Practices and issues in operational risk modeling under Basel II

Lithuanian Mathematical Journal, Vol. 51, No. 2, April, 2011, pp. 180–193

PRACTICES AND ISSUES IN OPERATIONAL RISK MODELING UNDER BASEL II

Paul Embrechts and Marius Hofert [1]

RiskLab, Department of Mathematics, ETH Zurich, 8092 Zurich, Switzerland
(e-mail: embrechts@math.ethz.ch; marius.hofert@math.ethz.ch)

Received December 9, 2010

Abstract. We provide an introduction and overview to operational risk modeling according to the Basel II legal documents and summarize observed practices and issues as well as suggested approaches for measuring and quantifying operational risk.

MSC: 91G99, 62P05

Keywords: operational risk modeling, Basel II, practices and issues

1 INTRODUCTION

The *Basel II framework* (Basel II), initially published in June 2004, is the second of the *Basel Accords* that provide recommendations on banking regulations. These accords are issued and updated by the *Basel Committee on Banking Supervision* (the Committee). Basel II consists of a three-pillar structure, the pillars being:

(1) *Pillar I*: minimum capital requirements (requirements for the calculation of the regulatory capital for credit, operational, and market risk in order to ensure that a bank holds sufficient capital for these risks);

(2) *Pillar II*: supervisory review process (supervisors should review bank's internal capital adequacy assessments, take appropriate actions to ensure that banks have adequate capital support, and encourage them to use good techniques for monitoring and managing their risks);

(3) *Pillar III*: market discipline (transparency requirements that require banks to publicly provide the information needed by third parties to form an accurate view of their capital adequacy).

The main risk classes addressed in Basel II are

(1) *credit risk* (also known as *default risk*): an investor's risk of loss arising from a borrower who fails to meet its obligations in accordance with agreed terms;

(2) *operational risk*: the risk arising from execution of company's business functions;

(3) *market risk*: the risk that a portfolio value will decrease due to the change in value of market risk factors.

[1] The author (Willis Research Fellow) thanks Willis Re for financial support while this work was being completed.

In what follows, we consider operational risk under Pillar I and present common practices and issues about operational risk modeling. In order to adhere to the legal requirements, the information is mainly drawn from publications of the *Bank for International Settlements* (BIS), including the documents [1, 2, 4]. The article should therefore be viewed as a summary of important aspects of these documents. For scientific work addressing various mathematical issues on operational risk, see, e.g., [5, 6, 7, 8, 9, 10, 12], and references therein.

The article is organized as follows. Section 2 presents three approaches for operational risk modeling according to Basel II. Section 3 gives an overview over issues, observed range of practice, and supervisory observations according to the 2008 loss data collection exercise. Addressed are internal governance (Section 3.2), data issues (Section 3.3), and modeling and quantification issues (Section 3.4). Section 4 concludes.

2 OPERATIONAL RISK MODELING IN BASEL II

According to [1, p. 144], operational risk is defined as follows:

DEFINITION 1 [Operational risk]. *Operational risk* (OR) is the risk of a loss resulting from inadequate or failed internal processes, people and systems, or from external events. This definition includes legal risk but excludes strategic and reputational risk.

Basel II presents three approaches for calculating the OR capital required for a bank to hold in a one-year period. These are, in increasing order of sophistication, the basic indicator approach, the standardized approach, and the advanced measurement approach. In what follows, we give an overview over these approaches.

2.1 Basic indicator approach

Let t denote the time in years for which the risk capital charge is to be calculated, GI_{t-k} the annual gross income in year $t-k$ (*gross income* is net interest income plus net noninterest income), $N_t = \sum_{k=1}^{3} \mathbf{1}_{\{\mathrm{GI}_{t-k}>0\}}$ the number of the previous three years for which the gross income is positive, and $\alpha = 0.15$. According to the *basic indicator approach* (BIA), the OR capital charge $\mathrm{RC}_t^{\mathrm{BIA}}$ for year t is calculated via

$$\mathrm{RC}_t^{\mathrm{BIA}} = \frac{\alpha}{N_t} \sum_{k=1}^{3} \max\{\mathrm{GI}_{t-k}, 0\}; \tag{2.1}$$

see [1, p. 144]. This means that the OR capital for year t is the α-fraction (set by the Committee) of the average over the previous three years of positive annual gross income. It is not defined in case the annual gross incomes in the three years previous to t are nonpositive.

2.2 Standardized approach

The standardized approach requires the bank's activities to be partitioned into eight *business lines* which are corporate finance, trading and sales, retail banking, commercial banking, payment and settlement, agency services, asset management, and retail brokerage. The gross income of the bank's activities have to be mapped into one of these eight business lines, and unless another mapping process (transparent to third parties; approved by the board of directors; independently reviewed) is developed, the bank has to use the business line yielding the highest charge. The OR capital charge according to the *standardized approach* (SA) is then calculated via

$$\mathrm{RC}_t^{\mathrm{SA}} = \frac{1}{3} \sum_{k=1}^{3} \max\left\{ \sum_{b=1}^{8} \beta_b \mathrm{GI}_{t-k}^b, 0 \right\}, \tag{2.2}$$

where GI_{t-k}^b is the annual gross income in year $t-k$ in business line b, and where $(\beta_1, \ldots, \beta_8) = (0.18, 0.18, 0.12, 0.15, 0.18, 0.15, 0.12, 0.12)$ are weights (set by the Committee) of the different business lines in the order

given before (see [1, p. 147]). Note that $\sum_{b=1}^{8} \beta_b = 1.2 = 8\alpha$. The idea behind this approach is that gross income serves as a proxy for the scale of business operations and thus the likely scale of OR exposure within each business line. The capital charge for each business line b, $b \in \{1, \dots, 8\}$, is then determined as the β_b-fraction of the gross income in that business line. Note that (2.2) implies that, in any year, negative capital charges in a business line may offset positive capital charges in other business lines.

For using the SA as opposed to the BIA for determining the OR capital charge, a bank must satisfy its supervisor the following general criteria to be fulfilled (see [1, p. 148]).

General criteria

(1) The board of directors and senior management must be actively involved in the OR management framework;
(2) The bank must have a conceptually sound OR management system which is implemented with integrity;
(3) The bank must have sufficient resources in the major business lines and in control and audit areas;
(4) The bank must have documented criteria for mapping gross income for their business lines and activities into the framework of the SA.

If the bank is internationally active, then the following additional criteria must be met (see [1, p. 149] for more details).

Additional criteria

(1) Responsibilities within the OR management system must be assigned to an OR management function;
(2) The bank must systematically track relevant OR data by business line;
(3) OR exposures must be regularly reported to business unit management, senior management, and to the board of directors. Further, the bank must have procedures in place for taking appropriate actions;
(4) The OR management system must be well documented;
(5) The OR management processes must be subject to validation and regular independent review;
(6) The OR assessment system must be regularly reviewed by external auditors or supervisors.

Remark 1. An interesting question is how much the risk capital charges $\mathrm{RC}_t^{\mathrm{BIA}}$ and $\mathrm{RC}_t^{\mathrm{SA}}$ might differ. To see this, consider the following.

(1) First, assume that $\mathrm{GI}_{t-k}^b = \frac{1}{8}\mathrm{GI}_{t-k}$ for $b \in \{1, \dots, 8\}$, which means that the annual gross income in year $t-k$ is evenly spread over the eight business lines. Then

$$\max\left\{\sum_{b=1}^{8} \beta_b \mathrm{GI}_{t-k}^b, 0\right\} = \max\left\{\mathrm{GI}_{t-k}\frac{1}{8}\sum_{b=1}^{8}\beta_b, 0\right\} = \alpha \max\{\mathrm{GI}_{t-k}, 0\},$$

so that

$$\mathrm{RC}_t^{\mathrm{SA}} = \frac{N_t}{3}\mathrm{RC}_t^{\mathrm{BIA}}.$$

If $\mathrm{GI}_{t-k} > 0$ for $k \in \{1, 2, 3\}$, then $\mathrm{RC}_t^{\mathrm{SA}} = \mathrm{RC}_t^{\mathrm{BIA}}$. However, if GI_{t-k} is only positive for precisely one $k \in \{1, 2, 3\}$, then $\mathrm{RC}_t^{\mathrm{SA}} = \frac{1}{3}\mathrm{RC}_t^{\mathrm{BIA}}$, which is a large difference in the capital charges. In particular, $\mathrm{RC}_t^{\mathrm{SA}}$ can be smaller than $\mathrm{RC}_t^{\mathrm{BIA}}$ in this setup.

(2) Even if $\mathrm{GI}_{t-k}^b > 0$ for all $k \in \{1, 2, 3\}$, $b \in \{1, \dots, 8\}$, and thus $\mathrm{GI}_{t-k} > 0$ for $k \in \{1, 2, 3\}$, the two approaches for calculating the risk capital charge can differ, and it is not clear which leads to the higher charge. To see this, note that

$$\frac{\mathrm{RC}_t^{\mathrm{SA}}}{\mathrm{RC}_t^{\mathrm{BIA}}} = \frac{N_t}{3\alpha}\frac{\sum_{k=1}^{3}\max\{\sum_{b=1}^{8}\beta_b \mathrm{GI}_{t-k}^b, 0\}}{\sum_{k=1}^{3}\max\{\mathrm{GI}_{t-k}, 0\}} = \frac{1}{\alpha}\sum_{b=1}^{8}\beta_b \frac{\sum_{k=1}^{3}\mathrm{GI}_{t-k}^b}{\sum_{k=1}^{3}\mathrm{GI}_{t-k}},$$

so that

$$\mathrm{RC}_t^{\mathrm{SA}} = 0.8\mathrm{RC}_t^{\mathrm{BIA}} \left(\text{i.e., } \mathrm{RC}_t^{\mathrm{SA}} < \mathrm{RC}_t^{\mathrm{BIA}}\right) \quad \text{if, e.g., } \mathrm{GI}_{t-k}^b = \mathrm{GI}_{t-k}\mathbf{1}_{\{b=1\}},$$
$$\mathrm{RC}_t^{\mathrm{SA}} = 1.2\mathrm{RC}_t^{\mathrm{BIA}} \left(\text{i.e., } \mathrm{RC}_t^{\mathrm{SA}} > \mathrm{RC}_t^{\mathrm{BIA}}\right) \quad \text{if, e.g., } \mathrm{GI}_{t-k}^b = \mathrm{GI}_{t-k}\mathbf{1}_{\{b=3\}}.$$

Therefore, we see that the two approaches can differ by (plus or minus) 20% in this case, depending on the allocation of the annual gross income to the different business lines.

2.3 Advanced measurement approach

Under an *advanced measurement approach* (AMA), the risk capital charge equals a certain risk measure generated by the bank's internal OR measurement system. Basel II intentionally provides banks with a significant degree of flexibility under this approach, to encourage growth in the discipline. For using an AMA as opposed to the SA, a bank must satisfy at least the general criteria for the latter, as well as the following qualitative and quantitative criteria, see [1, p. 150].

Qualitative criteria

(1) The bank must have an independent OR management function that is responsible for the design and implementation of the OR management framework;
(2) The internal OR measurement system must be integrated into the day-to-day risk management processes. The bank must have techniques for allocating OR capital to major business lines;
(3) Points (3)–(6) of the additional criteria for the SA have to be satisfied;
(4) The validation of the OR measurement system by external auditors or supervisory authorities must ensure that the internal validation processes are operating correctly and that the risk-measurement system is transparent.

Quantitative criteria

(1) The bank must be able to demonstrate that its approach captures potentially severe tail-loss events. Further, it must demonstrate that its chosen OR measure meets a soundness standard comparable to the internal ratings-based approach for credit risk (one year holding period, 0.999-quantile);
(2) Banks must have and maintain rigorous procedures for OR model development and validation;
(3) Any internal OR measurement system must be consistent with the scope of operational risk as given in Definition 1 and the following seven *event types* (see [1, p. 305]): Internal fraud; external fraud; employment practices and workplace security; clients, products, and business practices; damage to physical assets; business disruption and system failures; execution, delivery, and process management;
(4) The bank is required to calculate its regulatory capital charge as the sum of *expected loss* (i.e., the mean of the loss distribution) and *unexpected loss* (i.e., the difference Value-at-Risk (VaR) minus expected loss);
(5) The risk measurement system must be sufficiently granular to capture the major drivers of OR;
(6) Risk measures for different OR estimates must be added for calculating the minimum capital requirement. The bank may, however, use internally determined correlations of OR losses, provided that they are determined with sound methods, implemented with integrity, take into account the uncertainty of the correlation estimates, and that correlation assumptions are validated using quantitative and qualitative techniques;
(7) Any OR measurement system must use the *four data elements* internal data, relevant external data, scenario analysis, and business environment and internal control factors. Further, the bank needs to have a credible, transparent, well-documented, and verifiable approach for weighting these elements.

Note that an AMA is subject to a period of initial monitoring by the supervisor before it can be used for regulatory purposes. Further, supervisors expect that banks following this approach will continue efforts to develop increasingly risk-sensitive OR allocation techniques. An AMA may also incorporate risk mitigation

in form of insurances (see [1, p. 155]). Also note that under certain conditions (see [1, p. 156]), an AMA can be used for some parts of the bank's operations, and the BIA or SA for the other parts.

In what follows, we briefly describe requirements of an AMA for the four data elements on which any OR measurement system following an AMA must be based.

Internal data

Under an AMA, a bank must have documented procedures for assessing the ongoing relevance of historical loss data, e.g., for scaling historical data, and about who is authorized to make the corresponding decisions. Risk-measure estimates based on internal-loss data must be calculated with a minimum of five years of historical observations (three years if the bank first moves to an AMA). Further, the bank's internal loss-collection processes must satisfy the following criteria:

(1) A bank must be able to map its historical internal loss data into the aforementioned eight business lines and seven event types and to provide these data to supervisors. The allocation criteria must be documented and objective;
(2) The internal loss data must be comprehensive in that it captures all material activities and exposures. There must be an appropriate minimum gross loss threshold for internal loss data collection, e.g., 10 000 EUR;
(3) Aside from gross loss amounts, the bank should collect information about the date of the event, recoveries of gross loss amount, and descriptive information about the drivers of the event;
(4) A bank must develop criteria for assigning loss data from an event in a centralized function (e.g., information technology department) or events in time to the eight-by-seven matrix of business lines and event types;
(5) OR losses historically included in the bank's credit risk database are treated as credit risk for the purpose of calculating the minimum capital requirement. However, banks must identify these losses for internal OR management. For the purpose of calculating the minimum capital requirement, OR losses related to market risk are treated as OR losses.

Relevant external data

External loss data comprises operational risk losses experienced by third parties. It can offset the paucity of internal operational risk loss data in areas where a bank has a potential risk but has not experienced significant losses (forward-looking perspective). However, external data alone is unlikely to cover the full scope of operational risk of a bank.

The bank's OR management system must use relevant external data in the form of loss amounts, information on the scale of business operations, and information on the causes and circumstances of the loss events. Further, a bank must have a systematic process for determining the situations which require external data and the methodologies used to incorporate the data.

Scenario analysis

The bank must use scenario analysis of expert opinion in conjunction with external data to evaluate its exposure to high-severity events (e.g., the experts assessments could be expressed as parameters of a loss distribution). Scenario analysis should also be used to assess the impact of deviations from the correlation assumptions embedded in the bank's OR measurement framework, in particular, to evaluate potential losses arising from simultaneous OR loss events.

Business environment and internal control factors

A bank must capture key *business environment and internal control factors* (BEICFs) that can change its OR profile. These factors, reflecting the business environment and internal control systems, make a bank's risk assessment more forward-looking. The following standards must be met:

(1) Each factor should be a meaningful driver of risk, based on experience and expert judgment. The factors should be translatable to quantitative measures;

(2) The sensitivity of the risk estimated to changes in the factors and to the relative weighting of the factors needs to be well reasoned;
(3) The use of the factors in a bank's risk measurement framework must be documented and subject to independent review;
(4) Over time, the processes and outcomes need to be compared to actual internal loss experience and relevant external data, and appropriate adjustments have to be made.

Loss distribution approach

From a technical point of view, an AMA is commonly realized via the so-called *loss distribution approach* (LDA). A skeletal version of this approach can be described as follows. Note that the number of business lines and event types may vary for different banks, and they often depend on the available data.

We assume as given the historical loss data which we interpret as realizations of random variables

$$\big\{X^{b,l}_{t-k,i}\colon\, k\in\{1,\dots,T\},\ b\in\{1,\dots,8\},\ l\in\{1,\dots,7\},\ i\in\big\{1,\dots,N^{b,l}_{t-k}\big\}\big\},$$

where t is the year for which we would like to find the OR capital charge, T denotes the number of years for which historical data is considered, and $X^{b,l}_{t-k,i}$ denotes the ith of the $N^{b,l}_{t-k}$ (usually nonnegative) losses affecting business line b and event type l in year $t-k$. The total historical loss amount for business line b and event type l in year $t-k$ can therefore be modeled via the compound sum

$$L^{b,l}_{t-k}=\sum_{i=1}^{N^{b,l}_{t-k}}X^{b,l}_{t-k,i}.$$

The total historical loss amount in year $t-k$ is then

$$L_{t-k}=\sum_{b=1}^{8}\sum_{l=1}^{7}\sum_{i=1}^{N^{b,l}_{t-k}}X^{b,l}_{t-k,i},\quad k\in\{1,\dots,T\}.$$

Based on the historical data, the goal is to estimate the distribution of the total loss L_t in year t and to calculate the chosen risk measure ρ_α for the estimated distribution at the α-quantile (typically, $\alpha=0.999$), i.e., to calculate

$$\mathrm{RC}^{\mathrm{AMA}}_t=\rho_\alpha(L_t). \tag{2.3}$$

Since this problem is typically hard to solve as the distribution of L_t is generally unknown, one often aggregates risk measures computed for losses affecting certain business lines and event types for which enough information about the underlying distribution is available (note that this implies having enough data available to check distributional assumptions for the losses). In particular, one often aggregates risk measures computed for losses aggregated over event types for fixed business lines, i.e., one uses

$$\mathrm{RC}^{\mathrm{AMA}}_t=\sum_{b=1}^{8}\rho_\alpha\big(L^b_t\big), \tag{2.4}$$

where L^b_t is the loss in business line b in year t, estimated from $L^b_{t-k}=\sum_{l=1}^{7}\sum_{i=1}^{N^{b,l}_{t-k}}X^{b,l}_{t-k,i}$. It is important to know that, in general, (2.4) does not provide an upper bound for (2.3) unless ρ_α is a *coherent* risk measure (see, e.g., [11, p. 240]). Note that VaR is not coherent. Further note that if ρ_α is VaR and the total loss amounts L^b_t, $b\in\{1,\dots,8\}$, are comonotonic (i.e., perfectly positive dependent), then (2.4) and (2.3) coincide (see [11, p. 250]).

3 ISSUES, OBSERVED RANGE OF PRACTICE, AND SUPERVISORY OBSERVATIONS

The main duty of the *Standards Implementation Group's OR Subgroup* (SIGOR) is to consider the practical challenges arising from the development, implementation, and maintenance of an OR management and measurement framework under Basel II. After the Quantitative Impact Study (internal data from 30 banks over the period 1998–2000) and the second Loss Data Collection Exercise (internal data from 89 banks in 2001), the *2008 Loss Data Collection Exercise* (2008 LDCE) conducted by the SIGOR is the third international data collection effort for operational risk. It is the first to collect information on all four data elements of an AMA. In this section, we summarize issues, observed range of practice, and supervisory observations of the 2008 LDCE mainly described in the documents [2] and [4]. We believe that such information can be particularly useful for modeling purposes of OR, e.g., for justifying model assumptions and also identifying issues of such. If given percentages do not add to one hundred, then participants were allowed to provide multiple answers. Note that results depending on geographical differences are not specifically addressed in this overview.

3.1 The 2008 loss data collection exercise

The 2008 LDCE consists of three parts. The first part consists of templates for submission of internal loss data (minimum of three years; before the recent financial crisis; collected information for each loss event: date of occurrence, date of impact, date of discovery, business line and event type, gross loss amount, gross loss amount net of non-insurance recoveries, and the amount of any insurance recoveries) and scenario analysis data (individual scenarios specified by frequency and severity; interval scenarios specified by frequency and severity ranges; percentile scenarios specified by severity for certain percentiles of a loss distribution) along with questions to provide information on the underlying processes. The second part requested information on exposure indicators (including consolidated assets, consolidated gross income, consolidated Tier 1 capital, and line gross income; used to scale certain results to facilitate comparisons across institutions) and capital estimates. The final part contains range of practice questions regarding operational risk modeling, external loss data, and BEICFs. The main goals of the 2008 LDCE are to provide consistency in the implementation of Basel II and the opportunity for banks to compare and improve their operational risk management.

There are 121 participating banks, 20 of which follow the BIA, 51 the SA, and 42 an AMA. In general, operational risk capital for non-AMA banks is higher than for AMA banks (regardless of the exposure indicator used for scaling), whereas AMA banks have a (three times) higher frequency and (six times) higher severity of large losses. For the typical AMA bank (by *typical bank*, the median of all investigated banks is meant), the ratio of operational risk capital to gross income (10.8%) is significantly below the α (15%) of the BIA and also below the range of β's (12–18%) of the SA. Also, the amount of capital relative to the frequency of large losses is generally higher for non-AMA banks than for AMA banks.

Concerning internal loss data, a total of 10.6M internal losses with an overall loss amount of 59.6B EUR was submitted. The typical bank experienced 0.82 losses per year of 20 000 EUR or more for each B EUR in consolidated assets. The total loss amount for the typical bank for losses exceeding 20 000 EUR was 155 555 EUR per year for each B EUR in consolidated assets. The typical bank reported insurance recoveries for 2.1% of losses. However, for those losses with an insurance recovery, the reported recovery rate was 74.6%. The largest number of losses (55.8%) occurred in Retail Banking, followed by Retail Brokerage with 10.3%. By event type, the highest frequencies were related to Execution, Delivery, and Process Management (30.6%) and External Fraud (26.3%). Concerning severity, the largest amount of losses (91.3%) at the typical bank are less than 20 000 EUR. The largest severity bucket (losses of 100M EUR or more) accounts for only 0.02% of the total number of losses at the typical bank. However, the losses in this bucket account for 41.79% of the total gross loss amount. The business line with the highest annual loss amount was Retail Banking (32%), followed by Corporate Finance (28%), and the event type with the highest annual loss amount was Clients, Products, and Business Practices (52.4%), followed by Execution, Delivery, and Process Management (24.9%).

For external loss data, the main sources are vendors (71%), industry consortia (48%), or databases of public sources (e.g., newspapers and journals) (33%).

Concerning scenario analysis, 65 of the 121 LDCE participants submitted a total number of 9687 scenarios. The median number of scenarios is 115 with significant variation in both the number and size of scenarios used

by different banks. The expected annual frequency of losses exceeding 88M EUR for the typical bank was 1-in-100 years, and the expected annual frequency of losses exceeding 194M EUR was 1-in-1000 years. The typical bank has the largest proportion of scenarios in the "unallocated business line" (36%), which includes group-wide scenarios, and in Retail Banking (28%). By event type, the typical bank has the highest proportion of scenarios related to Execution, Delivery, and Process Management (29%) and Clients, Products, and Business Practices (20%). For generating scenarios, the individual approach (one severity estimate linked with probabilities for each scenario) is the most commonly used approach (52%), 28% use the percentile approach (severity estimates for specific percentiles of the loss distribution), and 20% the interval approach (frequency estimates for a series of distinct severity ranges).

3.2 Internal governance

According to the SIGOR, the governance structure commonly adopted by participants in the 2008 LDCE relies on three lines of defense: business line management, independent corporate OR function, and independent review and validation. On the first line of defense, governance recognizes that business units are responsible for identifying and managing their risks. The second line of defense is typically a *corporate OR function* (CORF) which has a reporting structure independent of the risk-generating business lines and is responsible for the design, maintenance, and ongoing development of the AMA framework within the bank. The third line of defense is an independent and periodic review and validation of the AMA framework to ensure that the risk measurement approach used by the bank is sufficiently robust and provides appropriate transparency.

Independent internal and external challenge

The independent internal and external challenge of the OR management and measurement function required by Basel II has two main components, review of the OR management processes and validation of the model used within an AMA.

The 2008 LDCE questionnaire collected data about how challenge functions are used to review the four data elements to maintain their integrity. Concerning internal loss data, review by a risk control function, review by internal and external audit, and comparisons with other data elements are the three primary challenge functions. For external loss data, it is mainly review by a risk control function. For scenario analysis, the four challenge functions, review by a risk control function, review by internal and external audit, comparisons by experts, and comparisons with other data elements, are applied. Challenge functions are not used as extensively to maintain the integrity of BEICFs as they are for the other three data elements.

As supervisors observe, OR control functions are found within a CORF or the business lines that are also responsible for the collection of internal and external loss data or that participate in the scenario development. It is important that the challenge functions of a CORF are appropriate. Further, additional challenge functions, like independent verification and validation of the four data elements, are also needed. The SIGOR mentions that there should be a greater use of external data and an implementation of strong challenge functions when using external data, e.g., how external events are selected and how they are excluded from consideration. Further, supervisors expect more active internal and external audit involvement in the review of a bank's use of BEICFs.

Scenario analysis

Scenario analysis is a process by which banks consider the impact of extreme but plausible events on their operations. As such, it can provide a forward-looking method for capturing tail events that may not have occurred in the bank's loss history. Scenario analysis is important for estimating a bank's OR exposure and for creating more effective OR management processes. It may also be used to supplement the lack of internal or appropriate external data. However, dependence on the skill and expertise of participants makes scenario analysis subjective in nature. An improperly structured scenario analysis process that does not have appropriate challenge functions or that does not consider potential biases exposes a bank to significant governance risks.

The development of scenarios may vary in many respects, including the rigor in which they are developed, the comprehensiveness of scenario workshops, the choice of the distribution for scenario losses, and how

scenarios are updated. As observed practices in the 2008 LDCE, banks mainly use workshops or individual meetings to gather scenario data. Sometimes, also questionnaires are used. As inputs, nearly all banks use internal and external loss data. Often, also financial indicators are used. The scenarios are developed both group-wide and specific to subgroups of a business line.

Supervisors observe a lack of consistent controls to address scenario bias. Banks need to further develop scenario analysis governance and standards for their generation and use. Concerning stress testing and scenario selection, see also [3].

Business environment and internal control factors

BEICFs are indicators of a bank's OR profile that reflect underlying business risk factors and the effectiveness of the internal control environment. Like scenario analysis, they provide a forward-looking element to an AMA by considering business environment indicators (e.g., the rate of growth, employee turnover, and new product introductions) and internal control factors (e.g., findings from the challenge process, internal audit results, and system downtime). As one of the four data elements of an AMA, BEICFs should be incorporated into the OR measurement process. However, this is more complicated than for the other three data elements, as they are typically not measured by loss amounts. BEICFs often rely on more subjective procedures that make validation of BEICFs more difficult.

The most commonly used BEICFs tools are risk and control self-assessments, audit results, and key risk and performance indicators. Although all banks following an AMA use some type of BEICFs for risk quantification and management, challenges remain in substantiating how banks quantify the impact of BEICFs on the capital calculation. Supervisory issues are therefore the identification of meaningful BEICFs, the most effective means to quantify BEICFs, and ways to incorporate BEICFs into an AMA model.

3.3 Data issues

Date of occurrence of internal legal event losses

OR losses arising from legal events are often not identified until months after the date of their occurrence. Therefore, the question arises about the date that a bank should assign such losses within its internal loss database (e.g., date of occurrence, date of discovery, date of accounting, date of agreement or settlement). Choices of this date are not specified by Basel II. However, this can have a significant impact on the assessment of a bank's OR profile. The SIGOR therefore encourages less variation on how legal settlements are treated and recorded as OR loss events.

According to the 2008 LDCE, 38% of the banks enter legal events into their internal loss database at the date of discovery, 29% upon establishing a legal reserve. The corresponding loss amounts are typically entered afterwards. Moreover, there is a wide range of practice when losses from legal events are used as a direct input into the capital quantification model (e.g., date of establishing a legal reserve, date of discovery, settlement date, accounting date).

Given the time lag between initiation of a legal case and its conclusion, supervisors believe using the date when a legal reserve is established adds consistency and better reflects the bank's OR profile.

Allocation of internal losses across business lines and event types

An individual OR event can lead to losses in multiple business lines, and losses arising from a single event can sometimes span multiple event types. Therefore, the question arises how banks should treat these losses for risk measurement purposes and how they should be included in the bank's internal loss database.

According to the 2008 LDCE, 36% of the banks allocate internal losses affecting multiple business lines on a pro rata basis and 33% assign the entire loss to the business line where the impact is greatest.

Collection of gross versus net internal loss amounts

A *net* internal *loss* amount is the loss incurred by a bank after taking into account recoveries from clients, insurance, or other sources. Although Basel II contains terms such as "gross loss" and "recoveries," it does not

specifically define them. Different practices among banks for similar events can lead to significant differences in capital calculations.

According to the 2008 LDCE, 43% of the banks use "gross loss after all recoveries (except insurance)" as the value for capital quantification and 29% use "gross loss before any recoveries."

Supervisors observe a particularly broad range of practice with regard to the use of net losses for risk quantification. Use of net losses poses challenges to the banks and supervisors in determining the percentage of insurance and other risk mitigating offsets embedded in the calculation of the OR capital charge. The SIGOR believes a more consistent practice to the use of net losses is needed.

Internal loss collection thresholds

Another issue concerns the loss collection threshold. According to Basel II, a bank must have an appropriate minimal gross loss threshold for internal loss data collection. The choice of such a threshold can significantly affect the calculation of expected loss and, to some extent, the distribution of unexpected loss.

The 2008 LDCE reports different thresholds for internal loss data collection: 19% of the banks use a threshold between 0 EUR and 1000 EUR, 19% one between 1000 EUR and 5000 EUR, and another 19% one between 5000 EUR and 10 000 EUR. 17% of the banks use a threshold between 10 000 EUR and 20 000 EUR. Concerning using internal loss data for modeling purposes, 50% of the participating banks limit the use of internal loss data by loss amount (43% limit the use of high-frequency/low-severity events to 20 000 EUR), 48% by date, and 62% by other criteria (e.g., boundary events, subsidiary losses).

Supervisors note that internal loss collection thresholds should be based on statistical evidence, showing that losses below the threshold have an immaterial impact on capital calculations. Threshold decisions may also take into account the costs and benefits of collecting data below a certain level and the benefits for risk management purposes. Most importantly, banks should be aware of the impact the choice of the threshold may have on capital charges.

Mapping of internal loss data to a matrix

Basel II requires that a bank be able to map its internal losses, upon request, to an eight-by-seven matrix, where each entry denotes the overall loss affecting a certain business line and event type.

According to the 2008 LDCE, banks were able to provide sufficient information to the SIGOR to allow mapping of their internal loss data to the matrix.

Validation of internal loss data

Validation of internal loss data ensures the comprehensiveness and overall integrity and the integrity of the data collection process.

According to the 2008 LDCE, almost all banks either use a risk control function (95%) or internal/external audit (93%) to review internal loss data. 62% of the banks compare internal loss data with other data elements. Other practices include the review by experts (43%) or business peers (24%).

As supervisors observe, banks should have robust challenge functions for ensuring the integrity of internal loss data. Further, an effective practice is the independent review by both internal and external parties to ensure the data's quality for risk measurement and management processes.

3.4 Modeling and quantification issues

The flexibility provided in an AMA reflects both the relative infancy of the OR discipline and the desire of the Committee to explore how best to obtain risk-sensitive estimates of OR exposure. The differences in modeling approaches under an AMA affect the amount of OR capital. It is possible that banks with similar risk profiles could hold different levels of capital if they rely on different modeling approaches and assumptions. Therefore, decisions made by a bank on the critical features of its model should be supported by quantitative and qualitative analysis and appropriately reflect the OR profile of the bank.

As factors which impact OR capital charges, the SIGOR addresses model granularity, dependence assumptions, distributional assumptions and estimation, use, and combination of the four data elements, use of insurance as a risk mitigant, and treatment of expected loss. Given the inherent flexibility that is embedded in the AMA measurement framework and the numerous OR measurement methodologies available to banks, it is essential that banks assess and validate the soundness of the capital measurement process and its results. For this, internal validation, internal audit, sensitivity analysis (for the model assumptions), uncertainty analysis (computing confidence intervals), backtesting (how well did the models perform compared to actual loss experience), and benchmarking (comparing capital estimates with other OR indicators) may be used.

Granularity

Granularity reflects the degree to which individual OR exposures are modeled. An *operational risk category* (ORC) is the level (e.g., organizational unit, operational event type, or risk category) at which the bank's model generates a separate distribution for estimating potential operational losses. Using a single ORC to measure bank-wide OR exposure (lowest granularity) allows loss data to be pooled and therefore may solve the data paucity issue. However, this approach may not capture the real sources of OR and therefore the bank's risk profile. A high granularity, in contrast, faces the challenge in adequately categorizing sources of OR and may pose challenges when summing up the risk exposure estimates.

According to the 2008 LDCE, 45% of the banks have 20 or fewer ORCs, 74% have 100 or fewer, and 9% have over 1000. For defining their ORCs, 21% use only business line designations, 29% use only event type designation, and 40% use a combination of both.

Basel II does not specify the degree of granularity required to model OR exposures. Instead, the risk management system should be "sufficiently granular" to capture major risk drivers. As supervisors note, the choice of granularity should be adequately supported by quantitative and qualitative analysis. ORCs should be identified such that losses in a given ORC are independent and identically distributed. The sensitivity of the estimation of total annual loss to other risk class segmentations should also be tested and further statistical or other analysis (not only based on data available) should be used to support the choice and the implied assumptions.

Correlation and dependence

To capture dependencies of potential OR losses across or within business lines or event types, the notion of correlations, or more general, the notion of copulas, may be used. Such dependencies may result from business cycles, bank-specific factors, or cross-dependence of large events. Usually, independence is assumed for simplifying calculations when finding OR capital. Banks employing more granular modeling approaches may incorporate a dependence structure for OR losses incurred across those business lines and/or event types for which separate OR models are used. Note that when using correlations to measure dependence, it is in general not true (e.g., for extremely heavy-tailed distributions) that higher correlations imply a larger risk capital outcome.

The range of practice observed in the 2008 LDCE is broad. 29% of the banks surveyed did not model dependencies. Among those who incorporate dependencies in their models, expert judgement (40%), internal loss data (36%), and external data (17%) are the means used to estimate dependencies. Here, the copula concept is applied by 43% (predominantly the Gaussian copula), 17% use correlation matrices, and 31% use other methods to incorporate dependence. The modeling of dependence at the typical bank results in a modest (8.3%) increase in capital relative to the assumption of full independence.

According to supervisors, the issue of dependence between large loss events is particularly relevant. The term "correlation" should be interpreted broadly to mean any type of dependence. Each risk estimate for each risk category should be calculated based on data which are, to the maximum extent possible, independent among different ORCs. Banks that do not model dependencies have to calculate their OR capital requirement as the sum of the individual OR measures arising from different ORCs. Banks should take into account the scarcity of data and uncertainties surrounding dependence modeling in OR. Given the uncertainties in calculations, more robust methods for calculating meaningful dependence relationships are needed. Institutions applying an AMA should demonstrate that their models do not underestimate the probability of joint extremes.

The soundness of dependency assumptions should be demonstrated by qualitative and quantitative techniques. Qualitative techniques should add useful information and an economic explanation to the quantitative calculation. The Gaussian copula, in general, is not the best choice for modeling OR because it may underestimate the probability of joint extreme events due to fact that it does not allow for tail dependence (see, e.g., [11, p. 211]).

Distributional assumptions and estimation

The basis of all operational risk models is the distribution of operational risk losses. Assumptions made about the frequency and severity of losses are crucial. One of the considerations in a bank's choice of distribution is the size of the threshold above which data are collected and modeled. Both the choice of the distribution and the choice of the threshold will have a significant impact on the OR capital, as will the statistical method used for fitting the distribution. The severity of operational risk loss data tends to be heavy-tailed and severity distributions must be able to capture this attribute. Note that from a statistical point of view, the data scarcity of operational risk losses is still one of the major problems to be solved to adequately estimate model parameters and test model assumptions.

According to the 2008 LDCE, the vast majority of banks model frequency and severity distributions separately. For modeling the frequency distribution, the Poisson (93%) and the Negative Binomial (19%) are usually used. For modeling the severity distribution, 31% of the banks use a single distributional model (with log-normal (33%) and Weibull (17%) the most common choices), 29% use two distributions glued together (for the body, empirical (26%) and log-normal (19%); for the tail, generalized Pareto (31%) and log-normal (14%)), and 19% use two separate distributions for high-frequency/low-severity and low-frequency/high-severity losses.

Supervisors note that the process of selecting the probability distribution must be well documented and validated. When choosing a probability distribution, banks should take into consideration exploratory analysis of each ORC to find the most appropriate distribution, appropriate estimation procedures, and appropriate goodness-of-fit techniques. Banks applying different distributions to the body (high-frequency/low-severity events) and tail (low-frequency/high-severity events) should carefully consider the choice of the threshold and the method to connect body and tail. Besides a good fit, the choice of distributions should be realistic (so that capital estimates are realistic), well specified (so that characteristics of the distribution are similar to those of the loss data), flexible (the model should be flexible enough to capture a wide variety of empirical loss data), and simple (estimation, goodness-of-fit, and simulation should be easy to apply in practice).

Use and combination of the four data elements

Another crucial feature of an OR model is how the four data elements are combined. Different emphasis on each element may more closely reflect a specific loss history and risk profile but also complicate a comparison across banks. Banks need to demonstrate that their chosen approach for weighting the elements is credible, transparent, well-documented, and verifiable.

According to the 2008 LDCE, scenario analysis is the most significant direct contributor (55%) of the four data elements to the OR capital, followed by external data (37%), internal data (31%), and BEICFs (11%).

The primary use of internal data is to estimate the frequency and severity parameters for the entire distribution and for high-frequency/low-severity events. External data is primarily used as input to scenario analysis (86%), as an aid for risk management purposes (71%) and only to a lesser extend as a direct model input (29%). It is mainly used (45%) to estimate the severity of low-frequency/high-severity events. Most AMA banks (88%) make a selection of the external data to be used in the quantification model, mainly based on geographical (57%) criteria or on loss thresholds (26%). 21% of the banks scale external data. Usually, a scalar based on revenues or assets is applied. As external data, scenario data is primarily used for estimating the severity distribution and low-frequency/high-severity events. 29% of the banks use separate calculations for scenarios and internal (external) data for incorporating scenario data into an AMA. Also 29% of the banks use scenario data to supplement internal loss data. BEICFs are very widely used as an indirect input into the quantification framework (69%), and as an ex-post adjustment to AMA capital (24%).

Given the many possible combination techniques for the four data elements and the impact they may have on the OR capital charge, supervisors note that banks must understand the impact that every element has on

capital. This can be done by producing separate calculations with each data element or evaluating the effect of gradually introducing different elements. Banks should demonstrate that the choice of the method of how scenarios are generated is appropriate to capture severe tail losses. Although supervisors believe that external loss data is an important component for estimating operational risk capital, none of the external data sources are sufficiently comprehensive or relevant to be used as the sole source of information for modeling operational risk. Also, external data must be assessed for its relevance and may need to be adjusted or scaled. Further, consortia data do not include the large tail events experienced by nonmember banks and scaling techniques still remain rudimentary. Although Basel II envisioned that banks would be able to scale external loss data, it is proving to be more difficult to implement in real-world situations. Given that scenarios and external data are used to supplement low-frequency/high-severity events information, it is expected that the inclusion of these sources of data will provide for a higher capital charge than calculated based on internal loss data only. Further, given that the use of BEICFs is the least developed area of quantification, supervisors will continue their work to determine an acceptable range of practice for incorporating BEICFs into AMA models.

Insurance as a risk mitigant

Banks may be able to incorporate insurance coverage as risk mitigation in their operational risk capital estimate.

According to the 2008 LDCE, only a small number of losses experienced by AMA banks had an associated insurance recovery, and very few AMA banks have estimated the impact of including insurance in their capital calculation.

Supervisors note that banks incorporating insurance in their capital calculation must provide the information supervisors need to assess the reasonableness of the results and establish appropriate criteria for ensuring that risk mitigants are mapped properly to OR exposures.

4 CONCLUSION

Based on Basel II legal documents, this article provides an introduction to operational risk and summarizes techniques, observed range of practice, and supervisory issues in operational risk modeling. Especially the latter reveal that there are still difficulties in adequately capturing this sort of risk. One of the largest problems in operational risk modeling is data scarcity. Frequently, sophisticated models for operational risk losses which seem to be realistic are invented and can be found in the literature. However, the role of statistics is to find out, given actual data, how well these models can be fitted and their implicit assumptions tested. Without an adequate amount of data, this is not possible and therefore still poses challenges to both academia and industry.

Acknowledgments. The authors would like to thank an anonymous referee for carefully reading the paper and giving useful suggestions.

REFERENCES

1. BIS, Basel II: International Convergence of Capital Measurement and Capital Standards: A Revised Framework—Comprehensive Version, 2006, available from: `http://bis.org/publ/bcbs128.pdf`. (17 May 2010)

2. BIS, Observed range of practice in key elements of Advanced Measurement Approaches (AMA), 2009, available from: `http://www.bis.org/publ/bcbs160b.pdf`. (17 May 2010)

3. BIS, Principles for sound stress testing practices and supervision, 2009, available from: `http://www.bis.org/publ/bcbs147.pdf`. (25 July 2010)

4. BIS, Results from the 2008 Loss Data Collection Exercise for Operational Risk, 2009, available from: `http://www.bis.org/publ/bcbs160a.pdf`. (17 May 2010)

5. V. Chavez-Demoulin, P. Embrechts, and J. Nešlehová, Quantitative models for operational risk: Extremes, dependence and aggregation, *J. Banking Finance*, **30**(10):2635–2658, 2006.

6. M. Degen, P. Embrechts, and D.D. Lambrigger, The quantitative modelling of operational risk: Between g-and-h and EVT, *Astin Bull.*, **37**(2):265–291, 2007.

7. P. Embrechts, D.D. Lambrigger, and M.V. Wüthrich, Multivariate extremes and the aggregation of dependent risks: Examples and counter-examples, *Extremes*, **12**:107–127, 2009.

8. P. Embrechts and G. Puccetti, Aggregating risk capital, with an application to operational risk, *Geneva Risk Insur. Rev.*, **30**(2):71–90, 2006.

9. P. Embrechts and G. Puccetti, Aggregating operational risk across matrix structured loss data, *J. Oper. Risk*, **3**(2):29–44, 2008.

10. P. Embrechts and G. Samorodnitsky, Ruin problem and how fast stochastic processes mix, *Ann. Appl. Probab.*, **13**(1):1–36, 2003.

11. A.J. McNeil, R. Frey, and P. Embrechts, *Quantitative Risk Management: Concepts, Techniques, Tools*, Princeton Univ. Press, 2005.

12. J. Nešlehová, P. Embrechts, and V. Chavez-Demoulin, Infinite mean models and the LDA for operational risk, *J. Oper. Risk*, **1**(1):3–25, 2006.