INSTITUTO UNIVERSITÁRIO DE LISBOA

Department of Finance

Fundamental Review of the Trading Book – Impact assessment on banks capital requirements under the Internal Models Approach

Marta Sofia Balseiro Rodrigues

Master in Finance

Supervisor:
Prof. Paulo Viegas de Carvalho, Assistant Professor, ISCTE Business School

November, 2020

Department of Finance

Fundamental Review of the Trading Book – Impact assessment on banks capital requirements under the Internal Models Approach

Marta Sofia Balseiro Rodrigues

Master in Finance

Supervisor:
Prof. Paulo Viegas de Carvalho, Assistant Professor, ISCTE Business School

November, 2020

Acknowledgements

I would like to express my sincerely gratitude to my supervisor, Professor Paulo Viegas de Carvalho, for his guidance, availability and understanding during the development of this Dissertation. These elements were quite important in order to make this study possible.

I thank my family and friends, and especially my parents, whose support and caring were essential during this year. They were, and always are, the ones who believe in me the most and allow me to follow my dreams and achieve my goals.

I would also like to express my appreciation to ISCTE-IUL and all the professors who were part of my journey as a student of this university, for the five years of continuous learning and growth.

Resumo

Este estudo avalia o impacto do FRTB nos requisitos de capital regulamentar dos bancos para risco de mercado, considerando a Abordagem de Modelos Internos. Para tal, o requisito de capital baseado na abordagem atual é comparado com o requisito de capital exigido com a implementação do FRTB, através da análise de uma carteira estilizada. De modo a avaliar se a estrutura de ativos da carteira afeta o resultado desta comparação, foi também efetuada uma análise de sensibilidade, através da alteração dos pesos relativos de algumas classes de ativos na carteira em relação ao cenário de base. Os resultados desta investigação evidenciam que o Expected Shortfall, por si só, implica um requisito de capital para risco de mercado mais elevado quando comparado com a soma das medidas Value at Risk e Stressed Value at Risk. Ambas as componentes diversificável e não diversificável do Expected Shortfall contribuem para tais aumentos, sendo esta última a principal responsável. Em relação ao requisito de capital para risco de mercado considerando o cálculo destas três medidas nos últimos 60 dias anteriores e o efeito do fator de multiplicação inerente a cada regulamentação, este é superior no âmbito da regulamentação atual para o cenário de base e para o cenário com um aumento nas posições de ações. Para o cenário com um aumento nas posições de obrigações, o requisito de capital é superior no âmbito do FRTB, embora de forma ligeira.

Classificações JEL: G21, G28

Palavras-chave: Acordos de Basileia, Carteira de Negociação, FRTB, Risco de Mercado

Abstract

This study assesses the impact of the FRTB on bank's regulatory capital requirements for market risk, considering the Internal Models Approach. To this end, the capital requirement based on the current approach is compared with the capital requirement required with the implementation of the FRTB, through the analysis of a stylized portfolio. In order to assess whether the asset structure of the portfolio affects this result, as sensitivity analysis was also carried out, by changing the relative weights of some asset classes on the portfolio in relation to the baseline scenario. The results of this investigation show that the overall Expected Shortfall, as a standalone measure, implies a higher market risk capital charge when compared to the sum of the Value at Risk and Stressed Value at Risk measures. Both the diversifiable and non-diversifiable components of the Expected Shortfall contribute to such increase, being the latter the main responsible. Regarding the market risk capital requirement considering the computation of all measures over the preceding 60 business days and the effect of the multiplication factor inherent to each regulation, the market risk capital requirement is higher under the current regulation for the baseline scenario and for the scenario with an increase in equity positions. For the scenario with an increase in bonds positions, the market risk capital requirement is higher under the FRTB, yet in a slight way.

JEL Classification: G21, G28

Keywords: Basel Accords, Trading Book, FRTB, Market Risk

Table of Contents

Index of Tables

Glossary of abbreviations and acronyms

ACC – Aggregate Capital Charge

AUD – Australian Dollar

AWHS – Age Weighted Historical Simulation

BCBS – Basel Committee on Banking Supervision

BIS – Bank for International Settlements

CAD – Canadian Dollar

CAR – Capital Adequacy Ratio

CET1 – Common Equity Tier 1

CRD – Capital Requirements Directive

CRR – Capital Requirements Regulation

CTE – Conditional Tail Expectation

DRC – Default Risk Charge

EBA – European Banking Authority

ECB – European Central Bank

ES – Expected Shortfall

ETF – Exchange Traded Fund

ETL – Expected Tail Loss

EU – European Union

EUR – Euro

FHS – Filtered Historical Simulation

FRTB – Fundamental Review of the Trading Book

FX – Foreign Exchange

GARCH – Generalized Autoregressive Conditional Heteroskedasticity

GBP – British Pound sterling

G-SII – Global Systemically Important Institution

HS – Historical Simulation

HY – High Yield

IG – Investment Grade

IMA – Internal Models Approach

IRC – Incremental Risk Charge

JPY – Japanese Yen

NMRF – Non-Modellable Risk Factor

P&L – Profit and Loss

PD – Probability of Default

RWA – Risk-Weighted Asset

SA – Standardized Approach

SEK – Swedish Krona

SVaR – Stressed Value at Risk

USD – United States Dollar

VaR – Value at Risk

VWHS – Volatility-Weighted Historical Simulation

Introduction

Banks play a key role in economic development, by accepting deposits from lenders and granting credit to borrowers. This process of financial intermediation helps in the creation of new capital in an economy and thus fosters economic growth. The modern worldwide economy is globalized, highly dynamic, and so is the banking system.

As in any other type of business, banks need to get profits to sustain their activity in a continuous and consistent way. A bank's profit results from the intermediation margin and from investment activities. However, banks profit sources also present risks. Therefore, risk-taking is an underlying factor in banking activity that needs to be properly managed. In fact, excessive risk-taking by systemically important financial institutions was the major cause for the 2007-2008 financial crisis. Banks had insufficient liquidity levels, the crisis was amplified by the interconnectedness of systemic institutions (BCBS, 2010), and market participants lost confidence in bank solvency, which was transmitted to the whole financial system (ElBannan, 2017).

Capital adequacy is the cornerstone of microprudential and macroprudential regulation of banks (Farkas *et al.,* 2020). Banking prudential supervision and regulation seek to establish standards on the minimum capital requirements that banks need to hold, in order to face their risks exposure. These standards have evolved and been reformed over the last years, to better reflect new requirements with respect to the banking industry. The latest reform issued by the Basel Committee on Banking Supervision (BCBS) corresponds to the Fundamental Review of the Trading Book (FRTB), the new framework for market risk arising out of activities within the trading book. Such framework represents a significant change to the banking industry's current risk management practices.

This dissertation addresses the FRTB by analysing the proposed changes to the Internal Models Approach (IMA) to risk measurement. Compared with the current approach, the new IMA essentially replaces Value at Risk (VaR) by Expected Shortfall (ES), as a new risk measure to determine capital requirements for market risk, and introduces varying liquidity horizons according to the liquidity of different asset classes. Also, there are much more demanding criteria regarding the approval process for the use of the IMA in the FRTB, in particular the fact that this approach is given at the trading desk level and not at the overall portfolio level, and the existence of regular Profit and Loss (P&L) and backtesting requirements. In fact, from the industry perspective, the time frame for implementation of the IMA is too short to implement and test complex model and system changes (BCBS, 2014: 17), and the European Banking Authority (EBA) "*is aware that the new P&L attribution requirements are one of the most pressing issues for the industry, and possibly the biggest hurdle to make the IMA workable for banks*" (European Banking Authority, 2017: 10).

As a way to properly address the topic and estimate the impact of this new framework on banks' market risk capital requirements, it becomes necessary to have an overview in terms of the existing literature. Some studies have been conducted over the recent years, either by competent authorities or by common researchers. The BCBS itself performed an impact study and concluded that on average, when it comes to the IMA under the FRTB, the market risk capital requirements are 54% higher when compared to the current IMA approach. The EBA also recognized an increase in market risk capital requirements with regard to the IMA, identifying the DRC (Default Risk Charge) and the Non-Modellable Risk Factors (NMRFs) as major factors for this increase. Also, as underlined by Pederzoli and Torricelli (2019) through the analysis of a stylized portfolio, market risk capital requirements registered a 17.6% increase under the IMA. Last but not least, although it was not possible to show differences between the VaR and ES measures, Drakenberg and Hegnell (2017) pointed out an increase in the capital charge using the IMA, through the analysis of three stock indices, and provided evidence that the introduction of liquidity horizons in the FRTB constitutes an important factor to such increase.

Considering that there is room for further research on the subject, given some insufficiencies in the existing literature, namely the impact of the reform depending on the structure of the asset classes, the main objective of this dissertation is to assess whether the new regulation, with the introduction of the FRTB, leads to greater capital charge as it happened in previous changes to capital requirements, namely with Basel II.5. Actually, there is a consensus among policy makers in favor of higher capital requirements (Chang *et al.*, 2019), and especially since the financial crisis, higher capital requirements are part of a set of financial regulatory reforms that have been put in place (Cohen, 2013). Also, according to the Bank of England, the capital requirements on large banks are now ten times higher than before the crisis (Bank of England, 2016). The fact that capital regulation has been at the core of banking regulation reforms over the last years tends to cause an expectation in the market of increased capital requirements whenever a new reform is issued. So, in order to measure such potential increase in capital charge, we compare the results from the use of the IMA within each framework, by computing the difference on the capital requirements between the current IMA and the IMA in the context of the FRTB.

This study is supported by an analysis based on a stylized portfolio, composed by assets sensitive to the risk factors most impacted by the FRTB and, therefore, assumed to be sufficiently representative of banks' asset classes in their trading books. The results obtained in this study provide answers to two key-questions: (i) how much is the impact arising from the introduction of the new capital requirements under the IMA; (ii) to what extent and in which circumstances ES is better than VaR. Furthermore, in order to assess whether the asset structure of the portfolio affects the performance of the comparison, a sensitivity analysis is also carried out, by changing the relative weights of some asset classes on the portfolio in relation to the baseline scenario.

The choice of the subject is mostly motivated by its importance nowadays, since it constitutes a current topic of discussion among banking supervisors and bank managers. The FRTB has fostered a debate in the banking industry, and not everyone is convinced about its effectiveness. Taking into account the importance of market risk and the financial crisis from the past decade, it becomes necessary to understand and gauge the magnitude and the added value of the new reform on this field. Understanding the FRTB's standards represents an opportunity to better know the market risk framework, aiming to increase the robustness of the financial system as a whole, in order to avoid a possible collapse in the future.

The results shown in this thesis are expected to bring new evidence to this topic, in which investigation is still scarce. Banking supervisors and regulators, risk managers and other decision makers within the banking industry are among the potential beneficiaries of this Dissertation. Future research on this subject may also benefit from the results shown here.

As to estimate the relevant risk measures for the portfolio, the Historical Simulation (HS) is used, since it is the most widely adopted approach by banks worldwide (Pérignon and Smith, 2009). In order to document the results, three scenarios were considered in the analysis: the baseline scenario; a scenario with a 20% increase in equity positions; and a scenario with a 20% increase in bond positions.

On the one hand, the market risk capital requirement under the current regulation corresponds to the sum of: the maximum amount between the VaR at the 99% confidence level and the VaR for the preceding 60 business days at the same confidence level taking into account the effect of a multiplication factor; and the maximum amount between the Stressed VaR (SVaR) at the 99% confidence level and the SVaR for the preceding 60 business days at the same confidence level taking into account the effect of a multiplication factor. On the other hand, the market risk capital requirement within the FRTB is equal to the maximum amount between: the sum of the capital risk charge for modellable risk factors and the capital risk charge for NMRFs, for IMA-approved trading desks; and the sum of the capital risk charge for modellable risk factors for the preceding 60 business days taking into account the effect of a multiplication factor and the capital risk charge for NMRFs for the preceding 60 business days, for IMA-approved trading desks. In particular, the capital charge for modellable risk factors corresponds to the ES, computed at the 97.5% confidence level, resulting from the weighted average of the constrained (or undiversified) ES and unconstrained (or diversified) ES measures.

A first general conclusion that can be drawn from this study is that the overall ES measure is greater than the sum of the VaR and SVaR measures, for the three scenarios considered in the analysis. For this result, the undiversified ES contributes the most, since it does not consider the correlations between risk factors.

When considering the VaR, SVaR and ES measures over the preceding 60 business days and applying the effect of the multiplication factors (i.e., equal to 3 for the current regulation and equal to 1.5 under the FRTB), the market risk capital requirement appears to be higher under the current regulation for the baseline scenario and for the scenario with a 20% increase in equity positions. For the scenario with a 20% increase in bond positions, the market risk capital requirement turns higher under the FRTB, yet slightly.

As a global effect, the expected increase on the market risk capital requirement under the FRTB will be sensitive to the bank’s trading book portfolio composition. According to this study, a greater effect from that reform is expected in the cases where the portfolio has a greater weight of bond positions.

This Dissertation is structured as follows. Section 1 comprises the review of the existing literature on the relationship between capital requirements and market risk. Section 2 encompasses the mechanism within the FRTB under the IMA, as well as the recent research on this subject. Section 3 focuses both on the description of the dataset and methodology. Section 4 contains the results on the capital requirements, establishing the difference between the current approach and the approach within the FRTB, for the three scenarios considered in the analysis. Section 5 discusses the results. Conclusions are presented in Section 6.

1. Relationship between Capital Requirements and Market Risk

1.1. Market risk and risk management

Financial risk is associated with the uncertainty on the future payoff of an investment. Whether one is referring to a bank, a large firm or simply a single trader or portfolio manager, we need to understand and manage a given financial risk, in order to minimize the potential losses and ensure the profitability of the investment.

Market risk is one of the different types of financial risks. It is defined as the risk of losses in on- and off-balance-sheet positions arising from movements in market prices. This risk type comprises the risks pertaining to interest rate related instruments and equities in the trading book, and foreign exchange risk and commodities risk throughout the bank (BCBS, 2019).

Two major categories of market risk may be outlined: systematic risk and specific risk. On the one hand, systematic risk (also referred to as undiversifiable risk) corresponds to the probability of a loss associated with the overall market and cannot be avoided or mitigated through portfolio diversification, only through hedging (i.e., a position to offset potential losses on an investment). On the other hand, specific risk (also referred to as idiosyncratic risk) only affects a given firm or a particular industry and can be diminished or even eliminated through diversification.

Along with credit risk and operational risk, market risk is one of the most important regulatory risk types for banks, for which they must observe minimum capital requirements in order to face their daily trading books exposures.

Regarding capital requirements for market risk, it is relevant to distinguish the definitions of the trading book and the banking book. A bank's trading book includes assets that are regularly traded (holding investments with a short-term perspective), while the banking book refers to assets expected to be held by the bank until maturity. Hence, the instruments included in the trading book are subject to market risk capital requirements, while those included in the banking book are subject to credit risk capital requirements. According to the BCBS (2019), the trading book may contain exposures on stocks, bonds with a trading perspective, derivative financial instruments, foreign exchange (FX) and commodities.

As described by Alexander (2008), banking risks are commonly measured in a so-called 'bottom-up' framework. This means that risks are first identified at the individual position level. Consequently, as those positions are combined into portfolios, a measure of portfolio risk is obtained from the individual risks of the various positions. As portfolios are grouped into larger and larger portfolios (first aggregating all the traders' portfolios in a particular trading unit, then aggregating across all trading units in a particular business line, then aggregating over all business lines in the bank), the risk manager in a bank will aggregate the portfolio's risks in a similar hierarchy.

According to Meyer (2000), in managing risk, banks must decide which risks to take, which risks to transfer and which to avoid altogether. Therefore, to take an appropriate decision, the risk manager needs to measure a given risk with a high level of accuracy, i.e., with a model that accurately describes asset returns, in order to be able to react "(…) *before it would be too late from the point of view of the bank and its business as well as from the aspect of financial sector stability*" (Mirković *et al.*, 2013). Most modelling approaches to quantify market risk lead to a single risk measure (a statistic of the P&L distribution), which summarizes the whole distribution of asset returns, and which is easy to interpret and compare with other statistics. VaR and ES are two examples of such approaches.

1.2. Risk measures

A risk measure determines the minimum amount of money that is required to cover the potential unexpected loss related with a certain risky position. In line with Filippova (2018), most modern portfolio risk measures are statistical quantities describing the conditional or unconditional loss distribution of a portfolio, over some predetermined time horizon Δt, such as VaR and ES. More specifically, denoting $\Delta V_{t+1} = V_{t+1} - V_t$ as the change in value of a portfolio per unit of time, where V_{t+1} is the value of the portfolio at the end of the time period $t+1$ and V_t is the value at the end of the previous period, the loss is defined as $L_{t+1} = min\,(0, \Delta V_{t+1})$. The values of L_{t+1} generate a loss distribution, whereas the values of ΔV_{t+1} generate a P&L distribution.

For a risk measure to correctly describe and reflect risk, and so facilitate a good decision-making by the risk manager, such measure should be considered coherent. According to Artzner *et al.* (1999), a risk measure $\rho(.)$ is said to be coherent if it satisfies the following axioms, for any number n and positive number t:

i. Sub-additivity: $\rho(X) + \rho(Y) \leq \rho(X+Y)$ (1)

ii. Positive homogeneity: $\rho(tX) = t\rho(X)$ (2)

iii. Monotonicity: $\rho(X) \geq \rho(Y)$, if $X \leq Y$ (3)

iv. Risk-free condition or Translation Invariance: $\rho(X+n) = \rho(X) - n$ (4)

where X and Y are the future payoffs generated by two risky positions, n is a given amount invested in cash or in a risk-free asset, and t is a scale factor. The properties above mean that merging portfolios cannot increase total risk (sub-additivity), increasing the size of a portfolio by a factor t should scale its risk measure by the same factor t (homogeneity), portfolios always performing worse than others are riskier (monotonicity), and adding cash or a risk-free asset to a portfolio reduces uncertainty and risk by the same amount (translation invariance).

Particularly, sub-additivity constitutes a very important and desirable property, since it guarantees the diversification principle, i.e., the risks of individual positions composing the portfolio do not increase the risk of the overall portfolio. If a risk measure is not sub-additive, it may discourage diversification or lead to regulatory arbitrage that underestimates the combined risks. Therefore, this axiom is a necessary condition for capital adequacy requirements in banking supervision and portfolio-optimization problems (Acerbi and Tasche, 2002). ES is an example of a coherent risk measure[1], while VaR is not. Moreover, in general the ES is a continuous measure with respect to the confidence level (i.e., it does not change drastically when there is a change in the confidence level), in contrast to VaR (Acerbi & Tasche, 2002).

Another relevant discussion related to the properties of a risk measure has to do with elicitability. Research by Roccioletti (2016), as cited by Gameiro (2017), defines elicitability as the property that allows for the ranking of risk models' performance. In a theoretical-decision framework, if a risk measure is elicitable, then it is possible to perform comparative and validation tests on different models, through a scoring function[2]. In this case, VaR is an elicitable risk measure, whereas ES is not. Nevertheless, despite the debate on the link between elicitability and backtesting power, according to Acerbi and Szekely (2014), elicitability is not a necessary condition to do backtesting in an appropriate way, and so to get significant results. VaR and ES are two risk measures that attempt to provide a single number that quantifies the existent risk in a portfolio and will be developed in the next sub-sections.

[1] See Acerbi (2002) for additional details on the definition of coherent measures of risk.
[2] See Gameiro (2017) for further details.

1.2.1. Value at Risk

Currently, VaR, which corresponds to a conditional quantile of the P&L distribution, is probably the most used risk measure. Pioneered by JP Morgan during the late 1980s, most of its popularity among regulators and managers is due to its simplicity, since it summarizes in a single number the overall market risk faced by an institution, within some confidence level. Thus, its meaning is easy to understand, compare and interpret.

Alexander (2008) defines VaR as the loss that we are fairly sure will not be exceeded if the current portfolio is held over some period of time. Therefore, VaR depends not only on the confidence level $(1-\alpha)$, but also on the risk horizon (h), the latter being the period of time, measured in trading days, over which VaR is measured. In the case of banks, both parameters are usually set by banking regulation[3].

To estimate the VaR of a portfolio, parametric or non-parametric approaches can be used. The first approach measures market risk by fitting probability curves to the observed data and then infer the VaR from the fitted curve (Abad *et al.,* 2014). Riskmetrics is just an example of such approach[4]. The parametric VaR is usually computed in relative terms as:

$$VaR = -V \cdot z_{\alpha} \cdot \sigma \tag{5}$$

where V is the market-to-market value of the financial asset or portfolio, z_{α} is the quantile in the P&L distribution corresponding to the α significance level, and σ is the standard deviation of returns.

Typically, this method assumes that asset returns follow a normal distribution, an assumption that sometimes is criticizable due to non-normal kurtosis and skewness typically observed in the historical distribution of returns. In turn, non-parametric approaches do not require strong distributional assumptions about the distribution of returns, since their objective is to use the empirical distribution to estimate VaR, based on the idea that what happened in the past will repeat in the future.

The HS is the most widely implemented case of non-parametric approaches[5], a result of its intuitiveness and simplicity. In accordance with Dowd (2002), the HS is a histogram-based approach, conceptually simple, easy to implement, widely used, and has a fairly good tracking

[3] The BCBS sets the significance level of VaR to 1% and the risk horizon to 10 trading days.
[4] Riskmetrics was developed by J. P. Morgan in 1996. See Abad *et al.* (2014) for further details.
[5] Research by Pérignon and Smith (2009), based on US, Canadian and international banks' disclosed data, revealed that 73% of banks use HS on their VaR method reports. Moreover, a study conducted by Mehta *et al.* (2012), based on a survey to 13 large banks from Europe and North America, showed that the HS is the dominant mode of simulation (about 75% of banks use this method).

record. In this case, the VaR in time period T is given by the α percentile in the distribution of hypothetical P&L scenarios, each of which determined using the historical price movements between the first and oldest observation and T:

$$v_{scenario\_t} = v_T \frac{v_t}{v_{t-1}} \qquad (t = 1, \dots, T) \tag{6}$$

As pointed by Dowd (2002), just like any other method the HS has its advantages and disadvantages. Some of the advantages have to do with its intuitiveness and simplicity. HS is very easy to implement (and consequently the results are easy to report and communicate to senior positions in an institution), it can accommodate any type of risk position (including derivatives) and can be easily modified to allow for the different forms of weighting past observations. Regarding the disadvantages, it has total dependence on the dataset, given its reliance on the empirical distribution of returns. This is probably the biggest disadvantage of this method when compared to others. Since it deals with an empirical distribution, if that distribution does not show some sort of volatility, it is expected that the VaR or ES estimates will often underestimate the actual risks. Along the same line of reasoning, if the empirical distribution shows a high level of volatility, the VaR and ES estimates will often overestimate the actual risks. Also, if a shift (e.g., an increase in risk associated with sudden market turbulence) takes place during the sample period, the estimates resulting from the HS method tend to delay in reflecting that shift. These drawbacks can be ameliorated resorting to some sophisticated versions of the HS, such as: the Age-Weighted Historical Simulation (AWHS), which incorporates a weighting structure that gives greater weight to more recent observations; the Volatility-Weighted Historical Simulation (VWHS), an approach that weights data by the relative volatility; and the Filtered Historical Simulation (FHS), which combines the non-parametric features of the HS with conditional volatility models (e.g., GARCH[6]). Additionally, to get reasonable risk estimates, a large sample size is needed. However, at the same time, a large sample means going further into the past, which decreases the relevance of the VaR and ES estimates, since the current market conditions will be less reflected by the sample. A study conducted by Harmantzis *et al.* (2006) pointed out the HS as a method with more correct estimations for the ES.

Another common strand on the computation of VaR relates to the SVaR, which is calculated analogously to the VaR, with the difference that the model here is calibrated for a crisis or stress situation (Neisen and Röth, 2017).

[6] Degiannakis *et al.* (2013) used this method to forecast VaR and ES estimates across 20 stock indices.

VaR has been predominantly used as the traditional risk measure by large financial institutions in their market risk internal model approaches for decades. However, several issues began to be identified by the BCBS. Despite its popularity, VaR is not sub-additive and neglects the loss on the tail, beyond the VaR level[7], i.e., two distributions may have the same VaR, but different losses that exceed the VaR (Nieto and Ruiz, 2016). Particularly, the drawbacks of VaR became painfully evident during the global financial crisis of 2008, as asset returns plummeted into the fat-tail region of non-normally shaped distributions. As a result, regulators were forced to recognise that VaR projections of possible losses far underestimated actual losses on extreme bad days (Saunders and Cornett, 2017), both in terms of the frequency and the magnitude of the exceptions (Johnson, 2011). This explains why the ES emerged as an alternative risk measure.

1.2.2. Expected Shortfall

ES is the average value of the losses exceeding VaR (Barrailler and Dufour, 2014). For example, for a VaR of 50 million euros determined with a 99% confidence level for a 10-day time period, the ES is the average amount lost over a 10-day time period given a minimum loss of 50 million euros. The ES is also termed as Conditional VaR, Conditional Tail Expectation (CTE) or Expected Tail Loss (ETL). Accordingly, its calculation can generally be formalized as:

$$E[X \mid X \leq -VaR] = \frac{\int_{-\infty}^{-VaR} x f(x)dx}{\int_{-\infty}^{-VaR} f(x)dx} \tag{7}$$

where X denotes the P&L over the time period used to compute VaR.

One may argue that ES considers worst case scenarios, by assessing the expected losses related to all scenarios above the threshold loss. In other words, ES accounts for tail risk, which is directly linked to the existence of fat tails. Tail risk[8] is thus related to the probability of a loss taking place due to an uncommon event, in some specific distribution. Although fatness may exist in both the left and right tails of the distribution, investors and regulators are particularly concerned with the left tail, where potential losses are located. The presence of fat tails in a distribution of returns (against the assumption of null excess kurtosis for a normal distribution), i.e., the observation of a leptokurtic distribution, implies larger effects on market returns that

[7] Despite this general conclusion, an analysis performed by Daníelsson *et al.* (2013) provided evidence that VaR can be sub-additive on the left tail region when asset returns are multivariate regularly varying and possibly dependent.

[8] See Yamai and Yoshiba (2005) to an illustration of the problem of tail risk.

need to be accounted when assessing the portfolio risk. This is the case when a financial crisis takes place.

From empirical evidence, one is able to argue that asset returns are not often normally distributed. In fact, fat tails (positive excess kurtosis) are more likely to occur than what is predicted by the normal distribution, and so VaR does not account for the potential size of the losses in the left tail, resulting in an underestimation of the risk of portfolios with fat-tailed properties and high potential for large losses (Yamai and Yoshiba, 2002). In other words, for situations in which probability distributions exhibit fat-tail losses, VaR may look relatively small, but ES may be very large (Saunders and Cornett, 2017). According to Mak and Meng (2014), neither the ES nor the VaR fully capture tail risk, but the ES's performance is relatively superior. Hence, ES is an improvement over VaR when one is in the presence of a distribution with fatter tails, the main cause why regulators are switching to this risk measure, after many years using VaR.

Despite its advantages, ES also has some shortcomings: it does not have the simplicity of VaR, and so it is more difficult to understand and interpret. In terms of backtesting, it is also more difficult to back-test a procedure for calculating ES when compared to a procedure for calculating VaR. Del Brio *et al.* (2020) conducted a recent research that analyses backtesting techniques for VaR and ES applied to commodity Exchange Traded Funds (ETFs), recommending the application of semi-nonparametric techniques. Besides that, an analysis carried out by Kellner and Rösch (2016) concluded that the level of model risk tends to be higher for the ES when compared to the VaR, being the heaviness in the tails of the model's distributions the main driver of this result. Effectively, since the ES takes into account the loss beyond the VaR level, its estimates will be affected when a large and infrequent loss takes place in the sample (Giannopoulos and Tunaru, 2005) (Yamai and Yoshiba, 2005).

1.3. Capital regulation and evolution of capital requirements

As a response to international financial instabilities that arose from globalization, the BCBS was founded in 1974, linked to the Bank for International Settlements (BIS)[9], aiming to improve banking regulation worldwide by creating a strong foundation on supervision. It was initially composed by the central banks of the G-10 countries and currently comprises members

[9] BIS was established in 1930, is headquartered in Basel, Switzerland and owned by 60 central banks from around the world. As main responsibilities, it contributes to international cooperation, acts as a bank to central banks in financial transactions and promotes monetary and financial stability worldwide.

from 28 international jurisdictions, involving central banks and authorities with formal responsibility for banking supervision. BCBS is responsible to set out the quantitative standards on the minimum capital requirements subject to banking risks, the so-called Basel Accords.

The first framework of such accords, Basel I, was implemented in 1988 and primarily focused on credit risk (i.e., possibility of a loss resulting from a counterparty's payment failure). This accord had three main objectives, as stated by Magnus *et al.* (2017): (i) aiming to guarantee that banks held sufficient capital to cover their risks; (ii) to level the playing field among international banks competing cross-border; (iii) to facilitate comparability of banks' capital positions.

Basel I was later updated, in 1996, to include a market risk section, focused on trading risks.[10] With this amendment, banks had the opportunity to choose between two broad methodologies in measuring market risk: the Standardized Approach (SA), with standardized measurement frameworks, and the IMA, in which banks could use their own risk management models. This choice was subject to the approval of the bank's national supervisory authority. In line with Hull (2018), Basel I calculations were based on a VaR calculated for a minimum holding period of 10 days, with a 99% confidence level. Banks were required to maintain a Capital Adequacy Ratio (CAR), composed by Tier 1[11] and Tier 2[12], equal to at least 8% of their Risk-Weighted Assets (RWAs).

Afterwards, as a need to address several changes to the first Basel Accord, the BCBS introduced Basel II in 2004, built on three complementary pillars: Minimum Capital Requirements, Supervisory Review Process and Market Discipline. Within these pillars, market risk remained unchanged, nonetheless a number of new elements emerged to overcome some limitations from Basel I[13].

Later on, with the financial crisis of 2007-2008, limitations regarding the determination of capital requirements for risks arising from trading activities were identified. As stated by the BCBS (2009), an important source of losses and of the build-up of leverage occurred in the trading book. In this way, the Committee released amendments to Basel II framework between 2008 and 2009, known as Basel II.5. One of these was the addition of a stressed VaR measure,

[10] See BCBS (1996) for further details. The amendment was formalized in 1998.

[11] Bank's core capital that includes permanent shareholders' equity and disclosed reserves.

[12] Bank's supplementary capital that includes fewer permanent forms of capital.

[13] Namely: introduction of operational risk, defined by the BCBS (2011: 3) as "*the risk of loss resulting from inadequate or failed internal processes, people and systems or from external events*" to the computation of the minimum capital requirement; national supervisors could impose additional capital charges above the Basel minimum; and increasing banks disclosure standards in terms of capital structure, risk exposure and capital adequacy, in order to increase market discipline.

intended to capture the behaviour of market variables during a 250-day period of stressed market conditions, i.e., in which there is a significant financial stress for the current portfolio. In practice, these amendments meant that capital requirements for market risk, at least, doubled.

Thereafter, Basel III was introduced by the BCBS in 2010, as a result of the economic and financial crisis from the end of the previous decade and aiming to strengthen and reinforce banks' regulatory capital and liquidity ratios. In this context, Basel III standards are transposed into the European Union (EU) through the implementation of the Capital Requirements Regulation (CRR) II (2019/876) and the Capital Requirements Directive (CRD) IV (2019/878) legislations[14]. Particularly, although the overall regulatory capital level remained the same, the minimum Common Equity Tier 1 (CET1) increased from 4% to 4.5% and the minimum Tier 1 rose from 4% to 6%. Additionally, higher capital requirements were imposed to Global Systemically Important Institutions (G-SIIs). In line with Neisen and Röth (2017), under the current regulatory framework, capital requirements on market risk using the IMA are based on three main indicators: the traditional VaR at a 99% confidence level and a holding period of 10 days, the SVaR, and the Incremental Risk Charge (IRC), which implies an additional capital requirement on the default and migration risk of trading book positions resulting from the special interest rate change risk. This last indicator was replaced by the Default Risk Charge (DRC) in the FRTB.

For the purpose of calculating the market risk capital requirement in Basel III and under the IMA, the following formula is used:

$$\begin{aligned} MRC_t^{IMA} &= max\ \left(VaR_{0.99,t-1}; (m_c + p_c) \times VaR_{0.99,avg}\right) \\ &+ max\ \left(SVaR_{0.99,t-1}; (m_s + p_s) \times SVaR_{0.99,avg}\right) \end{aligned} \tag{8}$$

where $VaR_{0.99,t-1}$ and $sVaR_{0.99,t-1}$ denote the previous day VaR and SVaR computed at a 99% confidence level, respectively, $VaR_{0.99,avg}$ and $SVaR_{0.99,avg}$ correspond to an average of the VaR and SVaR measures over the preceding 60 business days, respectively, m_c and m_s are multiplication factors set by national supervisory authorities, with a minimum value of 3, based on the assessment of the quality of the bank's risk management system, and p_c and p_s are plus factors, which can range from 0 to 1, depending on the outcome of the VaR backtesting, performed by the bank.

[14] Implemented by the European Parliament and by the Council of the EU on June 2019.

2. Fundamental Review of the Trading Book

2.1. The mechanism

The financial crisis of 2007-2008 revealed a number of weaknesses, known even before they occurred. For example, the banking sector faced that financial crisis with too much leverage and inadequate liquidity buffers (Filippova, 2018). Particularly, available capital was not sufficient to absorb losses when they materialised, mostly because the market risk framework was based on the idea that all risk positions on the trading book were equally liquid (i.e., banks could exit or hedge their positions over a 10-day horizon). As liquidity conditions deteriorated during the crisis, banks were forced to hold risk positions for much longer than expected and incurred large losses from changes in values due to fluctuations in liquidity premia (BCBS, 2013).

Consequently, and to tackle the remaining problems, the BCBS initiated a comprehensive review of the risk-weighted capital framework, aiming at finalizing the Basel III reform package and ensuring its consistent implementation. The objective was to "*help strengthen the resilience of the global banking system, maintain market confidence in regulatory ratios and provide a level playing field for banks operating internationally*" (BCBS, 2013). This review stands for the FRTB, issued by the BCBS in May 2012, and after several revisions is expected to be implemented in 2022[15]. It is expected to lead to a more rigorous and complex approach calculate regulatory capital for market risk, when compared to the previous approaches used in banking supervision. With the FRTB, all positions held for trading must be assigned to the trading book and are consequently subject to the respective regulatory requirements.

The new standards for minimum capital requirements for market risk set by the FRTB focus on the following aspects: a clearer boundary between the trading book and the banking book[16]; a revised SA and IMA; a limit to the diversification benefit; and incorporation of liquidity considerations, by introducing liquidity risk. According to the BCBS, "*the result of this review set out stricter criteria for assigning instruments to the trading book*", since it "*overhauled the internal models methodology to better address risks observed during the crisis, reinforced the process for supervisors to approve the use of internal models and introduced a new, more risk-sensitive standardised methodology*" (BCBS, 2019: 2).

[15] As suggested in ISDA & AMFE (2017: 8).

[16] It is important to note that financial institutions must conduct ongoing evaluations with regard to the instruments included in each book, to ensure that each instrument is allocated to the correct book.

In banking supervision, the principle of proportionality must be put into practice. In other words, supervision needs to be adapted according to the characteristics of the bank, namely its risk profile, business model and dimension. In line with the CRR II[17], depending on the size of the trading book and on given thresholds of on- and off-balance sheet trading book business, the calculation of capital requirements may differ. Hence, a bank with limited or small trading book activities (equal to or less than EUR 50 million and 5% of the institution's total assets) will be allowed to apply only the credit risk treatment for banking book positions, thereby having no market risk capital requirements. Also, according to the European Commission, banks having a medium trading book (trading book business is up to EUR 300 million and 10% of the bank's total assets) must permanently use the existing market risk standardized approach. Unlike Basel III, although both approaches are considered in the FRTB, the use of the SA is mandatory, since it works as a "floor" provider to the IMA and aims to facilitate consistent and comparable reporting of market risk across banks and jurisdictions. In this way, as stated by Hull (2018), even when banks have been allowed to use the IMA, they are required by regulators to calculate required capital under both approaches. For this reason, the adoption of an IMA by a bank in the context of the FRTB may be discouraged, since it represents a duplication of computational efforts for such banks: "*(…) the new prudential package will likely limit banks' use of internal models to estimate risk variables, giving preference instead to an augmented standardized approach*" (Amorello, 2016: 31), given that the development cost will be larger if a bank fails an internal model approval (Pearce, 2015).

The new review will require high quality data and experienced teams to support implementation (Orgeldinger, 2018), both for the IMA and SA. Nevertheless, the existence of an internal model approval to calculate capital requirements can impact the credibility of the business in the eyes of the banking supervisor, policyholders, shareholders and rating agencies (PwC, 2011), and so contribute to mitigate the reputational risk of the institution. For this reason, with the FRTB coming into effect, banks will need to manage the trade-off between the increased computational effort and their reputation and credibility.

[17] Regulation (EU) 2019/876 of the European Parliament and of the Council of 20 May 2019.

2.2. Internal Models Approach

In general terms, the new IMA can be summed up to the combination of 4 main elements.

As the primary way to measure the risk of fluctuations in market prices, ES replaces VaR. On top of that, in order to capture default risk, the DRC substitutes the old IRC. Lastly, as new elements compared with the previous approaches, the capital charge for NMRFs and the concept of market illiquidity emerge.

Beyond these components, under the IMA, calculations must be carried out at the trading desk level, instead at the whole portfolio level. The BCBS describes a trading desk as "*a group of traders or trading accounts that implements a well-defined business strategy operating within a clear risk management structure*" (BCBS, 2013: 25). Trading desks are defined by the bank itself, but subject to approval by the national supervisor. Escudero (2016: 166) refers that the model approval at the trading desk level "(…) *should facilitate the identification of the relevant risk factors in a particular desk, making it more accurate, and should allow a more granular monitoring of model performance, since the quantitative tests to grant and to keep approval are performed at the trading desk level.".* So, in order to be able to use the IMA to determine market risk capital requirements, banks need to receive such supervisory approval, which is based on several conditions. The process for trading desks approval within the IMA is described in Annex A.

First of all, each trading desk must pass the P&L attribution tests on an ongoing basis. This tool was introduced to evaluate the accuracy of the model at the trading desk level and compares the daily risk-theoretical P&L[18] with the daily hypothetical P&L[19], through the application of two test metrics: the Spearman correlation metric and the Kolmogorov-Smirnov test metric[20]. The results are evaluated according to the following thresholds:

Table 1: Liquidity horizon *n* by risk factor

Zone	Spearman correlation	Kolmogorov-Smirnov test
Amber zone thresholds	0.80	0.09 (p-value = 0.264)
Red zone thresholds	0.70	0.12 (p-value = 0.055)

Source: BCBS (2019).

[18] Defined as the P&L that is predicted by the valuation engines in the trading desk risk management model using all risk factors used in the trading desk risk management model, including the NMRFs (BCBS, 2019).

[19] Defined as the P&L produced by revaluing the positions held at the end of the previous day using the market data at the end of the current day (BCBS, 2019).

[20] The bank must use the most recent 250 trading days of observations for the purpose of calculating these metrics.

As per Table 1, if a trading desk falls on the red zone, it is automatically considered as non-eligible to use the IMA to determine market risk capital requirements. Moreover, if a trading desk is in the amber zone, it is still considered as being eligible to use the IMA to determine market risk capital requirements, but subject to an additional capital surcharge.

Besides P&L attribution, trading desks must satisfy the usual backtesting requirements as well, which work as a complementary tool. The backtesting compares each desk's one-day VaR (for the most recent 12 months' equally weighted observations) at both the 97.5% and 99% confidence levels. If there are more than 12 exceptions at the 99% confidence level or 30 exceptions at the 97.5% confidence level in the most recent 12-month period, then capital requirements must be computed using the SA.

Likewise, there are also backtesting requirements at the overall risk model level, which must be assessed with a VaR measure computed at the 99% confidence level. The BCBS (2019: 81) refers that "(…) *an exception or an outlier occurs when either the actual loss or the hypothetical loss of the bank-wide trading book registered in a day of the backtesting period exceeds the corresponding daily VaR measure given by the model.*". The results from this backtesting can be divided into three different categories, as shown in Table 2.

Table 2: Backtesting zones

Backtesting zone	Number of exceptions	Backtesting dependent multiplier (to be added to any qualitative add-on[21])
Green	0	1.50
	1	1.50
	2	1.50
	3	1.50
	4	1.50
Amber	5	1.70
	6	1.76
	7	1.83
	8	1.88
	9	1.92
Red	10 or more	2.00

Source: BCBS (2019).

[21] This add-on refers to the capital surcharge that can be added to the aggregate capital requirement for market risk if at least one eligible trading desk falls in the P&L attribution test amber zone.

Each category is interpreted as follows: the results that fall under the green zone do not indicate a problem in the bank's risk model; the results within the amber zone are inconclusive with regard to the accuracy of the bank's risk model; the red zone encompasses results that suggest a problem with the quality or accuracy of the bank's risk model.

Going further, the ES must be computed on a daily basis for each trading desk to be included (after respective approval) in the scope of the IMA, at a 97.5% one-tailed confidence level. This confidence level is advocated by the BCBS as being similar to the current VaR 99% confidence level. In fact, Hull (2018) states that for normal distributions, VaR 99% and ES 97.5% are almost the same. For non-normal distributions, they are not equivalent: when the loss distribution has a heavier tail than a normal distribution, the 97.5% ES can be considerably greater than the 99% VaR.

Concerning the second element, the process for computing the DRC is now more detailed when compared with the previous framework, including a VaR model to be conducted weekly (based on a one year time horizon at a one-tail, 99.9% confidence level), and stricter guidelines with regard to the recognition of the impact of correlations between defaults among obligors. Sovereign exposures, equity positions and defaulted debt positions are subject to this charge, and the probabilities of default (PDs) also have a minimum value of 0.03%. The DRC capital requirement corresponds to the greater of the average of the DRC requirement model measures over the previous 12 weeks or the most recent DRC requirement model measure.

With respect to the risk factors to be included in the internal model of each trading desk, there is a difference on the calculation of the capital requirement for modellable risk factors and NMRFs. Essentially, for the trading desks that are allowed to use the IMA, all the risk factors considered to be modellable must be included in the bank's internal, bank-wide ES model. The BCBS states that a modellable risk factor "(…) *should have at least 24 observations per year, with a maximum period of one month between two consecutive transactions*" with "*available real*[22] *prices for a sufficient set of representative transactions*" (BCBS, 2013: 38). If these conditions are not observed, the risk factor has to be classified as non-modellable and consequently is subject to the capital requirement to NMRFs.

In accordance with the BCBS (2019), the bank must calculate a series of partial ES capital requirements for the range of broad regulatory risk classes, which will then be summed to provide an aggregated risk class ES capital requirement. This aggregated capital requirement

---

[22] The price is considered "real" if it is a price at which the institution has conducted a transaction; it is a verifiable price for an actual transaction between other arms-length parties; or the price is obtained from a committed quote (BCBS, 2013).

for modellable risk factors ($IMCC$) is based on the weighted average of the constrained and unconstrained ES capital requirements:

$$IMCC = \rho\big(IMCC(C)\big) + (1-\rho)\left(\sum_{i=1}^{B} IMCC(C_i)\right) \tag{9}$$

where:

- $IMCC(C)$ corresponds to the ES unconstrained capital requirements;
- $IMCC(C_i)$ corresponds to the ES constrained capital requirements;
- ρ equals 0.5 and is the relative weight assigned to the bank's internal model;
- B represents the broad regulatory risk classes (i.e., interest rate risk, equity risk, FX risk, commodity risk and credit spread risk).

The constrained ES capital requirements correspond to the undiversified component of the capital charge, while unconstrained ES capital requirements are related with the diversified component (i.e., the component with no supervisory constraints within cross risk class correlations).

Furthermore, regarding the introduction of the concept of market illiquidity to the model, a liquidity horizon is defined by the BCBS as "*the time required to execute transactions that extinguish an exposure to a risk factor, without moving the price of the hedging instruments, in stress market conditions*" (BCBS, 2014: 16). Until now, all assets were assumed to have a 10-day liquidity horizon (i.e., all considered as equally liquid). With the introduction of the concept of market illiquidity through the FRTB, five liquidity horizons are defined, ranging from 10 days (most liquid) to one year (less liquid), in order to be assigned at the level of broad categories of risk factors. The scaled ES must be computed based on a liquidity horizon n, calculated through the following process: banks must map[23] each risk factor on to one of the risk factor categories, and n is determined for each broad category of those risk factors (Tables 3 and 4).

[23] This mapping must be set out in writing, validated by the bank's risk management, made available to supervisors and subject to internal audit (BCBS, 2019).

Table 3: Liquidity horizons according to the FRTB

j	LH_j
1	10
2	20
3	40
4	60
5	120

Source: BCBS (2019).

Table 4: Liquidity horizon n by risk factor

Risk factor category	n	Risk factor category	n
Interest rate: specified currencies – EUR, USD, GBP, AUD, JPY, SEK, CAD and domestic currency of a bank	10	Equity price (small cap): volatility	60
Interest rate: unspecified currencies	20	Equity: other types	60
Interest rate: volatility	60	FX rate: specified currency pairs[24]	10
Interest rate: other types	60	FX rate: currency pairs	20
Credit spread: sovereign (IG)	20	FX: volatility	40
Credit spread: sovereign (HY)	40	FX: other types	40
Credit spread: corporate (IG)	40	Energy and carbon emissions trading price	20
Credit spread: corporate (HY)	60	Precious metals and non-ferrous metals price	20
Credit spread: volatility	120	Other commodities price	60
Credit spread: other types	120	Energy and carbon emissions trading price: volatility	60
Equity price (large cap)	10	Precious metals and non-ferrous metals price: volatility	60
Equity price (small cap)	20	Other commodities price: volatility	120
Equity price (large cap): volatility	20	Commodity: other types	120

Source: BCBS (2019).

[24] For the purpose of this study, the currency pairs USD/EUR, EUR/GBP and EUR/JPY are included in this category.

Then, the ES for a given liquidity horizon will be the ES at a base liquidity horizon (i.e., 10 days) scaled to that specific liquidity horizon, as follows:

$$ES = \sqrt{\left(ES_T(P)\right)^2 + \sum_{j\geq 2}\left(ES_T(P,j)\sqrt{\frac{(LH_j - LH_{j-1})}{T}}\right)^2} \quad (10)$$

where:

- ES represents the regulatory liquidity-adjusted ES;
- T represents the length of the base horizon, i.e., 10 days;
- $ES_T(P)$ represents the ES at horizon T of a portfolio with positions $P = (p_i)$ with respect to shocks to all risk factors that the positions P are exposed to;
- $ES_T(P,j)$ represents the ES at horizon T of a portfolio with positions $P = (p_i)$ with respect to shocks for each position p_i in the subset of risk factors $Q(p_i, j)$ with all other risk factors held constant;
- LH_j represents the liquidity horizon j.

Similarly to what occurs with the concept of the SVaR in the previous Basel Accords, this ES measure is to be calibrated to a 12-month period of stress, such that it can replicate a situation in which the risk factors of the bank's current portfolio were experiencing a period of stress. According to the BCBS (2019), this calibration is based on a reduced set of risk factors that must be able to explain at least 75% of the variation of the full ES model. This reduced set is, once again, subject to supervisory approval. Also, the observation horizon for determining the most stressful 12 months must, at a minimum, span back to and include 2007, and the observations must be equally weighted.

Therefore, the ES for market risk capital purposes is expressed as a function of the ES using the reduced set of risk factors ($ES_{R,S}$), scaled up by a ratio composed by the current ES using the full set of risk factors ($ES_{F,C}$) and the current ES using the reduced set of risk factors ($ES_{R,C}$). This measure can be formalised as follows:

$$ES = ES_{R,S} \times \frac{ES_{F,C}}{ES_{R,C}} \quad (11)$$

In line with the BCBS (2019), the ratio is floored at 1. Hence, the unconstrained and constrained ES capital requirements from equation (9) will be equal to $ES_{R,S} \times \frac{ES_{F,C}}{ES_{R,C}}$ and $ES_{R,S,i} \times \frac{ES_{F,C,i}}{ES_{R,C,i}}$, respectively.

Then, the overall capital requirement for the trading desks eligible for the IMA (C_A) will be equal to the maximum of the most recent observation and a weighted average of the previous 60 days scaled by a multiplier (m_c), as follows:

$$C_A = max\left\{IMCC_{t-1} + SES_{t-1};\; m_c \times IMCC_{avg} + SES_{avg}\right\} \quad (12)$$

where:

- $IMCC$ represents the capital charge for modellable risk factors of the trading desks approved for the IMA;
- SES represents the aggregate regulatory capital measure for the risk factors in model-eligible trading desks that are non-modellable;
- The multiplication factor m_c is equal to 1.5 but can be set at a higher level by the supervisory authority to address a qualitative and/or backtesting add-on, based on an assessment of the bank's risk management system.

Finally, the aggregate capital charge (ACC) for the IMA will be equal to the above capital charge for eligible trading desks C_A, plus the default risk component (DRC) and the capital charge for ineligible trading desks:

$$ACC = C_A + DRC + C_U \quad (13)$$

being the last one in the scope of the SA.

2.3. Recent research and developments

To measure the capital impact of the FRTB, the BCBS conducted and published two assessment reports, covering a trading book Quantitative Impact Study (QIS), with voluntary and confidential data submitted from individual banks[25] to their national supervisors, with a reporting date of 31st December 2014.

Based on a sample of 44 banks, the change in non-securitization market risk capital charges would be equivalent to a 4.7% share of the overall Basel III minimum capital requirement (BCBS, 2015). However, this result is mainly due to the existence of a large bank on the sample, with a significant amount of market risk-weighted assets. If this bank was excluded from the sample, the increase in the overall capital requirement would fall to only 2.3%. Specifically, regarding the market risk component of the capital requirement and also based on

[25] Data was submitted from 78 banks from 26 jurisdictions, comprising 66 group 1 banks (i.e., internationally active banks that have Tier 1 capital of more than EUR 3 billion) and 12 group 2 banks (the remaining).

the 44 banks sample, the proposed framework would result in a weighted average increase of 74%. Also, when measured as a simple average, the capital requirement under the proposed IMA is 54% higher when compared to the current IMA approach. For the median bank, the same capital requirement is 13% higher. In this QIS, a comparison between the SA and the IMA is also made, based on a sample of 9 banks. According to the BCBS (2015), the capital requirements under the SA are 2 to 3 times higher than the IMA[26].

Likewise, the EBA also developed an impact study on the topic of the FRTB reform, using banking data from end-December 2018. However, the authority underlines that there is a level of uncertainty when interpreting the results obtained, due to the different assumptions taken by each bank when calculating their market risk capital requirements. Nonetheless, the main drivers of the increase in capital requirements when it comes to the IMA are the DRC and the NMRFs. Moreover, on average, the percentage change is higher for institutions using the IMA than it is for institutions only under the SA (increase of 108% versus 76%, respectively), except for medium-sized banks. Also, when referring to the banks business model, the impact is higher for cross-border universal banks, when compared to local universal banks: "*the average increase for the G-SIIs is somewhat higher, standing at around 124.3% (…)*" (European Banking Authority, 2019: 149).

Research by Pederzoli and Torricelli (2019), through the analysis of a stylized portfolio, has provided evidence that the three main FRTB objectives were reached (more fully capture tail risks by substituting VaR-based metrics with ES; incorporation of liquidity risk by introducing liquidity horizons that differ according to the specific risk factor considered; and reduction in the regulatory diversification benefits by introducing constraints on the use of correlations between risk factors), whereby the first two are highly intercurred, and the third appears to be fundamental in obtaining a higher capital charge than the capital requirement of the current regulation.

In that case, the portfolio was composed by a bond position, an index option, and a foreign currency cash position. Also, a 12-month period of stress was selected to estimate SVaR and ES by historical simulation. To the computation of capital requirements under the FRTB, four hypotheses were assumed by the authors: the full set of risk factors coincided with the reduced

[26] The analysis was performed on a risk class-by-risk class basis, with a multiplier of 1 for the ES capital calculation. See BCBS (2015) for further details.

set[27]; there were only modellable risk factors impacting the portfolio value[28]; the average risk metrics over the last sixty days as required by the regulation were not calculated (they were assumed not to be higher than the current estimates); and the DRC[29] was neglected (if considered, it would likely increase the capital charge). Comparing both IMA approaches, the market risk capital requirements under the IMA were increased in 17.6%, although this research did not consider the average of the last 60 days of VaR, SVaR and ES and the respective multiplication factors imposed by the regulation.

Furthermore, Drakenberg and Hegnell (2017) also discuss the implications of the FRTB through the analysis of three indices (large cap S&P 500, small cap S&P 600 and S&P 500 High Yield Corporate Bond Index), representing three different portfolios. In this case, the full set of risk factors was assumed to be equal to the reduced set as well, and the indices were assumed to be enough representative of their asset classes. Around 3000 observations were used for each index, from 2005 to 2016, and a stress period between the end of 2007 and 2008. This research is not able to prove great differences between VaR and ES under the presence of fat tails. Nevertheless, the inclusion of liquidity horizons in the FRTB is found to be an important factor, since it caused an increase in the capital charge.

With the purpose of understanding the impact of the new rules under the FRTB and preparing for its implementation, the ECB Banking Supervision conducted a questionnaire to banks regarding their intentions in applying for an IMA approval. This questionnaire informs that among banks currently using the IMA, approximately 40% aim to apply for the IMA approval. Concerning trading desks, half of these banks wish to include as many trading desks as possible, and the other half only want to include a subset. From the remaining banks, 40% intend to move from the IMA to the SA, and 20% have not yet reached a conclusion[30].

[27] To be consistent with the simple structure of the portfolio. All the risk factors were considered, so there was no need for the adjustment of the reduced set of risk factors to choose the stress period.

[28] The capital add-on for non-modellable risk factors is zero. A non-modellable risk factor is defined as a risk factor for which there are less than 24 observations in a year or more than one month between successive observations.

[29] DRC should also be estimated, in order to account for potential losses resulting from an obligor's default. It is then summed to the ES' capital charge.

[30] See European Central Bank (2020) for further details.

3. Portfolio, Dataset and Methodology

3.1. Sample description

In terms of composition, the portfolio would have to include the asset classes most impacted by the FRTB to be sufficiently representative. In this way, the following positions were chosen:

i. Index positions, sensitive to equity prices;
ii. Bond positions, sensitive to credit spread risk, interest rate and exchange rate;
iii. Commodity positions, sensitive to interest rate, volatility and exchange rate;
iv. An index option[31], sensitive to equity prices and volatility;
v. A foreign currency cash position, sensitive to exchange rate.

The sample of asset prices ranges from beginning-2007 until end-2019, in order to include the financial crisis period, as imposed by the BCBS for the computations of risk measures considering the stress period. Additionally, this observation horizon is in accordance with the minimum 10 years period required by the BCBS.

To estimate the relevant risk metrics, the date 31-12-2019 was considered. Thus, the overall sample period encompasses 3271 observations for each variable, and the stress period includes 253 observations. The descriptive statistics for each asset composing the portfolio are presented in Annex B. Furthermore, the analysis was carried out as having the EUR as the base currency to make the process as close as possible to the viewpoint of a euro-centred bank.

Taking advantage of the third pillar defined by the BCBS, which promotes and enhances bank transparency and disclosure, it is possible to have a minimum degree of access to relevant financial data, including the bank's risk management component and the type of investment portfolios under the market risk capital requirements. Thus, the positions composing the stylized portfolio were assumed to be consistent with the majority of the risk positions that banks typically hold.

[31] This option is an at the money (ATM) European vanilla call on the S&P500.

3.2. Methodology

In order to establish an answer to the key-questions under study and understand the impact of the new regulation, we measure the market risk capital requirements under the IMA, both for the current framework and for the FRTB, and then compare the results.

In what comes to data, after defining the assets composing the portfolio, all data is retrieved from *Bloomberg* and *Yahoo! Finance*. Regarding interest rates, data is downloaded through the official websites of the ECB (for EUR-denominated assets) and the Federal Reserve System (for assets denominated in USD).

After collecting the raw data, it was necessary to clean it up, as a means to eliminate gaps and null observations. As for null observations, the previous day's available price was considered. Regarding returns, log returns were used:

$$r_t = ln\left(\frac{P_t}{P_{t-1}}\right) \tag{14}$$

where P_t denotes the price of the asset at time t, and P_{t-1} is the price of the asset at time $t-1$.

The portfolios' P&L distributions are estimated by HS. Despite some criticism, this non-parametric method is in line with the approach followed by the majority of banks worldwide, as previously mentioned in Section 2.2.1. Consequently, no statistical distribution hypotheses were taken, only the future P&L distribution is assumed to be identical to the past distribution, since the risk factor dependencies are entirely driven by historical data. Considering that this method relies on historical data, one of its most important features corresponds to the way past observations are weighted. The plain version of HS assigns the same weight to all observations, giving the same importance to both recent and older data, which may not produce accurate risk estimates if there are recent trends on data (Čorkalo, 2011).

To overcome such flaw, the AWHS is used, with a lambda factor equal to 0.995. This more refined version of the simple HS increases the sensitivity of the risk estimates in the sense that it presumes a weighting structure that gives more contribution to recent observations rather than to older ones. Letting the ratio of consecutive weights be constant at lambda (λ) and $w(1)$ the weight given to the most recent observation, then the weight of the second most recent observation could be given by $w(2) = \lambda w(1)$. Along this line of reasoning, the weight of the third most recent observation could be given by $w(3) = \lambda^2 w(1)$, and so forth. In this case, lambda corresponds to a decay factor assuming a value between 0 and 1, reflecting the exponential rate of decay in the weight of observations with time (i.e., as time passes the weight given to a specific observation decreases exponentially). The closer to 1, the slower the rate of decay in the weights, while a value closer to 0 indicates a high rate of decay. The weight associated to an observation i days old is represented as follows:

$$w(i) = \frac{\lambda^{i-1}(1-\lambda)}{1-\lambda^{n}} \qquad (i = 1, \dots, N) \tag{15}$$

Comparing both versions of HS, with simple and exponential weight, one can state that the simple version of the HS assumes a lambda equal to 1.

As previously mentioned in Section 3.2., another key factor on the estimation of SVaR and ES has to do with the 12-month period of stress, which was selected considering the worst portfolio losses experienced during the observations' horizon. This period corresponds to the time between 02-09-2008 and 01-09-2009, coinciding with the international financial crisis period.

Both for the overall sample period and for the stress period, the market risk capital requirements were computed according to the current Basel III approach and to the FRTB approach. Specifically, with regard to the latter, the following assumptions were taken, in order to simplify the analysis:

i. The DRC was not considered, since this element is related to a default risk component[32], not in the scope of this study, which focus only on the market risk component;
ii. The capital add-on for NMRFs was not considered (i.e., assumed to be equal to zero), since there are only modellable risk factors composing the portfolio;
iii. The full set of risk factors was assumed to be equal to the reduced set (i.e., the adjustment ratio referred to in Section 3.2. is equal to 1).

Regarding the treatment of the different assets composing the portfolio, it is well known that the VaR computation for stock portfolios differs from the way it is computed for bond portfolios, mostly because in the former case the future volatility of the stock price return is estimated based on past observations of the stock price return. However, this approach is not appropriate when dealing with bonds, since their price behavior changes as time passes. Particularly, the price of a bond will fluctuate due to changes in the discount rates for the maturity of each of its cash-flows (i.e., if the interest rate increases the price of the bond will decrease, and vice-versa). For this reason, the valuation of each bond throughout the observation horizon was made based on the historical time structure of interest rates. Relevant data on the bonds composing the portfolio is presented in Annex C.

[32] See Laurent et al. (2016) for additional details on the default risk component of the FRTB.

With regard to the option position, in order to have enough data to cover the whole observation horizon, an option strategy was performed on *Bloomberg*, and its price was computed based on the inputs of the strategy, using the Black-Scholes (BS) pricing model:

$$C = S_t N(d_1) - Ke^{-rt} N(d_2) \quad (16)$$

with $d_1 = \frac{ln\frac{S_t}{K} + \left(r + \frac{\sigma^2}{2}\right) t}{\sigma_s \sqrt{t}}$ and $d_2 = d_1 - \sigma_s \sqrt{t}$,

where:

- C is the call option price;
- S is the current underlying price;
- K corresponds to the strike price;
- r is the risk-free interest rate;
- t denotes the time to maturity;
- N denotes a normal distribution.

For the calculation of the VaR, SVaR and ES under the HS, the portfolio's P&L was computed for each day in the observation horizon. After ranking the P&L according to the number of scenarios (3271 scenarios for the overall period and 253 scenarios for the stress period, i.e., as many as the historical information), the VaR and SVaR at a 99% confidence level were computed using the AWHS. As for the ES, each asset was mapped to one of the risk factor categories previously highlighted in Table 4, resulting in a total of 5 risk categories (equity price, precious metals price, credit spread, FX rate and interest rate) and comprising the liquidity horizons of 10, 20 and 40 days. This mapping is presented in Annex D.

Since the aggregate capital charge for modellable risk factors corresponds to the weighted average of the constrained and unconstrained ES, both requirements were calculated.

The first one, the non-diversifiable component of the market risk capital requirement, includes the computation of $ES_{R,S}$ (ES for reduced set of risk factors based on the stress period), $ES_{F,C}$ (ES for full set of risk factors based on current period) and $ES_{R,C}$ (ES for reduced set of risk factors based on current period). Recall that we assumed that the reduced set of risk factors equals the full set, and therefore $ES_{F,C}$ and $ES_{R,C}$ are the same and the ratio $\frac{ES_{F,C}}{ES_{R,C}}$ equals 1. In this way, the remaining overall ES measure ($ES_{R,S}$) corresponds to the sum of the breakdown of each risk factor $ES_{R,S}$. The second and diversified component is calculated analogously to the previous measure, but comprising all risk factors.

4. Capital Requirements: Before and After the FRTB

4.1. Results

To address the key-questions of this study, the baseline scenario is the first to be analyzed. In this scenario, the following portfolio composition was considered:

Table 5: Portfolio composition under the baseline scenario

Portfolio (as of 31-12-2019)	Position (in thousand EUR)	Weight
S&P 500	10,000.00	9,09%
NIKKEI 225	8,000.00	7,27%
FTSE 100	8,000.00	7,27%
CAC 40	4,250.00	3,86%
DAX 30	4,000.00	3,64%
IBEX 35	4,000.00	3,64%
Call Option	8,000.00	7,27%
Nickel	5,050.00	4,59%
Copper	5,050.00	4,59%
Bond #1	5,212.18	4,74%
Bond #2	22,489.42	20,44%
Bond #3	18,560.26	16,87%
JPY Cash position	7,390.98	6,72%
Total	**110,002.85 thousand EUR**	**100%**

According to the above composition and bridging to the risk factor mapping within the FRTB, the equity and credit asset classes comprise about 42% of the total portfolio value each one, commodities/precious metals constitute 9%, and FX represents 7%.

As a first step, the VaR and SVaR measures are computed at the 99% confidence level, leading to a total capital charge of 2581.80 thousand EUR, equivalent to 2.3% of the overall portfolio value. Then, the ES is computed at the 97.5% confidence level and based on the weighted average of the constrained and unconstrained components, amounting to 4,591.01 thousand EUR, representing 4% of the overall portfolio value. Compared to the sum of the VaR and SVaR, the ES represents an increase of about 2,009.21 thousand EUR, i.e.,78%). These results can be observed in Table 6.

Table 6: VaR, SVaR and ES for the baseline scenario

<table>
<tr><th>Metric</th><th colspan="2">Value</th><th colspan="2">Percentage of the portfolio value</th></tr>
<tr><td>VaR</td><td>745.98 th. EUR</td><td rowspan="2">2,581.80 th. EUR</td><td>0.68%</td><td rowspan="2">2.35%</td></tr>
<tr><td>SVaR</td><td>1,835.80 th. EUR</td><td>1.67%</td></tr>
<tr><td>ES</td><td colspan="2">4,591.01 th. EUR</td><td colspan="2">4.17%</td></tr>
</table>

In order to highlight the impact of the FRTB in what comes to the limits imposed to the diversification benefit, it is also interesting to breakdown the ES measure into its diversifiable and non-diversifiable elements. As expected, the non-diversifiable ES is higher than the diversifiable ES, constituting an increase of 2,837.52 thousand EUR when compared to the latter (about 89%), as shown in the table below.

Table 7: ES breakdown for the baseline scenario

<table>
<tr><th>Metric</th><th colspan="3">Value</th><th colspan="2">Percentage of the portfolio value</th></tr>
<tr><td rowspan="5">IMCC (C_i)</td><td>Equity</td><td>2,085.08 th. EUR</td><td rowspan="5">6,009.77 th. EUR</td><td>1.90%</td><td rowspan="5">5.46%</td></tr>
<tr><td>Metals</td><td>775.13 th. EUR</td><td>0.70%</td></tr>
<tr><td>Credit spread</td><td>599.62 th. EUR</td><td>0.55%</td></tr>
<tr><td>FX</td><td>1,509.84 th. EUR</td><td>1.37%</td></tr>
<tr><td>Interest rate</td><td>1,040.11 th. EUR</td><td>0.95%</td></tr>
<tr><td>IMCC (C)</td><td colspan="3">3,172.25 th. EUR</td><td colspan="2">2.88%</td></tr>
</table>

As per Table 7, regarding the contribution of the five risk factors considered for the computation of the constrained ES, one may conclude that the equity risk factor contributes the most, followed by the FX and interest rate components. Additionally, one key-aspect needs to be underlined: not only the diversifiable ES measure is greater than the sum of the VaR and SVaR measures (3,172.25 thousand EUR vs. 2,581.80 thousand EUR, a 23% increase), but also its non-diversifiable component represents almost 5.5% of the overall portfolio value, clearly emphasizing one of the main features of the FRTB when it comes to limiting the diversification benefit within the assets composing the portfolio.

However, when properly assessing the market risk capital requirement according to equations (8) and (12), i.e., considering the computation of the three measures over the preceding 60 business days and the respective multiplication factors associated with each regulation[33], the capital requirement appears to be higher under the current regulation, amounting to 7,908.92 thousand EUR (versus 6,911.12 thousand EUR under the FRTB):

Table 8: Market risk capital requirement – Current regulation vs. FRTB under the baseline scenario

Regulation	Market risk capital requirement	Percentage of the portfolio value
Current	7,908.92 th. EUR	7.19%
FRTB	6,911.12 th. EUR	6.28%

Nevertheless, when looking at this result it is important to keep in mind that this is the final market risk capital requirement for the current regulation's case, but it is not over for the FRTB. Indeed, for the market risk capital requirement under the FRTB, the DRC and the capital charge for unapproved trading desks (computed using the SA) will still be summed up, and will most likely increase the final capital requirement, since the difference between both regulations' capital requirement amounts to roughly a thousand EUR.

4.2. Sensitivity Analysis

4.2.1. Effect of an increase in the weight of equity positions

To better understand the impact of the FRTB through possible changes in the composition of the investment portfolio, we now analyse the case where the weight of equity positions increases by 20%, everything else held constant. These refer to the stocks and option positions, mapped to the equity, FX and interest rate risk factors within the computation of the ES under the FRTB, as specified in Annex D.

Following the same process as for the baseline scenario, the VaR, SVaR and ES measures, as well as the breakdown of the ES are presented in the next tables.

[33] In accordance with the previously mentioned in sections 1.3. and 2.2., the multiplication factors m_c and m_s within the current regulation are set at the minimum value of 3, and since the plus factors p_c and p_s related to backtesting can range from 0 to 1, these were assumed to be zero. Within the FRTB, the multiplication factor m_c is set at the minimum value of 1.5, and to be consistent with the assumption for the plus factors no more add-on was considered regarding backtesting.

Table 9: VaR, SVaR and ES for a 20% increase in equity

<table>
<tr><th>Metric</th><th colspan="2">Value</th><th colspan="2">Percentage of the portfolio value</th></tr>
<tr><td>VaR</td><td>1,664.34 th. EUR</td><td rowspan="2">4,884.39 th. EUR</td><td>1.00%</td><td rowspan="2">2.94%</td></tr>
<tr><td>SVaR</td><td>3,220.05 th. EUR</td><td>1.94%</td></tr>
<tr><td>ES</td><td colspan="2">8,106.64 th. EUR</td><td colspan="2">4.89%</td></tr>
</table>

Table 10: ES breakdown for a 20% increase in equity

<table>
<tr><th>Metric</th><th colspan="3">Value</th><th colspan="2">Percentage of the portfolio value</th></tr>
<tr><td rowspan="5">IMCC (C_i)</td><td>Equity</td><td>4,832.41 th. EUR</td><td rowspan="5">10,624.68 th. EUR</td><td>2.92%</td><td rowspan="5">6.41%</td></tr>
<tr><td>Metals</td><td>775.13 th. EUR</td><td>0.47%</td></tr>
<tr><td>Credit spread</td><td>599.62 th. EUR</td><td>0.36%</td></tr>
<tr><td>FX</td><td>2,328.73 th. EUR</td><td>1.40%</td></tr>
<tr><td>Interest rate</td><td>2,088.79 th. EUR</td><td>1.26%</td></tr>
<tr><td>IMCC (C)</td><td colspan="3">5,588.59 th. EUR</td><td colspan="2">3.37%</td></tr>
</table>

From Table 9, it is possible to conclude that the overall ES measure represents an increase in value of about 66% in relation to the sum of the VaR and SVaR measures, which is below the 78% increase in the baseline scenario and thus representing a smaller percentage of the portfolio value when compared to that case. Moreover, when looking at the breakdown of the ES, the contribution of the risk factors affected by the 20% increase in the weight on the portfolio suffers a large increase, and actually the equity risk factor more than doubles its contribution. Here, the diversifiable ES is also greater than the sum of the VaR and SVaR (a 25% increase), a similar result to the previous scenario.

As for the assessment of the market risk capital requirement, based on the information from Table 11, it is almost more than twice the capital requirement under the baseline scenario. Once again, the capital requirement from the current regulation exceeds the one from the FRTB, but only considering its market risk component. The DRC and the capital charge for unapproved trading desks still need to be added.

Table 11: Market risk capital requirement – Current regulation vs. FRTB under the scenario with a 20% increase in equity

Regulation	Market risk capital requirement	Percentage of the portfolio value
Current	14,564.84 th. EUR	8.79%
FRTB	12,140.12 th. EUR	7.32%

4.2.2. Effect of an increase in the weight of bond positions

Analogously to the previous situation, we now increase the weight of the bond positions also in 20%, with everything else held constant. These positions are mapped into the credit spread, FX and interest rate risk factors as per Annex D.

Starting with the standalone VaR, SVaR and ES measures, in this case the ES encompasses more than 100% of the sum of the VaR and SVaR, exceeding the 78% increase from the baseline scenario, and consequently the percentage in the portfolio value (Table 12). Based on the breakdown of the overall ES measure, as expected the weights of the risk factors impacted by this 20% increase on the non-diversifiable ES rise when compared with the baseline scenario. In particular, the credit spread risk factor almost triplicates its value in this case (Table 13). Regarding the diversifiable ES, it keeps being greater than the sum of the VaR and SVaR, representing in this case a 38% increase.

Table 12: VaR, SVaR and ES for a 20% increase in bonds

<table>
<tr><th>Metric</th><th colspan="2">Value</th><th colspan="2">Percentage of the portfolio value</th></tr>
<tr><td>VaR</td><td>896.02 th. EUR</td><td rowspan="2">3,093.22 th. EUR</td><td>0.53%</td><td rowspan="2">1.85%</td></tr>
<tr><td>SVaR</td><td>2,197.20 th. EUR</td><td>1.31%</td></tr>
<tr><td>ES</td><td colspan="2">6,227.50 th. EUR</td><td colspan="2">3.72%</td></tr>
</table>

Table 13: ES breakdown for a 20% increase in bonds

<table>
<tr><th>Metric</th><th colspan="3">Value</th><th colspan="2">Percentage of the portfolio value</th></tr>
<tr><td rowspan="5">IMCC (C_i)</td><td>Equity</td><td>2,085.08 th. EUR</td><td rowspan="5">8,171.17 th. EUR</td><td>1.24%</td><td rowspan="5">4.88%</td></tr>
<tr><td>Metals</td><td>775.13 th. EUR</td><td>0.46%</td></tr>
<tr><td>Credit spread</td><td>1,661.59 th. EUR</td><td>0.99%</td></tr>
<tr><td>FX</td><td>1,922.44 th. EUR</td><td>1.15%</td></tr>
<tr><td>Interest rate</td><td>1,726.93 th. EUR</td><td>1.03%</td></tr>
<tr><td>IMCC (C)</td><td colspan="3">4,283.84 th. EUR</td><td colspan="2">2.56%</td></tr>
</table>

Lastly, the market risk capital requirement from each regulation under this scenario is presented in Table 14. We can now notice a slightly increase in the market risk capital requirement within the FRTB approach, a different result from the previous scenarios. Once again, the introduction of the DRC and the capital charge for unapproved trading desks would be added to this result, causing the capital requirement to become even higher.

Table 14: Market risk capital requirement – Current regulation vs. FRTB under the scenario with a 20% increase in bonds

Regulation	Market risk capital requirement	Percentage of the portfolio value
Current	9,402.08 th. EUR	5.61%
FRTB	9,459.51 th. EUR	5.65%

5. Discussion of Results

To better address the achieved results and be able to draw sustained conclusions, it is important to keep in mind three key-aspects of the FRTB directly linked to the IMA: the establishment of the ES as the new risk measure, replacing the VaR and SVaR, with the goal of accounting for the tail risk; the limit to the diversification benefit, with the incorporation of the non-diversifiable and diversifiable ES measures; and the introduction of the five liquidity horizons, in order to distinguish the different levels of liquidity risk between asset classes.

Regardless of the scenario considered, the fact that the ES overall measure (obtained from the weighted average of the diversifiable and non-diversifiable ES) is greater than the sum of the VaR and SVaR measures is clearly evident. Summing up, this overall ES represents an increase of 78%, 66% and 101% for the baseline scenario and for the scenarios with a 20% increase in equity positions and bond positions, respectively. For this increase, not only the non-diversifiable ES is a contribution factor (as expected, because the diversification benefits between risk factors are neglected), but also the diversifiable ES, since the latter also stays above the sum of the VaR and SVaR in the three scenarios (increase of 23%, 25% and 38% for the baseline scenario and for the scenarios with a 20% increase in equity positions and bond positions, respectively).

Besides that, when properly assessing the market risk capital requirement by taking into account the computation of VaR, SVaR and ES over the preceding 60 business days and each regulation's multiplication factor (i.e., 3 for the current regulation and 1.5 for the FRTB), the capital requirement appears to be higher under the current regulation for the baseline scenario and for the scenario with a 20% increase in equity positions. When we consider the third scenario (20% increase in bond positions), the conclusion is the opposite. This result may suggest that an investment structure more focused on bond positions could lead to a higher market risk capital requirement, yet slight. Actually, a research performed by Righi and Ceretta (2015) highlighted larger ES estimates for this asset class when compared with the equity asset class, arguing the fact that the former is directly subject to policy shocks[34].

Nevertheless, it is not possible to get an unambiguous answer concerning the exact increase on the capital requirement. In fact, the DRC and the capital charge for non-approved trading desks still need to be summed up. Considering the preliminary results from the EBA regarding the impact of the FRTB under the IMA, this authority identifies the DRC and the

[34] See Righi and Ceretta (2015) for further details.

NMRFs as the main drivers of the increase in capital requirements[35], which gives greater importance to these factors. Based on this conclusion, it is very likely that the capital requirement within the FRTB becomes greater than the one from the current regulation in the cases where it does not happen only through the ES. Still, as a global effect, the expected increase on the capital requirement due to the FRTB is sensitive to the bank's trading book portfolio composition, and a greater effect is expected in the cases where the portfolio has a greater weight of bond positions.

[35] See European Banking Authority 2017 – Results from the 2018 market risk benchmarking exercise – for further details.

6. Conclusion

This study aims at assessing the impact on banks' capital requirements for market risk under the IMA resulting from the introduction of the FRTB, by computing the capital requirement under this approach for both the current and proposed frameworks, focusing on the market risk component. Considering the growing debate around the impacts arising from the implementation of the FRTB on banks' risk management practices, this study contributes for the investigation on the field, which is still scarce, on the particular case of the IMA, through an analysis based on a stylized portfolio, composed by the assets most impacted by the FRTB. Such ongoing debate makes this study to gain superior interest, at a time of regulatory transition, in which banks need to make important decisions with respect to their risk analysis methods. Besides that, this study also aims to gauge the impact of the new regulation when there are marginal changes on the composition of the portfolio, namely by increasing the weight of equity and bond positions on the portfolio.

The HS, because it constitutes the most adopted approach by banks worldwide, is used to compute the VaR, SVaR and ES measures, in order to answer two relevant questions: (i) how much is the impact arising from the introduction of the new capital requirements under the IMA; (ii) to what extent and in which circumstances ES is better than VaR.

A first conclusion that can be drawn from this investigation is that the overall ES, as a standalone measure, implies a higher capital charge when compared to the sum of the VaR and SVaR measures, representing increases of 89%, 90% and 101% for the baseline scenario and for the scenarios with a 20% increase in equity positions and bond positions, respectively. Both the diversifiable and non-diversifiable components of the ES contribute to such increases, being the latter the main responsible, since it gives no room for diversification benefits between risk factors correlations.

Regarding the market risk capital requirement considering the VaR, SVaR and ES over the preceding 60 business days and each regulation's multiplication factor (i.e., equal to 3 for the current regulation and equal to 1.5 for the FRTB), it is higher under the current regulation for the baseline scenario and for the scenario with a 20% increase in equity positions. For the scenario with a 20% increase in bonds positions, the market risk capital requirement is higher under the FRTB, yet in a slight way. This result may be explained by the effect of the greater liquidity horizon affecting bonds, particularly for bond number 3. However, it is important to recognize that these results focus only on the market risk component of the review, and thus the DRC and the capital charge for non-approved trading desks would still need to be summed up.

Beyond that aspect, another limitation that needs to be recognized in the analysis is the fact that full set of risk factors equals the reduced set. In fact, the ratio composed by the current ES using the full set of risk factors and the current ES using the reduced set of risk factors is floored at its minimum value of 1. If a reduced set of risk factors had been defined, this ratio would be higher, thus contributing to higher diversifiable and non-diversifiable ES measures, and consequently to a higher overall ES.

One critical issue for banks related with this reform has to do with their choice of adopting the IMA under the FRTB. Indeed, the FRTB will represent a great computational effort for financial institutions. As previously mentioned, the SA will constitute a mandatory approach with the implementation of this market risk framework, and according to the interim impact analysis of the BCBS (2015), the capital requirements under the SA are expected to be 2 to 3 times higher than the capital requirements under the IMA.

Whereas in the current regulation it is only necessary to compute the VaR and the SVaR, popular measures that have been used for years, from the implementation of the FRTB on, it will be necessary to calculate not only the diversifiable and non-diversifiable ES measures, but also to develop robust P&L attribution and backtesting procedures, and a well-defined structure of trading desks. In this way, banks will have to weigh the trade-off between opting for the SA or investing in high quality infrastructure (including high data quality procedures) in order to develop an internal risk model sophisticated enough to be approved by the supervisor. The bank's future profitability is inherent to this decision, which can be compromised either through even higher capital requirements under the SA, or through investment in infrastructure to give response to the challenges imposed by the FRTB.

Finally, further research on this field should contribute to have a more well-defined measurement in terms of the final capital requirement under the FRTB. For that, the default risk component, through a VaR model to assess the magnitude of the DRC, should indeed be considered.

Bibliographical References

Abad, P., Benito, S. & López C. (2014). A comprehensive review of value at risk methodologies. *The Spanish Review of Financial Economics,* 12, 15-32. https://www.elsevier.es/en-revista-the-spanish-review-financial-economics-332-pdf-S217312681300017X

Acerbi, C. (2002). Spectral measures of risk: a coherent representation of subjective risk aversion. *Journal of Banking and Finance*, 26: 1505-1518. https://www.sciencedirect.com/science/article/pii/S0378426602002819

Acerbi, C. & Szekely, B. (2014). Backtesting expected shortfall – introducing three model-independent, non-parametric back-test methodologies for expected shortfall. Working paper, *MSCI Inc*, 1-33. https://www.msci.com/documents/10199/22aa9922-f874-4060-b77a-0f0e267a489b

Acerbi, C. & Tasche, D. (2002). Expected shortfall: a natural coherent alternative to value at risk. *Economic Notes,* 31: 379-388. https://www.researchgate.net/publication/259482905_Expected_Shortfall_A_Natural_Coherent_Alternative_to_Value_at_Risk

Acerbi, C. & Tasche, D. (2002). On the coherence of expected shortfall. *Journal of Banking and Finance*, 26: 1487-1503. https://www.sciencedirect.com/science/article/pii/S0378426602002832

Alexander, C. (2008). *Market Risk Analysis, Value at Risk Models* (Vol. 4). Chichester: John Wiley & Sons, Ltd.

Amorello, L. (2016). Beyond the horizon of banking regulation: what to expect from Basel IV. *Harvard International Law Journal*, 58: 21-38. https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2888960

Artzner, P., Delbaen, F., Eber, J. & Heath, D. D. (1999). Coherent measures of risk. *Mathematical Finance,* 9: 203-228. https://www.researchgate.net/publication/227614132_Coherent_Measures_of_Risk

Bank of England (2016, July). *The financial crisis 10 years on: what's been done to make the system safer?* https://www.bankofengland.co.uk/-/media/boe/files/news/2017/september/the-financial-crisis-10-years-on-fact-sheet.pdf

Barrailler, M. & Dufour, T. (2014). Value-at-risk and expected shortfall. *Polytech Nice-Sophia*. https://www.thibautdufour.com/files/PFE_ES_Report.pdf

BCBS – Basel Committee on Banking Supervision (1996). Amendment to the capital accord to incorporate market risks. *Bank for International Settlements*. https://www.bis.org/publ/bcbs24.pdf

BCBS – Basel Committee on Banking Supervision (2009). Revisions to the Basel II market risk framework. *Bank for International Settlements.* https://www.bis.org/publ/bcbs158.pdf

BCBS – Basel Committee on Banking Supervision (2010). Basel III: a global regulatory framework for more resilient banks and banking systems. *Bank for International Settlements*. https://www.bis.org/publ/bcbs189.pdf

BCBS – Basel Committee on Banking Supervision (2011). Revisions to the Basel II market risk framework. *Bank for International Settlements*. https://www.bis.org/publ/bcbs193.pdf

BCBS – Basel Committee on Banking Supervision (2011). Principles for the sound management of operational risk. *Bank for International Settlements*. https://www.bis.org/publ/bcbs195.pdf

BCBS – Basel Committee on Banking Supervision (2013). Fundamental review of the trading book: a revised market risk framework. *Bank for International Settlements*. https://www.bis.org/publ/bcbs265.pdf

BCBS – Basel Committee on Banking Supervision (2014). Analysis of the trading book hypothetical portfolio exercise. *Bank for International Settlements*. https://www.bis.org/publ/bcbs288.pdf

BCBS – Basel Committee on Banking Supervision (2014). Fundamental review of the trading book: outstanding issues. *Bank for International Settlements*. https://www.bis.org/bcbs/publ/d305.pdf

BCBS – Basel Committee on Banking Supervision (2015). Fundamental review of the trading book – interim impact analysis. *Bank for International Settlements*. https://www.bis.org/bcbs/publ/d346.pdf

BCBS – Basel Committee on Banking Supervision (2019). MAR 10 Definition and application for market risk. *Bank for International Settlements*. https://www.bis.org/basel_framework/chapter/MAR/10.htm

BCBS – Basel Committee on Banking Supervision (2019). Minimum capital requirements for market risk. *Bank for International Settlements*. https://www.bis.org/bcbs/publ/d457.pdf

BCBS – Basel Committee on Banking Supervision (2019). The market risk framework in brief. *Bank for International Settlements*. https://www.bis.org/bcbs/publ/d457_inbrief.pdf

Chang, C-L., Jimenez-Martin, J-A., Maasoumi, E., McAleer, M. & Pérez-Amaral, T. (2019). Choosing expected shortfall over VaR in Basel III using stochastic dominance. *International Review of Economics and Finance*, 60: 95-113. https://www.sciencedirect.com/science/article/pii/S1059056018301072

Cohen, B. (2013). How have banks adjusted to higher capital requirements? *Bank for International Settlements Quarterly Review*, 25-39. https://www.bis.org/publ/qtrpdf/r_qt1309e.pdf

Čorkalo, Š. (2011). Comparison of value at risk approaches on a stock portfolio. *Croatian Operational Research Review,* 2: 81-90. https://hrcak.srce.hr/file/142176

Daníelsson, J., Jorgensen, B., Samorodnitsky, G., Sarma, M. & Vries, C. (2013). Fat tails, VaR and subadditivity. *Journal of Econometrics,* 172: 283-291. https://www.sciencedirect.com/science/article/pii/S0304407612001959

Degiannakis, S., Floros, C. & Dent, P. (2013). Forecasting value-at-risk and expected shortfall using fractionally integrated models of conditional volatility: international evidence. *International Review of Financial Analysis*, 27: 21-33. https://www.sciencedirect.com/science/article/pii/S1057521912000397

Del Brio, E. B., Mora-Valencia, A. & Perote, J. (2020). Risk quantification for commodity ETFs: backtesting value-at-risk and expected shortfall. *International Review of Financial Analysis*, 70: 101163. https://www.sciencedirect.com/science/article/pii/S1057521917301801

Dowd, K. (2002). *Measuring Market Risk.* Chichester: John Wiley & Sons, Ltd.

Drakenberg, J. & Hegnell, S. (2017). *Fundamental review of the trading book – the new approach to measure market risk* [Master's thesis, Lund University School of Economics and Management]. LUP Student Papers. https://lup.lub.lu.se/student-papers/search/publication/8912462

ElBannan, M. (2017). The financial crisis, Basel accords and bank regulations: an overview. *International Journal of Accounting and Financial Reporting*, 7: 225-275. http://www.macrothink.org/journal/index.php/ijafr/article/view/12122/9721

Escudero, J. (2016). The fundamental review of the trading book and the quest for a sound prudential framework for trading activities. *Cuadernos económicos de ICE*, 92: 156-173. http://www.revistasice.com/index.php/CICE/article/view/6139/6139

European Banking Authority (2017). *Discussion paper – implementation in the European Union of the revised market risk and counterparty credit risk frameworks*. https://eba.europa.eu/sites/default/documents/files/documents/10180/2161587/a5f47920-54be-4b68-a25c-119c70606186/Discussion%20Paper%20on%20EU%20implementation%20of%20MKR%20and%20CCR%20revised%20standards%20%28EBA-DP-2017-04%29.pdf?retry=1

European Banking Authority (2017). *Results from the 2018 market risk benchmarking exercise.* https://eba.europa.eu/sites/default/documents/files/documents/10180/2087449/d3afa519-b626-493a-8fe3-29de3b575592/EBA%20Report%20results%20from%20the%202018%20Market%20Risk%20Benchmarking%20Report.pdf?retry=1

European Banking Authority (2019). *Basel III reforms: impact study and key recommendations – macroeconomic assessment, credit valuation adjustment and market risk*. https://eba.europa.eu/sites/default/documents/files/document_library//Basel%20III%20reforms%20-%20Impact%20study%20and%20key%20recommendations%20%20macroeconomic%20assessment%20credit%20valuation%20adjustment%20and%20market%20risk.pdf

European Central Bank (2020, February). *Market risk: implementing new rules for internal models*. https://www.bankingsupervision.europa.eu/press/publications/newsletter/2020/html/ssm.nl200212_2.en.html

Farkas, W., Fringuellotti, F. & Tunary, R. (2020). A cost-benefit analysis of capital requirements adjusted for model risk. *Journal of Corporate Finance*, 65: 101753. https://www.sciencedirect.com/science/article/pii/S0929119920301978

Filippova, D. (2018). *From value-at-risk to expected shortfall* [Seminar Paper – Institute of Financial and Actuarial Mathematics at Vienna University of Technology]. Financial and Actuarial Mathematics. https://fam.tuwien.ac.at/~sgerhold/pub_files/sem18/s_filippova.pdf

Gameiro, A. (2017). *Avaliação empírica do risco de mercado: expected shortfall vs. value-at-risk* [Master's thesis - University of Lisbon and ISCTE-IUL]. Repositório UL. https://repositorio.ul.pt/handle/10451/30269

Giannopoulos, K. & Tunaru, R. (2005). Coherent risk measures under filtered historical simulation. *Journal of Banking and Finance,* 29: 979-996. https://www.sciencedirect.com/science/article/pii/S0378426604001487

Harmantzis, F. C., Miao L. & Chien Y. (2006). Empirical study of value-at-risk and expected shortfall – models with heavy tails. *Journal of Risk Finance*, 7: 117-135. https://www.emerald.com/insight/content/doi/10.1108/15265940610648571/full/html

Hull, J. C. (2018). *Risk Management and Financial Institutions* (5th edition). Hoboken: John Wiley & Sons, Ltd.

ISDA – International Swaps and Derivatives Association & AFME – Association for Financial Markets in Europe (2017). *Position Paper CRD V/CRR II: Fundamental review of the trading* book https://www.isda.org/a/HTiDE/frtb-position-paper.pdf

Johnson, G. (2011). A fundamental review of capital charges associated with trading activities. *Bank of Canada – Financial System Review*, 43-49. https://www.bankofcanada.ca/wp-content/uploads/2011/12/fsr-1211-johnson.pdf

Kellner, R. & Rösch, D. (2016). Quantifying market risk with value-at-risk or expected shortfall? – consequences for capital requirements and model risk. *Journal of Economic Dynamics and Control*, 68: 45-63. https://www.sciencedirect.com/science/article/pii/S0165188916300641

Laurent, J., Sestier, M. & Thomas, S. (2016). Trading book and credit risk: how fundamental is the Basel review? *Journal of Banking and Finance*, 73: 211-223. https://www.sciencedirect.com/science/article/pii/S0378426616301157

Magnus, M., Margerit A., Mesnard B. & Korpas A. (2017). Upgrading the Basel standards: from Basel III to Basel IV? *Economic Governance Support Unit of the European Parliament*. http://www.europarl.europa.eu/RegData/etudes/BRIE/2016/587361/IPOL_BRI(2016)587361_EN.pdf

Mak, P. & Meng, Q. (2014). *Value at risk and expected shortfall: a comparative analysis of performance in normal and crisis markets* [Master's thesis – Simon Fraser University]. Semanthic Scholar. https://pdfs.semanticscholar.org/22d5/569b13dc44c199daa160639d36d424a543f6.pdf

Mehta, A., Neukirchen, M., Pfetsch, S. & Poppensieker T. (2012). Managing market risk: today and tomorrow. *McKinsey Working Papers on Risk*, 32: 1-16. https://www.mckinsey.com/business-functions/risk/our-insights/managing-market-risk-today-and-tomorrow

Meyer, L. (2000, August 31). *Why risk management is important for global financial institutions* [Conference Session]. Before the Bank of Thailand Symposium, Risk Management of Financial Institutions, Bangkok, Thailand. https://www.bis.org/review/r000904b.pdf

Mirković, V., Dašić B. & Siljković B. (2013, September 12-15). Market risk management in banks. Paper presented at the 13th International Conference on "Research and Development in Mechanical Industry", Serbia. https://www.researchgate.net/publication/321749017_MARKET_RISK_MANAGEMENT_IN_BANKS

Neisen, M., & Röth, S. (2017). *Basel IV: The Next Generation of Risk Weighted Assets* (2nd edition). Weinheim: John Wiley & Sons, Ltd.

Nieto, M. R., Ruiz, E. (2016). Frontiers in VaR forecasting and backtesting. *International Journal of Forecasting*, 32: 475-501. https://www.sciencedirect.com/science/article/pii/S016920701500120X

Orgeldinger, J. (2018). Recent issues in the implementation of the new Basel minimum capital requirements for market risk. *Emerging Science Journal,* 2: 65-77. https://ijournalse.org/index.php/ESJ/article/view/69/35

Pearce, B. (2015). Field guide to internal models under the Basel committee's – "fundamental review of the trading book" framework. *Skew Vega Limited*. https://skewvega.net/sites/default/files/whitepapers/skewvega_frt10.pdf

Pederzoli, C. & Torricelli, C. (2019). The impact of the fundamental review of the trading book: a preliminary assessment on a stylized portfolio. *CEFIN,* 1-19.

Pérignon, C. & Smith, D. (2009). The level and quality of value-at-risk disclosure by commercial banks. *Journal of Banking and Finance*, 34: 362-377. https://www.sciencedirect.com/science/article/pii/S0378426609001940

PwC (2011). Is a full internal model a step too far? *PwC countdown to Solvency II.* https://www.pwc.com/gx/en/insurance/solvency-ii/countdown/pdf/pwc-countdown-july11-standard-formula-internal-model.pdf

Righi, M. B. & Ceretta, P. S. (2015). A comparison of expected shortfall estimation models. *Journal of Economics and Business*, 78: 14-47. https://www.sciencedirect.com/science/article/pii/S014861951400068X

Roccioletti, S. (2016). *Backtesting Value at Risk and Expected Shortfall*. Wiesbaden: Springer Gabler.

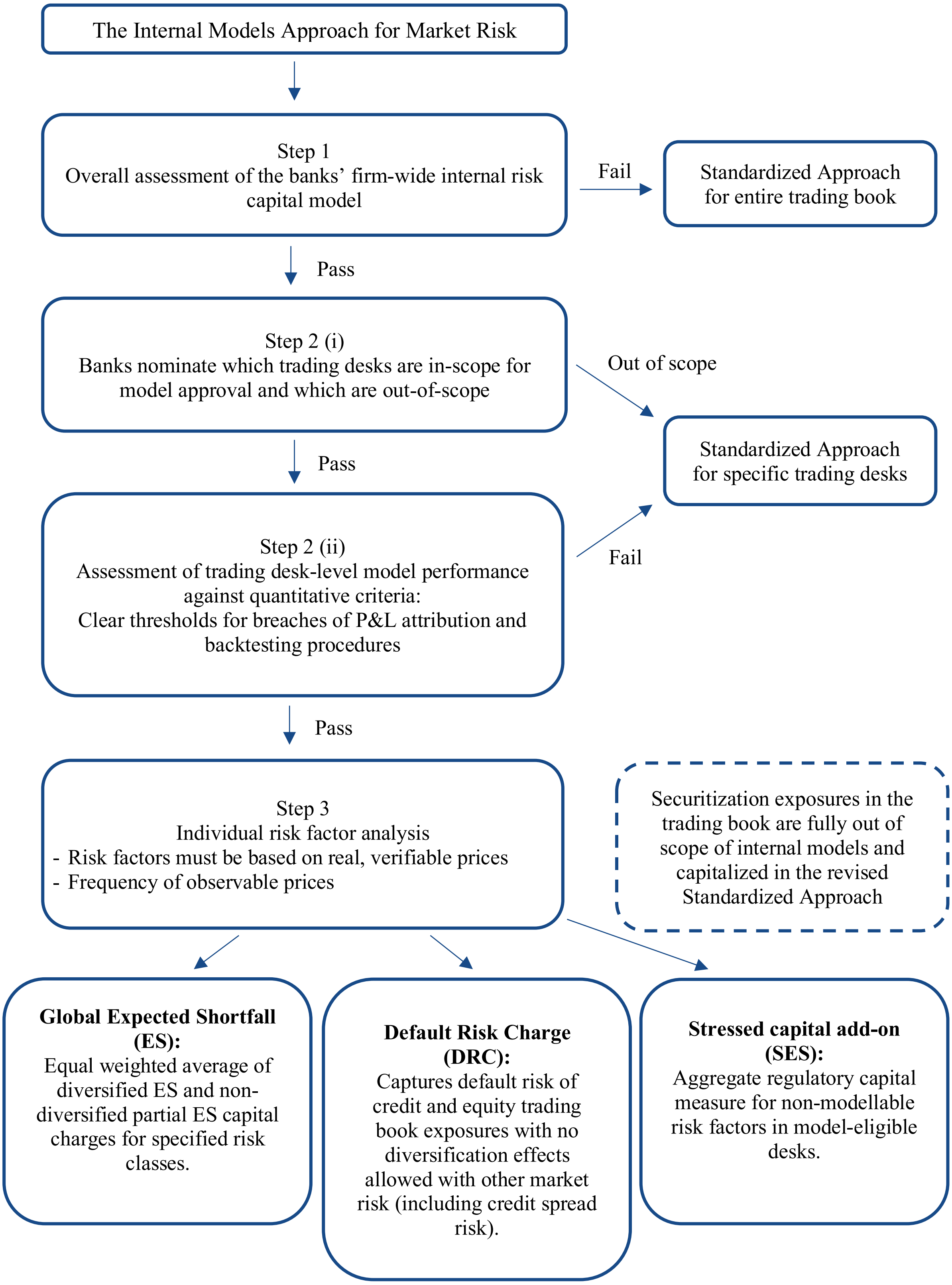
Saunders, A., & Cornett, M. M. (2017). *Financial Institutions Management: A Risk Management Approach* (10th edition). New York: McGraw-Hill.

Yamai, Y. & Yoshiba, T. (2002). Comparative analyses of expected shortfall and value at risk under market stress. *Monetary and Economic Studies, Institute for Monetary and Economic Studies, Bank of Japan*, 20: 216-270. https://www.bis.org/cgfs/Yamai-Yoshiba.pdf

Yamai, Y. & Yoshiba, T. (2005). Value-at-risk versus expected shortfall: a practical perspective. *Journal of Banking and Finance*, 29: 997-1015. https://www.sciencedirect.com/science/article/pii/S0378426604001499

Annexes

A. Process and policy design of the IMA.



Source: BCBS (2019).

B. Descriptive statistics of the assets composing the portfolio

Asset	Number of observations	Mean	Standard Deviation	Max	Min	Kurtosis	Skewness
S&P 500	3271	1,459.16	622.01	2,919.81	536.42	-1.08	0.49
	253	676.76	69.00	897.34	536.42	1.78	1.19
NIKKEI 225	3271	117.11	36.03	197.62	56.38	-1.17	0.44
	253	70.05	5.45	82.53	56.38	-0.16	-0.12
FTSE 100	3271	7,631.25	1,234.50	9,939.38	3,870.08	0.03	-0.63
	253	5,029.24	639.24	6,905.97	3,870.08	0.83	0.91
CAC 40	3271	4,428.44	841.56	6,168.15	2,519.29	-1.04	0.01
	253	3,265.66	387.24	4,539.07	2,519.29	1.31	1.04
DAX 30	3271	8,782.20	2,581.41	13,559.60	3,666.41	-1.25	0.14
	253	4,829.76	574.47	6,518.47	3,666.41	0.48	0.63
IBEX 35	3271	10,143.96	1,901.29	15,945.70	5,956.30	1.03	1.04
	253	9,324.82	1,140.60	11,903.89	6,817.39	-0.58	0.25
NICKEL	3271	13,408.91	5,100.98	37,967.28	6,707.90	5.79	2.10
	253	9,683.05	1,991.93	14,417.32	6,799.77	-0.65	0.65
COPPER	3271	5,242.47	845.50	7,531.61	2,022.05	1.70	-0.87
	253	3,362.13	739.04	5,069.295	2,022.05	-0.52	0.40
CALL OPTION	3020	491.54	165.62	1,165.58	272.67	0.72	1.11
	253	489.77	126.62	816.91	325.93	-0.50	0.71
BOND #1	3271	1,246.34	127.59	1,460.80	943.50	-0.85	-0.53
	253	1,132.47	55.53	1,260.14	1,044.99	-0.90	0.43
BOND #2	3271	12,031.32	1,822.05	15,422.30	9,588.68	-1.59	0.30
	253	10,137.86	139.45	10,576.24	9,836.21	0.08	0.53
BOND #3	3271	4,266.57	429.10	5,038.50	3,251.18	-0.85	-0.50
	253	3,885.94	197.04	4,365.88	3,580.68	-0.69	0.53
JPY CASH POSITION	3271	7,085.08	15.62	9,542.99	5,310.05	-0.14	0.17
	253	6,924.23	482.24	7,533.58	5,707.40	0.04	-0.31

Observations: The first row corresponds to the overall period and the second row to the stress period.

C. Bonds relevant information

	BOND #1	**BOND #2**	**BOND #3**
Bond type	Government (USA)	Government (Spain)	Corporate (*Apple Inc.*)
Currency	USD	EUR	USD
Settlement date	15/11/2010	09/09/2008	30/04/2013
Maturity date	15/11/2020	31/01/2024	03/05/2023
Redemption	bullet at par	bullet at par	bullet at par
Coupon frequency	semi-annual	annual	semi-annual
Coupon rate	2,625%	4,80%	2,40%
Face Value	100	1,000	1,000
HY/IG	IG	IG	IG

D. Risk factors mapping

Asset	Risk Factor Category(ies)	Liquidity horizon(s)
S&P 500	Equity price (large cap)	10
	FX rate: specified currency pairs	10
NIKKEI 225	Equity price (large cap)	10
	FX rate: specified currency pairs	10
FTSE 100	Equity price (large cap)	10
	FX rate: specified currency pairs	10
CAC 40	Equity price (large cap)	10
DAX 30	Equity price (large cap)	10
IBEX 35	Equity price (large cap)	10
NICKEL	Precious metals and non-ferrous metals price	20
	FX rate: specified currency pairs	10
COPPER	Precious metals and non-ferrous metals price	20
	FX rate: specified currency pairs	10
CALL OPTION	Equity price (large cap): volatility	20
	FX rate: specified currency pairs	10
	Interest Rate: specified currency pairs	10
BOND #1	Credit spread: sovereign (IG)	20
	FX rate: specified currency pairs	10
	Interest Rate: specified currency pairs	10
BOND #2	Credit spread: sovereign (IG)	20
	Interest rate: specified currency pair	10
BOND #3	Credit spread: corporate (IG)	40
	FX rate: specified currency pairs	10
	Interest Rate: specified currency pa	10
JPY CASH POSITION	FX rate: specified currency pairs	10