Integrated capital adequacy principles for institutional, asset and economic risk factor stress testing

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Abstract

It has become fashionable to blame global banking failures on the unfettered growth in 'hard to value and hard to sell' level 3 banking assets. With the majority of large UK and many US banks collapsing or forced to raise capital over the 2007-9 period, blaming bankers may be satisfying but is patently insufficient. Regulators, Basel II Pillar 2 and IFRS 7 guidelines also deserve justifiable criticism for failures in systemic oversight. Distinguishing macro from micro prudential shortfalls while simultaneously integrating their risk effects across asset classes and economic capital is central to understanding the banking crisis.

Asset growth has taken place in a regulatory environment lacking in at least two critical prudential respects. Firstly, overall (macro) leverage of systemically relevant institutions is not modelled, nor is there a requirement to model leverage at an institutional (micro) level. Secondly, there is no institutional regulatory guidance as to the most robust methodology for linking systemic asset stresses to economic capital. We propose the Pillar 2 inclusion of a 'integrated institutional economic capital risk framework', arguing that macro prudential oversight should be viewed by regulators as a necessary precondition for institutional (micro) stability.

A 'Euro bank' balance sheet is used to compare the capital effects of modular and scenario-based methodologies for dealing with institutional risks, both are allowable by Basel II regulations. The widespread use by practitioners of the modular covariance approach to Pillar 2 stress testing is not fit for purpose, it is methodologically flawed and is open to management "tweaking" and manipulation, underestimating capital by about 20 percent. By contrast, the application of integrated calibrated economic scenario principles increases our quantitative and qualitative understanding of institutional capital calculations and risk path dependencies. We leave as open the question as to whether the 'regulatory will' exists to distinguish macro from micro prudential responsibility.

I Introduction

The Economic Capital (EC) concept is clear; it is the capital charge that a financial institution requires in order to operate as a solvent concern at a specified confidence level for a given time horizon (McNeil et al. 2008). In the banking sector, Pillar 2 of Basel II was specifically intended to focus on the regulatory review and internal risk assessment, examining the extent to which risk management best practices are embedded into bank decision making. Moreover, banking institutions are required by Pillar 3 to disclose assets at fair value, and present EC and stress test results to external stakeholders. A fundamental problem, however, is that Pillar 2 EC valuation and stress tests, IFRS 7 asset fair value reporting and Pillar 3 disclosure requirements all exist without clear regulatory guidance as to the principles that complex institutional and, more worryingly, systemic regulatory capital models should employ to integrate risk effects across asset classes.

Broadly, EC encapsulates the concept of measuring all kinds of risks across a financial institution by having regard to the interaction of plausible macroeconomic economic risk scenarios with institutional balance sheet asset exposures. In reviewing the current state of financial regulation Brunnermeier et al. (2009) make it clear that "macro-economic analysis and insight has, in the past, been insufficiently applied to the design of financial regulation...the crisis which began in the US sub-prime mortgage market in early 2007 and then spread broadly and deeply was not the first banking crisis. It was closer to the 100th....". The problem of course is that if events with widespread and severe economic and social consequences keep revisiting, the onus is surely on regulatory authorities to accept responsibility for systemic risk and change the prudential oversight structure.

When regulatory mechanisms fail to mitigate boom/bust cycles, simply reinforcing their basic structure Brunnermeier et al. (2009) suggest is not likely to be a successful strategy for the future. The unfortunate effects of a regulatory framework that ignores the need to integrate risk factor effects on asset values (in deriving institutional capital) have become evident since September 2007. Market hubris has devastated sector economic capital over the past 24 months highlighting at last four categories of shortcomings in the Basel II risk weighted approach, namely: the calculation of asset loss distributions in response to multivariate exogenous risk factors, the treatment of dependency of the correlation parameter, a lack of guidance as to the treatment of diversification, and finally, how to best interpret confidence levels for asset loss distributions by linking economic capital and risk factors.

The lack of a principles based methodology is not limited to Basel II, it also affects the IFRS fair value accounting framework. It has to be remembered that every bank failure would have had audited financial statements, with asset fair values calculated in detail in the period preceding failure. Disclosure requirements have made it clear that each banking entity should group financial instruments into classes of similar instruments by asset class [IFRS 7.6]. The main categories of disclosures for financial instruments are also required to cover information about the nature and extent of risks; stipulating separate disclosure of fair value and profit and losses for trading and held-to-maturity investments [IFRS 7.8]. Again, no consistent guidance is provided as to the methodological principles that should underpin the computation and stress testing of accounting balance sheet fair asset values.

Despite demanding the computation of credit and market risk, accounting practitioners are also silent as to how isolate the pervasive effects of risk by asset class. The articulation of asset loss distributions with capital is also not dealt with by IFRS 7. In summing the difficulties facing practitioners the IASB Expert Advisory Panel (2008) concludes that when measuring asset fair value using a valuation technique....'An entity exercises judgement when making these decisions. As a result of applying judgement, two entities might arrive at different estimates of the fair value of the same instrument even though both still meet the objective of fair value measurement. This could be the case when, even if the two entities use the same model, (since) ... unobservable inputs used in the model (may be) different.'

A central question has to be asked as to what institutional risk methods were being used by bankers before, during and (perhaps) even after the crisis,i.e. how risk effects were stressed across asset classes and then integrated into a coherent capital framework. Much of the answer to the current state of the financial sector can be found in a comprehensive pre-crisis survey by the International Financial Risk Institute (IFRI Foundation and CRO Forum (2007)). The survey findings reveal that prior to the 2007-9 crisis, standalone stress tests were conducted on asset classes, an then integrated using simple modular asset correlation. This approach was favoured by 75 percent of leading global institutions (all of whom expressed satisfaction with their approach).

In fact McNeil et al. (2008) characterise the correlation method as a modular asset based calculation approach widely used for its simplicity. Capital requirements are estimated on a per asset class level by using a risk measure, for example Value-at-Risk (VaR). The level of EC diversification is then simplistically computed by using a matrix overlay capturing correlation coefficients between asset types and industry sectors. Individual capital charges are calculated for each book, name and sector within the portfolio, and where dependence across business unit categories is observable, a resultant downward adjustment to the total capital charge may be applied.

It has become clear that the modular approach is not fit for purpose and that the effects of asset valuation risks on EC is a soberingly important methodological issue that requires urgent global regulatory guidance. Financial Stability Forum (2008) supervisors have acknowledged the need for Pillar 2 principles to strengthen banks' risk management practices, to sharpen banks' control of tail risks and mitigate the build-up of excessive exposures and risk concentrations. Modular asset class correlation parameters are hard to justify, subject to sampling error, and moreover, historic correlations typically show large variation over time. What modular overlooks is that judgment decisions also need to be made about systemic leverage effects on market and credit risk, the calibration of correlations between the risk vectors of interest rates, equities, credit, property and inflation. These effects underpin asset pricing, and make it necessary to decide whether calibrations are conditional based on current market conditions, or long-term unconditional, based on long run future expectations.

A framework for distinguishing macro from micro prudential shortfalls while simultaneously integrating their effects across asset classes and economic capital is central to understanding the banking crisis. Asset growth has, we suggest, taken place in a regulatory environment fundamentally lacking in at least two critical prudential respects. Firstly, systemic (macro) overall leverage of systemically relevant institutions is not modelled, nor is there a requirement to model leverage at an institutional (micro) level. Secondly, there is no institutional regulatory guidance as to the most robust methodology for linking systemic asset stresses to economic capital.

We focus on the second of these methodological gaps, proposing the Pillar 2 inclusion of a 'integrated economic capital risk framework'. Systemic macro prudential oversight is left as an open question but should be viewed as a necessary precondition for institutional (micro) stability.

II The Institutional Effects of Gaps in Macro Prudential Guidelines

Aggressive asset origination banking models saw unprecedented balance sheet growth in leveraged assets, often in illiquid markets. Few banks experienced more spectacular growth than the Royal Bank of Scotland (RBS). September 2007 saw an acquisitive RBS led consortium succeed in its bid for the Dutch banking giant ABN Amro. The effects of ABN's assets on the bidding consortium's economic capital structures were clearly an institutional issue requiring micro stress testing. What is often glossed over in headlines dealing with the crisis is that no individual institution could have known the overall level of systemic gearing that the newly acquired ABN assets were exposed to. This lack of systemic leverage feedback is a central gap in managing global financial regulation.

As Brunnermeier et al. (2009) note, 'a critical component of macro-prudential regulation must be to act as a countervailing force to the natural decline in measured risks in a boom and the subsequent rise in measured risks in the subsequent collapse. This countervailing force has to be as much rule based as possible.' Supervisors they suggest, have plenty of discretion, but their ability to utilize it is limited by the general short-sighted desire to prolong booms, a desire expressed by the Gordon Brown addressing the Confederation of Business Industry as far back as 1997. The problem not widely commented on is that when regulators ignore the possibility of downturns it is extremely difficult for institutional asset classes to be adequately stressed with respect to these unregulated systemic risks.

The subsequent failure of two out of three of the consortium in 2008 has resulted in the Dutch government nationalising the ABN assets previously acquired by Fortis and the UK government taking up 70 percent of the failed bank RBS. The net result of institutional and regulatory gaps in applying integrated risk management principles is that the now fractured ABN group is owned by RFS Holdings, a consortium of Royal Bank of Scotland Group, the Government of the Netherlands, and Banco Santander. The effects of systemic oversight continue to be widely felt in the sector. In separate high profile failures, the banking and insurance group HBOS (largely due to illiquid exposures to 'hard to value assets' in the property sector) has become a wholly owned subsidiary of the Lloyds Banking Group (which, after credit guarantees are included, has itself has become 77% government owned). Smaller banks have also been affected; Northern Rock, an acquisitive British mortgage lender, has been under government ownership since 2008. In the same year Bradford & Bingley was split in two, a deposits and branch network, which was sold to the Spanish bank Grupo Santander, and their mortgage business, which was nationalised.

We argue that lessons have still not been fully learned. A lack of coherent international economic scenario stress testing principles means that hard to value asset acquisitions continue to affect global capital ratios. In the USA, Lehman Brothers filed for Chapter 11 bankruptcy protection on September 15, 2008. The following day, Barclays announced its agreement to purchase Lehman's North American investment-banking and trading divisions. Barclays is now struggling to absorb this stake and is seeking to raise new capital, as is the banking behemoth HSBC.

A Systemic Risk vs Individual Bank Exposures

Chastising individual bankers may satisfy the popular press and assuage the conscience of regulators; but is patently insufficient. Regulatory management of systemic risk is a necessary precondition for individual bank capital management. In fact Brunnermeier et al. (2009) propose that regulation has been excessively focussed on seeking to improve the behaviour and risk management practices of individual banks, too micro-prudential. They assert that there is little justification for this approach in the theory of regulation. Their criticism is that regulation has been too little focussed on wider systemic issues, by being insufficiently macro-prudential in areas where regulators should have locus.

At the institutional level there is also a methodological paucity as regards the definition of key economic capital risk building blocks. Area requiring urgent regulatory attention range from confidence interval definitions, clarifying time periods over which capital adequacy is required to be assessed, the need for economic scenario models, levels of asset stresses, institutional leverage limits, economic stress calibrations and their quantitative and qualitative interpretation and the treatment of the linkage between asset loss distribution projections and economic capital.

The suggestion by Brunnermeier et al. (2009) is that by consciously seeking to make prudential capital move in accord with banks' own models of institutional economic capital, regulation did too little to restrain systemic bank expansion in the upswing, nor has it been able to provide any support against the current implosion of the system as a whole. that There are four present candidates Brunnermeier et al. (2009) suggest, who can rectify the malaise. The first candidate is the banks themselves, second, could be private insurance. Third, the Central Bank could become the market maker of last resort when markets become illiquid by taking bad assets off the hands of the banks. The fourth candidate is the Government (Treasury) which could provide public sector insurance against credit counter-party risk. This is now being done on a wide scale in the UK and the USA, and guarantees mortgage-based securities against risk, effectively transforming these previously toxic assets into public sector debt.

Importantly however, (Brunnermeier et al. 2009) point out that solvency is not exogenous to liquidity. When there is a generalised liquidity problem attempts to deal with it will likely lead to declines in asset values, creating a solvency problem, even where none existed before. In short, there is an amplifying process (liquidity spirals) leading banks to make more sales in the interests of deleveraging, which further drives down asset prices and balance sheet net worth. Brunnermeier et al. (2009) suggest it is this internal, self-amplifying dynamic that has lain at the root of both the recent, and virtually all prior, financial crises. They suggest that financial crises are predominantly caused by market dynamics, not just by external shocks, though such shocks, e.g. it is suggested the downturn in the US housing market in 2006, the quadrupling of oil prices in 1973/74, the Stock Market collapse in 1929, may well have been triggers. The problem of course is that when the trigger or risk is endogenous to the financial system all institutions are affected.

One immediate implication of the existing framework is to conclude that the standard format of banking stress tests is fundamentally insufficient. Current stress tests review the effect on each bank's profits and capital of (historically-based) exogenous shock. This is usually performed at time 0 (now) by calculating Greeks based on asset responses to a standalone shock in, say, interest rates, property or equity. But, if Brunnermeier et al. (2009) are correct financial crises are primarily caused by endogenous risk, whereby the banks' reactions to such a trigger sets off an amplifying spiral via declines in asset prices and reductions in credit expansion, stress tests, focussing only on exogenous risk, will miss out on the (more important) second round effects.

We constrain our focus to the banks themselves and the need to model in an integrated manner exogenous effects of market risk. The integrated approach to modelling capital works well but current market conditions have shown that capital requirements really are conditional on the control of systemic 'feedback' loops that control the overall amount of leverage in the overall financial system, see Anderson et al. (2008).

In the absence of regulatory management of systemic risk, real world calibration assumptions would need to cater for condition of financial frisson, making market estimation and model calibration extremely difficult. Put another way - if banks needed to calibrate to market fission, asset value ranges at $(t+1)$ and the capital requirements would be extremely difficult. We use a coherent economic capital framework as applied to a sample of European banks to demonstrate that losses are based on insufficient stress testing of 2007 asset holdings against calibrated real world economic conditions that were actually observable in the second half of 2007. By no measure can the current regulatory framework of Basel II reasonably claim to have insulated the sector against capital losses.

B Distinguishing Macro from Micro Prudential Principles

Systemic oversight is a necessary precondition for institutional stability - and not as regulators would have us believe the other way around. Current FSA regulations have ignored systemic or macro risks and attempted to push the responsibility for managing risk to the institutional (micro) level. The methodological problem with this approach, as Brunnermeier et al. (2009) note, is that micro prudential regulation is only concerned with factors that affect the stability of individual institutions. By contrast, macro-prudential regulation concerns itself with factors that affect the stability of the financial system as a whole. As they, and we, attempt to show, the success of regulation as applied to an individual financial institution depends crucially on how 'systemic' institutional asset exposures are. It needs to be acknowledged that if there is no systemic oversight then there is very little individual institutions can do to immunise themselves or their assets against systemic failure (under these conditions risk becomes pervasive and endogenous to the banking system).

If, however, macro prudential oversight exists institutions are able to justifiably model micro risk and treat systemic risk factors as exogenous. In this work we concern ourselves with the integration of exogenous economic risks at the institutional level. We address the methodological shortfall of Basel II and IFRS 7 by identifying integrated economic capital and stress testing principles that need to underpin fair asset valuation and Basel II Pillar 2 EC.

Whether we look at overall EC or just market and credit risk, dependence modelling is an important challenge, particularly in extreme financial market conditions. Aggregate risk capital depends on changes in the valuation of asset positions which, in turn, are driven by high-dimensional macro vectors of defined risk factors which are calibrated to real world economic conditions. This concept is important because capital held to support asset positions should be computed for all business units and only be reduced by diversification due to imperfect correlation between macro risk drivers. Simply put, it may be possible for banks to limit risks by not holding certain asset classes, but it is far more difficult to avoid the pervasive systemic effects of risk factors such as interest, inflation, credit, equity and property volatilities. These macro factors, together with overall levels of leverage are strongly systematic and are the responsibility of regulatory authorities.

C Implementing modular and fully integrated approaches to EC

To provide empirical insights into the differing effects of implementing both modular and fully integrated approaches to capital, we construct a composite 2006 balance sheet of a representative European bank. Balance sheets for 51 European banks for the year 2006 are selected to provide a cross section assessment of capital adequacy prior to the credit crisis. Summary statistics presented in the Fifth Quantitative Impact Study, (QIS5, Basel Comittee 2006) inform our split of aggregate asset positions by exposure type and credit class, ensuring consistency with asset profiles held by European banks.

Using our integrated approach, economic capital projections of asset value responses to calibrated real world economic scenarios are shown to be path dependent. For EC calculation and management actions, we are naturally concerned with the extreme events and the composition and tail-distributions. In our integrated modelling framework, we define stochastic dynamics for short-term interest rate behaviour, foreign exchange rates and assets within equity and bond markets. Due to model complexity in the fully integrated approach, Monte Carlo simulation is used throughout our study. This approach allows us to capture (fat) tail risk dependencies which are understated in a deterministic modular covariance framework.

Despite using a method which underestimates tail dependence, the majority of the banks in the survey felt comfortable with their modelling of economic capital stresses in 2006/07. This is a central methodological problem facing the sector. A modular approach with correlations calibrated to normal market conditions will only give reliable estimates under limited market conditions. A modelling framework using standard correlation assumptions is likely to understate the 'true' extent or dependence correlation under extreme events.Tail risk composition of asset and risk factor distributions is not the subject of this paper, but is undertaken in depth for the same sample of 51 banks by Kirchner et al. (2009). We find that when compared to EC calculations under the fully integrated economic capital model proposed in this paper, the extent of systematic undercapitalization, based on pre-credit crisis calibration may actually have been as much as 18 percent.

Our EC results are consistent with current market events where the effects of risky asset holdings on EC has been savage. Since September 2007, of the 51 banks included in our Eurobank sample, all have experienced dramatic capital reductions. Many institutions have been recapitalized, partially nationalized, nationalized and some like Northern Rock and Lehman Brothers even declared insolvent. Five years after Basel II principles were promulgated it seems necessary and timely to identify the regulatory principles that should underpin an EC framework.

Regulators such as the FSA (Financial Services Authority 2007) have shown strong commitment to move towards principles based regulation and favour constructive engagement at the senior level of the company. The FSA approach is echoed by **?** who require that National supervisors strengthen their assessments of the robustness of banks' stress testing practices and capital cushions over the cycle [p18]. Supervisors are now required to ensure that firms appropriately assess their own capital adequacy based on the risks that may emerge over the full credit cycle, taking account of current and future economic and credit conditions, and the uncertainty that attaches to valuations.

The widespread use of the modular asset covariance approach to capital stress testing allows the use of a method open to management "tweaking" and manipulation. Static asset correlations are shown to underestimate tail risk dependencies and capital effects under stressed economic conditions. By contrast, the application of integrated calibrated economic scenario principles increases our understanding of capital calculation, stress tests, risk path dependency - enabling effective risk management.

The modular asset covariance approach is simply not fit for purpose. For a full methodological proof for preferring integrated economic capital principles over modular see McNeil et al. (2008) who make the case for integrating asset valuation and economic scenario interaction. Integrated economic capital principles, as opposed to difficult to justify static asset correlations, should underpin the calculation of institutional EC in Pillar 2.

D Deriving an average European bank

Our EC results for an individual bank are consistent with 2007/8 market events where the effects of risky asset holdings on EC has been savage. Since September 2007, of the 51 banks included in our Eurobank sample, all have experienced dramatic capital reductions. Figure 1 illustrates the drop in market capitalization for a sub-sample of major European banks for the period Q2 2007 to January 20th 2009. Major European banks started 2009 on average at 26.15% of their 2007 market capitalization. The most dramatic falls were experienced by RBS with a fall of 96.16% and Barclays 91.87%.

To illustrate asset and risk factor interaction, a representative sample of European banks is used to derive a "typical European bank". A typical European bank with typical exposure across a variety of assets, hereafter called EuroBank, is constructed based on the arithmetic average of balance sheets of selected 51 European banks. We use attributes from the Fifth Quantitative Impact Study (Basel Comittee 2006) to determine individual asset compositions for EuroBank. Risk measures VaR at 99% and Expected Shortfall (ES) at 99% and 95% are used to compute Economic Capital for the constructed bank. The reason we specifically select European banks as at 2006 is that Europe offers a fertile ground for investigating the basic effects of diversification on EC in the context of implementing Basel II Pillar 2 regulations. Our data enables a pre "credit crunch" view of sector capital adequacy.

We reformulate individual bank balance sheets into a format that can be utilized to compare EC approaches. Thomson Worldscope database is used to collect an initial sample of 90 banks whose primary listings are the six largest banking nations in Europe: the United Kingdom (GBR), France (FRA), Germany (GER), Italy (ITA), Spain (ESP) and the Netherlands (NED). We exclude small banks (defined as banks with less than £500 million in total assets) and banks not engaged in either investment banking, deposit-taking or loan-making. Institutions classified as Islamic banks are also excluded as their asset accounting information is not consistent with the rest of the sample. After exclusions the sample set is reduced to 51 banks, with the majority of their assets regulated in the UK and the Euro-zone, and therefore subject to Basel

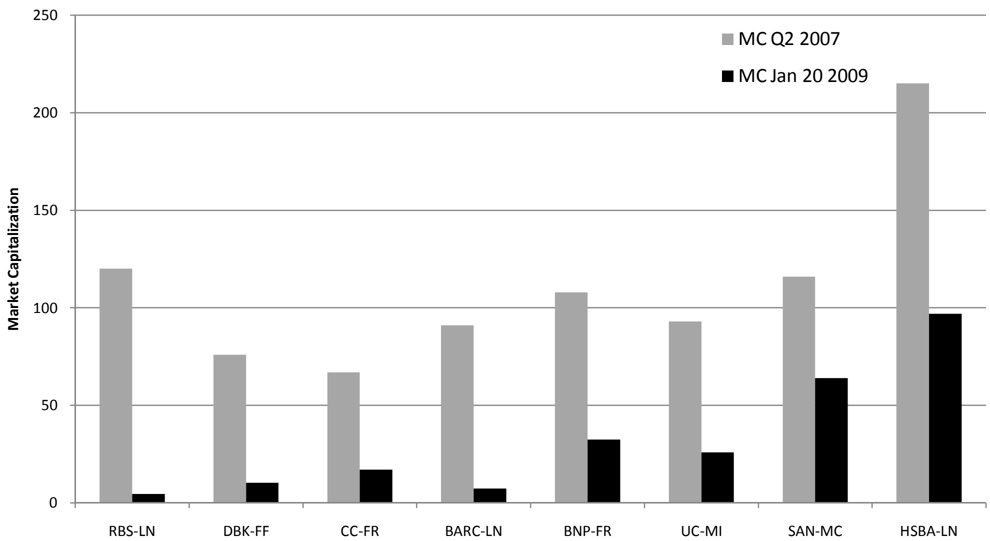

Figure 1. Selected Banks' Market Capitalization as at Q2 2007 compared to January 20th 2009

This Figure illustrates the drop in market capitalization for a sub-sample of major European banks for the period Q2 2007 to January 20th 2009. Major European banks started 2009 on average at 26.15% of their 2007 market capitalization. The most dramatic falls were experienced by RBS with a fall of 96.16% and Barclays with 91.87%. All figures are in billions of US dollars. *Source: Bloomberg and JP Morgan Sector Analysis, Jan 20th 2009*

II Pillar 2. Categorisation of individual banks' balance sheet items into broader asset classes is informed by notes accompanying the institutions' annual reports. Table 1 gives a summary overview of the distribution of total asset value for the sample. For simplification we assume that the composition of EuroBank's portfolio does not include proprietary derivative positions, a reasonable assumption given the objective of this work: to compare modular and integrated EC.

Credit risky assets are split into five categories dependent on their Basel II exposure type: claims on sovereign, bank, corporate, retail and specialized lending. For example, the capital charge for lending to a corporate is higher than for lending to a government. As shown in Table 2, lending to corporates and retail/mortgage products are EuroBank's core business. To reflect credit asset characteristics, we impute the original portfolio to QIS 5 rating asset attributes for these classes. Worldscope data disclose nominal figures for each bank's investment and loan portfolio, and so detailed information on the asset composition of each bank's investment and loan portfolio is hand collected from the annual financial statements. The majority of banks supply data that enables the derivation of asset composition for investment and loan portfolios. Based on an evaluation of accounting notes contained in the 2006 Annual Reports we obtain an approximate picture of weighted average asset holdings of each bank's investment and loan portfolios.

The Basel Committee on Banking Supervision has conducted several Quantitative Impact Studies to gather information to assess the effect of the Basel II regulatory framework on capital requirements. Quantitative impact studies are based on data from European bank asset exposures gauging the different risk profiles of a broad range of banks and asset classes to calibrate risk model parameters. In the Fifth QIS (Basel

Table 1 Geographic Data of the Sample Set in £ million.

This table gives the geographical distribution of the 51 European banks in the sample set (Appendix A Table 12). It displays the total asset value per country, the total number of banks per country and the percentage of total assets in the entire sample set represented by each respective country and in the final column for the entire sample set. The remainder of our EuroBank's example excludes any derivative position.

Country	GBR	GER	FRA	ITA	ESP	NED	Europe
Total Asset	3654142.88	1314256.21	2401069.29	1111829.91	982681.26	600281.90	10064261.47
Number of Banks	9	7	6	18	9	2	51
Percentage	36.31%	13.06%	23.86%	11.05%	9.76%	5.96%	100.00%

Table 2 Balance Sheet Assets (December 2006) of EuroBank in £ million.

This table illustrates the arithmetic average of 51 banks' balance sheets which will be used as the EuroBank's balance sheet (last two rows of Appendix A Table 12). Derivative positions are excluded.

Asset Class	Average Exposure	% Total Assets
Cash	2898.33	1%
Claims on Government	22716.34	12%
Claims on Banks	31281.68	16%
Claims on Corporates	65914.72	33%
Retail Loans	11441.62	6%
ABS	2897.66	1%
Residential Loans	37761.59	19%
Commercial Real Estate	6061.13	3%
Property	2283.87	1%
Equity	14081.54	7%
Total Assets	197338.46	100%

Comittee 2006), the probability distribution of default for every category of credit asset is calibrated and linked to the corresponding credit rating and asset model (see Crouhy et al. (2000) for full discussion of model alternatives). The percentage of exposure in three PD ranges are mapped to external credit rating grades of *A and better*, *BBB*, and *worse than BBB*. Table 3 illustrates the portfolio composition.

We make the simplifying assumption that all sovereign bonds are AAA rated. For group *A and better*, we assume that one-third are AA rated. The category *worse than BBB* is considered as uniformly BB rated, see Table 4. For example, 38.5% of exposure in corporate loan portfolio show a probability of default less than 0.2%, which implies a credit rating better than BBB for 38.5% of corporate portfolio. For currency we apply

Table 3 The calibration of probability distribution of default for three categories of credit assets given in QIS 5 (Basel Comittee 2006)

This table displays the calibration of probability distribution of default for categories of credit assets (bank loan, corporate loan and retail loan) given in QIS 5 (Basel Comittee 2006). Three credit ratings (A, BBB and BBB-) are related to the corresponding probability of default. For example, 86.2% of claims on bank loan with PD less than 0.2% are rated as A.

	PD $<$ 0.2% (A)	0.2% $\leq$ PD $<$ 0.8% (BBB)	PD $\geq$ 0.8% (BBB-)
Banks	86.2%	9.1%	4.7%
Corporates	38.5%	31.8%	29.7%
Retails	30.8%	34.6%	34.6%

a 70%/30% split to recognize that balance sheet assets are denominated in both GBP and Eurozone currency.

The QIS 5 composition parameters for investment and loan portfolios are applied consistently across all 51 banks to replicate detailed balance sheet attributes (Appendix A Table 12). In projecting and simulating EuroBank, we use Table 2 as the initial balance sheet (arithmetic average of Appendix A Table 12). Banks across the European region differ in size and asset structure; nonetheless the analysis of EuroBank is representative of QIS 5 asset attributes and is therefore useful for examining the difference between modular and integrated EC calculations.

One very real enterprise risk management (ERM) challenge is how different portfolios perform over different time horizons. As one of the key confidence setting parameters in ERM, the time period for capital management directly affects the choice between conditional (point in time) and unconditional (through the cycle) calibration processes which is discussed in detail in the following section. Using Table 4, we transform EuroBank's original balance sheet into a rating based balance sheet (Table 5), and then compute the EC by modular approach. For objective comparison with the fully integrated approach, we use the covariance matrix proposed by Standard and Poor's (2008); firstly, it lacks bank specific institutional bias and secondly, it is an informed and well-justified approximation of asset class correlations.

Table 4 Mapping Balance Sheet Data to Asset Models Using the Fifth Quantitative Impact Study (QIS 5) Statistical Parameters

This table provides mapping parameters for each asset class that appears in bank's balance sheet (Table 2). These percentage parameters are collected from QIS 5 (Basel Comittee 2006) and adjusted by our assumptions. The second and third columns together represent the asset classes and credit ratings to which balance sheet items are mapped for modeling purposes. For example, 63% and 27% of the claims on government are mapped into domestic and foreign AAA risk-free nominal bonds respectively with the remaining 10% mapped to AAA risk-free index-linked bonds.

Asset	Modeled as	Credit Rating[a)]	Percentage	Domestic 70%	Foreign 30%
Claims on Government[c)]	Risk-free nominal bonds	AAA	90%	63%	27%
	Risk-free index-linked bonds[b)]	AAA	10%	-	-
	Nominal Sovereign Bonds	AA			
	Nominal Sovereign Bonds	A			
	Nominal Sovereign Bonds	BBB			
	Nominal Sovereign Bonds	BB			
			100.00%		
Claims on Bank[d)]	Nominal corporate bonds	AA	26%	18%	8%
	Nominal corporate bonds	A	52%	36%	16%
	Nominal corporate bonds	BBB	8%	6%	2%
	Nominal corporate bonds	BB	4%	3%	1%
	Index linked corporate bonds[b)]	A	10%	-	-
			100.00%		
Claims on Corporates[e)]	Nominal corporate bonds	AA	12%	8%	3%
	Nominal corporate bonds	A	23%	16%	7%
	Nominal corporate bonds	BBB	29%	20%	9%
	Nominal corporate bonds	BB	27%	19%	8%
	Index linked corporate bonds[b)]	A	10%	-	-
			100.00%		
Retail Loans[f)]	Nominal corporate bonds	AA	4%	3%	1%
	Nominal corporate bonds	A	8%	6%	3%
	Nominal corporate bonds	BBB	30%	21%	9%
	Nominal corporate bonds	BB	58%	40%	17%
			100.00%		
Residential Loans[g)]	Nominal corporate bonds	AA	4%	3%	1%
	Nominal corporate bonds	A	8%	6%	3%
	Nominal corporate bonds	BBB	30%	21%	9%
	Nominal corporate bonds	BB	58%	40%	17%
			100.00%		
Commerical Real estate	Nominal corporate bonds	BB	100%	70%	30%
ABS	Nominal corporate bonds	BBB	100%	70%	30%
Cash	Fixed Risk-Free bonds	AAA	100%	-	-
Equities	Equities	-	100%	70%	30%
Property	Property	-	100%		

a) For A rated bonds and better, we assume that one-third are AA rated and two-third are A rated.

b) The proportions for risk-free/corporate Index-linked bonds are all fixed at 10%, the rest (90%) are assigned rating categories according to QIS 5.

c) Table 16 Committee of European Banking Supervisors (CEBS) Group 1 gives a different set of estimates with only 30% AAA, so it may not be appropriate to use QIS 5 parameters for Sovereigns bonds. We assume that 90% of Sovereign bonds are all AAA rated.

d) Table 15 CEBS Group 1.

e) Table 14 CEBS Group 1.

f) Table 17 Other non-G10 Group 1. QIS 5 doesn't provide the full PD calibration for Retail but only a simplified Table 18. The reason we use Table 17 is that it has close values of average PD and In Default to Table 18.

g) Table 17 Other non-G10 Group 1. We assume Residential Loans share the same rating parameter with Retail Loans.

Table 5 The transformation of EuroBank Balance Sheet

This table gives the consolidated balance sheet used in comparing fully integrated and modular approaches. The fully integrated approach models all assets in the first column simultaneously, where the EuroBank's credit risky assets are mapped by credit rating (Table 4). The modular approach however models the assets in each of the last six columns separately, where the corresponding sub portfolios are mapped to credit ratings individually (Table 4); Economic Capital is then computed using a fixed correlation matrix. The sovereign sector consists of all cash and claims on government that appear on EuroBank's balance sheet. The retail sector (fifth column) consists of all retail loans, residential loans, commercial real estate and asset backed securities (ABS). Derivative positions are not considered.

Currency £M	Fully Integrated	Sovereigns	Institution	Corporate	Retail	Equity	Property
Fixed Risk-Free AAA	2898.33	2898.33	-	-	-	-	-
Domestic Equities	9857.08	-	-	-	-	9857.08	-
O'Seas Equities	4224.46	-	-	-	-	4224.46	-
Property	2283.87	-	-	-	-	-	2283.87
AAA (D)†	14311.29	14311.29	-	-	-	-	-
AA (D)	12438.39	-	5662.61	5329.21	1446.57	-	-
A (D)	24876.78	-	11325.22	10658.41	2893.15	-	-
BBB (D)	27325.32	-	1793.38	13205.35	12326.59	-	-
BB (D)	37306.63	-	926.25	12333.30	24047.08	-	-
AAA (F)‡	6133.41	6133.41	-	-	-	-	-
AA (F)	5330.74	-	2426.83	2283.95	619.96	-	-
A (F)	10661.48	-	4853.66	4567.89	1239.92	-	-
BBB (F)	11710.85	-	768.59	5659.44	5282.82	-	-
BB (F)	15988.56	-	396.96	5285.70	10305.89	-	-
Index-linked AAA	2271.63	2271.63	-	-	-	-	-
Index linked A	9719.64	-	3128.17	6591.47	-	-	-
Total Value	197338.46	25614.67	31281.68	65914.72	58161.98	14081.54	2283.87

†D is Domestic

‡F is Foreign

III Economic capital modeling - a theoretical framework

The fully integrated framework we use to project the Euro bank balance sheet in this paper is based on the general conceptual framework set out in McNeil et al. (2008). We recapitulate key concepts and add detail concerning specific asset model choices.

A Economic capital and risk measurement

Our economic capital computation for Eurobank will be based on the application of *suitable* risk measures to the balance sheet, deriving the distribution of *unexpected losses*. These losses are incurred by value changes in the asset portfolio V_t and liabilities B_t due to fluctuations in underlying risk drivers. At time t, Eurobank is considered to be sufficiently capitalised when capital $E_t \geq V_t - B_t$ for $V_t > B_t$.

Let us now assume that between time t and a future time $t+1$, expected increase in asset value exceeds the increase in the value of liabilities plus any shortfall in income I_s such that

$$\mathrm{E}(V_s - V_t) \geq (B_s - B_t) - I_s.$$

We now take the simplifying assumption that Eurobank replicates their liabilities by a portfolio of assets. For a given confidence level α (say 99% for a century event) and with $\Delta_s = V_s - V_t$, the enterprise would be sufficiently capitalized if

$$P(\Delta_s - \mathrm{E}(\Delta_s) + E_t > 0) = \alpha$$

or equivalently, expressed in terms of losses with $L_s = -\Delta_s$ if

$$P(L_s - \mathrm{E}(L_s) < E_t) = \alpha.$$

If V_t denotes the value of the portfolio at time t then the unexpected loss L_{t+1} at a future time $t+1$ is given by $L_{t+1} = -\Delta_{t+1} = -(V_{t+1} - V_t)$.

The cumulative distribution function of a generic loss L will be denoted by $F_L(l) := \mathrm{P}(L \leq l)$. All risk measures we consider are statistical measures computed from F_L; in particular we consider Value-at-Risk (VaR), and expected shortfall (ES). The former is the α-quantile of F_L for an appropriate choice of $0 < \alpha < 1$, i.e. the measure

$$\mathrm{VaR}_\alpha(L) := \inf\{l \in \mathbb{R} : F_L(l) \geq \alpha\};$$

see McNeil et al. (2005, Definition 2.10). For economic capital calculation, α is typically chosen to match the target credit rating of the enterprise (e.g. 99.97% for a AA-rating). The 99.97% VaR is interpreted as indicating that there is a 0.03% chance that the portfolio loss is at least $\mathrm{VaR}_{99.97\%}$.

Expected shortfall, also used in this paper, is closely related to the to VaR. It is defined as the tail average of the loss distribution above a given confidence level α. A formal definition used in Tasche (2002) and McNeil et al. (2005) is

$$\mathrm{ES}_\alpha(L) := \frac{1}{1-\alpha}\int_\alpha^1 \mathrm{VaR}_u(L)du,$$

which for continuous loss distributions reduces to the more common expression

$$\mathrm{ES}_\alpha = \frac{1}{1-\alpha}\mathrm{E}\left[L\mathbf{1}_{[L \geq \varrho_\alpha(F_L)]}\right] = \mathrm{E}\left[L | L \geq \mathrm{VaR}_\alpha\right],$$

the expected loss given that the VaR at level α is exceeded.

The question of suitability of a risk measure has been addressed by Artzner et al. (1999) who propose four axioms which a sound risk measure should satisfy. Leaving aside technical details, let $\mathcal{M}$ denote a set of random variables representing portfolio losses over the time period in question and let the function $\varrho : \mathcal{M} \to \mathbb{R}$ denote a risk measure. A "coherent" risk measure $\varrho(L)$ should satisfy the following four properties:

Axiom III.1 (Monotonicity). *For $L_1, L_2 \in \mathcal{M}$ such that $L_1 \leq L_2$, we have $\varrho(L_1) \leq \varrho(L_2)$.*

Axiom III.2 (Subadditivity). *For any $L_1, L_2 \in \mathcal{M}$ we have $\varrho(L_1 + L_2) \leq \varrho(L_1) + \varrho(L_2)$.*

Axiom III.3 (Positive homogeneity). *For all $L \in \mathcal{M}$ and $\lambda > 0$ we have $\varrho(\lambda L) = \lambda\varrho(L)$.*

Axiom III.4 (Translation invariance). *For all $L \in \mathcal{M}$ and $a \in \mathbb{R}$ we have $\varrho(L+a) = \varrho(L) + a$.*

Subadditivity implies that capital charges computed with the risk measure can be reduced by diversification, an important principle in finance. Conversely, if a regulator uses a non-subadditive risk measure to determine the capital charge for a financial institution, the institution is incentivised to split its operations into various subsidiaries in an attempt to reduce the overall capital requirement.

ES, when defined as above, is a coherent risk measure; see McNeil et al. (2005, chap. 6). VaR however, is not a coherent risk measure in general due to non-subadditivity. For comparison, we compute economic capital requirements under both risk measures in this paper. We subtract expected loss from our risk measures, since expected losses are covered by operating incomes and capital is held as a buffer against unexpected losses. In effect this means that the risk measures we use are $\text{VaR}(L) - E(L)$ and $\text{ES}(L) - E(L)$, which share the same properties as VaR and ES.

B Loss distributions via economic scenario generation

Valuing the portfolio in the present (V_t) and in the future (V_{t+1}) is a significant challenge hat has been recognised by IFRS 7. The ideal method is *market-consistent* (or fair-value) valuation. Certain assets are capable of being marked to market while others are required to be marked to model. We assume that liabilities are modeled by a matched replicating portfolio of assets. This is a simplification we make in order to illustrate the asset valuation differences between modular and integrated methodologies. In practice, there are two ways of dealing with the evolution of liabilities on capital; in the case of central bankers modelling systemic risk, access to proprietary data enables the feedback loop to be linked to detailed sector leverage data from regulatory returns (Anderson et al. 2008). The difference between these two feedback loops can be characterized in terms of the information known by the modeler.

Structural feedback loops assume that the modeler has the same information set as the central bank - complete knowledge about systemic leverage based on all banks (usually from regulatory returns). For enterprises without systemic data access, the liability needs to be linked to a market observable systemic risk driver. Effectively though, all asset values at $\mathbf{Z}_t = (Z_{t1}$ can be viewed as being dependent on a high-dimensional vector of underlying risk factors $\mathbf{Z}_t = (Z_{t1}, \ldots, Z_{td})$ consisting of such items as equity returns (index and some single stocks), exchange rates, points on the yield curve, credit spreads and default or rating migration indicators.

Projecting forward the underlying risk factors for purposes of valuation at $t+1$ is the role that can be filled by an economic scenario generator. Suppose we denote the risk factors at time t by the vector $\mathbf{Z}_t = (Z_{t1}, \dots, Z_{td})$. We set up a multivariate stochastic process $\mathbf{Z} = (\mathbf{Z}_s, s \geq t)$ which projects the values of these risk factors into the future and gives us snapshots $\mathbf{Z}_s$ of the economy at future times $s \geq t$. The value of the portfolio at future times V_s can be considered as a random variable of the form

$$V_s = f_s(\mathbf{Z}_s, s)$$

where f_s is a function that we will refer to as the *portfolio mapping at time* s. It contains information about the portfolio composition at time s and incorporates the valuation formulas that are used to value the more complex (derivative) assets with respect to the underlying risk factors $\mathbf{Z}_s$. Note that, in general, it depends not only on the value of the risk factors at time s, but also on the time s itself; this is because the value of a derivative position with maturity/expiry T typically depends on the remaining time to maturity $T - s$. Note also that there is a time subscript on the mapping function f_s to allow for the possibility of dynamic rebalancing which could change the entire composition of the mapping over time.

An economic scenario generator generally takes a Monte Carlo (simulation) approach and generates a series of realisations/paths $(\mathbf{Z}_s(\omega_i), s \geq t)$ for $i = 1, \dots, m$. Each ω_i is in effect the label for a particular economic scenario and $(\mathbf{Z}_s(\omega_i), s \geq t)$ is the manifestation of that scenario in terms of a path for the fundamental risk factors.

Risk measures such as VaR and expected shortfall are estimated by corresponding empirical quantities derived from the Monte Carlo samples, such as sample quantiles. As such, they are prone to Monte Carlo error, which diminishes with the number of paths m. Errors and runtimes can be further reduced by employing standard Monte Carlo variance reduction techniques such as the use of antithetic variates (Robert and Casella 1999).

C Calibration: conditional versus unconditional

There are subtle questions concerning the calibration of the stochastic model that is used to generate $\mathbf{Z} = (\mathbf{Z}_s, s > t)$. The most natural form of projection is conditional on past realized values of the process $(\mathbf{Z}_s, s \leq t)$. This effectively conditions the projection on the current and recent economic climate, whether benign or stressed. There is some debate whether this is always desirable. In a benign epoch, a conditional projection may fail to anticipate stress events over the horizon. In volatile periods, economic capital calculations based on conditional projections will share that volatility and actions taken on the basis of these figures may be pro-cyclical and serve to amplify volatility.

An alternative approach is to calibrate the stochastic process $\mathbf{Z} = (\mathbf{Z}_s, s > t)$ based on longer-term information including historical tail events and to generate an unconditional realization that is less influenced by the most recent realized values.

To illustrate this problem; in the internal ratings basis, regulators have coined the term "rating philosophy" to describe where a rating system sits on the spectrum between the stylised extremes of: Point in Time (PiT); in which firms seek to explicitly estimate default risk over a fixed period, typically one year. A consequence of the use of such an approach is that the increased credit default risk in a downturn results in a general tendency for migration to lower grades. When combined with the fixed estimate of the long run default rate for the grade, the result is higher IRB capital requirements. By contrast, Through The Cycle (TTC); in which firms seek to take cyclical volatility out of the estimation of default risk, by assessing a borrower's performance across the business cycle. Such ratings do not therefore react to changes in the cycle when it occurs, so there is no consequent volatility in capital requirements. Of course the actual numbers of defaults for a portfolio are the same under both approaches as the choice of rating system does not change the underlying default risk - the problem is that the effects on Economic capital are different.

The literal definition of economic capital in terms of limiting the probability of insolvency over a defined time horizon seems to come down on the side of conditional calibration as being appropriate, but a less literal interpretation allows us more space for interpretation, our model choices are discussed in more detail in section D below. There might for instance be an argument for computing capital as a maximum of the numbers derived from a conditional and an unconditional calibration. This would have the effect of smoothing out capital numbers in more benign periods and elevating them only in crises, so that the procyclicalty problem is lessened (although still present in crises).

D Calibrating the economic scenario generator

The architecture of a generic economic scenario generator is described in McNeil et al. (2008). The study in this paper is carried out with the Barrie & Hibbert economic scenario generator (B&H ESG) which conforms to the general template. Figure 2 shows the main features of the model. A supporting technical document (Morrison et al. 2009) gives a detailed description of all model sub-components.

Calibrating interest, inflation, credit, equity and property models to observable "real world" financial yield curves and instruments enables us to capture market conditions extant at September 2007 preceding the credit crisis. Importantly, fully integrated balance sheet projection based on economic scenarios measures the full range of asset responses to observable multivariate risk distributions. By contrast, covariance calculations of capital typically rely on asset correlations based on "normal" markets, underestimating asset response to extreme conditions. In this section we give a non-technical overview of the model and calibration choices that have been made to address the economic capital questions which are of central interest in this paper (See Figure 2).

Interest rate models are at the core of our ESG which, in turn, allows the user to chose among several available model for nominal and real interest rates. For our analysis, we select a 2-factor Black-Karasinski model for nominal interest rates as its logarithmic structure guarantees positive nominal interest rates. The parameter settings for the model are included in Appendix B Table 13 displaying an interest rate calibration that is consistent with our best estimates of interest rate volatility and mean reversion (σ and γ). The market price of risk parameter (r) was chosen to achieve target long-run expected (unconditional) short rates of 4.5%. The initial yield curve is a direct input to the Extended 2FBK Model. We derive an initial curve by fitting a smooth curve to the available market rates.

Real interest rates are assumed to follow a standard 2-factor Vasicek which allows for positive and negative real rates while inflation is not explicitly modelled but inferred as the differential between nominal and real rates. Our calibration is consistent with the best estimates of nominal and index-linked bond volatility and produces yield curves that are consistent with gilt prices (including index-linked gilts) at 30 September 2007. The index-linked coupon bond yields are semi-annually compounded. All spot rates are continuously compounded, where the model impled inflation rate is defined as the

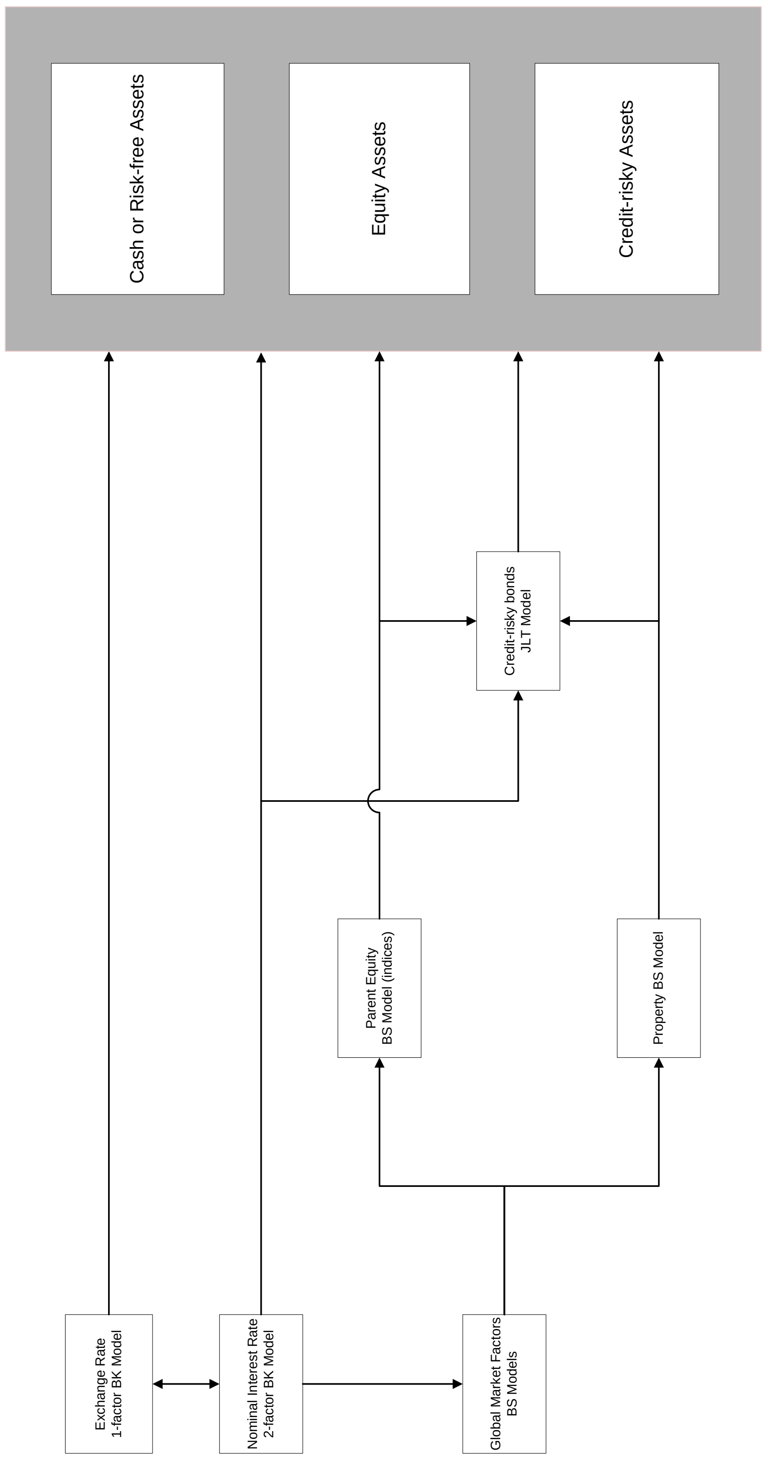

Figure 2. Diagram of model tree used for fully integrated calculation of EC

difference between model nominal and real short rates and is broadly consistent with RPI forecasts. See Appendix B Table 13 for Vasicek model parameters and Table 15 for goodness-of-fit calibrations. Since we are limited to financial data from annual reports, we simply group assets in two economies, domestic and overseas. Exchange rates are modelled based on the assumption of purchasing power parity (PPP). Over time, real exchange rates are allowed to fluctuate around a long term target; deviation of nominal exchange rates from real exchanges rates arises relative to the inflation differences between economies.

For equities, we adopt a multi factor modelling approach where factors are statistical and derived by principal component analysis (PCA). In our analysis, equities are modelled at the macro level, i.e. as a representative index for the economy. The starting yield is the dividend yield on the FTSE 100 index as at September 30, 2007. The annual model parameters are as follows:

μ (geometric)	2%
μ (arithmetic)	4%
σ (specific)	13.78%
σ (total)	20%
Starting yield	3.60%

where the "geometric" expected return satisfies

$$\mu(geometric) = \text{Expectation} \quad [\log_e(\text{equity roll up / cash roll up})] \;/\; \text{T}$$

and "arithmetic" expected excess return satisfies

$$\mu(arithmetic) = \log_e \quad [\text{Expectation} \quad (\text{equity roll up / cash roll up})] \;/\; \text{T}$$

for any time horizon T.

Property returns are modelled according to the same underlying factor model used to project equity returns but calibrated with different factor sensitivities. The annual model parameters are as follows:

μ (geometric)	1.875%
μ (arithmetic)	3%
σ (specific)	9.51%
σ (total)	15%
Starting yield	4.30%

where the "geometric" and "arithmetic" excess return notations are used consistently with those for equity calibration model.

Credit architecture in our ESG combines a Jarrow-Lando-Turnbull (JLT) reduced-form model with a one factor (gaussian) copula (Jarrow et al. 1997). Our modelling framework uses a reduced-form ratings based credit model. The JLT model is extended to allow for stochastic spreads following a Cox-Ingersoll-Ross (CIR) process. To mitigate the static and lag effects of credit ratings, transition shocks are generated by structurally linking idiosyncratic and systematic shocks. A market risk driver, in our case the equity index of the corresponding economy (domestic or overseas), is assigned to the systematic shock term. For heterogenous credit risky assets in multiple economies, this design effectively allows for multiple structural linkages based on the relevant underlying systematic exposures and offers enhanced flexibility.

Table 16 of the Appendix B summarizes the calibration parameters of our credit model, consistent with our best estimates of long-term transition probabilities, spread volatility and corporate bond spreads at September 30, 2007. To fit the model, we target our fit to the market spread on a 7-year A rated bond only. The difference in model and market spreads are included in Appendix B Table 17 for 2, 7, 15 and 20 year maturities.

Our robust Barrie & Hibbert ESG modelling suite allows us to project the underlying fundamental risk factors for possible future states of the economy. Together with asset pricing models, these factors enable us to project Eurobank's cash (risk free), equity and credit-risky asset positions over time. To recognise practical management action and investment policies, with the exception of defaults, credit risky portfolios are rebalanced annually to their credit quality at the beginning of each year.

E Implementing the modular and fully integrated approaches

The asset portfolio of our representative Eurobank may be divided by asset class into d sub-portfolios. For each sub-portfolio $j = 1, \ldots, d$ we have to consider possible losses

$$L_{j,t+1} = -\Delta_{j,t+1} = -(V_{j,t+1} - V_{j,t}),$$

which aggregate by simple summation to give the overall value change of the enterprise

$$L_{t+1} = -(V_{t+1} - V_t) = -\left(\sum_{j=1}^{d} V_{j,t+1} - \sum_{j=1}^{d} V_{j,t}\right) = \sum_{j=1}^{d} L_{j,t+1}.$$

The modular approach. In the modular approach to capital adequacy individual risks at subportfolio level are transformed into capital charges $\mathrm{EC}_1, \ldots, \mathrm{EC}_d$. These are then combined to calculate the overall economic capital EC, usually by using a correlation matrix approach.

The economic scenario generation approach gives us the framework for a fully integrated model of economic capital, but clearly it also allows us to derive economic capital estimates for individual asset classes by considering them one at a time. In this way we have the opportunity to compare a modular, correlation-based approach to economic capital with a fully integrated approach. Companies without fully-integrated, enterprise-wide models have no choice in the matter; they require a method for combining the capital charges that they compute for individual classes of asset using a variety of different models and approaches. The overall EC is generally computed to be

$$EC = \sqrt{\sum_{i=1}^{d} \sum_{j=1}^{d} \rho_{ij} EC_i EC_j} \tag{1}$$

where ρ_{ij} are the correlations between the asset classes.

In McNeil et al. (2008) the modular method of aggregation is only justified when underlying losses in different asset classes have a joint elliptical distribution and when capital is set using a positive homogeneous, translation-invariant risk measure, such as

VaR or expected shortfall. However, it is argued that the distributional assumption is never met in practice and, even if it were, the difficulty of calibrating the correlations and of taking into account taildependence, is a serious limitation.

In this paper we use economic scenario generation to calculate capital requirements for each asset class using our two risk measures. In other words we set $EC_i = VaR_\alpha(L_i) - E(L_i)$ and $EC_i = ES_\alpha(L_i) - E(L_i)$ in turn and use (1) to compute overall economic capital.

Standard and Poor's (2008) adopts a modular approach and provides a calibration for the correlation matrix. Table 6 shows the correlation matrix between various exposure classes in credit market.

To summarise, in the modular approach we compute EC through the following steps:

1. We impute the initial value of every credit asset class in the portfolio balance sheet using Table 4
2. We simulate every credit asset class over a given time horizon and obtain the loss distributions. Then, compute VaR and ES of every loss.
3. We calculate the capital charges for credit risk using the correlation matrix of Table 6.
4. Using equity factor models we simulate equity asset values given the initial value in the balance sheet; computing VaR and ES of equity losses.
5. Calculate the overall EC using the correlation coefficient between credit market and equity market.

Table 6 The correlation matrix. For objectivity we use the matrix suggested by Standard and Poor's (2008) modular approach.

This table gives the correlation coefficients ρ_{ij} which are used in for capital calculating Equation 1 in modular approach proposed by Standard and Poor's (2008).

ρ	Sovereigns	Institutions	Corporates	Retails
Sovereigns	100%	-	-	-
Institutions	75%	100%	-	-
Corporates	50%	50%	100%	-
Retails	25%	25%	25%	100%

We also compute the upper bound of EC requirement for the case where there is no diversification as a special case of the modular approach (referred to as simple additive approach) with $EC = \sum_{i=1}^{d} EC_i$.

Fully integrated approach. Losses in sub-portfolios depend on value changes ($L_{j,t+1} = -\Delta_{j,t+1} = -(V_{j,t+1} - V_{j,t})$) and future valuations are driven by fundamental risk factors $\mathbf{Z}_{t+1}^{(j)}$ according to $V_{j,t+1} = f_{j,t+1}(\mathbf{Z}_{t+1}^{(j)}, t+1)$. Many of these risk factors, for example those describing the structure of the yield curve or the average performance of equity markets, are common to many sub-portfolios of assets.

This is the origin of dependence in a fully integrated model: correlation arises from the mutual dependence of future values across an enterprise on a set of common risk drivers. Fully integrated models are common factor models. The risk factors $\mathbf{Z}_{t+1}^{(j)}$ that enter into the future valuation of sub-portfolio j contain a subset in common with the risk factors $\mathbf{Z}_{t+1}^{(k)}$ that enter into the future valuation of sub-portfolio k. These common factors are the drivers of dependence between $V_{j,t+1}$ and $V_{k,t+1}$ and consequently between $L_{j,t+1}$ and $L_{k,t+1}$. The dependence arises endogenously through the specification of the model.

In practical terms we treat the enterprise as a single portfolio and simulate overall losses for all asset classes and compute capital using selected and defined risk measures.

F Eurobank Capital allocation

The advantage of using an integrated risk framework is that economic capital calculated for an asset portfolio or enterprise can be broken up into pieces that are attributable to sub-portfolios or business units. While this is not performed for Eurobank, this process of capital allocation can be used as the basis of risk-adjusted performance comparison across sub-portfolios and there is now a considerable literature on the theory of fair allocation of capital including Tasche (1999); Denault (2001); Kalkbrener (2002).

The generic principle that is commonly adopted is known as Euler allocation and is applicable to any positive homogeneous risk measure under the integrated capital methodology. Suppose that the multivariate distribution of the vector $(L_1, \ldots, L_d)$, representing future losses in d sub-portfolios, is held fixed. We consider hypothetical portfolio losses of the form $L(\boldsymbol{\lambda}) = \sum_{i=1}^{d} \lambda_i L_i$ where $\boldsymbol{\lambda} = (\lambda_1, \ldots, \lambda_d)$ is a vector of unconstrained portfolio weights. In reality our portfolio loss will be $L = L(\mathbf{1}) = \sum_{i=1}^{d} L_i$

but by considering $L(\boldsymbol{\lambda})$ for general $\boldsymbol{\lambda}$ we can examine how the risk changes as we hypothetically vary the size of each sub-portfolio.

Let ϱ be a positive homogeneous, translation preserving risk measure (like VaR or expected shortfall) and assume that overall economic capital is determined according to $\mathrm{EC}(\boldsymbol{\lambda}) = \varrho(L(\boldsymbol{\lambda})) - E(L(\boldsymbol{\lambda}))$. Then the Euler capital allocation to the ith risk will be given by

$$\mathrm{AC}_i = \frac{\partial \varrho\left(\mathrm{EC}\left(\boldsymbol{\lambda}\right)\right)}{\partial \lambda_i}\Big|_{\boldsymbol{\lambda}=\mathbf{1}} = \frac{\partial \varrho\left(L\left(\boldsymbol{\lambda}\right)\right)}{\partial \lambda_i}\Big|_{\boldsymbol{\lambda}=\mathbf{1}} - E(L_i)\ ;$$

we will write this as

$$\mathrm{AC}_i = \varrho(L_i \mid L) - E(L_i)$$

for simplicity. Note that the individual contributions add up to give a complete capital allocation: $\sum_{i=1}^{d} \mathrm{AC}_i = \varrho(L) - E(L) = \mathrm{EC}$.

Using arguments in Tasche (2000) it can be shown that under some technical assumptions on the distribution of $(L_1, \ldots, L_d)$ (fulfilled, for example, by the existence of a joint probability density) the term $\varrho(L_i \mid L)$ takes the following forms in the case of VaR and expected shortfall:

$$\begin{aligned} \mathrm{VaR}_\alpha(L_i \mid L) &= E(L_i \mid L = \mathrm{VaR}_\alpha(L)) \\ \mathrm{ES}_\alpha(L_i \mid L) &= E(L_i \mid L \geq \mathrm{VaR}_\alpha(L))\ . \end{aligned}$$

The forms of these expressions reveal, at least in theory, how the economic capital contribution may be estimated using the Monte Carlo output from an economic scenario generator. For example, in the case of expected shortfall, we would average the losses in each subportfolio over all scenarios where the total portfolio loss exceeded the Value at risk. In practice, the problem of rare event simulation arises, and long run times may be necessary to get accurate results. But the main point is that the necessary prerequisite for computing allocations is a fully-specified joint model for $(L_1, \ldots, L_d)$ and this is delivered by a fully integrated model but not by a modular model and correlation matrix. (A modular approach with copulas would permit the calculation of allocations.)

A further development, described in Tasche (2006), is the calculation of diversification scores to give a measure of the extent of diversification in the total portfolio of an enterprise. A global diversification index can be calculated as

$$\mathrm{DI} = \frac{\varrho(L) - E(L)}{\sum_{i=1}^{d} \varrho(L_i) - E(L)} = \frac{\mathrm{EC}}{\sum_{i=1}^{d} \mathrm{EC}_i}.$$

This is simply the total economic capital for the portfolio divided by the sum of stand-alone economic capital amounts for the sub-portfolios.

A sub-portfolio diversification index can be calculated as

$$\mathrm{DI}_i = \frac{\varrho(L_i \mid L) - E(L_i)}{\varrho(L_i) - E(L_i)} = \frac{\mathrm{AC}_i}{\mathrm{EC}_i}.$$

This shows the reduction in capital that the sub-portfolio enjoys through being part of the enterprise. Where the ratio is small, this is an indication that sub-portfolio i is well-diversified with respect to the rest of the enterprise. If the global diversification is less impressive, it may be possible to gain a global improvement by increasing the size of sub-portfolio i at the expense of other sub-portfolios.

IV Projecting EuroBank's balance sheet and computing EC requirements

A Projected portfolio loss distributions

Following the modular approach, we first estimate the loss distribution for sub portfolios covering credit risky asset class by simulation. Descriptive statistics of loss distributions for sub portfolios of sovereign bonds, interbank lending, corporate bonds and retail products are shown in the Table 7, describing distributions for simulated portfolio loss over a one and five year projection horizon. Note that every distribution shows a different degree of skewness. In particular, the loss distribution of retail assets has the heaviest upper tail out of the four credit risk exposures types. By contrast, the right hand tail of sovereign bonds is the 'lightest'. Results imply that the riskiness of purchasing sovereign bonds is much lower than mortgage business as would clearly be expected. We also simulate total returns of equity and property assets over one and five years based on an equity multi-factor model to obtain two corresponding loss distributions. Both loss distributions have skewed non-normal shapes, which coincides with our expectation for parent equities, Table 7

B Projected Economic Capital requirements and capital attribution under different risk measures

Risk measures VaR and ES for each asset class are computed based on portfolio loss distributions. Tables 8 and 9 show EC requirements for every asset class for one-year through five-year projections. For the modular approach, we obtain the total EC by aggregating individual risk measures with and without diversification benefit. The special case of aggregation without diversification benefit is referred to as an 'additive' approach where modular EC is calculated using a variance-covariance matrix overlay. Tables 8 and 9 illustrate EC results under additive and modular approaches with risk measures 99% VaR, 99% ES and 95% ES. With a fully integrated approach, we simulate the total value of the portfolio over one and five years and obtain the loss distribution which exhibits a high degree of skewness. EC is computed under three measures of VaR and ES and given in Tables 8 and 9.

Table 7 Descriptive statistics for loss distributions

This table shows statistical sample parameters for the simulated one-year and five year loss distributions. All distributions fail the Jarque-Bera test of nomality according to the p-values.

	Mean	Median	StdDev	Skewness	Kurtosis	Max	Min	p-value
				Panel A: One-year Loss Distribution				
Sovereign	0.09	-24.94	1209.13	0.07	-0.23	3390.84	-3572.74	0.00
Institutional	-362.28	-467.17	1891.23	0.09	0.03	5951.95	-6560.55	0.00
Corporate	-1080.56	-1246.79	4478.40	0.11	0.20	14669.39	-15432.77	0.00
Retail	-1287.55	-1581.66	4706.91	0.11	0.32	15917.12	-16397.23	0.00
Equity	-637.16	-309.73	2947.55	-0.51	0.31	6284.98	-12062.11	0.00
Property	-74.18	-45.45	380.65	-0.46	0.35	902.29	-1592.42	0.00
Fully Integrated	-3441.62	-4030.40	13993.46	0.09	0.20	45990.98	-48027.38	0.00
				Panel A: Five-year Loss Distribution				
Sovereign	62.51	61.21	2547.93	-0.02	0.13	7824.31	-8632.50	0.00
Institutional	-2028.07	-2057.58	4077.70	-0.01	-0.01	10497.51	-14795.54	0.00
Corporate	-5917.73	-5960.25	9740.86	-0.02	-0.05	25339.82	-36061.48	0.00
Retail	-6957.87	-7067.96	10493.26	-0.07	-0.04	26855.20	-40430.02	0.00
Equity	-4008.44	-2291.68	9361.30	-1.43	3.57	12829.63	-59179.59	0.00
Property	-463.22	-288.62	1143.18	-1.06	2.08	1844.88	-6525.12	0.00
Fully Integrated	-19168.12	-18107.17	31864.71	-0.16	0.05	81244.36	-132269.84	0.00

Comparing the EC calculated under all three methods, the additive capital requirements are highest, in line with our expectations for all three risk measures and both projection horizons (Tables 8 and 9). Under a modular approach, the lowest Economic Capital number is computed. Modular EC is primarily driven by the correlation matrix used to derive cross asset class diversification benefit. For our study, we used the correlation matrix specified by Standard and Poor's (2008) as a benchmark.

EC projections for portfolios which contain a more diversified and less correlated asset mix result in an increased diversification benefit for capital requirements. We conclude that the dependence between various assets in global financial markets should be much higher than conventional assumptions applied in deterministic covariance and correlation calculations. In particular, the equity market and credit market have a dependence on each other, the current credit crisis is evidence of this heavy dependence. Importantly however, economic capital calculated over a one year projection horizon shows an undercapitalisation of around 18% for the modular covariance based approach compared to the fully integrated model (Table 8). Modular economic capital remains more than double the average amount of regulatory capital required under Basel II Pillar 1 when compared to Bank Tier 1 capital average across 51 banks.

C Capital allocation and diversification

As noted earlier, overall capital requirements computed under a fully integrated approach can be allocated down to sub portfolios using Euler Allocation (Tasche 2007). Euler risk contributions $\varrho(X_i|X)$ are calculated for three risk measures and all asset class. The sum of all attributions $\sum_{i=1}^{d} \varrho(X_i|X)$ is equal to total capital requirement for the fully integrated approach. Capital requirements attributed to sub portfolio include respective shares of the total diversification benefit implicit in the fully integrated EC projection.

The differences between modular sub portfolio EC calculation and attributed fully integrated illustrate the diversification benefit effect on a sub portfolio level. Tasche (2007) proposed the computation of diversification indices. Results over one and five year horizons for all three risk measures are shown in Tables 10 and 11. From these table, it is apparent that there is a discount for the contribution to overall capital as measured on a standalone vs contribution basis. Using 99 percent ES over 1 year for example, property requires standalone capital of 770.53 but only 286.01 of capital when it is part of Eurobank's balance sheet structure. Naturally this computation is sensitive to model choice and calibration, but unlike the covariance approach it is possible to isolate the source and cause of the capital diversification.

D A Framework for management and regulatory action

In the modular approach, static correlations are somewhat arbitrary and hard to justify. The fully integrated approach gives a more structural and explanatory way to construct dependence of assets on risk factors for which data and policies are capable of being analysed. The fully integrated approach is more sophisticated because it enables a risk-based allocation of capital and facilitates "use" by isolating worst case paths for EC, and creating a clear framework for informing management actions. The main points taken from our results suggest that:

- Fully integrated capital is greater than modular capital but less than additive capital. See Table 8
- The main contributions to fully integrated capital come from corporate lending and retail advances, this is a function of the effect of balance sheet exposures to these assets - and the credit risk rating embodied in our credit risk calibration. See Table for capital contributions 8, column 2.
- The overall diversification score is low, Table 10. Note - a portfolio with a diversification index of close to 100% would have high levels of risk concentration. This measure reflects diversification potential rather than absolute diversification. In this sense a portfolio with high unrealised diversification potential could be regarded by management as concentrated (Tasche 2007) . Note also that dependence assumptions are quite conservative in the model. We would expect that the inclusion of complex assets and derivative positions would greatly enhance diversification.
- Corporate and retail have low diversification scores, see Table 10, whereas equity and property are higher.
- Conclusions are broadly similar for all risk measures, aditive i the highest with the modular correlated the lowest, fully integrated EC consistently falls between the two.

Table 8 One year Economic Capital requirements and risk measures for the enterprise and individual asset classes

The original balance sheet of EuroBank's portfolio in € million. The one-year standalone risk measures for every asset class calculated in modular approach. The one-year Euler risk contributions $\varrho(X_i|X)$ based on three risk measures for every asst class together with their sum $\sum_{i=1}^{d} \varrho(X_i|X)$. EC Modular is calculated using a variance-covariance matrix overlay. Figures are in € million.

Asset	Balance Sheet	99% 1 year VaR		99% 1 year ES		95% 1 year ES	
	t=0	Standalone	Contribution	Standalone	Contribution	Standalone	Contribution
Sovereign	25614.67	2806.85	3214.85	3110.95	2254.84	2523.13	2068.33
Institutional	31281.68	4129.21	4602.81	4694.06	4480.61	3665.38	3534.87
Corporate	65914.72	10032.46	10115.11	11448.57	11394.58	8609.56	8550.03
Retail	58161.98	9950.04	10312.50	12163.98	12021.01	8970.62	8931.69
Equity	14081.54	4946.09	1980.55	5677.10	5305.00	4483.16	3565.85
Property	2283.87	712.10	-192.54	770.53	286.01	617.68	134.60
Sum	197338.46	32576.75	30033.28	37865.19	35742.05	28869.52	26785.36
EC Additive	–	32576.75	–	37865.19	–	28869.52	–
EC Modular	–	24756.55	–	28744.45	–	21927.07	–
EC Fully Integrated	–	–	30037.00	–	35742.06	–	26785.38

Table 9 Five year Economic Capital requirements and risk measures for the enterprise and individual asset classes

The original balance sheet of EuroBank's portfolio in € million. The five-year standalone risk measures for every asset class calculated in modular approach. The five-year Euler risk contributions $\varrho(X_i|X)$ based on three risk measures for every asst class together with their sum $\sum_{i=1}^{d} \varrho(X_i|X)$. EC Modular is calculated using a variance-covariance matrix overlay. Figures are in € million.

Asset	Balance Sheet	99% 5 year VaR		99% 5 year ES		95% 5 year ES	
	t=0	Standalone	Contribution	Standalone	Contribution	Standalone	Contribution
Sovereign	25614.67	5901.87	1148.53	6898.74	5082.56	5356.10	4290.52
Institutional	31281.68	7407.95	3501.51	8614.26	7714.31	6345.27	5897.07
Corporate	65914.72	15600.69	12394.32	18785.63	18103.49	13896.11	13607.96
Retail	58161.98	15833.99	14513.59	18739.28	18465.21	13974.84	13696.57
Equity	14081.54	10232.94	12613.27	11131.77	7434.16	9020.38	6031.08
Property	2283.87	1401.99	1090.58	1595.18	508.80	1283.42	-4.69
Sum	197338.46	56379.43	45261.81	65764.85	57308.52	49876.12	43518.51
EC Additive	–	56379.43	–	65764.85	–	49876.12	–
EC Modular	–	43006.76	–	50062.16	–	38059.94	–
EC Fully Integrated	–	–	48863.14	–	57041.64	–	43763.47

Table 10 One year diversification indices

The one-year marginal $DI_{\varrho}(X_i|X)$ of every asset class with respect to three risk measures. The one-year "absolute" $DI_{\varrho}(X)$ of whole portfolio with respect to three risk measures.

Asset	Risk Measure		
	99% VaR	99% ES	95% ES
Panel A: Marginal Diversification Index			
Sovereigns	1.145	0.725	0.820
Institutions	1.115	0.955	0.964
Corporates	1.008	0.995	0.993
Retails	1.036	0.988	0.996
Equity	0.400	0.934	0.795
Property	-0.270	0.371	0.218
Panel B: Absolute Diversification Index			
Total Portfolio	0.922	0.944	0.928

Table 11 Five year diversification indices

The five-year marginal $DI_{\varrho}(X_i|X)$ of every asset class with respect to three risk measures. The five-year "absolute" $DI_{\varrho}(X)$ of whole portfolio with respect to three risk measures.

Asset	Risk Measure		
	99% VaR	99% ES	95% ES
Panel A: Marginal Diversification Index			
Sovereigns	0.195	0.737	0.801
Institutions	0.473	0.896	0.929
Corporates	0.794	0.964	0.979
Retails	0.917	0.985	0.980
Equity	1.233	0.668	0.669
Property	0.778	0.319	-0.004
Panel B: Absolute Diversification Index			
Total Portfolio	0.867	0.867	0.877

V Conclusion

At an institutional level we observe materially different results for Economic Capital computations for identical asset classes under modular and fully integrated approaches. Both are methods currently permissible under Basel II, Pillar 2. The modular approach uses a correlation matrix overlay to capture dependence between different asset class risks. By contrast, in the fully integrated approach, correlations are due to mutual dependencies in the driving risk factors in global markets. The advantages (and issues) with the two approaches show that, precisely in stress episodes (like credit contagion) capital derived using a static correlation matrix is discrepant and can only be accordant by accident with the fully integrated framework. In summary the fully integrated approach:

- Avoids theoretical pitfalls and practical limitations of more modular approaches.
- Opens the door to capital allocation, risk-adjusted performance comparison and risk-based enterprise steering, as is the ultimate goal of Enterprise Risk Management.
- Provides a framework for rational (probability-based) stress testing. Our analyses show how we can identify risk factors that "correlate" highly with asset value losses and reveal the factors that are particularly influential in the tail, i.e. we can get a proper handle on tail dependence.
- Allows the isolation of model and calibration effects on EC.
- provides capital results that capture path dependence. Of course the quality of the results is model dependent and this entails a process of continual refinement and backtesting.

In summary, it is clear that different risk measures and approaches give different risk capital. Modular additive Economic Capital requirements are highest, in line with our expectations. Under a modular approach using a static covariance overlay, the lowest capital number is computed, this is not an argument to simply increase the correlations. We find that the fully integrated approach results in (18 percent) higher capital requirements than modular with correlation but lower than the additive modular approach. The critical point being that in the absence of regulatory guidance as to methodology and the treatment of confidence intervals, risk practitioners could simply change modular correlation coefficients and easily “beat” fully integrated capital numbers.

Modular correlation matrices are susceptible to widespread manipulation, opening a “tweaker’s paradise” for retail, commercial and investment bankers. Simply put, in the modular approach, Equation (1) is dependent on the widely misunderstood concept of correlation. In conclusion, we suggest that the inclusion of integrated principles for calculating economic capital would greatly enhance Pillar 2’s application and indeed rejuvenate the relevance of Basel II. An important open question remains as to the ‘regulatory will’ to distinguish macro from micro prudential responsibility. We suggest that doing so is necessary and will greatly clarify the attribution of responsibility in managing future crises.

A Appendix

Table 12 Balance Sheet Assets (December 2006) of 51 European Bank in £ million.

This table displays 51 European banks' balance sheets, modified using detailed accounting notes. The last three rows summarize the total value of the balance sheets, the average which we will use as the EuroBank's balance sheet and the percentages of the composition. This table does not take account of derivative positions.

Ticker	Country	Cash	Claims on Gov.	Claims on Banks	Claims on Corp.	Retail Loans	ABS	Res. Loans	Comm. Real Estate	Prop.	Eq.	Total Assets
AABA-AE	NED	8299	52416	92955	201340	39267	6686	129597	20802	4224	32492	588077
ACA-FR	FRA	10637	104292	112107	235869	33014	13303	108960	17489	4650	64649	704971
AL.-LN	GBR	2390	3308	10177	21310	5148	422	16990	2727	556	2051	65077
BARC-LN	GBR	9753	152788	137133	267327	31579	19489	104223	16729	2492	94711	836224
BB.-LN	GBR	233	1285	7138	15120	3973	164	13111	2104	91	796	44015
BBVA-MC	ESP	8432	17256	38969	83161	18109	2201	59768	9593	3175	10697	251362
BDB-MI	ITA	70	379	702	1511	302	48	997	160	102	235	4507
BEB2-FF	GER	643	9171	13663	28209	5260	1170	17359	2786	469	5685	84415
BKT-MC	ESP	367	1951	4593	9465	2164	249	7141	1146	232	1209	28516
BMPS-MI	ITA	1214	5862	13876	33284	6547	748	21608	3468	1728	3634	91968
BNP-FR	FRA	7983	136077	127131	263670	31220	17358	103036	16538	12318	84352	799684
BPE-MI	ITA	482	1152	4473	9610	2368	147	7816	1255	625	714	28642
BPI-MI	ITA	410	1161	4030	9864	2091	148	6899	1107	638	720	27069
BPSO-MI	ITA	47	503	1543	3212	780	64	2574	413	87	312	9535
BPVN-MI	ITA	781	1688	6791	14698	3616	215	11936	1916	363	1046	43050
BTO-MC	ESP	282	5439	10361	21640	4518	694	14910	2393	634	3371	64241
BVA-MC	ESP	83	129	1662	3563	985	16	3250	522	157	80	10445
CAP-MI	ITA	1076	3241	13104	29128	6984	413	23050	3700	1959	2009	84663
CBK-FF	GER	3456	35778	59916	122667	24615	4564	81239	13040	935	22178	368387
CC-FR	FRA	6208	19986	18740	36038	4627	2549	15272	2451	939	12389	119200
CE-MI	ITA	372	1147	2339	4911	1048	146	3460	555	227	711	14917
CRG-MI	ITA	395	896	2296	5052	1109	114	3660	588	795	555	15460
CVAL-MI	ITA	226	272	1441	3144	798	35	2633	423	313	168	9452
DBK-FF	GER	4722	123463	90187	200227	12744	15749	42058	6751	2795	76533	575229
DPB-FF	GER	684	12066	18031	36991	6954	1539	22952	3684	684	7480	111065
EHY-FF	GER	83	9738	23124	47808	10921	1242	36045	5786	209	6036	140992
GLE-FR	FRA	6305	91368	85510	174873	21054	11655	69487	11153	7373	56638	535417
GUI-MC	ESP	115	120	929	1982	533	15	1760	283	84	75	5896
HBOS-LN	GBR	2846	40670	86156	181455	39158	5188	129237	20744	11264	25211	541928
HSBA-LN	GBR	22068	78148	131680	281316	54266	9968	179099	28747	8393	48443	842129
IKB-FF	GER	33	2387	4617	9486	2026	305	6686	1073	161	1480	28255
ISP-MI	ITA	3645	11322	28495	60369	13695	1444	45198	7255	1973	7019	180414
KN-FR	FRA	513	48165	38662	81407	7126	6144	23517	3775	1145	29857	240311
LANS-AE	NED	35	229	1950	4247	1128	29	3722	597	126	142	12204
LLOY-LN	GBR	3329	21510	49392	105285	23080	2744	76172	12226	8991	13333	316062
MB-MI	ITA	46	2695	4465	9110	1824	344	6021	966	209	1671	27352
MEL-MI	ITA	14	99	379	810	200	13	661	106	3	61	2347
NRK-LN	GBR	956	1670	15968	34112	9306	213	30714	4930	197	1035	99101
OLB-FF	GER	43	151	945	2015	533	19	1758	282	74	93	5913
PAS-MC	ESP	570	240	2400	5166	1403	31	4629	743	229	149	15558
PEL-MI	ITA	30	178	740	1554	396	23	1308	210	114	110	4662
PIN-MI	ITA	31	78	413	900	228	10	754	121	44	49	2628
PMI-MI	ITA	332	1250	3891	8479	1973	159	6513	1045	502	775	24918
POP-MC	ESP	1012	1191	9436	20390	5428	152	17915	2875	477	738	59614
RBS-LN	GBR	6121	61181	123944	266102	55400	7804	182840	29348	18420	37925	789085
SAB-MC	ESP	610	1083	7060	16002	3994	138	13183	2116	662	671	45519
SAN-MC	ESP	13734	37970	78002	167329	35051	4843	115683	18568	6812	23537	501529
STAN-LN	GBR	3934	9317	18484	41136	8194	1188	27044	4341	1108	5775	120521
TRNO-FR	FRA	18	16	238	508	142	2	467	75	10	10	1486
UBI-MI	ITA	273	2089	7212	15069	3737	266	12334	1980	908	1295	45163
UC-MI	ITA	11876	43965	77916	163729	32904	5608	108597	17431	5805	27253	495083
Total		147815	1158533	1595366	3361651	583522	147781	1925841	309117	116477	718158	10064261
Average		2898.33	22716.34	31281.68	65914.72	11441.62	2897.66	37761.59	6061.13	2283.87	14081.54	197338.46
%		1%	12%	16%	33%	6%	1%	19%	3%	1%	7%	100%

B Appendix

Table 13 Model parameters - Interest rates and inflation models calibration

Parameter set presented in Panel A provides an interest rate calibration that is consistent with our best estimates of interest rate volatility and mean reversion (alpha and sigma). The market price of risk parameter ("gamma") was chosen to achieve target long-run expected (unconditional) short rates of 4.5%. The initial yield curve is a direct input to the Extended 2FBK Model. We derive an initial curve by fitting a smooth curve to the available market rates. Parameter sets presented in Panels B and C provide our best-estimate calibration of the joint model for real interest-rates and inflation in which real-rates and inflation individually follow a 2-factor Vasicek model. This calibration is consistent with our best estimates of nominal and index-linked bond volatility and produces yield curves that are consistent with gilt prices (including index-linked gilts) at 30 September 2007. The index-linked coupon bond yields are semi-annually compounded. All spot rates are continuously compounded, where the model impled inflation rate is defined as the difference between model nominal and real short rates and is broadly consistent with RPI forecasts.

	30 Sep 2007	30 Jun 2007
Panel A: Calibrated to Government Nominal Bond Yields Model: Extended 2-factor Black-Karasinski		
r_1 (0)	0.0491	0.0564
r_2 (0)	0.0470	0.0525
α_1	0.3000	0.3000
α_2	0.0750	0.0750
σ_1	0.3000	0.3000
σ_2	0.2500	0.2500
$\mu(rn)$	0.0329	0.0299
γ	0.0162	0.0385
Panel B: Calibrated to Government Real Yield Curve Model: 2-factor Vasicek		
r_1 (0)	0.0217	0.0327
r_2 (0)	0.0193	0.0212
α_1	0.3000	0.3000
α_2	0.0750	0.0750
σ_1	0.0150	0.0150
σ_2	0.0125	0.0125
$\mu(rn)$	0.0110	0.0111
γ	0.0415	0.0411
Panel C: Inflation Expectations Model: 2-factor Vasicek		
r_1 (0)	0.0272	0.0272
r_2 (0)	0.0333	0.0330
α_1	0.2500	0.2500
α_2	0.0500	0.0500
σ_1	0.0050	0.0050
σ_2	0.0100	0.0100
$\mu(rn)$	0.0461	0.0454
γ	-0.0957	-0.0929

Table 14 Quality of Fit - Government Nominal Bond Yields

All yields are semi-annually compounded. Average Difference is the average difference in market and model yields over the bonds in each term band.

Term Band	No. Bonds	Mean Model Yield	Average Difference (bp)
<1	4	5.08	14.3
1-2	4	5.08	4.6
2-3	4	5.06	6.9
3-4	4	5.05	2.9
4-5	4	5.04	3.3
5-7	8	5.01	1.3
7-10	12	4.96	1.6
10-15	20	4.87	1.4
15-20	20	4.75	0.6
20-25	20	4.63	0.7
25-30	17	4.53	1.7
30-50	19	4.27	0.9
50+	0		0.0

Sources: Bank of England, Bloomberg

Table 15 Quality of Fit - Government Real Yield Curve and Inflation Expectations

All yields are semi-annually compounded. Average Difference is the average difference in market and model yields over the bonds in each term band.

Term	Government real spot	Model	Difference (b.p)
Panel A: Quality of Fit - Government real yield curve			
2.5	1.90	2.07	17
3.5	1.98	2.03	5
5	2.01	1.96	-5
6	1.99	1.92	-7
7	1.95	1.88	-8
8	1.90	1.83	-7
9	1.85	1.79	-6
10	1.79	1.74	-5
12	1.67	1.66	-2
15	1.50	1.53	2
20	1.27	1.32	5
25	1.08	1.14	5
Panel B: Quality of Fit - Inflation linked			
30.1	1.04	1.03	-1
48.1	0.84	0.66	-18
Panel C: Quality of Fit - Inflation expectations			
2.5	4.97	4.96	-1
3	4.96	4.97	1
3.5	4.96	4.97	1
4	4.97	4.98	1
4.5	4.97	4.98	1
5	4.98	4.98	0
6	4.99	4.98	-1
7	4.99	4.98	-1
8	4.98	4.97	-1
9	4.97	4.96	-1
10	4.95	4.94	-1
12	4.90	4.90	0
15	4.81	4.82	1
20	4.64	4.65	1
25	4.49	4.47	-2

Sources: Bank of England, Bloomberg

Table 16 **Stochastic spread model Government Calibration**

The table summarizes the calibration parameters of our credit model, based on Jarrow - Lando - Turnbull (JLT) model, consistent with our best estimates of long-term transition probabilities, spread volatility and corporate bond spreads at September 30, 2007. To fit the model, we target our fit to the market spread on a 7-year A rated bond only.

	Calibrated to Government Bonds Model: Jarrow-Lando-Turnbull	
	30 Sep 2007	30 Jun 2007
α	0.1000	0.1000
σ	0.7500	0.7500
μ	3.0000	3.0000
π	4.0743	2.7496
No. of Corp. Bonds	527	533
AAA	139	137
AA	165	162
A	139	150
BBB	84	84

Source: Bloomberg

Table 17 **Stochastic spread model Government Calibration**

The table displays the difference in Jarrow - Lando - Turnbull model and market spreads for 2, 7, 15 and 20 year maturities.

	Model - Market Spread (bps)			
Term	AAA	AA	A	BBB
2	-56	-17	-21	82
7	-35	7	0	46
15	5	26	0	9
20	9	22	-4	-5

Source: Bloomberg

References

Anderson, N., Brennan, S., Coppins, G., Eklund, B., Noss, J., Vause, N., and Webber, L. (2008). A structural model for banks. Bank of England Working Paper.

Artzner, P., Delbaen, F., Eber, J., and Heath, D. (1999). Coherent measures of risk. *Math. Finance*, 9:203–228.

Basel Comittee (2006). *Results of the fifth quantitative impact study (QIS 5).* Basel Committee on Banking Supervision.

Brunnermeier, M., Crockett, A., Goodhar, C., Persaud, A. D., and Shin, H. (2009). The Fundamental Principles of Financial Regulation. *Geneva Reports on the World Economy – Preliminary Conference Draft 11.*

Crouhy, M., Galai, D., and Mark, R. (2000). A comparative analysis of current credit risk models. *J. Banking Finance*, 24:59–117.

Denault, M. (2001). Coherent allocation of risk capital. *Journal of Risk*, 4(1).

Financial Services Authority (2007). Principles-based regulation. FSA Press Release.

Financial Stability Forum (2008). Report of the financial stability forum on enhancing market and institutional resilience. *Financial Stability Forum.*

IASB Expert Advisory Panel (2008). Measuring and disclosing the fair value of financial instruments in markets that are no longer active. *International Accounting Standards Board.*

IFRI Foundation and CRO Forum (2007). Insights from the joint IFRI/CRO Forum survey on Economic Capital practice and applications. KPMG Business Advisory Services.

Jarrow, R., Lando, D., and Turnbull, S. (1997). A Markov model for the term structure of credit risk spreads. *Rev. Finan. Stud.*, 10:481–523.

Kalkbrener, M. (2002). An axiomatic approach to capital allocation. Preprint, Deutsche Bank AG, Frankfurt.

Kirchner, A., Kretzschmar, G., and McNeil, A. (2009). Was the 2008 financial crisis a century event? an integrated framework for interpreting economic capital under stressed conditions. Barrie and Hibbert Working Paper.

McNeil, A., Frey, R., and Embrechts, P. (2005). *Quantitative Risk Management: Concepts, Techniques and Tools*. Princeton University Press, Princeton.

McNeil, A., Kretzschmar, G., and Kirchner, A. (2008). The case for fully integrated models of Economic Capital. Working paper.

Robert, C. and Casella, G. (1999). *Monte Carlo Statistical Methods*. Springer, New York.

Standard and Poor's (2008). Risk-adjusted capital framework for financial institutions.

Tasche, D. (1999). Risk contributions and performance measurement. Preprint, TU-Munich.

Tasche, D. (2000). Conditional expectation as a quantile derivative. Preprint, TU-Munich.

Tasche, D. (2002). Expected shortfall and beyond. *J. Banking Finance*, 26:1519–1533.

Tasche, D. (2006). measuring sectoral diversification in an asymptotic multifactor framework. *Journal of Credit Risk*, 2(3):33–55.

Tasche, D. (2007). Capital allocation to business units and sub-portfolios: The Euler principle. Working Paper.