Capital allocation for operational risk

Received (in revised form): 27th October, 2008

Michael Brunner*
is a member of the team responsible for developing and maintaining UniCredit Group's operational risk capital model. This includes capital calculation, regulatory and economic capital allocation, and regulatory notification. Prior to joining the holding company of UniCredit Group one year ago, Michael worked as an IT consultant at HVB IS, where he was responsible for implementation and maintenance of the central operational risk management tool. Michael has a PhD in physics and a degree in business economics. He is the author of several articles.

Fabio Piacenza
is a senior quantitative analyst in operational risk management at UniCredit Group in Milan. He has been working in operational risk management for the firm since 2002. He contributed to the development of the firm's advanced measurement approach (AMA) model by helping to build the statistical methodology and implement the codes for calculating the AMA capital requirement. A graduate in mathematics, he has written a number of articles and one book on topics related to operational risk.

Fabio Monti
is a senior quantitative analyst in operational risk management at UniCredit Group in Milan. He joined the group's operational risk management team in 2007, working mainly on the development of the Advanced Measurement Approaches model. A graduate in physics, before joining UniCredit he worked as a research assistant at the University of Milan's General and Applied Physics Institute. He is the author of several articles on physics.

Davide Bazzarello
is Group Head of Operational Risk at UniCredit Group. He joined the group's risk management area in 2000, subsequently moving to market risk control for Central and East European countries. In 2003 he helped to set up the firm's operational risk function, running the research and development team until the advanced measurement approach application went live. Davide has written a number of papers on operational risk modelling and insurance.

*UniCredit Group, Operational Risk Management, Corso Italia 3, 20122 Milan, Italy
Tel: +39 02 7292 9341; Fax: +39 02 7292 9496; E-mail: michael.brunner@unicreditgroup.eu

Abstract The allocation of consolidated operational risk capital to different business units or legal entities is a problem that up to now has not received widespread investigation. Nevertheless, this is an important problem, as the Basel II regulation and its annotations stress a number of demands for the allocation of operational risk capital in lieu of standalone calculations for all legal entities within banking groups. This paper presents a simple, yet statistically sound, framework to help cope with the technical requirements of the regulatory context.

Keywords: *capital allocation, operational risk, loss distribution approach, Basel*

INTRODUCTION

After the adoption of the Basel II framework[1] in many jurisdictions and the subsequent run for advanced measurement approach (AMA) compliance, many banking institutions are now facing an increasingly difficult task, namely, how to get operational risk management and measurement to work effectively. One of the key elements to achieve this goal is to steer regulatory and economic capital properly at a consolidated and local level. One important aspect in this context is the definition of an efficient allocation mechanism.

Within the financial industry, institutions have historically tended to focus a lot on measurement methodologies such as loss distribution approach (LDA) models or scenario based approach (SBA) models in order to hold, at a consolidated level, sufficient capital to protect against severe operational risk losses. Until now, less attention has been paid to allocation mechanisms, even though these are as crucial as the overall model. (Indeed, due to the home-host regulations of Basel II,[2,3] the allocation mechanism could indeed be more important than the actual consolidated model for local regulators of international banking groups.)

Guidelines for benchmarking the allocation mechanism should address business requirements, which can be roughly summed up as:

- risk sensitivity;
- balanced, clear and susceptible risk drivers; and
- simplicity.

In addition, an extensive set of regulatory requirements and recommendations laid out by the Basel Committee on Banking Supervision must also be taken into account.[3] Although these specifically pertain to stability goals within the international environment, the general principles should also be considered as applicable to banks and financial groups more generally, notably as concerns the relationship between the banking group and its subsidiaries. To a large extent, these requirements mirror and define more precisely the abovementioned requirements:

- *Risk sensitivity:* The allocation mechanism should reflect the operational risk profile of the subsidiary, with special attention to the legal entity perspective.
- *Adequacy of capital and subsidiary level management support:* It is the board's responsibility to understand and manage the operational risk profile of the single subsidiary, including any diversification benefits included in the capital figures. The allocated capital should represent the marginal contribution of the legal entity to the group.
- *Part of Pillar I:* 'The allocation mechanism is an integral part of a bank's AMA'.
- *Implementation:* The allocation mechanism should be kept as simple as possible, balancing accuracy and complexity.
- *Stability:* Both allocated capital and the allocation mechanism itself should be kept relatively stable.
- *Documentation, internal review and supervisory assessment:* The documentation of the allocation mechanism must be adequate and readily available for necessary internal, external and regulatory validation and examination.

This paper presents a pragmatic approach that addresses both the business requirements and the regulatory requirements in the context of operational risk capital allocation. The final point in the above list is to a large extent organisational and beyond the scope of this rather technical analysis. One should however bear in mind that simplicity in the algorithm itself will substantially reduce the effort required to be invested here.

REGULATORY APPROACH AND DIVERSIFICATION

Within the Basel II regulatory framework,[1] institutions can decide to calculate their capital requirements based on the basic indicator approach (BIA), the standardised approach (TSA), or by the advanced measurement approach (AMA). Whereas both TSA and BIA are based on the volume indicator of the gross income of the institution, with very limited discretion for either the banking group or the regulators, institutions have a great deal of freedom concerning the development and appliance of their AMA.

By construction, neither BIA nor TSA are affected substantially by diversification effects within the banking group. Additionally, the regulatory framework typically requires BIA and TSA banks to hold capital on a standalone basis (ie the calculations are based on entity rather than consolidated group-level figures), so even in the event of a significant diversification effect at the group level, the problem of top-down capital allocation should not arise for these banks.

On the other hand, AMA capital figures are often obtained at a consolidated level, and are influenced by diversification among the different group entities, in addition to other complex effects, such as the mixing of severity distributions within operational risk cells that cannot be attributed to one single bank. These figures might be generated by calculating the capital requirement according to a common, group-wide model in the first place, or by aggregating the standalone figures for all the different legal entities. (The regulatory framework provides a set of conditions and requisites for applying an allocation mechanism on a consolidated capital number as opposed to using standalone figures for every single bank in the banking group.[1–3]) In both cases, the diversification benefit the subsidiaries have within the group must be allocated back to them in a balanced, even-handed and consistent way. Although the present paper only considers allocation to legal entities, the allocation of operational risk capital to, for example, different products, processes and business lines should take place along similar lines.

The granularity to which operational risk capital can be reasonably disaggregated is coarser than that of other types for two reasons. First, any statistical analysis on small units is hindered by the scarcity of available data. Secondly, many relevant losses cannot be understood on the level of very small units at all, because they are triggered by simultaneous failures of processes and controls in multiple organisational parts.

A FRAMEWORK FOR A BALANCED ALLOCATION MECHANISM

Proposed algorithm

The algorithm presented in the following tries to reconcile the potentially conflicting objectives of simplicity, risk sensitivity and fair balance. To obtain the first two features, the algorithm adheres as far as possible to the group-level AMA model, meaning that there is no additional complexity, and the risk sensitivity of the group-wide AMA is the correct one by assumption. Fair balance in the context of this algorithm is attributed to the fact that each individual subsidiary of the banking group should receive an adequate part of the diversification benefits of the banking group.

To illustrate the requirement of adequate allocation, a banking group consisting of L banks that are obliged to hold capital on their own is considered. The banking group is using an AMA, and is allowed to fully distribute the advantages of diversification back to its subsidiaries, and every subsidiary of the banking group is allowed to use the diversification effect for their individual capital requirement.

The banking group's capital C is derived from an AMA model, which can always be stated as:

$$C = C(\mathbf{R}, V), \tag{1}$$

where $\mathbf{R}$ is a set of parameters to describe the risk profile of the banking group, whereas V is the overall size of the banking group. According to the definition followed here, the parameter $\mathbf{R}$ must not contain information about the size of the bank ($d\mathbf{R}/dV = 0, \forall \mathbf{R}, V$). Typically, a change of variables will be required to fulfil the independence of $\mathbf{R}$ and V.

Using the same notation, the capital $\bar{C}_i$ for a single subsidiary i on a standalone basis, before any group-level diversification effect, is given by the same model as:

$$\bar{C}_i = \bar{C}_i\ (\mathbf{R}_i, V_i), \tag{2}$$

where the size $\sum_{i=1}^{L} V_i = V$ is required, ie the overall size of the banking group is identical to the sum of the sizes of its L subsidiaries. As the banking group is allowed to fully distribute diversification effects for the allocated capital C_i back to the single subsidiary, it is further necessary for the following equation to hold:

$$\sum_{i=1}^{L} C_i = C\left(< \sum_{i=1}^{L} -\bar{C}_i\right) \tag{3}$$

By assumption, the sum of the capital allocated to the single legal entities is equal to the overall capital of the banking group,[5] which in turn is smaller than the sum of the standalone capital. (Diversification can theoretically lead to the case $C > \sum - \bar{C}_i$. The allocation of a detriment due to diversification effects will probably not be pursued in practice, however, as the subsidiaries will likely opt for a standalone calculation for their individual requirement.)

Additional to the above, the allocation mechanism shall consider the diversification effect for all banks with respect to the whole group, and not only the diversification effects the subsidiary has within itself. The allocation mechanism is considered balanced when a subsidiary is not (dis)-favoured because of its size.

Another formulation for this requirement of the allocation mechanism is a framework, where for the overall allocated capital it is (as far as possible) irrelevant whether multiple banks within the banking group are considered together or separately:

$$\forall i, j : C_i + C_j \equiv C_{i+j}, \tag{4}$$

or as a special case $\mathrm{C}_{n \times i} = nC_i$. From this, the demand is derived, and the allocated capital should, all other parameters $\mathbf{R_i}$ unchanged, scale linearly with the size V_i. The requirement of Equation (3), that the consolidated capital C shall be exactly distributed among the subsidiaries, is contained as a limiting case in the stronger requirement of Equation (4).

The definition of the parameters $\mathbf{R_i}$ and of the sizes V_i are dependent on the specific AMA model of the banking group.

The importance and consequence of this requirement in practice become obvious when one considers the frequent legal and structural reorganisations that typically take place in today's financial industry. For controlling and planning purposes, and all related internal and external communication objectives, it is clearly of great advantage, when, after reorganisation, the operational risk capital of a unit is approximately equal to the operational risk capital of the old units that merged into the new one. This is even more true considering the effect that, in an allocation mechanism, the capital requirement of an unaffected subsidiary in the banking group should not be affected by organisational changes elsewhere.

Unlike market risk (and to some extent in credit risk), the diversification effects in operational risk are, in practice, not actively managed properties of a portfolio, but are mainly attributed to the size of the subsidiary. As such, it is not meaningful to treat diversification of operational risk in the same manner as other types of risk. Business units cannot and should not be provided with incentives for diversification effects within their own unit.

One possible allocation mechanism, fulfilling Equations (3) and (4), is an allocation by a properly defined volume indicator such as gross income or BIA/TSA capital. However, the requirement of risk sensitivity is not fulfilled sufficiently in these approaches. On the other hand, an allocation of AMA capital on a pro rata basis of the standalone AMA capital $\bar{C}_i$ alone will in general lead to a violation of Equation (4), as typically $\bar{C}_i + \bar{C}_j > \bar{C}_{i+j}$ due to diversification effects. Therefore, the capital allocation to units i and j based on C_i and C_j would in sum be larger than the capital allocation to a unit $i+j$ based on the standalone capital C_{i+j}. The same is true for other allocation mechanisms proposed in the literature. For example, an allocation by expected shortfall based on a standalone calculation, despite its other advantageous properties, does not fulfil the crucial request of adequate allocation in the definition presented here.[6]

Due to the fact that the AMA model of the banking group is by definition considered optimum, an allocation of consolidated capital by a very similar model as used for the calculation of C itself is sought. Additionally, using a similar model for capital calculation and allocation purposes is most preferable for transparency and consistency reasons. Based on these objectives, the following allocation mechanism is proposed:

- the consolidated capital $C(\mathbf{R}, V)$ for the whole banking group with size V is derived;
- for each bank, an *adjusted standalone* capital is calculated and given by

$$\tilde{C}_i = \bar{C}((\mathbf{R_i}, V))V_i/V \tag{5}$$

- each subsidiary is allocated capital according to the formula:

$$C_i = \frac{\tilde{C}_i(\mathbf{R_i}, V_i, V)}{\sum_{j=1}^{L} \tilde{C}_j(\mathbf{R_j}, V_j, V)} C \tag{6}$$

The figure in $\tilde{C}_i$ can be interpreted in the following way: assuming the banking group as a whole has exactly the same risk profile $\mathbf{R_i}$ as subsidiary i, then the pro rata share of risk capital for the subsidiary i would be exactly $\tilde{C}_i$. As the risk profile throughout the banking group is not exactly the same, the capital allocated to the single subsidiary is different, namely C_i. The figure C_i is an excellent approximation to the marginal contribution of subsidiary i to the capital of the banking group in the regulatory sense.[2]

Using this algorithm, Equation (4) is fulfilled whenever $\mathbf{R_i} = \mathbf{R_j}$ by construction, so the desired behaviour is attained, at least in the limiting cases of banks sharing the same risk profile except for their size. When $\mathbf{R_i} \neq \mathbf{R_j}$ the strong requirement, $C_i + C_j \equiv C_{i+j}$, will typically only be fulfilled approximately, depending on the exact way the parameter set $\mathbf{R_{i+j}}$ is derived from $\mathbf{R_i}$ and $\mathbf{R_j}$. The weaker requirement of Equation (3) is taken into account by construction. In line with expectations, in the limiting case $\mathbf{R_i} = \mathbf{R} =$ const $\forall_i$, the allocation mechanism reduces to an allocation by the relative volumes V_i (see Equation (5)).

Application to a simple loss distribution approach

For exemplification and application to a relevant example, a simple loss distribution approach (LDA) is considered. Here the required capital number C is derived (eg as a certain quantile) from an aggregated loss distribution defined by a set of random variables S given by:

$$S = \sum_{n=1}^{N} X_n. \qquad (7)$$

The random variable $N = N(\lambda)$ represents the frequency distribution (eg a Poisson distribution with an expected number of events per year given by λ), the random variable $X_n = X_n(\mathbf{R})$ is derived from the severity distribution $S(\mathbf{R})$. This is typically a heavy-tailed distribution such as the generalised Pareto distribution (GPD) (for the motivation of such a model see the literature[6,7]):

$$S(x) = \frac{1}{\beta}\left(1 + \frac{\xi(x-u)}{\beta}\right)^{(-1/\xi)-1}, \qquad (8)$$

where $\mathbf{R}$ is identified with (β, ξ, u) and λ. Defining the new parameter frequency per size $\nu = \lambda/V$, $\tilde{C}_i$ can be derived from the aggregate loss distributions given by:

$$\begin{aligned}\tilde{S}_i(\mathbf{R_i}, V_i, V) &= \bar{S}_i(\mathbf{R_i}, V)(V_i/V) \\ &= \left(\sum_{n=1}^{N(\nu_i V)} X_i(\beta_i, \xi_i, u_i)\right)(V_i/V) \qquad (9)\end{aligned}$$

where the size V and the vector $\mathbf{R_i} = (\xi_i, \beta_i, u_i, \nu_i)$ contain all the parameters of the LDA. The allocated capital to each subsidiary i is subsequently given by Equation (6). The underlying assumption in this example is that the number of losses scales linearly with an appropriately defined volume indicator V_i of the bank, whereas no other parameters are affected by it. Clearly, this definition of $\mathbf{R_i}$ and V implies a certain interpretation of the model parameters of the LDA. It should be pointed out that the assumption is not that control structure and business model, and therefore the risk profile $\mathbf{R_i} = (\xi_i, \beta_i, u_i, \nu_i)$ do not change with size of the subsidiary V_i in reality. The assertion is that an increase in size while keeping the old risk profile should be identified with a change in the frequency. This assumption is self-evident when two banks with identical risk profiles are considered together. When the risk profile of the joint entity does not change (and it will not, when the merger is only done *pro forma* for the calculation of the operational risk capital, but not in organisational practice), the frequency of the merged company will obviously be exactly the sum of the two original companies. Dependencies of the severity distribution on the firm size, that are indeed observed empirically,[8–10] are changes of the risk profile $\mathbf{R_i}$. Such changes to the empirically observed risk profile could reflect the potential to cover new markets and business models and accordingly the acceptance of the associated operational risks. At the same time, an increase in size could allow for the implementation of additional control structures that would be out of scope for a smaller banking group.

More complex assumptions could be established, although the allocation mechanism should not try to include minor or speculative effects on the cost of increasing complexity. For the size of the subsidiary V_i, the TSA capital (or gross income figure) can serve as a useful proxy, but in specific cases, another volume indicator could be more relevant. For example, the number of employees can be useful for service subsidiaries such as IT and back office, where the gross income figure results from different constituents than for 'normal' banks.

One very useful aspect of using gross income or TSA capital in practice is their general acceptance by the regulatory and business community. In fact, it is the distinguished starting point mentioned in the regulatory context.[1] Due to the additional finding that regression analysis on external data using a large variety of different microeconomic covariates does not suggest a different approach,[8] and the property of TSA capital being found to be normally invariant to structural changes, this paper considers it reasonable to identify the TSA with the size of a legal entity. In cases when the gross income falls below zero in parts of the group, the sum of the TSA capital does depend on the structure; this special case is, however, beyond the scope of the present discussion.

Simplification of the allocation mechanism

Although the above mechanism is highly consistent with the desired behaviour, it adds an additional layer of procedural complexity to the overall framework, namely the necessity to calculate and explain the adjusted standalone capital $\tilde{C}_i$. The illustration of yet another capital number to the management of all involved subsidiaries, local regulators and the market can, however, be problematic.

In practice the following simplifying approximation for the evaluation of the adjusted standalone capital can be useful:

$$\tilde{C}_i = \bar{C}(\mathbf{R_i}, V)V_i/V \approx \bar{C}_i(\mathbf{R_i}, V_i)f(V_i, V). \tag{10}$$

The allocation is then based on the non-modified standalone AMA capital of the bank, and a scaling factor that only depends on the size of the subsidiary and the banking group, but not on the risk profile. To be expedient, the function f should have the following properties:

$f(V, V) = 1$, $f(V_i, V) \geq 0$, and $\partial f(V_i, V)/\partial V_i \geq 0$.

From a process-related point of view, the following two advantages arise. First, the standalone capital is a well-understood figure, which is useful at the banking group and individual level, and is thus to be already known.[2] Furthermore, the scaling function $f(V_i, V)$ can be kept constant for longer time periods without a significant loss of accuracy, which adds predictability and continuity to the allocation mechanism. The equation above can be rearranged to $\bar{C}_i(\mathbf{R_i}, V) \approx \tilde{C}_i(\mathbf{R_i}, V)/f(V_i, V)$, presenting the standalone capital of a subsidiary as a product of one part capturing the specific risk profile $\tilde{C}_i(\mathbf{R_i}, V)$, and another part showing the effect of (lost) diversification effects.

As an example, the simple LDA as defined in Equation (7) is reconsidered. Based on the one event approximation,[11,12] fixing the quantile considered for regulatory purposes at $(1-\kappa) = 99.9$ per cent, and making additional approximations due to $(\lambda_i/\kappa)^{\xi_i} \gg 1$, and $\beta_i/\xi_i(\lambda_i/\kappa)^{\xi} \gg u_i$, one arrives at:

$$\bar{C}_i \approx u_i + \frac{\beta_i}{\xi_i}\left[\left(\frac{\nu_i V_i}{\kappa}\right)^{\xi_i} - 1\right] \approx \frac{\beta_i}{\xi_i}\left(\frac{\nu_i V_i}{\kappa}\right)^{\xi_i}$$

$$\tilde{C}_i \approx \left\{u_i + \frac{\beta_i}{\xi_i}\left[\left(\frac{\nu_i V}{\kappa}\right)^{\xi_i} - 1\right]\right\}\frac{V_i}{V} \approx \frac{\beta_i}{\xi_i}\left(\frac{\nu_i V}{\kappa}\right)^{\xi_i}\frac{V_i}{V}. \qquad (11)$$

The function $f(V_i, V)$ is therefore approximately given by:

$$f(V_i, V) = \frac{\tilde{C}_i}{\bar{C}_i} \approx \left[\frac{\beta_i}{\xi_i}\left(\frac{\nu_i V}{\kappa}\right)^{\xi_i}\frac{V_i}{V}\right] \Big/ \left[\frac{\beta_i}{\xi_i}\left(\frac{\nu_i V_i}{\kappa}\right)^{\xi_i}\right] = \left(\frac{V_i}{V}\right)^{1-\xi_i}. \qquad (12)$$

Typically, the tail parameter ξ in LDA models is mainly driven by external data, which are identical for all subsidiaries; thus, with $\xi_i \approx \xi$, $\forall_i$ one ends with the banking group-wide scaling function:

$$f(V_i, V) = \left(\frac{V_i}{V}\right)^{1-\xi}. \qquad (13)$$

One possibility to verify the above scaling law is a test on the equation

$$\sum_{j=1}^{L} \tilde{C}_j(\mathbf{R_j}, V_j, V) \simeq C$$

which should hold approximatively when the risk profiles of the different subsidiaries R_j are not too different throughout the banking group.

To verify the above algorithm in practice, the adjusted standalone capital figures for the business and support divisions of UniCredit Group (eight divisions with relative sizes ranging from 4 to 30 per cent) have been analysed. The difference of the sum of the adjusted standalone capital to the consolidated capital figure was on average around 10 per cent for the seven single Basel event types. The sum of the nonadjusted standalone capital on the other hand was on average 90 per cent higher than the consolidated capital. As the risk profile of the different divisions is not exactly the same, and the derived scaling law is subject to a set of approximations, a deviation of 10 per cent is an excellent result compared with the result of the naïve standalone calculation, substantially supporting the presented approach empirically.

Alternatively, the parameter here could be set to enforce the equation $\sum_{j=1}^{L} \tilde{C}_j(\mathbf{R_j}, V_j, V) = C$. Although the parameter here is not backed by statistical analysis, the possibility to allocate exactly the adjusted standalone capital to the legal entities could be very convenient in practice.

Having the diversification effect separated into the function $f(V_i, V)$ opens another potentially interesting option. Even when, unlike with the presented example, there is no possibility to analytically extract some approximative scaling laws for the diversification effects within an approach, typically there is some expert opinion/assumption regarding how operational risk diversifies within a banking group. This expert opinion easily translates into an approximation for f, so a balanced allocation mechanism is feasible even for qualitative approaches, as long as a standalone calculation exists.

The soundness of $f(V_i, V)$ can further be verified statistically by joining together or splitting up arbitrary parts of the banking group to form virtual single banks. Although the number of data points that can be obtained this way is very large, one should bear in mind that these points are highly correlated with each other, limiting the statistical analysis. Technically such an analysis could be performed by calculating the standalone capital for a large number of groups of subsidiaries of the banking group, including the possibility to include multiple copies of one subsidiary in the sample. Then regression analysis and statistical tests can be applied to verify the validity of the diversification model f and the setting of its parameters.

It should further be pointed out that the diversification effect between companies should in principle not depend on the specific AMA used within the banking group. Therefore, when a banking group is accepting the validity of the simple LDA presented above, then Equation (13) should be a reasonable approximation for the diversification effect within the group, even when the AMA model is not based on an LDA.

Finally, the technical main recommendations of the regulatory community, namely risk sensitivity, adequacy and simplicity of the capital allocation mechanism,[2] are reconsidered briefly. As pointed out, the presented allocation algorithm is, apart from the size renormalisation, exactly identical to the capital model on the consolidated level. It is therefore perfectly integrated into the consolidated AMA model and is providing a capital allocation scheme that is to a large extent invariant to structural organisational changes. Furthermore, the algorithm allows for the quantification of diversification effects in a very simple, yet stringent way.

CONCLUSION AND OUTLOOK

This paper presented a framework to allocate diversified operational risk capital to single business units. The framework has two main features: it can exactly mirror the risk sensitivity of the model at the consolidated level, and, in the event of the legal entity's risk profile being (pairwise) identical, it can reduce to an allocation by a volume indicator. At the same time, the algorithm gives explicit notice of the diversification effects included in the capital numbers of the single legal entities.

An analysis of UniCredit Group data shows that both the algorithm and its simplified version hold reasonably well in practice.

It would be interesting to extend the empirical analysis performed in this paper to other banking groups, especially ones that are not using an LDA model. This would give insight into the diversification effect of operational risk, which is at least implicitly applied by all banks using an LDA model similar to the one presented here, consistent both with other approaches for modelling operational risk and with empirical data.

NOTE

This paper reflects the personal opinion of the authors and does not necessarily represent UniCredit Group's approach.

References

1 Basel Committee on Banking Supervision (2006) 'International Convergence of Capital Measurement and Capital Standards: A Revised Framework — Comprehensive Version', Bank for International Settlements, Basel.

2 Basel Committee on Banking Supervision (2007) 'Principles for Home-Host Supervisory Cooperation and Allocation Mechanisms in the Context of Advanced Measurement Approaches (AMA)', Bank for International Settlements, Basel.

3 Basel Committee on Banking Supervision (2006) 'Home-Host Information Sharing for Effective Basel II Implementation', Bank for International Settlements, Basel.

4 Kuritzkes, A. and Schuermann, T. (2008) 'What we know, don't know and can't know about bank risk: A view from the trenches', in Diebold, F. X., Doherty, N. and Herring, R. J. (eds) 'The Known, The Unknown and The Unknowable in Financial Risk Management', Princeton University Press, Princeton, NJ, available at: http://www.newyorkfed.org/research/economists/schuermannkuritzkes_Schuermann_KUU_23Mar2008.pdf (accessed February 2009).

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

6 Aue, F. and Kalkbrenner, M. (2006) 'LDA at work: Deutsche Bank's approach to quantifying operational risk', *Journal of Operational Risk*, Vol. 1, No. 4, pp. 49–93.

7 Moscadelli, M. (2004) 'The modeling of operational risk: Experience with the analysis of the data collected by the Basel Committee', Technical Report 517, Banca d'Italia, Rome, Italy.

8 Chernobai, A. S., Jorion, P. and Yu, F. (2008) 'The determinants of operational losses', working paper, Syracuse University, available at: http://www.fma.org/Texas/Papers/Chernobai.Jorion_Yu-TheDeterminantsOfOperationalLosses.pdf (accessed February 2009).

9 Colombo, A. and Quartu, R. (2008) 'Scaling in op risk data', *OpRisk & Compliance*, Vol. 9, No. 8, August, pp. 42–53.

10 De Fontnouvelle, P., DeJesus-Rueff, V., Jordan, J. and Rosengren, E. (2003) 'Capital and risk: New evidence on implications of large operational losses', *Journal of Money, Credit and Banking*, Vol. 38, No. 7, pp. 1819–1846.

11 Böcker, K. and Klüppelberg, C. (2005) 'Operational VaR: A closed form approximation', *Risk Magazine*, Vol. 18, No. 12, pp. 90–94.

12 Böcker, K. (2006) 'Operational risk: Analytical results when high severity losses follow a generalized Pareto distribution (GPD) — A note', *The Journal of Risk*, Vol. 8, No. 4, pp. 117–120.

