quantify it. That technique being in a manner 'derived from' but certainly appropriate to the specific real world situation for which we are trying to price or quantify risk.

3.4.1 Holistic Risk Analysis: Difficult but Do-Able.

The possibility of lowering the total capital requirement through integrating credit and market risk modeling does seem rather remote. There may be special situation institutions where this possibility would be real such as a hedge fund or private equity portfolio (such portfolios being considered for supervision given their recent significant exposure to banking and credit assets).

The main argument against integrated credit and market risk e.cap modeling is that it is simply difficult. Given that it is already hard to estimate precisely market and credit risk independently thus to estimate them jointly you need to take a stand on some structural model. The compound effects of model risk and estimation error may make your estimates quite unreliable. A case in point was the announcement by Goldman Sachs last summer (2007) that they were hit by a 25 standard deviation shock twice in a row. Clearly this does not make sense[17]. Difficult or not it does appear from a recent survey of risk

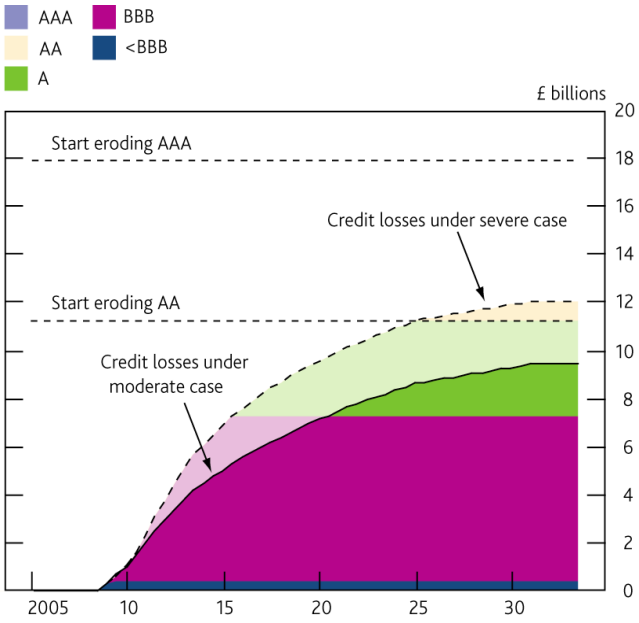
[17] Simone Manganelli, Principal Economist, Financial Research Division, DG-Research, ECB

management practice by the BIS[18] that this is the direction in which the larger banking groups are moving. The survey notes that "*risk concentrations at most financial conglomerates are still chiefly identified, measured and managed within separate risk categories and within business lines*". This is characterized as 'silo management'. However, risk concentrations may arise from interrelated exposures across risk categories.

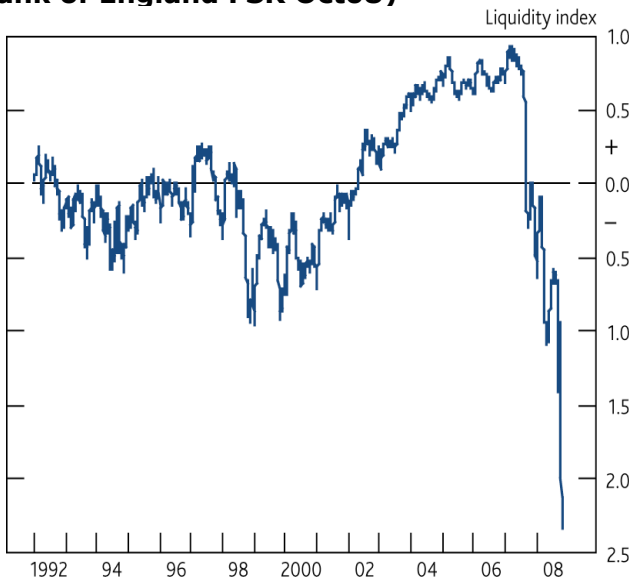
3.4.2 The Endogeneity of Liquidity Risk to Credit Risk

If the Credit Crunch has taught us anything which we didn't already know it is surely about correlations and endogeneity. It is clear that Liquidity Risk and possibly most market risks are in fact endogenous to Credit Risk. We model this now by simply recognising in strong correlations (i.e. those identified as stable over the appropriate time period) the impact upon total risk economic capital of credit risk (i.e. that it implies further risk in terms of liquidity as it increases). It is in these correlations that our knowledge and quantification of risk capital is most fundamentally defined. In fact it is the mathematical nature of risk and its associated capital which we must confront if we are to understand it, at all.

Credit losses on UK prime RMBS (Bank of England FSR Oct08)



Financial Market Liquidity (Bank of England FSR Oct08)



[18] Basel Committee on Banking Supervision, The Joint Forum Cross-Sectoral review of group-wide identification and management of risk concentrations, April 2008

4. Modern Quantitative Approaches to Economic Capital

The Bank for International Settlements recently produced a paper specifically on the subject of Economic Capital[19] which must be referred. This exposition will focus upon the annexes to the document since the body of the document is simply a paradigm exposition of "best practice" and if that is your focus then the document is thoroughly recommended.

The Annex opens with a plain statement of fact "*The majority of banks use one of three types of credit models. These models, often referred to by their commercial names, are Moody's/KMV (MKMV), CreditMetrics, and CreditRisk+.*" It then refers to a recent (2006) comparative study of these models[20] pointing out "*the crucial issue regarding credit risk models is the way the dependencies between borrowers are modeled*." Crucially the BIS paper argues to its own conclusion, making a strong expression of supervisory concern about the Banks' use of these models (note: this does not appear to be a conclusion about the models themselves), the concern is expressed as follows; "*banks use credit portfolio models without having a full understanding of the underlying assumptions and techniques embedded in them. They may also not fully understand whether such models are suitable for different portfolios as well as for the specific concentration and exposure mix characteristics of their own portfolios*."

The main criticism of the manner of deployment of these Credit Risk model packages is that shortcuts are deployed uncritically and that explicit dependency modeling is generally not done by the banks, the paper concludes with some indications of practice which would be deemed to be optimal by supervisors in the future "*it is unclear why banks do not use their own internal data to derive more realistic, less assumption-driven correlations …….. Assuming that banks gather enough data to estimate more reliable correlations using internal data in the future, it would be useful for the industry to make progress in estimating correlations for other exposures, such as SME and retail, and to analyze which data, models, and techniques are the most relevant for these portfolios.*"

4.1 Quantitative Risk Management (QRM)

The BIS review of Economic Capital practices and issues, referred above, focuses upon Dependency modeling, the copula and refers the ASRF technique (which could be generalised to a more explicit Factor Model) as examples of best practice in modeling Credit Economic Capital.

The best exposition of 'Copulas and Dependency Modeling' is that in Chapter 5 of Prof. Alexander J McNeil's book "Quantitative Risk Management" (written with his co-authors, the eminent risk management academics; Rudiger Frey and Paul Embrechts). This book is referred in the BIS paper discussed above and is generally the key reference for professionals building 'internal' models of Credit Economic Capital using Predictive Analytic development environments, throughout the world. We will refer to it as QRM.

[19] Basel Committee on Banking Supervision Consultative Document, Range of practices and issues in economic capital modelling, Issued for comment by 28 November 2008

[20] The International Association of Credit Portfolio Managers (IACPM) and International Swaps and Derivatives Association (ISDA) conducted a study in 2006 to explore the economic credit capital models in use by their member institutions.

4.1.1 The Copula, fundamental to Credit Risk

In QRM, Professor McNeil points out (in Chapter 5) that every joint distribution function for a random vector of risk factors implicitly contains both a description of the marginal behaviour of individual risk factors and a description of their dependence structure. What the copula approach adds is a way of isolating that dependence structure, allowing the analyst to focus in detail explicitly on the dependency between factors in a joint distribution (in Credit Economic Capital terms, examples would be GNP and Retail Lending Defaults or The Term Structure and SME default rates). As QRM states; "*copulas help in understanding dependence at a deeper level … they express dependence on a quantile scale, useful for describing the dependence of extreme outcomes*." The individual default risk of an obligor, QRM continues is something we can get a handle on from a model of the obligors marginal behaviour (a factor model) adding a copula approach "*allows us to combine our marginal models with a variety of possible dependence models and to investigate the sensitivity of risk to the dependence specification*".

4.1.2 Practical applications of the Copula

The copula is crucial to Credit Risk modeling in particular since it is dependence between types of default which makes the lending institution most exposed to economic risk. We see that now in housing and property collapses, to quantify economic risk at the extreme outturn, particularly in credit exposures; the copula technique which is layered upon the basic factor model is fundamental to quantitatively teasing out the manner in which types of similar credit exposures will behave in a similar manner. Basically it is quantifying the likelihood that "once one goes, they all go!"

Thus the copula technique is the basis for quantitatively exploring concentration risk and stress testing credit risk in a Basel II context. As the Deutsche Bundesbank has argued recently; "Pillar I estimates do not explicitly take portfolio concentration into account[21]." It is intensifying the dependence between exposures beyond the B2 regulatory minimum that you can begin to quantify the economic risk at the extreme of the portfolio.

4.1.3 Stochastic Inference, a Supervisory Requirement

We must be clear what we are doing here is Stochastic Inference; an approach which seemed to be fundamental to economic capital modeling when the Basel accords were first published (2004) but which was resisted and avoided throughout the banking industry in the UK and Europe right up to the Credit Crunch (CC) period. The UK House of Commons Treasury Select Committee report into Northern Rock[22] zooms in on failures in Stress Testing and Quantification of Liquidity Risk as the key failures of both Northern Rock risk management and of UK FSA supervision of Northern Rock.

The Committee recommended that the UK supervisor, the FSA, enhance its supervision framework immediately consistently with its Discussion Paper (DP) of December

[21] Stress testing of real credit portfolios, Ferdinand Mager (Queensland University of Technology and School of Economics and Finance), Christian Schmieder (Deutsche Bundesbank and European Investment Bank), Deutsche Bundesbank, Discussion Paper, Series 2: Banking and Financial Studies No 17/2008

[22] "The Run on the Rock", January 24th 2008, House of Commons.

2007[23]. In that DP, the FSA explicitly states that internal models should be in place to quantify liquidity and the FSA states clearly that an internal model is "*any internal system, process or methodology that is used to quantify risk, but especially those that rely upon statistical or stochastic inference*". This is in a discussion specifically of issues of Liquidity Risk but it is applicable to all Modeling and Stress testing of Economic Capital. We can therefore conclude that to achieve the requirements of the UK supervisor in 2008 and beyond, robust stochastic inference models must be deployed to quantify credit economic capital.

4.1.4 Multivariate Distribution Functions

QRM presents the mathematics which demonstrates that the Copula is available to analyze all multivariate continuous distribution functions and copulas may be used with univariate functions to create new multivariate functions. More concrete examples of the applicability of the mathematics the professor is using here is useful. Recently the most frequently used example of the deployment of the Copula has been in the pricing of CDOs (intuitively obvious since CDOs are collections of dependent securities) but using that example would seem to be a little irrelevant now after the CC!

Where you model Economic Capital (or risk) as being a function of a multivariate distribution; e.g. historic default in Asset Class A, Asset Class B, the term structure and FTSE100 (a Factor Model, implemented in a GARCH function), you can also say how default in Asset Class A is dependent specifically on the FTSE100 for example or any other factor in your model. More precisely our multivariate function of the type described above has the objective of discovering the risk of that portfolio of factors as it were; what the Copula adds to the risk (or Economic Capital) model "*is the ability for us to discriminate whether the change in risk is sourced in the joint distribution or from the marginal i.e. during extreme periods, the risk could come from either the fact that the marginal f are heavy-tailed or their dependence c is heavy-tailed, or both.*"

In the univariate case, the copula joins the marginal distributions together, to form a full, joint, distribution and thus shows how economic risk may rise in the extreme case. I was interested to learn in preparing this exposition that in Norwegian the Copula is called the 'Joining Function' ("Koblingsfuncsjon"[24]). Just for clarity a single variable (univariate) probability distribution is concerned with only a single random variable; e.g., roll of a dice, default of a single obligor. A multivariate probability density function concerns the outcome of an experiment with more than one random variable. This includes, the simplest case, two variables, referred to as a bivariate distribution. A copula function nicely illustrates the difference between univariate and multivariate. The copula function takes as inputs univariate (marginal) unconditional probabilities and "joins" them to produce a multivariate distribution function.

[23] Financial Services Authority, Review of the liquidity, requirements for banks and building societies DP07/7, http://www.fsa.gov.uk/pubs/discussion/dp07_07.pdf

[24] Economic Implications of Copulas and Extremes, Norges Bank, 2008 http://www.norges-bank.no/upload/71737/economic%20implications_pek_02_08.pdf

Put very simply then a copula is a function that links marginal (unconditional) distributions to a joint distribution. They are useful and popular for credit portfolios: if a marginal (CDF) distribution M1(X1) characterizes the probability of default of an individual credit and M2(X2) characterizes the same for another credit, then J(X1,X2) = C[M1(x1),M2(x2)] is the joint CDF distribution that links the marginal distributions by way of the copula C() function[25].

4.1.5 Linear Dependence Modeling

Professor McNeil (QRM) makes the focus of his discussion of correlation its shortcomings and subtle pitfalls (which is why we have focused on the copula above which alongside Extreme Value Theory (EVT) the professor is most famous for). However as McNeil states correlation plays a central role in financial theory.

In a recently published very useful book[26], Linear Regression is described as one of the most widely used tools in statistics for analyzing the (linear) influence of some variables or factors on another or others and thus to uncover explanatory and predictive patterns. As the authors comment, "*a large proportion of statistical analyses deal with the representation of dependencies among several observed quantities.*"

Linear dependence modeling is the basic workhorse of credit economic capital; it is in using regression techniques which support this approach that an analyst can understand the manner in which economic capital is as it were driven by the factors which the modeling process demonstrates explain it. Modeling economic capital is all about the reliability of the correlations which your regression model identifies. This is why QRM points out clearly what linear correlation does tell us and what it is does not. So, that in the hands of even a naïve user, we know what we can say, with reliability and what we cannot.

4.1.6 QRM: Two important fallacies

QRM points out two important fallacies in the use of correlation: 1) that the marginal distributions and pairwise correlations of a random vector determine its joint distribution and 2) for given univariate distributions F_1 and F_2 it is always possible to construct a joint distribution F (it is not). As QRM concludes in the strictest sense the concept of correlation is meaningless unless applied in the context of a well defined joint model. Any interpretation of correlation values in the absence of such a model should be avoided. The implication of this for us mere mortals simply wishing to estimate credit economic capital using a linear regression model is that we are always exposed to Model Risk and we should always be conscious of this and not be 'slapdash' in our use of regression modeling techniques, striving to achieve the highest reliability in our modeling approach that we can. Thus the copula is key to understanding joint distributions properly.

[25] http://www.bionicturtle.com/learn/article/the_problem_with_copulas/#When:19:19:00

[26] 'Bayesian Core, A Practical Approach to Computational Bayesian Statistics' Jean Michel Marin and Christian P Robert, Springer Texts in Statistics, 2007.

Following the presentation of the fallacies referred above in the Embrechts, McNeil and Straumann paper of 2002[27], recent papers in the credit economic capital space begin with the copula; a good example of such a paper is this reference[28].

4.2 Plight of the Fortune Tellers

Ricardo Rebonato in his book[29] much like the McNeil et al paper is pointing out key fallacies of "common" dependence modeling. Rebonato is doing a similar demolition job in his book but a valuable one, showing us data and techniques which we can rely upon in modeling credit economic capital and where the pitfalls and blind stupidities are.

In chapter seven; "Looking beneath the surface: hidden problems", Rebonato points out that the applications of statistics the book is concerned with are uses in order to make predictions about what will happen in the future, i.e. Financial Predictive Analytics. It is sometimes not necessarily obvious that in quantifying credit economic capital we are actually making a prediction of how much capital (the quantum) is necessary over the life of an exposure or position or portfolio to assure us (the institution writing the deal) that we are not exposed to losses even in extremis.

Rebonato goes to great lengths to make the point that in predicting the future we need as much data as we can get to be able to rely upon our predictions but that the further back our time series goes, the more historic data may be irrelevant to the conditions into which we are trying to predict. As he describes the issue; "*If we cannot rely on gathering a lot of frequent and recent data, we must trawl our data set in search of relevant "patches" of [the] past.*" From this Rebonato argues that in selecting "relevant patches" we are relying on an implicit model of the future which is in our head, which we may or may not have externalized i.e. we have already made assumptions about the future in selecting the data appropriate to predict it.

Later in the book Rebonato converts his concept of 'relevant patches' to sub-series of a data series which he describes as 'self similar'. This is an important concept sometimes referred to as a "regime" or in context "regime switching" in the academic econometric literature.

4.2.1 The Bayesian Prior – Implicit Assumption

Reliance upon an implicit model to pre-select appropriate data is what is known as modeling with a "Bayesian Prior"[30], i.e. that view of appropriate data to predict our unknown univariate distribution (at its most simplest) is an implicit prior "model" or set of assumptions about the future which we make before predictive modeling even commences, as Rebonato states "*I cannot stress enough the importance of the fact that what constitutes the relevant past is not contained in the data but comes from what I have called an "external model".*"

[27] http://www.math.ethz.ch/~mcneil/ftp/risk.pdf
[28] http://sfb649.wiwi.hu-berlin.de/papers/pdf/SFB649DP2008-043.pdf
[29] Plight of the Fortune Tellers: Why We Need to Manage Financial Risk Differently, Ricardo Rebonato.

[30] http://en.wikipedia.org/wiki/Bayes_theorem

Chapter seven of the book proceeds to review common approaches to assessing Value at Risk (VaR); it looks at Nonparametric Historic Simulation, where we make no prior assumptions and simply predict the future with "brute force" dependent upon the past, it then reviews "Empirical Fitting" where we select a distribution of our historic data which "looks good" or fits that data and thus on the basis of that distribution we can make 'predictions' about high percentile or extreme conditions of that data. But Rebonato argues that "*puts us in a state of sin*" since in our original data we have no evidence really for what we say about extreme conditions of that data in the future via our selected distribution.

4.2.2 The Issue of Dimensionality

In many banks right now 'Monte Carlo' is seen as the instant solution technique to overcome the important fallacies raised by both Professor McNeil and Ricardo Rebonato and summarized above. Rebonato describes Monte Carlo as "*a very efficient technique for sampling high dimensional probability densities … it does not suffer from the "curse of dimensionality"*".

The Curse of dimensionality is the problem with statistical inference encountered as a result of 'noise'; as the number of regression variables (dimensions or factors driving prediction) is increased the 'performance' or predictability of the model reduces as a result of noise i.e. "*the fraction of sample points that are close to any point at which we wish to evaluate our expectation declines rapidly as the number of dimensions is increased*"[31]. Although Rebonato refers to "the curse of dimensionality" as not really belonging in his book the problem is fundamental to his logic; as argued in another econometric textbook, this problem stops us throwing the kitchen sink at a prediction challenge where economic theory (of which credit theory is a subset) gives us no guide on selection of the appropriate model[32].

The corollary of the 'Curse of Dimensionality' is 'The Parsimony Principle', normally associated with Factor Modeling, in its strictest sense it states; "*When two or more theories explain the data equally well, select the simplest theory. In specific relation to Factor Analysis; if a two-factor and a three-factor model explain about the same amount of variance, interpret the two-factor model.*" This is an important rule in setting up your Credit Risk Economic Capital Model[33].

4.2.3 The Appropriate Use of Monte Carlo

From the above it can be seen that Monte Carlo is not the only way out of model noise caused by high dimensionality; some thinking and iterative re-specification of a factor model may be another, more intellectually taxing path. Rebonato argues that on the basis of 1,000 historic data points, Monte Carlo (MC) can generate "*10,000 or 100,000 zillion of synthetic data points….for MC to really work magic, I must have fundamental a priori reasons to believe that the data to be sampled is of a particular distribution…… when it comes to rare events that the risk manager is concerned about the precision determining the shape of the tails is ultimately dictated by the quantity and quality of the real data."*

[31] 'Econometric Theory and Methods', Russell Davidson, James G MacKinnon, OUP 2004

[32] A guide to Modern Econometrics, Marno Verbeek, 3rd Edition, Wiley, 2008.

[33] http://en.wikipedia.org/wiki/Parsimony

This is a strong an argument against the use of MC in Credit Risk models but it is a positive argument in favour of the analytic techniques of the Factor Model, the Copula and simple Linear regression techniques. As Rebonato concludes "*the MC technique will do very little to increase my confidence over and above what analysis with the real data had suggested"*.

QRM makes an equally strong criticism and gives some advice if the analyst runs out of ideas encountering an intractable challenge that may require MC; "*the method does not solve the problem of finding a[n appropriate] multivariate model and any results that are obtained will only be as good as the model that is used. In the market risk context a dynamic model seems desirable and some kind of GARCH structure with a heavy-tailed multivariate conditional distribution… might be considered."*

Rebonato concludes his discussion of MC then with a reference to the reliance of Moody's on the MC technique as what he describes as "*giving him some cause for concern*". This goes to the supervisor's counsel from the BIS referred above about the uncritical use of "black box" models; technology is never a replacement for thinking!

5. The Credit Economic Capital Stress Test

It is not always intuitively obvious to everyone (particularly not software engineers) that the dependent variable in your credit economic capital model (that's the variable on the Left Hand Side (LHS) e.g. "g=") is economic capital. Economic Capital is a term which quantifies risk and the dependent variable of a credit risk model is risk as driven by the independent variables (or factors) which you the analyst select as its drivers. This selection is either a result of your economic theory of risk (which you may be testing with this equation) or as a result of an iterative fitting process where you have evidenced the drivers for risk with "best fit". In this section 'economic capital' and Basel II Pillar 2 (B2P2) are used interchangeably as synonyms; since in this mature phase of Basel II, post Credit Crunch and probably approaching Basel III; that is what they have, in effect, become.

It is a BIS[34] paper which introduced the language of quantifying in the banking supervisory context economic capital or the Basel II Pillar 2 number for credit risk. This BIS working paper is seminal and defines the mathematical logic of a framework for a Stress Test of Credit Risk and thereby determines the methodology of an Economic Capital calculation in a banking supervisory context. In preparing an earlier White Paper on B2P2[35] this author used the exposition of this paper as the core of the logic of that paper.

5.1 B2P2, ICAAP & SRP.

The B2P2 requirement to compute economic capital is a key aspect of the ICAAP (Internal Capital Adequacy Assessment Process) which is part of the Basel II Supervisory Review Process (SRP). For Credit Risk, the stress testing requirements of B2P2 require that contrafactual macro-economic assumptions are applied to the Bank's internal time series models of default behaviour (and additionally time series histories of costs of operations if an integrated finance and risk approach to risk modeling is to be deployed). Since it does not seem sensible to take a view on Credit Economic Capital Modeling in abstraction from Basel II we will present here an exposition of the Credit Economic Capital quantification entirely consistent with Basel II (in spite of the fact that it looks to be supplanted by a Basel III framework in the not to distant future).

5.2 The Factor Model

Any Financial Institution today already has deployed certainly two distinct methodological approaches and possibly more in different business units. The two certain implementations will be some deployment of Structural Credit Risk models and some deployment of the Financial Mathematics of the Reduced Form in the trading room for the pricing of derivative instruments and trading book transactions. When optimizing the choice of a methodology for the Stress Test, it is necessary to select an approach which allows these existent approaches to coexist with the Stress Test methodology; B2P2 is not about contradicting or replacing existent operational techniques.

[34] BIS Working Papers, No 165, Stress-testing financial systems: an overview of current methodologies, by Marco Sorge, BIS, Monetary and Economic Department, December 2004

[35] http://www.sap.com/uk/images/baselii/whitepaper.pdf

The correct approach, then, to Stress Testing Credit Economic Capital, is called Factor Modeling. This is consistent with the approach to Stress Testing outlined by BIS in the paper by Marco Sorge. The Reduced Form models in the Front Office of the Trading Book are Factor models also; designed for quick calculations to support valuation and pricing tools. Both the trading model and the economic stress test model are Factor models because they take the value we wish to understand on the left hand side of the equation and explain its possible values as a relationship between the factors which drive it, and are related on the right hand side of the equation. The difference is the degree of importance in the 'fitting' process and the type of variables of the RHS of the equation.

The exposition of the Factor Model technique here is not a "deep dive" into the technique; it is an overview, an introduction. The technique has many powerful second and third order tools and functions available to the practiced user and student; not least around the latent variable.

5.2.1 Factor Models & Structural Models (the Black Box)

The Structural models of Credit risk implemented by Moody's KMV or Credit Metrics are factor models but of a complex and structural nature. Structural means that the models are structured of a multiplicity of factor equations, each explaining layers of the detailed assumptions of each factor. Structural models are by definition therefore high-dimensional. They can be understood by a single factor equation. The proprietary Structural Credit Risk Models of KMV or Credit Metrics are easier to understand expressed in their Reduced Form (RF) factor model but that is not how they function internally. They are highly dimensionally complex, therefore not amenable to subtle amendment and refinement and not responsive to changes in the economic model of credit risk which the banks' executives may hold.
See the brief discussion of Rational Expectations (RE) below. It is an important hypothesis in this context; at its simplest it means that the experienced individual understands the business cycle and the location of his / her business in it. Conceptually there is an economic model in the senior executive's mind, which the predictive analytic modeling process effectively teases out and makes empirically testable. This is the basis of the Basel II requirement to have full engagement of the board of directors in the development of macroeconomic scenarios for stress testing. It is often missed that further engagement and direction of these executives to the modeling team is required in the iterative stress testing process.

The proprietary aspect of the Structural Credit Risk models is the manner in which they arrive at levels of default for corporate exposures expected under current conditions which flows from the large (proprietary) databases of corporate default (usually US oriented) maintained by the companies selling these tools. The structural model is therefore the explanation or the story of default under current conditions. As has been argued however the inability of the user to intensify assumptions of default dependence (as is possible in the deployment of the copula) means that these black box models with constant assumptions of asset correlations are not appropriate modeling tools for economic risk capital under extreme conditions[36].

[36] Modelling Dependent Defaults: Asset Correlations Are Not Enough! Rudiger Frey, Swiss Banking Institute, University of Zurich. Alexander J. McNeil, Department of Mathematics, ETH Zurich, Mark A. Nyfeler, Investment Office RTC, UBS Zurich, March 9, 2001

5.2.2 Factor Model; Appropriate tool approved by Supervisors

The essence of credit risk modeling is the reduction in the dimension of the risk exposure attributable to a number of factors. Factor Modeling is the optimal approach to the Stress Test and the Basel II ICAAP; it models portfolios simply and tractably. It is a methodology which can be deployed by any type of Financial Institution within the governance processes required by BIS and CEBS for P2, supported by an appropriate Solution Architecture. Multivariate factor modeling is the type of factor modeling which is the best possible approach, single factor modeling (like the ASRF of the B2 Supervisory Formula Approach (SFA)) is probably over simplified, using one factor means you miss some driving behaviour of pockets of the influencing conditions on risk but the Gordy single factor approach may be necessary where other complexities exist in the risk being modeled (e.g. the complex transaction structure of a securitised instrument).

5.2.3 Model Setup

Factor models are implemented statistically by Bernoulli mixture models (Bernoulli = Binary and Credit Default requires that essentially binary nature of the model since a credit default event can be understood analogously to a "death event"). Factors make Bernoulli variables dependent. A mixture model is placing probabilities on independent variables to make them more dependent. This sort of analytical approach must be a capability of the application architecture to support financial or economic stress testing of credit risk portfolios. A factor model is fundamental whether the calculation of economic returns proceeds analytically (via formulas) or by simulation, in the latter case the Factor Modeling approach is the underlying model for Monte Carlo Simulation.

In the Sorge (BIS) function the factor g is particular to each financial institution; g is the portfolio weight of that aggregated asset class or in other words the portfolio asset allocation of that asset class. These weights (this vector of weights) are dollar value numbers and therefore the g function will provide the dollar value of economic capital. Therefore we would expect that the supervisor will wish to see the capability of the institution to stress factor impacts on the g value and possibly will guide on the stress levels (the 1/100 or 1/1000 event which equates to a 30% fall in FTSE or a 4% rise in base rates, for example).

5.2.4 External and Internal Factors

A Factor Model for the Stress Test of any Risk Type consists of two types of Factors; Internal and External. Internal Factors will generally be the dependent variables (from a regression perspective) which the Stress Test should explain or Stress, they may however be deployed as independent variables also; what you will find is that a lot of the internal time series simply behave collinearly with e.Cap and may not explain it, that is they behave in the same way in response to the external driving factors as e.Cap does. External Factors are the independent variables which explain the dependent variable or evaluate the level of stress on the explained (dependent) variable, these are usually macroeconomic variables. All factor variables are time-series data for which we must know and define a period of observation and an observation frequency which optimally common to all independent variables.

The internal factors for the Credit Risk Stress Test are simply observed intensities of default collected from internal bank records over as long an historic time period as possible. You should also consider including in your internal factor set the (internal) history of bank profits and provisions, Tier One Capital, Nett Interest Income and other KPIs and performance proxies as you see fit over the time period of the other internal factors described above and observed with the same frequency.

5.3 Stress Test Factor Models; Central Banks

The Central Banks provide two distinct types of expositions of Stress Testing methodologies in their working papers and other publications. The volume of output on this subject grew from very little in 2003 through the Basel II implementation period to currently during the credit crisis when we have a wealth of resource to rely upon in designing the Stress Testing process. Almost all of the Central Banks deploy some variant of the Factor Model technique to conduct Stress Testing now, albeit that one can see more and more sophistication in the techniques layered upon the basic Factor Model which has been described here.

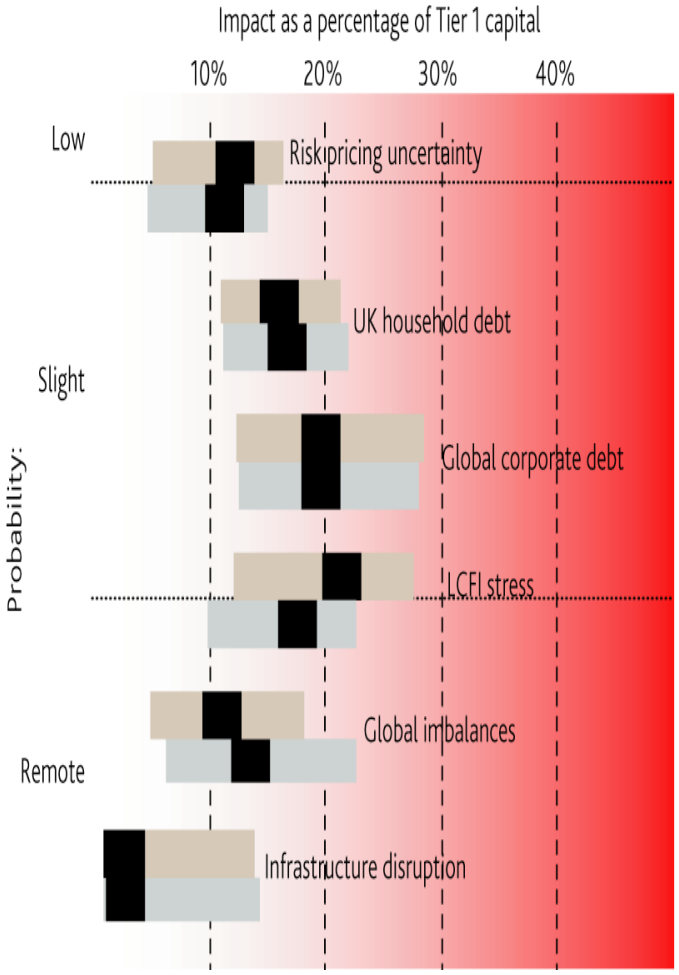
The two types of exposition are subtly different; the first is where the Central Banks are effectively talking to each other, describing how they stress test the country and its collection of banks for which they are each individually responsible; the second is where the Central Banks in a quasi academic manner are publishing papers to guide their client institutions directly on how they wish the stress test to be conducted in that institution specifically. Certainly in Europe right now, such guidance published in one country is equally relevant in another and from a reading of the techniques this is true globally also. Each type of publication is actually relevant to the stress testing team in an individual bank; the first because it guides you on the factors and relationships which the Central Bank sees as crucial to financial stability in the country and the second because it is simply didactic!

The private sector and academic community have made significant contributions to the literature in recent years and recent personnel exchanges between these three sectors looks positive for the cross fertilization of ideas in the economic capital estimation.

5.4 Stress Test Factor Models; Blueprints

A number of good blueprints have already been referred in the discussion above but since the volume of publication has increased so dramatically in the last eight months, listed below as references are a number of papers (mostly from Central Banks) which have generally been regarded as most useful.[37]

SEVERE STRESS SCENARIOS (BANK OF ENGLAND FSR 2007)



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4. Stress testing of real credit portfolios, Ferdinand Mager, Christian Schmieder, Discussion Paper, Series 2: Banking and Financial Studies, No 17/2008
5. Modelling The Distribution Of Credit Losses With Observable And Latent Factors, Gabriel Jiménez and Javier Mencía, 2007, Documentos de Trabajo, No. 0709, Banco de Espana
6. Stress Tests for the Austrian FSAP Update, 2007: Methodology, Scenarios and Results, Michael Boss, Gerhard Fenz, Gerald Krenn, Johannes Pann, Claus Puhr, Thomas Scheiber, Stefan W. Schmitz, Martin Schneider and Eva Ubl,
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9. The Basel II framework: the role and implementation of Pillar 2, PIERRE-YVES HORAVAL General Secretariat of the Commission Bancaire, Banque de France Financial Stability Review No. 9 December 2006.
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11. Integrating credit and interest rate risk: A theoretical framework and an application to banks' balance sheets Mathias Drehmann, Steffen Sorensen & Marco Stringa; First Draft, April 2006
12. Adjusting Multi-Factor Models for Basel II-consistent Economic Capital by Marc Gürtler, Martin Hibbeln, and Clemens Vöhringer, summer 2008.
13. A Tractable Model to Measure Sector Concentration Risk in Credit Portfolios, Klaus Düllmann and Nancy Masschelein, version: October 2006
14. Stress testing as a tool for assessing systemic risks Bank of England Financial Stability Review: June 2005
15. Liquidity Stress-Tester: A macro model for stress-testing banks' liquidity risk, Jan Willem van den End, Netherlands Central Bank, Research Department in its series DNB Working Papers 175, May 2008,
16. Credit Risk Factor Modeling and the Basel II IRB Approach, Alfred Hamerle, Thilo Liebig, Daniel Rösch, Deutsche Bundesbank, Preliminary Draft from: October 7, 2002
17. Stresstests in Banken, Von Basel II bis ICAAP, Kai-Oliver Klauck, Claus Stegmann, iFB, 2006

5.5 Factor Models and Market (CDS) Prices

Recently Factor Models have been developed to take account of market prices as key indicators of risk. There is some controversy here since this approach relies upon the seemingly slightly tenuous idea that the market can price risk in a financial institution or a corporate from an external perspective when only that institution's private and confidential internal data should be able to support accurately and up to date prices of its risk. "Do they know something we don't?!"

On the basis of Credit Default Swap (CDS) prices (spreads in particular); repeated empirical testing of this proposition (generally expressed in factor models) has demonstrated its efficacy and validity and many theoretic explanations have been presented in terms of the Factor Model's latent variable[38]. The data, the 'fit' and the explanation all seem to add up and there is movement towards general consensus that the CDS price (both index and stock-specific) is becoming a common shared indicator of credit risk. Significant market developments in loan pricing predicated upon CDS prices rather than LIBOR, consequent upon the failure of the latter in the CC are good evidence of this and further evidence of the application of quantitative techniques in mainstream financial transactions[39].

The importance of the Credit Swap Default (CDS) market but more particularly the index prices and the specific prices of corporate CDS has moved from being of interest only to credit specialists before the CC to becoming general interest post-CC. This is changing the manner in which these prices are regarded by market participants and by supervisors in particular. These products will be brought "on exchange"[40] (a detailed exploration of this issue is beyond this paper but it is fundamental to modern Factor of Modeling of Credit Risk[41]). Bringing CDS products 'on exchange' will provide a market source (thus regulated and public) of post trade execution prices of these products[42]. This will massively enhance the efficacy of the factor model technique in the quantitative predictive modeling process for credit risk. Maybe the CC has had one benefit?

The proposition is that statistical modeling (using the Factor Model) is possible based upon multiple default indicators (CDS spreads) to drive out the latent variable scores[43], thus quantifying risk economic capital. This type of factor analytic is typical in other areas of applied statistical modeling that use multiple observable indicators of the true (latent) endogenous variable (risk).

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[38] BIS Working Papers, No 214; The pricing of portfolio credit risk by Nikola Tarashev and Haibin Zhu, Monetary and Economic Department, September 2006

[39] Nokia prices loans according to CDSs, The Financial Times, By Anousha Sakoui Published: October 21 2008 20:21 http://www.ft.com/cms/s/0/a47df5fe-9fa1-11dd-a3fa-000077b07658.html

[40] http://www.ft.com/cms/s/0/90dde6a4-a05e-11dd-80a0-000077b07658.html
CDS traders asked to reduce risks, The Financial Times, By Nikki Tait in Brussels, October 22 2008

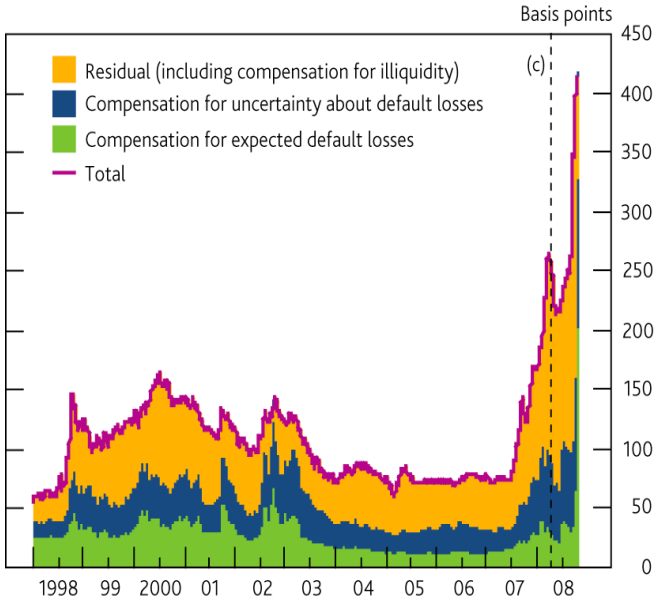
[41] http://www.ft.com/cms/s/0/39ce5062-9a1c-11dd-960e-000077b07658.html
Calls for derivatives clearing intensify, By Jeremy Grant, Gillian Tett and Aline Van Duyn, The Financial Times, Published: October 14 2008 20:28

[42] http://www.ft.com/cms/s/0/d885b4ea-9493-11dd-953e-000077b07658.html
CME-Citadel form CDS clearing facility, The Financial Times By Hal Weitzman in Chicago and Jeremy Grant in London, Published: October 7 2008 22:56

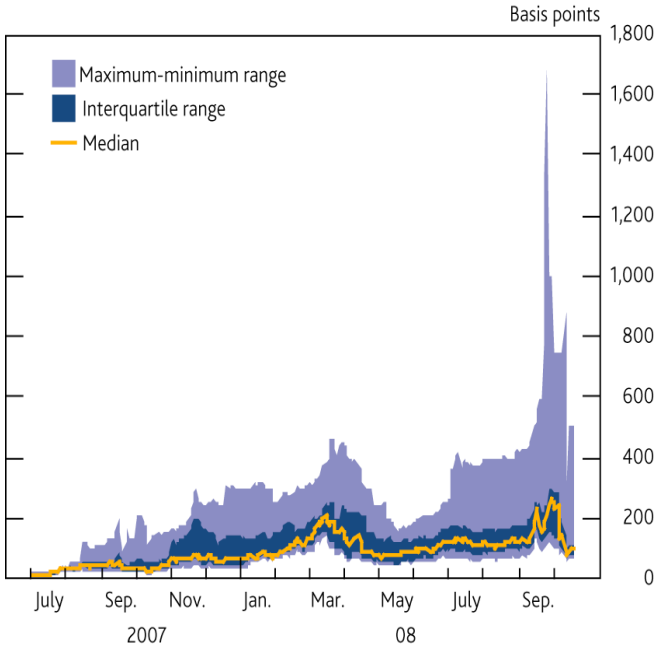
[43] The pricing of correlated default risk: evidence from the credit derivatives market, Nikola Tarashev, (Bank for International Settlements) Haibin Zhu, (Bank for International Settlements) Discussion Paper Series 2: Banking and Financial Studies, No 09/2008

Use of external prices of default risk (optimally market prices form an exchange) helps Banks enormously where there are gaps in internal data series, further where internal data series are good, one can deploy this type of modeling to validate risk estimates predicated upon internal data stressed by external macroeconomic factors. The idea would be to develop factor models for default and recovery that combine actual observed macroeconomic factors with the "latent" factor effects that seem to be necessary to explain the excess heterogeneity of default rates and to forecast credit loss distributions with realistic tails for economic capital setting. Consider also one important scenario: you run a regression (e.g. GLM) on a single (say "best") indicator of default, you get so-so results; R-squared of .6-.7; then you estimate a factor model (a dynamic latent variable model and use the latent variable scores based on multiple default indicators); then the regression gives a much better fit, your R-squared gets up to .9 or higher and all macro factors have more significant effects. Needless to say, such a model is then much better for stress testing and Economic Capital estimation. The reference paper for this type of thinking which is seminal is Darryl Duffie[44], for a "latest thinking" exposition and a how to guide see this paper[45].

Decomposition of sterling-denominated investment-grade corporate bond spreads



Major UK banks' credit default swap premia



[44] BIS Working Papers, No 173, Measuring default risk premia from default swap rates and EDFsby Antje Berndt, Rohan Douglas, Darrell Duffie, Mark Ferguson and David Schranz Monetary and Economic Department March 2005,http://www.bis.org/publ/work173.pdf?noframes=1

[45] McNeil AJ and Wendin JP: Bayesian inference for generalized linear mixed models of portfolio credit risk. Journal of Empirical Finance, 14(2): 131-149. 2007 Earlier preprint version may be found here: http://www.defaultrisk.com/pp_model_09.htm

5.6 The Regression Modeling Process with R

Some find the regression programming aspect to statistical modeling too detailed and also divorced from the underlying mathematical logic. For a good exposition of the underlying mathematics of the regression technique (and thus possibly an added assurance of its validity) please see the concluding chapters of a recent very useful book (Chapters 33 through 35)[46].

The R language[47] will be used for this exposition of the regression practicalities; R is a language and environment for statistical computing and graphics. R provides a wide variety of statistical (linear and nonlinear modeling, classical statistical tests, time-series analysis, classification and clustering etc) and graphical techniques and is highly extensible. On the web you can find special interest groups, application catalogues and a standard open source forge.

It must be stressed that the process of defining the equations and finding the best fit between internal and external data is by no means mechanistic or automated. 'Expert Judgment' must be exercised by the analytic team and in the case of Economic Capital the responsible executives on whose behalf the modeling process is undertaken. The best fits and appropriate factor sets are found by trial and error, both in defining how the stress scenarios are to be tested (e.g. choice of exogenous variables) and in judging the best fit between internal and external data.

The overall process is an iterative one; in which models are regressed in order to relate external factors to internal history data to derive Factor equations to describe the manner in which risk may respond to changing Macroeconomic conditions. Once the equation has been created which expresses your view of the risk model that equation can then be applied in the running of scenarios – both baseline (unstressed, assuming current conditions continue to prevail) and stressed – i.e. what is normally thought of as constituting the Stress Test. The stages involved in building the model and running the Stress Test may be summarized under the following three headings:

1. Collate input data for the Stress Test
2. Define the Factor Model for the Risk Type
3. Run the Stress Test
4. Repeat Iteratively towards Fit.

'Expert Judgment' must be exercised by informed and skilled staff throughout; both in defining how the stress scenarios are to be tested (e.g. choice of exogenous variables) and in judging the best fit between internal and external data. Deciding the validity of some assumptions or restrictions on parameters is a key part of the quantitative analyst's toolkit. In an ideal world when building a regression model, we should include all relevant pieces of information, which in the regression context means including all predictor variable which might help explain 'g' or 'economic capital'. Rebonato has counseled us on the 'curse of dimensionality' already and some judgment and empirical testing is required to optimize your explanatory model in this regard.

Once you have your basic Low Dimensional Factor Model to be implemented in a Generalised Linear Model supported in an appropriate regression technique in R; you have a wealth of further tools to empirically test and validate the

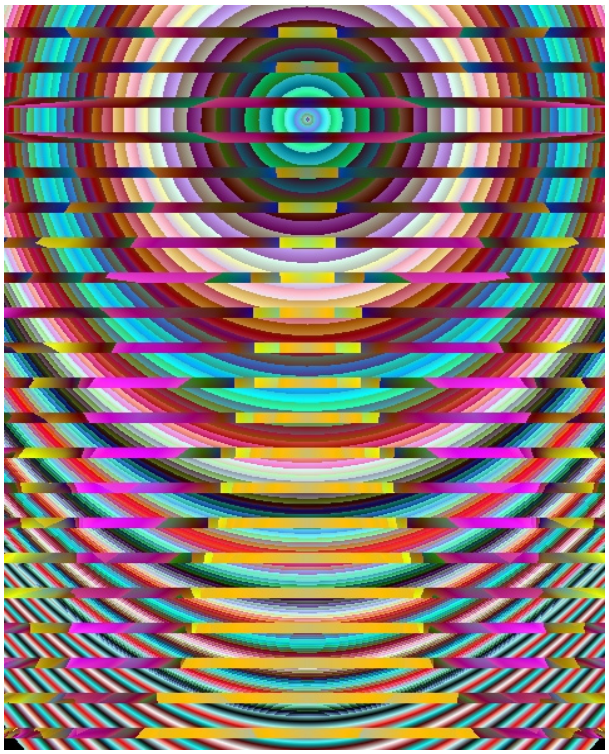
[46] Economists Mathematical Manual, Knut Sydstaeter, Arne Strom and Peter Berc, Springer 2005.
[47] http://www.r-project.org/

model you have built. These tools are for the most part explained in the literature much of which has been referred here and is supported in R objects.

Multivariate Linear regression (MLR) is the general family name of the type of regression models required to support Stress Testing using the Factor Model technique. MLR would suffice for a basic understanding of the statistical relationships between factors and default. GLMM is a Generalized Linear Mixed Model. To model the idiosyncratic part of the explanation of a stressed PD you do need a GLMM to do thorough Stress Testing of Credit Risk. The arguments of the GLMM function are presented below. GLMM is a generalization of MLR and therefore slightly more complex. The implementation of factors as operands in both methods is analogous in a precise way.

In summary the workflow for Credit Risk Economic Capital modeling consists of the following key elements in a practical regression modeling sense; A Data layer consisting of the bank's own internal data, data from rating agencies, macroeconomic and market data; Graphical analysis, Multivariate diffusion models in continuous time, Vasicek and CIR state-space models for long-run short and long maturities, Bayesian VAR forecasting models for short-run interest shocks prediction, Simulation and scenario-based stress testing, Statistical generation of hypothetical stress scenarios, Monte Carlo and conditional estimation approaches to stress testing and thus Economic capital estimates conditional on stress test scenarios.

The R language and the packages of software objects developed in an open source, shared manner by the R user community include support for all of the mathematical methods, required in Economic Capital modeling; including Copula, Bayesian methods, Monte Carlo simulation, etc. Moreover the time-series objects available in the R language are much more powerful and easy use than in nearly every other of the development languages commonly used for financial modeling and simulation. Two specific R package sets of particular interest in economic capital terms are RMetrics[48], and the equally impressive PerformanceAnalytics[49] package, a very comprehensive and widely used package for performance and risk analysis in econometrics. Many of the PerformanceAnalytics methods can be adapted easily to the underlying toolset required to model economic capital.



[48] http://www.rmetrics.org/
[49] http://braverock.com/brian/R/PerformanceAnalytics/html/PerformanceAnalytics-package.html

6. Predictive Analytics and Economic Capital

We are all familiar with the term 'Business Intelligence' (BI). BI is arguably the single most significant aspect of Information Technology (IT) investment in Banking and Financial Services globally right now. The BI product market has intensely consolidated in 2008, reflecting the importance of BI to financial and non-financial users today.

Economic Capital is a product of a forecasting process. This means that in BI terms or in terms of the technology stack required to implement economic capital models, the software tools which robustly support such prediction modeling are part of what is called "3rd generation" BI tools or 'Predictive Analytic' software. A crucial aspect of 'Economic Capital' as a reporting number is common with the reports which '1st generation' BI developments were designed to produce: key summary numbers for the most senior executives in the organization characterized by issues of sensitivity.

In a recent interview[50], Patrick Walsh of Intel Capital stated "*We expect that real-time access to large and growing data sets, coupled with the increasingly complex computations needed for modeling will drive all aspects of platform evolution*" going forward, he continued "*BI will continue to involve more and more math on ever-larger data sets, with users demanding accurate predictive modeling and immersive, collaborative, visualizations of results. On the analytics front, we believe we'll continue to see end user demand for improved predictions based on large-scale data sets. Traditional reporting is necessary, but, in the absence of predictive modeling and analysis, it can result in information overload and decision bottlenecks. Analytics leads us towards applications that use predictive models effectively, rather than ones that react to reported data.*"

Clearly Economic Capital requires a Financial Predictive Analytic toolset to support the process of modeling this critical metric in banking going forward. Financial Predictive Analytics have a long pedigree in the discipline of Econometrics. Through the Basel II implementation period in Europe (roughly 2003-2007) there remained resistance to the implementation of robust Financial Predictive Analytic toolsets in banking and this process was not enforced by supervisors, as has been argued above. In 2005 the Bank for International Settlements published a seminal working paper[51], looking at sidebar aspects of the Basel II deployments which were occurring around the world at that time.

In that paper, the authors encouraged the development of risk management systems; "*Risk measurement technology has made enormous strides over the last 30 years or so. The ability to price options represented a major breakthrough (Black and Scholes (1973)). The application of conceptual breakthroughs to the day-to-day risk management of firms is challenging the capital investments in the IT systems required to measure risk. The limitations in information technology that lie at the origin of the existing gaps in risk management systems have constrained both the elaboration of the corresponding concepts and their practical implementation. Implementation is more closely associated with the actual cost of elaborating the information, as*

[50] Open Source BI: The Venture Capital Perspective - Intel Capital Does the Math, Steve Miller
DM Review Online, April 10, 2008

[51] The ideal information set - a taxonomy, BIS Working Papers, No 180; by Claudio Borio and Kostas Tsatsaronis September 2005

determined by the cost of computational capacity. There are still significant advances to be made in the aggregation of risks across apparently disparate categories, such as credit and liquidity risk."

The BIS is arguing that it is the development of analytic techniques in a feedback loop with advancing technology, particularly technological innovation which reduces the total cost of computing power in the manner of Moore's Law which entails that more stringent supervision of the banks can be considered and also that the banks are expected as a consequence of this to become better at risk management. This is consistent with the development of Financial Predictive Analytics (FPA) (or 'econometrics') last century.

6.1 Financial Predictive Analytic Software Development

Over the last 50 years, econometric software has developed from complicated sets of computer-specific instructions into widespread easy-to-use software packages and programming languages[52]. Commercial econometric software in the US started in Boston at the Massachusetts Institute of Technology (MIT), more specifically at the Center for Computational Research in Economics and Management Science in the 1970s. The software was built to be shared with the FED and other universities. Through the 60s and 70s various statistical modeling packages for economics were built particularly at Wharton, the University of Michigan and the University of Chicago. At Princeton the focus was on development of econometric models in FORTRAN in the 70s and 80s; the use of FORTRAN is much declining now but Chris Sims[53], now at Princeton, who developed the VAR methodology and was at the forefront of RE in the 1970s now makes all his models freely available in R.

6.2 The R Language

More and more econometricians are switching to the freely-available statistical system R. Free procedure libraries are available for R, http://www.r-project.org, an Open Source statistical system which was initiated by statisticians Ross Ihaka and Robert Gentleman[54]. A comprehensive package for financial engineering (in R), is available at http://www.rmetrics.org, which encompasses many econometric time series functions, it has recently been built by Diethelm Wurtz at the ETH in Zurich.

The R language, whilst becoming the lingua franca of statistical computing, and the bleeding edge of new model development, remains an open source project. Like notable open source projects before it, the backing of a commercial vendor to package the language for commercial use, and - in the case of R - to enable high performance support for production environments, is critical to the adoption of R in mission critical banking environments.

REvolution Computing was set up to address exactly these issues by providing a high performance commercially supported distribution of R.

[52] Econometric software development: past, present and future, Marius Ooms, Department of Econometrics, Vrije Universiteit Amsterdam, Jurgen A. Doornik Nuffield College, Oxford.

[53] "Business Cycle Modeling Without Pretending to Have Too Much a Priori Economic Theory," (Thomas J. Sargent with C.A. Sims) in: New Methods in Business Cycle Research: Federal Reserve Bank of Minneapolis, 1977.

[54] R: yet another econometric programming environment, Journal of Applied Econometrics 14 Cribari-Neto and Zarkos (1999).

7. REvolution Computing

Working closely with the open source R Community, and drawing on the resources of Intel Capital, REvolution Computing provides commercial software extensions and support for open source R. Anyone looking for "on demand analytics" featuring 100% R and more, backed with full service and support, including REvolution clients in investment banking and enterprise risk management, can benefit from REvolution Computing's products: RPRo™ and ParallelR™

Whether deploying RPRo™ or ParallelR™ for predictive modeling in a development or in a full production environment, REvolution's clients benefit from a "quantitative engine" capable of producing answers from large sets of data built right into enterprise data management systems and workflows.

7.1 The R project and REvolution Computing

REvolution Computing[55] is the leading commercial provider of software and support for the statistical computing language known as "R." REvolution's products enable statisticians, scientists and others to derive meaning from large sets of mission-critical data in record time, and to create predictive models that help to answer their most difficult questions.

The syntax of R is simple enough to allow learning by trial and error in a few hours. The bookstore on the REvolution Computing website is a great place to select a guide to learning R for your requirement[56]. R is in essence the programming interface between your ideas of the macroeconomic factor stress test and thus quantification of risk economic capital and the analysis using technology (software and hardware) of the data required to test your propositions and thence estimate capital. R is free, it is "open source"[57]. The R Project is an ongoing initiative by the open source community, involving an international ecosystem of academics, statisticians, data miners, and others committed to the advancement of statistical computing. Through the contributions of this community, innovations in methodology can be rapidly incorporated and disseminated. R users can participate in this vibrant statistical research community by using, creating, and contributing extensions known as "packages." REvolution Computing provide commercial support, validation and scalability around R as a platform in order to make it a viable choice for banks and other commercial organizations as a production system, addressing open source and scalability issues.

[55] http://www.revolution-computing.com

[56] http://www.revolution-computing.com
[57] http://www.opensource.org/

The basic elements of the R language are the objects. An R object can be of many types, including vector, matrix, time series or graphics. An R object is mostly characterized by a mode which describes its contents and a class which describes its structure. R is primarily a statistical language; R has become the de facto standard for statistical computing for quantitative finance in academia the world over. It is increasingly adopted as a useful technology within commercial organizations, in particular Investment Banks. The key strength of R is the combination of its object oriented nature, its open source availability and it being the de facto standard. The advantage of this is that it is highly likely that you may never actually need to develop an object to do what you need from scratch; you can find libraries of financial objects already developed on academic sites all over the world or join a community at your workplace. All you need to so is the analytical thinking necessary to define the modeling you need and ensure your data and its parameters are correct, then select from the 'open source' the object you require and optimize it for your implementation.

There is an enormous take up of the R language in general, which is almost universal in academic data analysis disciplines, with evidence of usage in all areas of financial analytics and an impressive, publicly accessible body of work from academia in computational finance.

Typically, however, unsupported installations of R in institutional finance can suffer from being limited to guru users and can place an unnecessary burden on IT and other expensive in-house resources such as quantitative analysts in model maintenance and systems support.

Furthermore, use of the R language in such environments is usually confined to prototyping models only, with the expensive overhead entailed of redevelopment of these models into production development environments.

The mission of REvolution Computing is to enable widespread use of the R language through its supported, optimized distribution of RPro, and to enable interoperability and scalability through to parallel programming with ParallelR.

REvolution Computing have Predictive Analytic product architectures for enterprise production deployment within the data management stack through supported modules enabling high data throughput.

The REvolution products also ensure web services compatibility, and components required for scalability and integration as a production analytics engine for financial risk management.

REvolution Computing has tier 1 investment banks and finance houses amongst its customers for such applications.

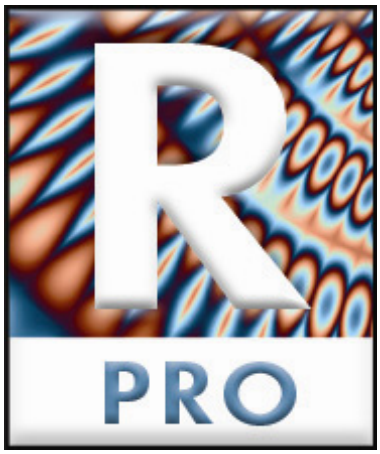
An exposition of the detailed components of REvolution Computing's Predictive Analytic architecture will be available soon in a companion White Paper to this one but this is not the specific locus of such a detailed presentation.

7.2 RPro

RPro brings R users an enterprise-ready statistical analysis environment. RPro is an enterprise distribution of the R language packaged for a wide variety of enterprise operating environments that includes REvolution's high-performance numeric libraries, code validation and commercial support.

Bringing the power of the open source R language; RPro provides a validated R as pre-compiled binaries and an installation program, getting R up and running quickly and painlessly.

- REvolution's high performance linear algebra libraries provide significant performance enhancements to many R analyses without requiring any script modifications.
- Matrix and vector operations can run as much as 10 times faster (depending on the analysis type and problem size).
- With RPro, many key R routines automatically execute in parallel on multiprocessor computers.
- REvolution provides all released bug fixes and patches to R to insure RPro installations are up-to-date.



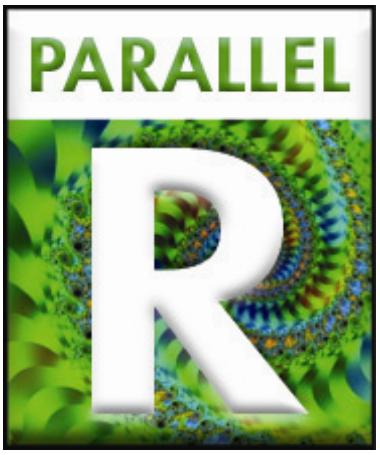
The RPro suite of products:

- Harnesses the statistical modeling language of choice for the world's top research statisticians in finance and elsewhere
- Supports cutting edge algorithms for data analysis, mining, regression and classification
- There are hundreds of active developers including world's leading statisticians and risk modeling experts
- Future-proof long-term code path leveraging open source community, backed by Revolution, who are backed by Intel Capital
- Are Audit-ready for IT and regulatory authorities.
- No more black box for risk.

The RPro Quantitative Engine is:

- Enterprise SOA integration and deployment ready
- Lightweight, flexible architecture
- Optimized for computationally intensive, large-scale analyses
- Embeds ParallelR, includes highly-tuned numeric libraries
- Embed analyses directly in XML documents and reporting
- Adjust and tune risk models, run scenario analysis.
- No more black box for risk.

7.3 ParallelR



REvolution's ParallelR™ enables R users to complete their statistical analyses much more rapidly by taking full advantage of multiprocessor systems and network computers, usually without writing a line of parallel code.

Runs parallel R analyses on any parallel computing resource, from a dual processor laptop to a network cluster to an intercontinental grid.

- Automatic parallel R execution via ready-to-run parallel implementations of key R routines which seamlessly replace the serial versions.
- R scripts and general R routines are easily run in parallel using ParallelR's simple wrapper functions.
- The NetWorkSpaces coordination framework underlying these parallel capabilities is also accessible for low-level parallel programming in R.
- Based on proven parallelization technology arising from REvolution's 20+ years of parallel computing expertise.
- Includes advanced parallel execution control capabilities, including built-in fault tolerance with respect to node failures, load balancing across heterogeneous CPU resources, and transparent integration with enterprise scheduling systems.
- Incorporates REvolution's validated version of R, along with its high performance matrix and vector libraries and easy-to-install binaries.

7.4 REvolution Computing and Economic Capital

The Financial Predictive Analytic process is particularly sensitive for the bank. When modeling economic capital, the analyst should be conscious that sensitive data is being deployed particularly in internal time series of loss quantities or default rates or profit figures. When these are enriched with macroeconomic drivers to predict risk capital, this further intensifies the sensitivity of the data being created; "the news" which regression results produce. There are four aspects to the results of this process which make it extremely sensitive;

- Criticality: Pillar 2 stress tests produce 'contra-factual' "forward-looking statements"; their outcome will drive economic capital allocation & risk strategy of the Bank as a whole.

- Materiality: Material errors in Pillar 2 inputs or outputs could have adverse impacts on Bank strategy thus a 'robust process' & 'software architecture integrity' is paramount.

- Confidentiality: Pillar 2 assumptions & stress test outcomes are market sensitive and could be used by competitors if leaked, they must be secure.

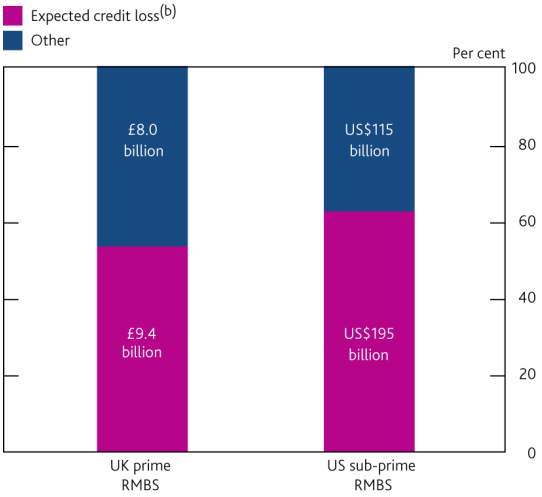
- Conflict: If the Bank is assessing economic capital at the Business Unit (BU) level, based on economic capital in an asset class (i.e. assuming a close to 1:1 relationship between Asset Class and BU) then that risk capital must be subtracted from the Gross Profit of that BU thus lowering any profit related bonus paid to personnel in that BU.

It is in this sense that the mission of REvolution Computing is such a crucial aspect of the solution to economic capital modeling requirements today. As Patrick Walsh of Intel Capital put this point in the interview referred above; "*R is widely used by statisticians in many areas, but is typically not deployed for commercial statistical work because it's not supported or certified for regulated environments such as Pharmaceutical and Financial Services. REvolution Computing was formed to address the need in the marketplace for a certified, supported version of R, as well as a high-capability parallel-computing solution for the most demanding R users.*"

8. Conclusion

One of the primary causes of the Credit Crunch (CC) was the failure to comprehensively compute risk capital in structured instruments. It is clear however that these products cannot be abandoned entirely since that would send the banking industry and the wider economy back to a prehistoric wilderness.

We are systemically dependent upon innovations in financial technology now. Computation of risk capital in an holistic and comprehensive manner is the key to recovery from this crisis episode.



Comparison of Mark to Market Losses on UK prime and US sub prime securities (Bank of England FSR Oct08)

The CC revealed through market failure how crucial it was for participants to behave with the type of blind expertise (what we sometimes, today call 'professionalism') expected by Adam Smith of his pin maker or butcher, from "The Wealth of Nations" is "*It is not from the benevolence of the Butcher, the Brewer or the baker that we expect our dinner but from their regard to their own interest*"[58]. The CC further revealed as Smith indicated the consequences if a market participant attempts to game the system and break the rules forcing supervisory authorities to react and increase the force of regulatory and supervisory oversight.

The necessity is to re-start the market in structured products which can only be done if higher standards of risk quantification and disclosure (transparency) are deployed as soon as possible.

Software vendors like REvolution Computing (and its partners on the data management side of the solution architecture equation) have thought harder about this challenge and through 2008 particularly have brought to bear more high performance components of their product ranges in appropriate configurations to really solve this challenge.

It has taken a crisis to bring the banks and their supervisors closer together, sharing a common objective and that at the very least is one good thing to evolve from this crisis. Supervisors and senior Bankers are at least on adjacent pages in 2008 and look to remain there as the requirements of what will be by any other name a Basel 3 framework are worked out and agreed upon in the coming months.

[58] The Invisible Hand, Adam Smith, Great Ideas, Penguin Books, 2008.

9. Acknowledgments

SPONSOR

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REVIEW - REvolution

Colin Magee, Bryan Lewis, David Smith and Martin Schultz

REVIEW - UL

Dario Ciraki, Fiona Lunny, Robert McDowell, Alistair Menzies Anderson, Peter Lindmark and Gareth Reynolds

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UL assists our clients in the Development of integrated Data Management and Predictive Analytic platforms for Financial Predictive Analytics.

Integration of standard BI toolsets with High Performance Computing environments for Predictive Analytics is our area of expertise. We also understand further integration of General Ledger functions with Risk Management data warehouses. We support our client to move towards Target Operating Models predicated upon the integration of Analytics for Credit, Market and Liquidity Risk.

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