MODELLING CAPITAL REQUIREMENTS FOR OPERATIONAL RISK IN FINANCIAL INSTITUTIONS OF EMERGING MARKETS USING THE GAUSSIAN COPULA

ABSTRACT

This paper seeks to provide a more efficient estimation of capital requirement for operational risk in financial institutions across emergent markets by applying the LDA and modelling multivariate dependence between severities using Gaussian copula. Two models were built in order to draw conclusions. Model (*i*) estimates capital requirements for operational risk using the standard model LDA (BCBS 2004). Model (*ii*) incorporates into the LDA the multivariate analysis of dependences between operational losses (severities) using the multivariate symmetric elliptical Gaussian copula. This research analyses an updated operational loss data set, SAS® Operational Risk Global Data (SAS OpRisk Global Data), to model operational risk at international financial institutions from emerging markets between 1990 and 2013.

The impact of model (*ii*) was evaluated on the estimates of the total regulatory capital for operational risk, and compared with the one predicted by (*i*). The results confirm the existence of diversification benefit up to 33%.

INTRODUCTION

Modelling capital requirements via Advanced Measurement Approach (AMA) for operational risk (i.e. total Operational Value at Risk – OpVaR) has been widely investigated using data from financial institutions based in developed countries (Chapelle et al., 2008; Chavez-Demoulin et al., 2006; Ivell, Jaeggi, & Sekeris, 2016; Pavel V. Shevchenko, Gareth

W. Peters, Bertrand Hassani, 2009). However, little attention has received the estimation of OpVaR across financial institutions in emerging markets[1]. This paper addresses this gap.

The Basel Committee on Banking Supervision (BCBS) allows banks to estimate the regulatory capital that covers their annual operational risk exposure using their own models via the AMA (Basel II/III Capital Accord 2004/2011). Among the AMA models, the Loss Distribution Approach (LDA) has been one of the most popular methods used by international banks (Chavez-Demoulin et al. 2006; Pavel V. Shevchenko, Gareth W. Peters, Bertrand Hassani 2009). Among the eligible variants of the LDA, there is a complex and reliable statistical model widely used to model dependence that is *copula* models. The modelling of dependences between losses and the quantification of the capital to be held for covering operational risk exposure have been essentials issues for both financial institutions and regulators over the past two decades (Breymann, Dias, and Embrechts 2003; Chavez-Demoulin et al. 2006; CSBB 2004, 2011; McNeil, Frey, and Embrechts 2015).

The importance of understanding, measuring and modelling operational risk at the multivariate level is due to the high dimensions involved when constructing regulatory capital. For instance, for regulatory capital a financial institution has to consider eight business lines (Corporate finance, Trading and sales, Retail Banking, Commercial banking, Payment and settlement, Agency services, Asset management, Retail brokerage) and seven event types (Internal fraud, External fraud, Employment practices and workplace safety, Clients, products and business practices, Damage to physical assets, Business disruption and system failures, Execution, delivery and process management) to model operational risk.

Therefore, the main objective of this paper is to model the multivariate dependence between losses (i.e. severities) using Gaussian elliptical copula and to calculate the capital to be held to cover operational risk exposure at financial institutions in emerging markets. The motivation for looking at these markets is because they are assuming an increasingly

[1] We follow the definition provided by Antoine van Agtmael, economist of World Bank, emerging markets are rapidly growing economies with rapid industrialization (Economy Watch 2010).

prominent position in the world economy (Bruton et al. 2013; Hoskisson et al. 2000; Wright et al. 2005; Zhang et al. 2013). The emerging markets considered in this research are those established by The MSCI Global Investable Market Indexes (GIMI) Methodology Country Classification (MSCI 2018), which are: Brazil, Chile, China, Colombia, Czech Republic, Egypt, Greece, Hungary, India , Indonesia, Malaysia, Mexico, Pakistan, Peru, the Philippines, Poland, Qatar, Russia, South Africa, South Korea, Taiwan, Thailand, Turkey and the United Arab Emirates.

KEYWORDS

- Operational risk
- Loss Distribution Approach, LDA
- Advanced Measurement Approach, AMA
- Monte Carlo Simulation
- Multivariate Copulas
- Emerging Markets

LITERATURE REVIEW

The banking industry has given significant losses due to operational risk over the last decade. The recent large-scale financial failures such as Barings, Orange County, Allied Irish Banks, Enron and Banco Popular Español were caused for the most widely known sort of operational loss: unauthorized trading, breakdowns of internal controls, methods and systems failures, etc. In order to wane these financial failures, the Basel Committee on Banking Supervision (BCBS) published in 2004 a New Capital Accord (BCBS 2004) in which financial institutions were encouraged to measure, control and manage operational risk.

After the Accord, operational risk became as important as credit risk or market risk. Moreover, measurement for the computation of regulatory capital, i.e. estimate the Operational Value at Risk (VaR) became the most complex and, at the same time, the most

important aspect when dealing with operational risk. The Accord, which has been fully implemented since the end of 2007 in developed markets, imposes new methods of calculating regulatory capital that apply to the banking industry. Besides credit and market risk, the new Accord focuses on operational risk, which is defined as "the risk of losses resulting from inadequate or failed internal processes, people and systems, or from external events" (BCBS 2004). This definition includes legal risk but excludes strategic and reputational risk.

The Basel II framework is based on a three-pillar concept.

i. Pillar I. Minimum capital requirements. This pillar requires an explicit minimum capital allocated for operational risk that can be calculated using different approaches. This research focuses on this Pillar.
ii. Pillar II. Supervisory review process. This pillar focuses on the supervision of a bank's systems and capital adequacy by regulatory authorities.
iii. Pillar III. Market discipline. The objective of this pillar is to establish market discipline through public disclosure of risk measures and other relevant information on risk management.

The table in Annex I shows the literature review carried out in this work. 58 bibliographic references of related topics were considered. Of the studies, 88% (52 references) were based on the financial sector and 81% (48 references) had information on the calculation of OpVaR, that is, they focused their studies on operational risk analysis.

It can be appreciated that only 45% (27 references) of the studies carried out tests of goodness of fit in their studies. 29 references (49%) used Monte Carlo simulation in their calculations and 25 references (42%) applied copulations. The diversification benefit was calculated by 38% (23 articles) of the studies. Of the 59 articles related to the subject, only 38% (23 articles) focused on emerging markets.

The contributions of this research are that, unlike published work, first we apply for the first time the operational risk analysis over financial entities of emerging markets including LDA, Monte Carlo Simulation and the modeling of dependencies with Gaussian copula.

CONCEPTUAL MODEL

The Basel Committee requires that financial institutions adopt one of the three methods proposed by the Accord to measure the capital charge required to cover operational risk. Ranked from lower to higher degree of sophistication and sensitivity to such risk, these are:

i. The Basic Indicator Approach (BIA)
ii. The Standardised Approach (SA)
iii. The Advanced Measurement Approach (AMA)

This research focuses on the AMA approaches because these are calculated from internal loss data classified by loss event type and business line. A required feature of the AMA is to allow for explicit correlations between different operational risks events. More precisely, according to the Basel II Accord banks should allocate losses to one of *eight* business lines and to one of *seven* loss event types, i.e. within the matrix of Basel II risk cells; 7x8 = 56 cells in total. Tables 1, 2 and 3 illustrate this matrix.

Table 1.

Basel II business lines (BL).

j	**Business line, BL(*j*)**	*j*	**Business line, BL(*j*)**
1	Corporate finance	**5**	Payment and settlement
2	Trading and sales	**6**	Agency services
3	Retail Banking	**7**	Asset management
4	Commercial banking	**8**	Retail brokerage

The original texts and data are available free of charge on the BIS website www.BIS.org/bcbs/publ.htm. See (Bank of International Settlements 2004)

Table 2.

Basel II event types (ET

i	**Event type, ET(*i*)**
1	Internal fraud
2	External fraud
3	Employment practices and workplace safety
4	Clients, products and business practices
5	Damage to physical assets
6	Business disruption and system failures
7	Execution, delivery and process management

The original texts and data are available free of charge on the BIS website www.BIS.org/bcbs/publ.htm. See (Bank of International Settlements 2004)

Table 3.

Basel risk matrix of business lines (BL) and event types (ET)

	ET (*1*)	**ET (*2*)**	**…**	**ET (*i*)**	**…**	**ET (*7*)**
BL (*1*)						
BL (*2*)						
:	Annual losses to be predicted over a one-year time horizon					
BL (*j*)						
:						
BL (*8*)						

A diversification benefit would imply that high quantiles of the total annual loss distribution would be less than the sum of the corresponding quantiles of the annual loss distribution from each category. In other words, there is a diversification benefit if the VaR of the total loss (Gaussian copula model) is smaller than the sum of the individual VaR (Standard model LDA). Thus to quantify the diversification benefit the measure proposed by (Chavez-Demoulin et al. 2006) is adopted here:

$$D_\alpha = \frac{VaR_\alpha\left(\sum_{j=1}^{8} l'_{s_j}\right) - \sum_{j=1}^{8} VaR_\alpha(L_j)}{\sum_{j=1}^{8} VaR_\alpha(L_j)}, \qquad (1)$$

Negative values of D_α indicate that the total risk capital calculated with model of Gaussian copula is smaller than the value computed from the standard approach LDA. If $D_\alpha < 0$, there is a diversification benefit. Positive values indicate the contrary.

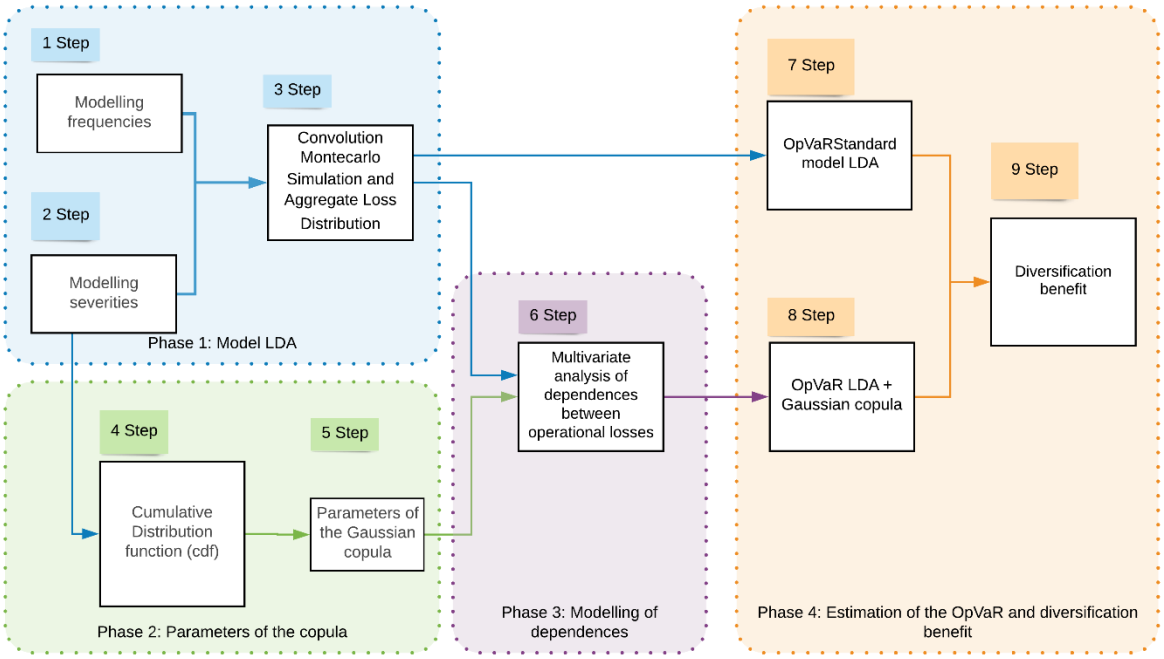
HYPOTHESIS

The incorporation of multivariate dependence between operational losses (severities) of all business lines using the Gaussian multivariate symmetric elliptical copula, in the Loss Distribution Approach (LDA) model, provides a more efficient estimation of capital requirement for operational risk between 1980 and 2013 in financial institutions of emerging markets, compared to capital requirement for operational risk estimated by the standard model LDA.

METHODOLOGY

The structure of this investigation is outlined in Figure 1, which facilitates the understanding of the flow in different phases and steps. In the first phase, the Standard Model of Loss Distribution Approach (LDA) (proposed in the Basel II agreement 2004) is implemented; in the second phase, the parameters of the Gaussian multivariate copula were modeled; in the third phase, the modeling of dependencies between severities was included in the standard model LDA; Finally, in the fourth phase, the estimation of capital requirement for operational risk was calculated for each model and the diversification benefit.

Figure 1. Methodological structure



RESULTS

Table 4 and Table 5 shows the estimation of the OpVaR with the models: (*i*) estimated capital requirements for operational risk using the standard model LDA (BCBS 2004). Model (*ii*) incorporated into the LDA the multivariate analysis of dependences between operational losses (severities) using the multivariate symmetric elliptical Gaussian copula.

Table 4.

OpVaR – Standard LDA

α	**90,0%**	**95,0%**	**99,0%**	**99,5%**	**99,9%**
OpVaR	1.199,76	1.577,11	2.478,84	2.854,11	3.706,22

Source: Own elaboration based on LDA standard model.

Table 5.

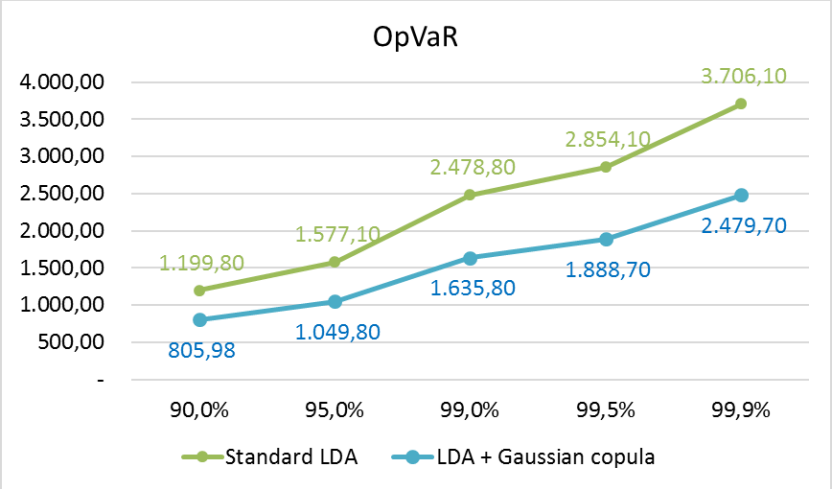
OpVaR - LDA and Gaussian copula

α	**90,0%**	**95,0%**	**99,0%**	**99,5%**	**99,9%**
OpVaR	805,98	1.049,80	1.635,80	1.888,70	2.479,70

Source: Own elaboration based on modelling of Gaussian copula.

As is shown in Figure 2, the model that incorporate the multivariate analysis of dependencies between operational losses (severities) using the Gaussian multivariate symmetric elliptical copulation functions has operating risk capital values lower than those obtained under the standard LDA model proposed by Basel II.

Figure 2. OpVaR estimated

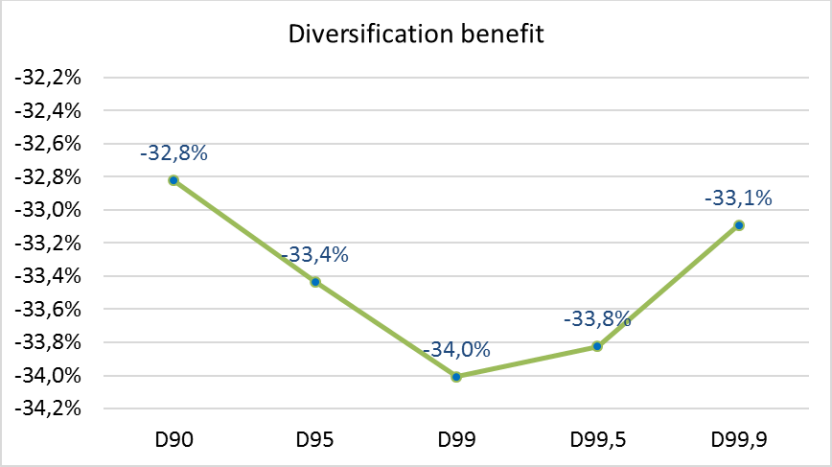


Another interesting result from Figure 2 is the clear capital increase between the 99.5% and 99.9% percentiles. This indicates that when the probability level is higher, for example, 99.9% percentile, the OpVaR capital differences for the Gaussian copula are more noticeable if compared to the standard LDA model.

Since all the values presented in Figure 3 are negative values for both model 1 vs 2 and model 1 vs 3, the existence of the diversification benefit for models 2 and 3 is corroborated.

In this way it is verified that the incorporation of dependency modeling using Gaussian multivariate copula in the LDA Standard Model, provides a more efficient estimation of capital for operational risk between 1990 and 2013 in financial institutions of emerging markets in comparison with the capital for operational risk estimated under the standard LDA model.

Figure 3. Diversification benefit



CONCLUSIONS

The main contribution of the present investigation was the incorporation of the multivariate modeling of dependencies between operating losses (severities) using the Gaussian multivariate copula in the estimation of OpVaR operational risk capital under the Advanced Measurement Approach (AMA), using specifically the LDA model in financial institutions of emerging markets. With this research, the understanding of more sophisticated and robust techniques for the measurement of requirements of capital by operational risk is academically socialized, and thus, tools are provided for decision-making (Bedoya 2009) and for the management of operational risk in financial entities from emerging markets.

By incorporating the multivariate modeling of the dependency in the calculation of the OpVaR in financial entities of emerging markets, a reduction in the capital charge for operational risk was obtained for modeled entities of up to 34% in the model that uses Gaussian intercourse (model 2). Therefore, this is an important result in terms of capital required by the financial institution that adopts this approach.

The results of this research are an important contribution not only for the academic community and researchers in applying Advanced Measurement Approach (AMA) in the

estimation of capital for operational risk and the Copula Models to model dependencies, but also for market financial entities of emerging markets by requiring less capital to cover exposure to operational risk, government supervisors by providing tools to move towards compliance with international standards, financial consulting companies, risk professionals and financial operators.

In the academy, researchers can use these results as a point of comparison or frame of reference. Financial sector institutions may apply the methodology implemented in this study using internal databases to improve the understanding of operational risk in their organizations.

ANNEX 1.

Literature Review

	Banking Industry	OpVaR	AMA	LDA	Monte Carlo Simulation	Copula	Emerging Markets
(Jorion 2000)	X	X	X		X	X	
(Cumming and Hirtle 2001)	X	X					
(Frachot, Georges, and Roncalli 2001)	X	X	X	X	X	X	
(Johnson 2001)	X	X			X		X
(Cruz 2002)	X	X					
(Breymann et al. 2003)	X					X	
(Di Clemente and Romano 2004)	X	X		X	X	X	
(Moscadelli 2004)	X	X	X	X	X		
(Becerra, Guzmán, and Trujillo 2005)	X	X	X				X
(Böcker and Klüppelberg 2008)	X	X	X	X	X		
(Chavez-Demoulin et al. 2006)	X	X	X			X	
(Fontnouvelle et al. 2006)	X	X		X	X		
(García-Herrero and Gavilá 2006)	X	X					X
(Panjer and John Wiley & Sons. 2006)	X	X					
(Varela and Rodríguez 2006)	X	X	X	X			X
(Giacometti et al. 2007)	X	X	X	X	X	X	
(Ozun and Cifter 2007)	X	X				X	X
(Shevchenko 2007)	X	X	X	X	X	X	
(Chapelle et al. 2008)	X	X	X	X	X	X	
(Franco and Murillo 2008)	X	X	X	X	X		X
(Hu and Kercheval 2008)	X				X	X	
(Pinto Gaviria and Leyva Lemarie 2008)	X	X					X
(Bedoya 2009)	X	X	X	X	X		X
(Correa Vilizzio, Alejandra; Galione Klot 2009)	X	X	X	X			X
(Gourier, Abbate, and Farkas 2009)	X	X			X	X	
(LI, FENG, and CHEN 2009)	X	X	X	X	X		X
(Lopera, Jaramillo, and Arcila 2009)	X					X	

(Murillo Gómez 2009)	X	X		X	X			
(Otero and Venerio 2009)	X	X	X	X	X			
(Pavel V. Shevchenko, Gareth W. Peters, Bertrand Hassani 2009)	X	X	X	X	X			
(Shevchenko and Temnov 2009)		X	X	X	X			
(Monti et al. 2010)	X	X	X	X	X	X		
(Mora Valencia 2010)	X	X	X	X	X		X	
(Peters 2010)		X					X	
(Mittnik, Paterlini, and Yener 2011)	X	X		X	X	X		
(Rachedi and Fantazzini 2011)	X	X				X		
(POSADA ESPINAL 2012)	X	X	X	X	X		X	
(Christian Brechmann and Czado 2013)	X	X				X		
(Gregoriou 2013)	X	X						
(Marco Flores 2013)	X					X		
(Martínez-sánchez and Venegas-martínez 2013)		X	X		X			
(Nikonov, Vlasov, and Medvedeva 2013)	X	X		X	X			
(Páez Tovar and Gómez González 2013)		X	X	X			X	
(Brechmann, Czado, and Paterlini 2014)	X	X	X		X	X		
(Chernobai, Rachev, and Fabozzi 2015)		X		X	X			
(Feria-Domínguez, Jiménez-Rodríguez, and Sholarin 2015)	X	X	X	X			X	
(Figuet, Humblot, and Lahet 2015)	X	X					X	
(McNeil et al. 2015)	X	X	X	X	X	X		
(Mitra et al. 2015)	X	X					X	
(Garzón Rozo, Crook, and Moreira 2016)	X	X	X	X	X	X		
(Ivell et al. 2016)	X	X	X					
(Mensi, Hammoudeh, Shahzad, and Shahbaz 2017)	X					X	X	
(Mensi, Hammoudeh, Shahzad, Al-Yahyaee, et al. 2017)	X					X	X	
(de Oliveira et al. 2018)	X					X	X	
(Internal Model Industry Forum 2018)		X	X					
(Ji et al. 2018)	X					X	X	
(Li and Wei 2018)	X					X	X	

Source: Own elaboration based on literature review.

REFERENCES

Bank of International Settlements. 2004. "Basel II: Revised International Capital Framework." Retrieved October 21, 2018 (https://www.bis.org/publ/bcbsca.htm).

Becerra, Gisele, Alexánder Guzmán, and María Andrea Trujillo. 2005. *La Importancia de La Administración Del Riesgo Operativo En Las Entidades Crediticias*. Vol. 8.

Bedoya, David. 2009. "Propuesta Para El Modelamiento Del Riesgo Operativo En Una Entidad Financiera." *Universidad Nacional de Colombia* 01–130.

Böcker, Klaus and Claudia Klüppelberg. 2008. *Operational VaR: A Closed-Form Approximation*.

Brechmann, Eike, Claudia Czado, and Sandra Paterlini. 2014. "Flexible Dependence Modeling of Operational Risk Losses and Its Impact on Total Capital Requirements." *Journal of Banking & Finance* 40:271–85.

Breymann, Wolfgang, Alexandra Dias, and Paul Embrechts. 2003. *Dependence Structures for Multivariate High-Frequency Data in Finance*.

Bruton, Garry D., Igor Filatotchev, Steven Si, and Mike Wright. 2013. "ENTREPRENEURSHIP AND STRATEGY IN EMERGING ECONOMIES."

Chapelle, Ariane, Yves Crama, Georges Hübner, and Jean-Philippe Peters. 2008. "Practical Methods for Measuring and Managing Operational Risk in the Financial Sector: A Clinical Study." *Journal of Banking & Finance* 32(6):1049–61.

Chavez-Demoulin, V., P. Embrechts, and J. Nešlehová. 2006. "Quantitative Models for Operational Risk: Extremes, Dependence and Aggregation." *Journal of Banking and Finance* 30(10):2635–58.

Chernobai, Anna, Svetlozar T. Rachev, and Frank J. Fabozzi. 2015. "Composite Goodness-of-Fit Tests for Left-Truncated Loss Samples." *Handbook of Financial Econometrics and Statistics* 1(805):575–96.

Christian Brechmann, Eike and Claudia Czado. 2013. *Risk Management with High-Dimensional Vine Copulas: An Analysis of the Euro Stoxx 50*.

Di Clemente, Annalisa and Claudio Romano. 2004. "Measuring and Optimizing Portfolio Credit Risk: A Copula-Based Approach*." *Economic Notes* 33(3):325–57.

Correa Vilizzio, Alejandra; Galione Klot, Graciela. 2009. "' Requerimiento de Capital Por Riesgo Operativo . Referencia Al Caso Uruguayo ." *Universidad de La República Oriental Del Uruguay Facultad de Ciencias Económicas y Administración*.

Cruz, Marcelo G. 2002. *Modeling, Measuring and Hedging Operational Risk*. John Wiley & Sons.

CSBB. 2004. *Basilea II. Convergencia Internacional de Medidas y Normas de Capital*.

CSBB. 2011. "Basilea III: Marco Regulatorio Internacional Para Bancos." Retrieved October 21, 2018 (https://www.bis.org/bcbs/basel3.htm).

Cumming, Christine M. and Beverly J. Hirtle. 2001. "The Challenges of Risk Management in Diversified Financial Companies." *FRBNY Economic Policy Review* (March):1–17.

Economy Watch. 2010. "Emerging Markets | Economy Watch." Retrieved November 19, 2018 (http://www.economywatch.com/world_economy/emerging-markets).

Feria-Domínguez, José Manuel, Enrique Jiménez-Rodríguez, and Ola Sholarin. 2015. "Tackling the Over-Dispersion of Operational Risk: Implications on Capital Adequacy Requirements." *The North American Journal of Economics and Finance* 31:206–21.

Figuet, Jean-Marc, Thomas Humblot, and Delphine Lahet. 2015. "Cross-Border Banking Claims on Emerging Countries: The Basel III Banking Reforms in a Push and Pull Framework." *Journal of International Financial Markets, Institutions and Money* 34:294–310.

Fontnouvelle, Patrick De, Virginia Dejesus-Rueff, John S. Jordan, and Eric S. Rosengreen. 2006. "Capital and Risk : New Evidence on Implications Of." *Journal of Money, Credit, and Banking* 38(7):1819–46.

Frachot, a, P. Georges, and T. Roncalli. 2001. "Loss Distribution Approach for Operational Risk." *Available at SSRN 1032523* 1–43.

Franco, Luis Ceferino and Juan Guillermo Murillo. 2008. "Loss Distribution Aproach (LDA): Metodología Actuarial Aplicada Al Riesgo Operacional." *Revista Ingenierías Universidad de Medellín* 7(13):143–56.

García-Herrero, Alicia and Sergio Gavilá. 2006. "Posible Impacto de Basilea II En Los Países Emergentes." *Occasional Papers*.

Garzón Rozo, Betty Johanna, Jonathan Crook, and Fernando Moreira. 2016. "Modelling

Operational Risk Using Extreme Value Theory and Skew T-Copulas via Bayesian Inference."

Giacometti, Rosella, Svetlozar Rachev, Anna Chernobai, Marida Bertocchi, and Giorgio Consigli. 2007. "Heavy-Tailed Distributional Model." *Journal of Operational Risk* 2(1):55–90.

Gourier, Elise ;., Donato ;. Abbate, and Walter Farkas. 2009. "Operational Risk Quantification Using Extreme Value Theory and Copulas: From Theory to Practice."

Gregoriou, Greg N. 2013. *Operational Risk toward Basel Iii : Best Practices and Issues in Modeling, Management, and Regulation*. Wiley.

Hoskisson, R. E., L. Eden, C. M. Lau, and M. Wright. 2000. "STRATEGY IN EMERGING ECONOMIES." *Academy of Management Journal* 43(3):249–67.

Hu, Wenbo and Alec N. Kercheval. 2008. "The Skewed t Distribution for Portfolio Credit Risk." *Advances in Econometrics* 22:55–83.

Internal Model Industry Forum. 2018. *Aligning Operational Risk and Insurance*.

Ivell, Tom, Thomas Jaeggi, and Evan Sekeris. 2016. *Principal BEYOND AMA PUTTING OPERATIONAL RISK MODELS TO GOOD USE*.

Ji, Qiang, Elie Bouri, David Roubaud, and Syed Jawad Hussain Shahzad. 2018. "Risk Spillover between Energy and Agricultural Commodity Markets: A Dependence-Switching CoVaR-Copula Model." *Energy Economics* 75:14–27.

Johnson, Christian A. 2001. *VALUE AT RISK: TEORIA Y APLICACIONES**. Vol. 28.

Jorion, Philippe. 2000. *VALUE AT RISK: The New Benchmark for Managing Financial Risk*.

LI, JIANPING, JICHUANG FENG, and JIANMING CHEN. 2009. "A PIECEWISE-DEFINED SEVERITY DISTRIBUTION-BASED LOSS DISTRIBUTION APPROACH TO ESTIMATE OPERATIONAL RISK: EVIDENCE FROM CHINESE NATIONAL COMMERCIAL BANKS." *International Journal of Information Technology & Decision Making* 08(04):727–47.

Li, Xiafei and Yu Wei. 2018. "The Dependence and Risk Spillover between Crude Oil Market and China Stock Market: New Evidence from a Variational Mode Decomposition-Based Copula Method." *Energy Economics* 74:565–81.

Lopera, C. M., M. C. Jaramillo, and L. D. Arcila. 2009. "Selection of a Copula Model to Fit

Bivariate Dependent Data." *Dyna-Colombia* 76(158):253–64.

Marco Flores. 2013. "Cuantificación Del Riesgo Operacional Mediante Modelos de Pérdidas Agregadas y Simulación Monte Carlo Operational Risk Quanti." Retrieved October 22, 2018 (https://webcache.googleusercontent.com/search?q=cache:wn_vcN7RXWgJ:https://dialnet.unirioja.es/descarga/articulo/4647633.pdf+&cd=2&hl=es&ct=clnk&gl=co).

Martínez-sánchez, José Francisco and Francisco Venegas-martínez. 2013. "Riesgo Operacional En La Banca Trasnacional : Un Enfoque Bayesiano." (1):31–72.

McNeil, Alexander J., Rüdiger Frey, and Paul Embrechts. 2015. *Quantitative Risk Management : Concepts, Techniques and Tools*.

Mensi, Walid, Shawkat Hammoudeh, Syed Jawad Hussain Shahzad, Khamis Hamed Al-Yahyaee, and Muhammad Shahbaz. 2017. "Oil and Foreign Exchange Market Tail Dependence and Risk Spillovers for MENA, Emerging and Developed Countries: VMD Decomposition Based Copulas." *Energy Economics* 67:476–95.

Mensi, Walid, Shawkat Hammoudeh, Syed Jawad Hussain Shahzad, and Muhammad Shahbaz. 2017. "Modeling Systemic Risk and Dependence Structure between Oil and Stock Markets Using a Variational Mode Decomposition-Based Copula Method." *Journal of Banking & Finance* 75:258–79.

Mitra, Sovan, Andreas Karathanasopoulos, Georgios Sermpinis, Christian Dunis, and John Hood. 2015. "Operational Risk: Emerging Markets, Sectors and Measurement." *European Journal of Operational Research* 241(1):122–32.

Mittnik, Stefan, Sandra Paterlini, and Tina Yener. 2011. "Operational-Risk Dependencies and the Determination of Risk Capital." *SSRN Electronic Journal*.

Monti, Fabio, Michael Brunner, Fabio Piacenza, and Davide Bazzarello. 2010. "Diversification Effects in Operational Risk: A Robust Approach."

Mora Valencia, Andrés. 2010. *Una Comparación de Algunos Métodos Para Cuantificar Riesgo Operativo*.

Moscadelli, Marco. 2004. "The Modeling of Operational Risk: Experience with the Analysis of the Data Collected by the Basel Committee." *Bank of Italy, Banking Supervision Department.* (517).

MSCI. 2018. “Index Methodology - MSCI.” Retrieved October 22, 2018 (https://www.msci.com/index-methodology).

Murillo Gómez, Juan Guillermo. 2009. *EXTREME VALUE THEORY AND OPERATIONAL RISK: AN APPLICATION TO A FINANCIAL INSTITUTION*.

Nikonov, Oleg I., Vladimir E. Vlasov, and Marina A. Medvedeva. 2013. “Operational Risk Economic Capital Allocation.” Pp. 1550–53 in.

de Oliveira, Felipe A., Sinézio F. Maia, Diego P. de Jesus, and Cássio da N. Besarria. 2018. “Which Information Matters to Market Risk Spreading in Brazil? Volatility Transmission Modelling Using MGARCH-BEKK, DCC, t-Copulas.” *The North American Journal of Economics and Finance* 45:83–100.

Otero, Pablo and Omar Venerio. 2009. “Determinación Del Requerimiento de Capital Por Riesgo Operacional.” *Quantum* IV(Nº1).

Ozun, Alper and Atilla Cifter. 2007. “Portfolio Value-at-Risk with Time-Varying Copula: Evidence from Latin America.” *Journal of Applied Sciences* 7(14):1916–23.

Páez Tovar, F. M. and J. E. Gómez González. 2013. “Estimación Del Capital Necesario Para Mitigar El Riesgo Operativo En El Mercado Asegurador Colombiano.”

Panjer, Harry H. and John Wiley & Sons. 2006. *Operational Risk : Modeling Analytics*. Wiley Interscience.

Pavel V. Shevchenko, Gareth W. Peters, Bertrand Hassani, Ariane Chapelle. 2009. “Consistent Quantitative Operational Risk Measurement.” *Operational Risk Towards Basel III, Best Practices and Issues in Modeling, Management and Regulation. New York: John Wiley & Sons.* To appear in chapter 2.

Peters, Sanjay. 2010. *Riegos y Oportunidades de Los Mercados Emergentes: Los Casos de India y China*.

Pinto Gaviria, Luz Mercedes and Alejandro Leyva Lemarie. 2008. “Administración Del Riesgo Operacional Comité de Basilea Sobre Supervisión Bancaria Administración Del Riesgo Operacional.” *AD MINISTER Universidad EAFIT* 12:89–106.

POSADA ESPINAL, FERNANDO ESTEBAN. 2012. “IDENTIFICACIÓN DE UNA METODOLOGÍA DE MEDICIÓN DEL RIESGO OPERACIONAL UTILIZANDO REDES BAYESIANAS.”

Rachedi, Omar and Dean Fantazzini. 2011. “Multivariate Models for Operational Risk: A Copula Approach Using Extreme Value Theory and Poisson Shock Models.” Pp. 197–218 in *Operational Risk toward Basel III*. Hoboken, NJ, USA: John Wiley & Sons, Inc.

Shevchenko, Pavel and Grigory Temnov. 2009. “Modeling Operational Risk Data Reported above a Time-Varying Threshold.” *The Journal of Operational Risk* 4(2):19–42.

Shevchenko, Pavel V. 2007. “Implementing Loss Distribution Approach for Operational Risk.” *Applied Stochastic Models in Business and Industry* 23(January):157–64.

Varela, R. and S. Rodríguez. 2006. “Impacto de Las Metodologías Propuestas Por El Comité de Basilea Para El Cálculo de Los Requerimientos de Capital Por Riesgo Operativo En El Sector Bancario Colombiano.”

Wright, M., I. Filatotchev, R. E. Hoskisson, and M. Peng. 2005. “Strategic Research in Emerging Markets: Challenging the Conventional Wisdom.” *Journal of Management Studies* 42(1):1–33.

Zhang, Yuli, Jun Yang, Jintong Tang, Kevin Au, and Hongzhi Xue. 2013. “Prior Experience and Social Class as Moderators of the Planning-Performance Relationship in China’s Emerging Economy.” *Strategic Entrepreneurship Journal* 7(3):214–29.