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What impacts will the Fundamental Review of the Trading Book have on banks' capital requirements in a post-COVID-19 context?

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List of abbreviations

Basel Committee on Banking Supervision (BCBS)

Capital Requirements Directive (CRD)

Collateralized Debt Obligation (CDO)

Correlation Trading Portfolio (CTP)

Correlation Trading Portfolio (CTP)

Credit Spread Risk (CSR)

Default Risk Charge (DRC)

European Central Bank (ECB)

Expected Shortfall (ES)

Foreign Exchange (FX)

Foreign Exchange (FX)

Fundamental Review of the Trading Book (FRTB)

General Interest Rate Risk (GIRR)

Global Financial Crisis (GFC)

Group of Central Bank Governors and Heads of Supervision (GHOS)

High yield (HY)

Internal Model Approach (IMA)

Internal Rating-Based (IRB)

Investment Grade (IG)

Jump-To-Default (JTD)

Liquidity Horizons (LH)

Minimum Capital Requirements (MRC)

Mortgage-Backed Securities (MBS)

New York Stock Exchange (NYSE)

Non-Modellable Risk Factors (NMRF)

Non-Modellable Risk Factors (NMRF)

Non-Rated (NR)

Operating Sub-Desk (OSD

Profit and Loss (P&L)

Quantitative Impact Studies (QIS)

Regulatory Trading Desk (RTD)

Residual Risk Add-On (RRAO)

Risk Weighted Asset (RWA)

Sensitivity-Based Approach (SBA)

Simplified Supervisory Formula Approach (SSFA)

Small and medium-sized enterprises (SMEs)

Stressed VaR (sVaR)

Supervisory Formula Approach (SFA)

Value-at-Risk (VaR)

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Introduction

In January 1996, the Basel Committee on Banking Supervision (BCBS) issued the first version of its framework for the market risk minimum capital requirements. Under this framework, banks were required to maintain a minimum level of regulatory capital to allow them to absorb potential losses arising from fluctuations in the market price of instruments held in the trading book.

Following the financial crisis of 2008, which highlighted serious shortcomings in the versions published until then, the BCBS began work on a Fundamental Review of the Trading Book (FRTB) in order to adapt the existing rules for market risk capitalization. In February 2019, the final version was released. This framework provides a comprehensive view by covering all aspects of minimum capital requirements for market risk. It clarifies the methods for assessing and quantifying the risks associated with banks' trading activities and portfolios.

Concretely, the key points of this framework are the definition of a clear boundary between trading and banking books, the replacement of Value-at-Risk (VaR) by Expected Shortfall (ES) as a measure of risk, the setting up of a revised Standardized Approach (SA) now based on sensitivity and of a revised approach to internal models (IMA) based on ES with differentiated liquidity horizons. A significant difference with the currently frameworks also results from the freedom given to banks to apply the method they deem appropriate at the desk level.

The objectives of the BCBS with this new version are multiple. It wishes to establish consistency between each jurisdiction so that the standardized approach appears as a solid foundation for the internal model approach. The Committee's wish is that the application of this framework should not, however, lead to a significant increase in banks' capital requirements, but that they should be better calculated. According to initial predictions, this desire will not become a reality. Indeed, the requirements will be much higher than those of Basel 2.5 currently in force.

In any case, these forecasts, if they are proved to be accurate, will obviously have a significant impact between banks or desks depending on the method they adopt. In the case of an IMA approach, they could allocate down to half or less of the capital than under the SA - giving them twice the return on capital compared to the SA bank, all other factors being equal, thus opening the door to a new form of competition between different financial institutions (Woodall, 2019).

Beyond changes in capital requirements, FRTB regulation will encourage managers to review their existing data, risk analysis and technology frameworks. It will also lead to profound changes in models, validation processes and parameter calculations. Finally, trading books will be organized, capitalized, managed and regulated differently. In concrete terms, this will intensify the workload for banks and create a number of technological and operational challenges (KPMG, 2020).

FRTB is therefore "the most important change to bank capital requirements in a generation" as Adam Litke, former Chief Risk Strategist and Head of Enterprise Risk Services at Bloomberg, L.P. recently stressed (Sharma & Beckwith, 2018, p. 704). This new regulatory framework is essential as both a considerable challenge for financial institutions and an important step towards building a more robust global economy that is able to react anticipatively to future shocks and crises.

This need and necessity for reforms in the area of market risk is even more tangible today with the COVID-19 pandemic that is currently affecting our entire society and directly challenging financial markets around the globe as well as the balance that seemed to have been restored since the 2007-2008 Global Financial Crisis (GFC).

The choice of this topic is therefore motivated by several rational and topical reasons. It aims to fill a gap in the literature since the final version of FRTB is recent (2019). Furthermore, it addresses the recent period of market stress by analyzing its consequences on the market risk issue.

On a more personal note, I joined the International Business Program with the aim of surpassing myself and developing my curiosity on various subjects. While taking the International Financial Management class, I discovered a theme that interested me and in which I wanted to strengthen my skills.

This paper is structured as the following: In section I, a review of the relevant literature is proposed, and the different hypotheses are presented. The problematic, methodology and data used are highlighted in the sections II and III. Section IV presents the results of our simulations. The discussion of these results and their confrontation with the theory will follow and, last but not least, sections VI and VII conclude the paper by summarizing the findings, limitations and future prospects of this work.

Fundamentals of risk

Risk and uncertainty

Defining risk is a topic that has been discussed at length by several authors (e.g. Best, 1999; Gallati, 2003; Tapiero 2004). Bessis (2015) notes that in the majority of these published works, uncertainty of outcomes and the probability of an event are the elements that appear each time. He defines risk as "the potential negative outcome that an event could have given the uncertainty of the future" (Bessis, 2015, p.6).

Financial risk therefore refers to the possibility of losing money on an investment (Investopedia, 2020). It is implied that only the downside risk is taken into account, i.e. the potential for financial loss and the uncertainty as to its magnitude (McNeil et al., 2005).

These definitions underpin the popular adage "there ain't no such thing as a free lunch" developed by Friedman (1975). The idea is that in every possible future scenario, risk is always present. Moreover, the greater the risk, the higher the expected return on investment.

Financial risk management

Banks, as major financial players, are logically concerned by these risk-related issues. These issues and their management are crucial to ensure the sustainability of banks. During the Global Financial Crisis (GFC), several banks went bankrupt (e.g. Lehman Brothers, Bernstein). This was a strong reminder of the importance of forecasting all possible future scenarios and of basing these forecasts on solid foundations.

Financial risk management has several dimensions: understanding, measuring, controlling and communicating the risks faced by financial institutions in order to reduce the likelihood of occurrence and/or its impact in case of occurrence. In this way, financial risk management protects and/or creates value for all involved stakeholders (Dionne, 2013).

Main classes of financial risks

The risks that a bank or other financial institution may encounter are sources of various uncertainties. Bessis (2015) proposes dividing financial risk into credit risk, operational risk and market risk. Each of these three categories can then be further subdivided into risk subclasses based on the events that trigger losses.

In this master’s thesis, the focus will be exclusively on market risk since it deals with the new regulation issued by the Basel Committee to better manage this type of risk.

Market risk and trading book

Market risk is defined as “the risk of losses arising from movements in market prices” (BCBS, 2020, p. 3). The subcategories of market risk, which may require capital to offset them are default risk, interest rate risk, credit spread risk, equity risk, foreign exchange (FX) risk, commodities risk...

Market risk framework mainly applies to positions in the trading book. It consists of all positions that are held with the intention of selling in the short term. Other items that are held with the intention of holding them for a longer period of time are placed on the financial institution's banking book (Olieslagers, 2019).

Market risk regulatory frameworks

In order to regulate and prepare banks for extreme market stress situations such as the GFC, a global committee has been set up: the Basel Committee. This section traces its history and the regulations it has put in place to address market risk since its creation.

Origin of Basel Committee

Since 1944, the Bretton Woods Agreement had defined the gold exchange standard system. The value of the U.S. dollar was directly indexed to the value of gold, while other currencies were indexed to the value of the U.S. dollar. One of the objectives of this agreement was to stimulate international trade (Gray, 2007).

President Nixon renounced these agreements on December 18, 1971 at the Washington conference at the Smithsonian Institute. For the first time in its history, the United States is facing a trade deficit with disastrous consequences for the dollar. This situation forces Nixon to take exceptional measures that sow panic on the foreign exchange market. In March 1973, the fixed exchange rate system collapses definitively. The major countries switched from a fixed model for their currencies to a floating model in order to avoid the excessive inflow of dollars. The European central banks refused to continue to support the dollar and henceforth renounced being pegged to the greenback. Still in force today, this system was endorsed by the Jamaican agreements on January 8, 1976 (Renard-Gourdon, 2011).

These upheavals had a direct impact on some banks whose foreign exchange exposure had become several times greater than their capital. In 1974, Bankhaus Herstatt, a German bank that was very active in the foreign exchange market, was hit hard. Following the volatility of the US dollar in 1973-74, the bank faced more than DM470 million in losses (Galati, 2002).

These losses were not covered by sufficient capital. National standards on capital regulation were not linked to the real level of risk. On June 26, 1974, the German regulators therefore forced Bank Herstatt into liquidation. Several foreign banks suffered the consequences of this bankruptcy by never receiving their due payments. This situation highlighted the need to create international regulations to prevent these failures from being repeated, each time with a domino effect on other banks (King and Tarbert, 2011).

Faced with this situation, the central banks of the G10 countries created the Basel Committee on Banking Supervision (BCBS) in October 1974. Initially made up of the G10 countries' central bank governors, the BCBS now comprises 45 institutions from 28 jurisdictions. Each jurisdiction is represented by the central bank of its territory and by the prudential supervision of banking activities when it is not the central bank of the BCBS (Goodhart, 2011). Its main mission is to strengthen the regulation, supervision and practices of banks around the world in order to improve financial stability (BCBS, 2013).

Regulators at the national level, however, remain the actors responsible for banking practices in their territories (Braithwaite, 2000). The supervisory authorities can therefore more or less implement the standards issued by the Basel Committee, by deciding to lighten certain measures or, on the contrary, to go deeper. For example, the United States did not immediately require its banks to comply with the Basel II treaty, although the country was involved in negotiating this regulation (Elliot, 2010). The Basel Committee therefore acts as an informal forum, not by imposing binding regulations but by trying to bring the financial world together towards common standards (Kerwer, 2005).

Basel I

This committee really started its mission after the Latin American debt crisis of 1982. Following this financial earthquake, the capital of the main international banks deteriorated. In 1988, after several years of work, the Basel Committee published the first Basel Accord, or Basel I, which seeks to converge the supervisory rules governing capital adequacy and the minimum standard to be achieved. The national supervisory authorities represented in the BCBS all agreed to implement this Accord in their respective countries (BCBS, 1988).

This agreement mainly addressed the issue of credit risk by proposing a bucket approach. Each asset was classified according to its credit risk and assigned to a bucket. For each bucket, there was a specific risk weighting, which is called the Risk Weighted Asset (RWA) method. The Basel I accord was very simple as they defined only five weights (0, 10, 20, 50 and 100%). Once these assets were weighted, Basel I defined a capital ratio, called the Cooke ratio in reference to the name of the then Chairman of the Committee. To be adequately capitalized, a bank operating internationally had to maintain a capital ratio of at least 8% of its risk-weighted assets (BCBS, 1988).

Basel I quickly showed flaws. The risk-weighted categories encouraged regulatory arbitrage. All OECD member countries were classified with a 0% risk weight for their debt. For example, Greece had the same weighting as the United States. The credit rating of debt issuers was not taken into account, allowing banks to pursue higher returns with riskier assets without holding additional capital (Tarbert 2000). Finally, as mentioned before, the Cooke ratio focused solely on credit risk. The 1990s saw the emergence of the derivatives market and thus of "off-balance sheet" risks. Market-related risks thus became a key variable in determining the level of capital required for a bank. As early as 1996, an updated version of Basel I was published to take into account of market risk (Dionne, 2013). It was defined as "the risk of loss of balance sheet and off-balance sheet positions resulting from changes in market prices" at that time (BCBS, 1996).

Basel II

The BCBS had taken into account the evolution of banking practices and the shortcomings of its first publication. In 2004, the Committee released the Basel II framework whose objectives were:

- Ensure that capital allocation is more risk-sensitive;
- Strengthen disclosure requirements that would allow market participants to assess an institution's capital adequacy;
- Ensure that credit, operational and market risks are quantified on the basis of formal data and techniques;
- Align economic and regulatory capital to reduce opportunities for regulatory arbitrage (Bakiciol et al., 2009).

To achieve its objectives, Basel II defined the notion of Minimum Capital Requirements (MRC). The Cooke ratio was replaced by the McDonough ratio. This ratio integrated market and operational risks, in addition to credit risk. For each of these three risks, BCBS (2004) provided approaches to determine them:

- Credit risk could be determined using a standardized approach, the Foundation Internal Rating-Based (IRB) approach or the advanced IRB approach;
- Operational risk was determined using the basic indicator approach, the standardized approach or the Internal Model Approach (IMA);
- The preferred approach for market risk was the Value-at-Risk (VaR) approach.

Basel II was applied on a consolidated basis to mainly internationally active banks. In the European Union, it has been translated into the Capital Requirements Directive (CRD) and all banks participated in it. However, this implementation was not fully uniform, as more than 140 points were subject to interpretation by national banking authorities. The Basel II framework has been accepted and interpreted by many countries around the world, including in Asia. However, the United States has slowed down the implementation of Basel II by raising:

- A competitive disadvantage for smaller banks;
- A large drop in capital requirements for some large U.S. banks;
- A possibility of over-reliance on credit rating agencies for the calculation of capital (Olieslagers, 2019).

Basel 2.5

Following the GFC of 2007-2008 and the observed failures of certain banks, the BCBS decided to address certain points of the Basel II regulation. In 2009, these changes resulted in Basel 2.5, which, for market risk, is still the framework in application.

Among the shortcomings that needed to be resolved, defining a more precise regulatory limit between the banking book and the trading book was urgently needed. In addition, the methods for determining risk measures were not sufficiently robust, leaving banks free to determine their risk drivers and thus leading to insufficient capital requirements in times of market stress (BCBS, January 2016).

To address these weaknesses, the BCBS required banks to hold more capital to cover default risk and migration risk ratings. This is the risk "that a rating change triggers significant mark-to-market losses" (BCBS, 2016, p.2).

One of the major advances introduced by Basel 2.5 is also the requirement to calculate an additional capital charge according to VaR in stressed market conditions (stressed-VaR) (BCBS, 2016).

While this is an important improvement, Basel 2.5 has not addressed all the structural shortcomings of the market risk framework. The VaR metric showed limits as a measure of risk; the boundary between the two books was not yet fully accurate; the Standardized Approach (SA) was not a credible fallback solution for banks unable or unwilling to adopt the IMA. By publishing the Fundamental Review of the Trading Book (FRTB), the BCBS was keen to offer banks a regulation that resolved all these weaknesses. The following sections will explain how these elements represented flaws in the determination of relevant capital requirements and describe the solutions provided by FRTB.

From VaR to ES

VaR

Since 1996, the VaR method has been widely applied in all the regulations published by the BCBS thanks to its "conceptual simplicity, ease of calculation and immediate applicability" (BCBS, 2011, p.26). However, following the GFC of 2007-08, regulators became aware of the limitations of this risk calculation method and particularly its inability to capture tail risk. This led the BCBS to replace VaR with Expected Shortfall (ES) as the main risk parameter in determining capital requirements. This section will describe the path that led the BCBS to favor ES over VaR in its new FRTB regulation.

Brief history

As early as 1922, the New York Stock Exchange imposed on its member companies a framework based loosely on VaR as defined today. Since then, the concept of VaR has evolved from a simple answer to the question "how much could I lose on a trading desk tomorrow?" to a universal and widely used concept in all regulations setting capital requirements. VaR provided a simple answer to this question: losses due to price movements would not exceed the VaR threshold more than five times over the next year. In the decade prior to the GFC, VaR has thus emerged as a reliable risk measure, accepted by the majority of institutions and encouraged by regulators (Sharma & Beckwith, 2018).

By being considered an accurate measure of market risk, VaR could serve as a sound basis for setting capital requirements. Capital requirements were determined either as a simple multiple of VaR at a defined confidence interval or by increasing the confidence level so that the probability of losses exceeding all thresholds was very low. The popularity of VaR has even extended its application to illiquid portfolios with long holding periods.

All these extensions and excesses led to the creation of a popular misconception that VaR was the maximum loss an institution could sustain. GFC has highlighted all the limitations of VaR and the excesses of applying this market risk assessment method. The main criticism of the VaR methodology was its inability to measure the impacts of tail events (Sharma & Beckwith, 2018).

As mentioned before, Basel 2.5 attempted to address some of the shortcomings by defining stressed VaR (sVaR). It is defined as conventional VaR, but at a 99% confidence level, at a holding period of 10 days and at a one-year history of data that encompasses a continuous 12-month period of significant financial stress (BCBS, 2011).

Definition

Value-at-Risk is defined by Gallati as "the expected worst-case loss at a specific confidence level over a period of time" (as cited in Laforêt, 2018, p. 17). In other words, VaR thus statistically measures the maximum loss that a portfolio can sustain in the event of an adverse market shock over a given horizon.

VaR is characterized by the holding period, often one day, and by a confidence level, generally 95 to 99% (Sharma & Beckwith, 2018).

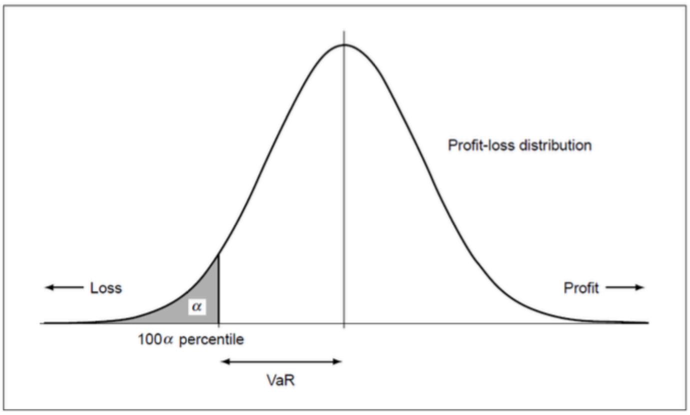

Figure 1: Value-at-Risk representation on normal distribution (Yamai & Yoshiba, 2002, p.59)

Computational overview

The methodology for calculating VaR is not clearly defined by regulators. There is neither a universal method nor a common consensus among practitioners. As a result, methodologies are diverse and numerous across financial institutions and industries, making comparisons difficult (Sharma & Beckwith, 2018).

However, it is possible to identify three basic steps for calculating VaR:

- Generating a distribution of daily asset prices and estimating the value of the portfolio for each day of the observation or simulation period;
- Estimating and creating a distribution of values of the portfolio over the chosen asset holding period;
- Selecting the confidence level and picking the point estimate of loss.

There are three different approaches to assessing asset price distribution.

First, the historical distribution method is the most widely used. It uses historical prices and returns to create the distribution of asset values. This method therefore implies that future scenarios are entirely related to what has happened historically. Correlations between instruments and asset classes are therefore historical facts and do not need to be estimated. Other parameters such as volatility are assumed to be implicit and therefore historically correct. This makes the historical approach simple to apply and encompasses all sources of risk (Bohdalova, 2007).

Secondly, there is the Monte Carlo method. To provide a distribution, this method creates a multitude of portfolio value scenarios by applying random disturbances in securities prices (equity, bond, etc.) or factors (interest rates, volatility, etc.). The Monte Carlo method therefore involves a much higher calculation charge. It can be applied to long periods, which also makes it a good measure for credit risk (Gallati, 2003).

Finally, the parametric method, also known as the variance-covariance approach, assumes that asset returns are normally distributed. Once this assumption is made, the historical price distributions can be estimated if the average returns, variance and correlations of the assets are known or assumed. This assumption of normal distribution makes this approach easy but is also its main weakness. Indeed, some asset class distributions do not follow a normal distribution and have fat tails. They can suffer significant losses in extremely stressed scenarios (Sharma & Beckwith, 2018).

These three methods described are all based on the use of historical data or the calculation of parameters on the basis of historical data. Depending on the period chosen, these data or parameters differ and may not be relevant. For this reason, the regulators have imposed the selection of historical windows corresponding to a "stressed" period (sVaR). In this way, they favor a pessimistic approach so that capital requirements are always sufficient (BCBS, 2016).

Limitations

As a measure of market risk, VaR has a number of limits that have become evident as a result of GFC. The first weakness lies in the simplification of certain assumptions on which VaR is based, in particular that concerning the normal distribution. Although it is expressed in monetary units, VaR is still a probabilistic estimate and is therefore not uniquely defined as the price of a security. As a risk measure, it is valid only if the assumption of normal distribution of Profit and Loss (P&L) for computation of VaR systematically understates the risk of a position or portfolio (Gustafson, 2004).

Furthermore, VaR is based on historical volatility and correlation. It suggests that fluctuations in prices and thus returns are defined and captured by their past volatilities and correlations. These factors would therefore be implicitly stable over time. The VaR does not take into account that periods of market stress may be prolonged (Trenca et al., 2011).

Another weakness of VaR is that it cannot be used for every asset class or type of security. Indeed, price volatility for certain assets is not a critical risk factor due to their nature or expected holding periods. However, VaR is directly derived from the underlying volatility of the assets and securities in a portfolio (Sharma & Beckwith, 2018).

One of the main VaR's weaknesses emerged during GFC: its inability to capture the risks of tail events. VaR is a percentile of the loss distribution and is therefore insensitive to the behavior of the loss distribution beyond this percentile. By relying solely on a confidence level, VaR neglects the magnitude and distribution of risks in the tail above the set level. VaR is therefore not an estimate of the size of losses that could be incurred in very tense market conditions. Since price and yield are statistically modelled as random variables, once the VaR threshold is exceeded, losses could be significantly higher than expected (Sharma & Beckwith, 2018).

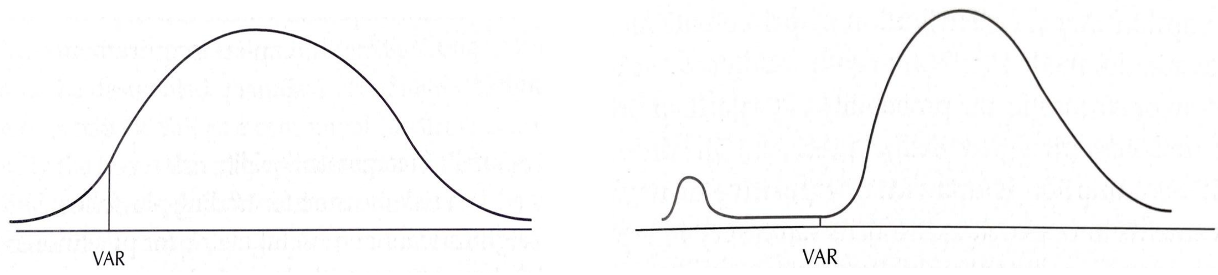

Figure 2: Examples of calculation of same VaR from probability distribution of changes in portfolio value (Sharma & Beckwith, 2018, pp. 74-75)

Furthermore, VaR violates a robust measure's principle which is the subadditivity. This principle implies that the VaR of a portfolio cannot exceed the sum of the VaR of its two sub-portfolios, because of the benefits of diversification. However, VaR tends to rank the combination of non-diversified but low-volatility portfolios as superior to diversified portfolios. This leads to the creation of concentrated portfolios as diversification is not recognized (Berkowitz & O'Brien, 2002).

In addition, VaR does not naturally capture liquidity risk. Indeed, it assumes that any asset or security is liquid and at prices that have existed during the historical or simulated period. Calculating VaR for portfolios that become illiquid or are held to maturity is therefore problematic. Although this can be offset by extending the period over which VaR is calculated, there is no specific liquidity measure built into the calculation process (Čorkalo, 2011).

Desirable properties of risk measures

Having identified all the weaknesses of VaR as a measure of market risk, this section will define all the properties that a perfect risk measure should have.

A consensus has emerged among the authors and clearly identifies several properties that constitute an ideal risk measure. The risk measures that satisfy the first four properties define a so-called "consistent risk measure" (Artzner et al., 1999).

First, the monotonicity property requires that if a loss in portfolio A is always greater than the loss in portfolio B in any scenario, then the risk in portfolio A should always exceed the risk in portfolio B. The invariance translation property implies that adding a risk-free position to a portfolio should reduce the risk measure by the size of the position. The homogeneity property implies that a change in the size of a portfolio by one factor, keeping its composition the same, should result in an increase in the risk measure by the same factor. Finally, the sub-additivity property has been described above. These four properties describe a consistent measure of risk.

Other authors have completed this definition. The elasticity property emphasizes the importance of being able to compare competing models leading to the values of risk measures (Sharma & Beckwith, 2018). The robustness property implies that a risk measure should not be highly sensitive to small perturbations in input parameters or measurement errors, nor to the addition of new data points or observations (Cont et al., 2010).

Expected Shortfall

The lack of subadditivity of VaR was widely criticized following the GFC and could no longer be considered a valid risk measure for future BCBS publications.

FRTB introduces the Expected Shortfall measure. It proves to be a consistent measure, capturing tail risks and filling some of the gaps in VaR. It answers the question: "if things get really bad, what is our expected loss?". The parameters of ES remain the same as VaR: the confidence level and the holding period (Sharma & Beckwith, 2018).

This risk measure has been proposed by Acerbi and Tasche (2001). It is described as the average of the losses in the tail of the P&L distribution at a certain confidence level and time period.

Thus, ES is simply calculated by estimating VaR at a specific threshold and then taking an average of the losses in the tail. In other words, ES can be defined as the assessment of the conditional expectation of loss beyond the VaR measure (Yamai & Yoshiba, 2002).

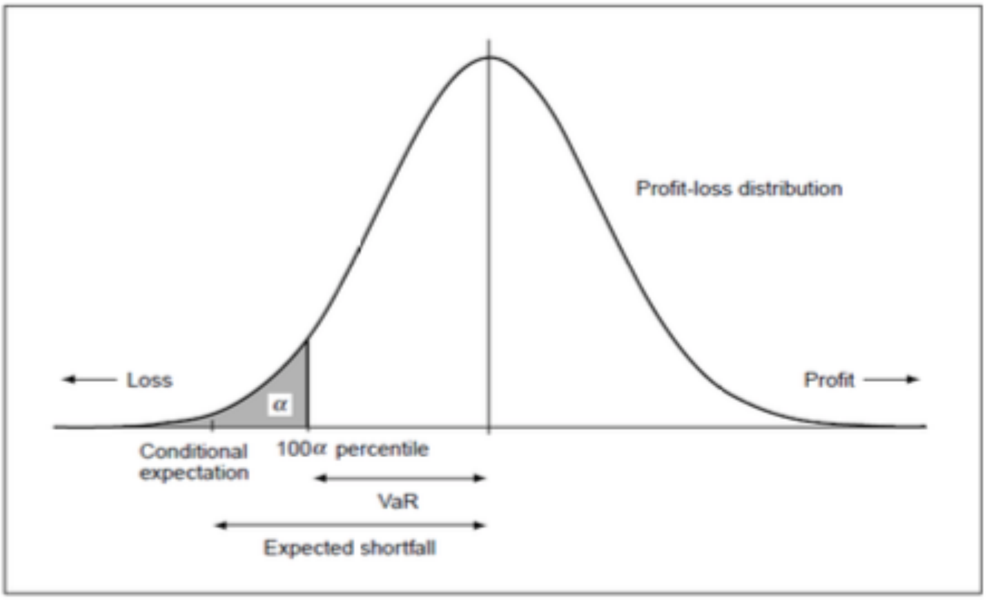

Figure 3: Profit and loss distribution, VaR and ES (Yamai & Yoshiba, 2002, p.60)

ES under FRTB

FRTB regulation will impose ES at a confidence level of 97.5%, whereas Basel 2.5 previously imposed VaR and a confidence level of 99%. Regulators justify this change in the confidence level by its neutrality in terms of capital requirements. Moreover, according to them, there are enough observations beyond the 97.5% VaR to allow an accurate estimate of the corresponding ES (BCBS, 2019).

Calculation models will have to capture and quantify losses related to extremely rare events beyond this 97.5% threshold. The challenge is therefore to model these losses correctly. Estimating the probability and impact of a specific tail event is subject to uncertainty. This is further exacerbated by the prescribed calibration horizon of one year.

To take this into account, FRTB regulation requires ESs to be calibrated to periods of market stress based on risk factors selected by banks that can explain at least 75% of the modelled change during periods of stress.

FRTB prescribes the use of overlapping time periods for the calculation of ES when historical simulation is used. Hull and White (2012) illustrated a methodology for performing historical simulation with overlapping time periods determined by the liquidity horizons or holding periods that can be applied under FRTB.

For example:

- In the first test, a shock equal to the change between day 0 and day 10 (which is the liquidity horizon prescribed by FRTB) is considered for the price of a large-cap equity, and between day 0 and day 120 for the credit spread.
- In the second test, a shock equal to the change between day 1 and day 11 is considered for the price of the large-cap equity, and between day 1 and day 121 for the credit spread.
- Recurrently, the last test looks at the shock between days 249 and 259 for the large-cap equity, and between day 249 and 369 for the credit spread.
- ES is calculated as the average losses in the 2.5% of the tail of the distribution produced by the 250 trials.

Boundary between trading and banking books

One of FRTB's main objectives is to create an impermeable border between trading and banking books. Following the financial crisis of 2007-2008, the Basel Committee studied what contributed to the global crash. The permeability between these two portfolios was identified as a major factor, allowing traders to apply, intentionally or unintentionally, the wrong risk models. A non-exhaustive list of problems related to these boundaries includes according to Sharma and Beckwith (2018):

- Intentional arbitrage between banking and trading book to optimize capital or P&L issues;
- Different treatments of similar risks held in different portfolios;
- Subjective definition of the boundary dictated by the principles of intent to trade;
- Risks related to hidden liquidity until the occurrence of a stressful event.

This section describes the boundaries as defined under Basel 2.5 and highlights the improvements provided by FRTB.

Under Basel 2.5

Loans on the banking book are considered illiquid and the expected credit loss assumes that the loans are held to maturity. Therefore, the projected loss is calculated based on theoretical values using probabilities of default and estimating losses and exposures in the event of default.

Stress in the loan portfolio is therefore measured by creating adverse economic scenarios and analyzing the change in the factors in the following formula:

$$EL = PD \times LGD \times EAD \tag{1}$$

Instruments held on the trading book are supposed to be saleable at a certain price over a 10-day horizon. The calculation of the expected loss therefore focuses on possible price changes within this 10-day horizon. These risks are currently mainly calculated using the VaR method. Market risk models do not assume that positions will be held to maturity. Stress scenarios, using sVaR measures, examine historical periods of high market price volatility to extrapolate potential new stress events. If no market data is available for a certain historical period, risk calculations are determined by interpolation, proxy creation or mark-to-model methodologies. The models described to determine expected and stressed losses are no longer relevant if they are used for the wrong portfolio (BCBS, 2010).

Under FRTB

This new regulation provides clear and strict definitions as well as constraints on movements from one portfolio to another. In concrete terms, FRTB defines new concepts such as the Regulatory Trading Desk (RTD) and the Operating Sub-Desk (OSD). Trading financial instruments will be defined by distinct risk factors and by Liquidity Horizons (LH) extending up to 120 days. Some of these risk factors may be considered as Non-Modellable Risk Factors (NMRF) if there is insufficient trading history and some will be relegated to the banking book from the outset. Finally, instruments will be strictly defined as belonging to only one of the two portfolios.

FRTB's boundary concepts

FRTB introduces new concepts and redefines others described under Basel 2.5 (see *Appendix 1*).

FRTB defines four criteria for an instrument or portfolio to benefit from trading book treatment (BCBS, 2020).

First, it must meet the definition of a trading instrument. Under FRTB, a trading book instrument is defined as "a financial instrument, foreign exchange or commodity trade where there is no legal impediment against selling or fully hedging the instrument" (BCBS, 2020, p.3)

Nor should it appear on the mandatory banking book list. The following financial instruments must all be held on the banking book:

- Unlisted equities;
- Warehouse securitization;
- Fund investments without daily asset transparency;
- Real estate holdings;
- Retail and small and medium-sized enterprise (SME) credit;
- Equity investments in a fund except conditions;
- Hedge funds;
- Derivatives of any of these assets;
- Instruments used to hedge any of these assets.

Third, the instrument or portfolio must be held for a valid business purpose. Any instrument held for one or more of the purposes listed below must be kept on the trading book:

- Short-term resale;
- Profiting from short-term price movements;
- Locking in arbitrage profits;
- Hedging risks that arise from the above;
- Correlation trading;
- Credit or equity short;
- Underwriting commitments of securities that are actually expected to be purchased on settlement date (except loan underwritings).

Some instruments are widely interpreted as being part of the trading book instruments:

- Instruments held as accounting trading assets or liabilities;
- Instruments resulting from market-making activities;
- Equity instruments in a fund excluding those assigned to the banking book;
- Listed equities;
- Trading-related repo-style transaction;
- Options including embedded derivatives from instruments that the institution issued out of its banking book and that relate to credit or equity risk.

Finally, under FRTB, the instrument must be managed through an RTD. A RTD is defined as "a group of traders or trading accounts that implements a well-defined business strategy operating within a clear risk management structure" (BCBS, 2020, p.2). Each RTD is supervised by a head trader who is responsible for all aspects of a RTD: its approval by management and supervisors, its appropriateness, compliance and implementation.

Movement across and within the boundary

FRTB provides for restrictions and procedures not only across the border but also within the trading and banking books themselves. In concrete terms, the Basel Committee expects very few movements across the border, which would be limited only to extraordinary events. The FRTB therefore raises significant and costly hurdles to movement (see *Appendix 2*).

Setting the FRTB frame

This section describes in depth the two main approaches proposed by FRTB. A third approach was added in 2019. This is a simplified standardized approach, defining scalar multiplication, ranging from 120% for FX Risk to 350% for Equity Risk, to be applied to the capital charges calculated under Basel 2.5. In Europe, it can be used for all trading portfolios of less than €300M (Coyne, 2019).

This approach will be avoided as much as possible by banks as it implies an increase in capital requirements of 57% on a weighted basis versus 40% for the SA compared to the current regulation (BCBS, 2019). This master's thesis will therefore not describe this simplified approach.

Standardized Approach

The Standardized Approach (SA) is based on risk sensitivity and represents a significant methodological improvement over previous approaches for estimating capital charges. A SA-based capital charge has three components: sensitivities-based charge, standardized Default Risk Charge (DRC) and Residual Risk Add-On (RRAO).

The SA under FRTB has several objectives (BCBS, 2019):

- To facilitate consistent and comparable communication of market risks across banks and jurisdictions;
- To enable banks with relatively small trading platforms to calculate capital requirements without the need for sophisticated measurement frameworks;
- To provide a credible fallback if the internal model is rejected by supervisors;
- To serve as a basis or complement for a charge based on internal models.

This FRTB-prescribed method will be applicable across all banks and regulatory jurisdictions in all asset classes. It does not require extensive back testing nor any consequential calculation needs. There is a single set of sensitivity calculations for each instrument in a market environment, as opposed to a constant revaluation of each instrument. SA is therefore much simpler to implement than IMA, but much more complex than the SA described under Basel 2.5 (Sharma & Beckwith, 2018).

Another difference compared to Basel 2.5 is the approval given for the use of IMA. Under Basel 2.5, this was granted at the level of the bank. This regulation regularly prevented regulators from not granting the right to apply the IMA. Indeed, if they refused, the entire bank would have had to apply a SA which would not have properly represented complex banks and would have required disproportionate capital requirements. Under FRTB, the sensitivity-based SA is a credible and operational fallback solution for the IMA. In addition, it offers the possibility for regulators to be more selective in granting IMA approval and allows revocation if risk models do not match the market (Smith et al., 2019).

The SA described under FRTB is more conservative in its design and therefore should lead to higher capital requirements than the IMA (Deloitte, 2018).

Concepts

FRTB describes 7 *risk classes* that correspond to what the instrument is sensitive to:

- General Interest Rate Risk (GIRR);
- Equity Risk;
- Commodity Risk;
- Foreign Exchange (FX) Risk;
- Credit Spread Risk (CSR) non-securitization;
- CSR securitization (Correlation Trading Portfolio (CTP));
- CSR securitization (non-CTP).

Risk classes are divided into *risk buckets*, a set of risk positions that are grouped together by common characteristics. For example, GIRR is grouped by currency while Equity Risk is grouped by market capitalization, economy type and industry sector. The buckets for each risk class are specified in *Appendix 3* (BCBS, 2019).

Each risk bucket is subdivided into related *risk factors*. FRTB defines risk factor as "variables within a pricing function decomposed from instruments and which fall within scope of the risk factor definitions" (BCBS, 2016, p.43). Risk factors are mapped to a risk class. The price of an equity or commodity, or a change in an interest rate, credit spread or FX rate, could be a risk factor.

The same financial instrument can be sensitive to several risk factors. For example, a cross-currency swap has sensibility to the underlying currency exchange rates and interest rates. It is then said that this financial instrument is both a GIRR *risk position*, involving rates of different tenors across the IR curves of the two currencies, and a FX risk position, involving the spot FX rate. Of course, not all financial instruments have risk positions against all risk factors.

The *risk capital requirement* is the amount of capital that a bank must hold as a result of the risks it takes. It is calculated as the sum of the risk positions, first at the bucket level and then at the risk class level.

Sensitivity computation under SA

The capital requirement can be broken down into three components (BCBS, 2019, p.4).:

- *Delta risk* is “the linear estimate of the change in value of a financial instrument due to a movement in the value of a risk factor”.
- *Vega risk* is “the potential loss resulting from the change in value of a derivative due to a change in the implied volatility of its underlying”.
- *Curvature risk* is “the additional potential loss beyond delta risk due to a change in a risk factor for financial instruments with optionality”.

The instruments subject to vega and curvature risks are the following:

- Any instrument with optionality;
- Any instrument with an embedded prepayment option;
- Instruments whose cash flows cannot be written as a linear function of underlying notional.

To determine the sensitivities-based charge, it is necessary to follow the steps described below.

1. Delta risk charge

To determine the capital charge of these three components, it is necessary to identify the sensitivities of each financial instrument in the portfolio. Sensitivity is defined as "a bank's estimate of the change in value of an instrument due to a small change in one of its underlying risk factors" (BCBS, 2019, p.4). The sensitivities for each risk class must be expressed in the bank's reporting currency (BCBS, 2019). FRTB describes the variations to be applied to each risk factor in order to determine the delta risk charge.

1.1. GIRR

$$s_{k,r_t} = \frac{V_i(r_t + 0.0001, cs_t) - V_i(r_t, cs_t)}{0.0001} \tag{2}$$

Where:

- r_t is the risk-free yield curve at tenor t;
- cs_t is the credit spread curve at tenor t;
- V_i is the market value of the instrument i as a function of the risk-free interest rate curve and credit spread curve.

1.2. CSR non-securitization, securitization (non-CTP) and securitization (CTP)

$$s_{k,cs_t} = \frac{V_i(r_t, cs_t + 0.0001) - V_i(r_t, cs_t)}{0.0001} \tag{3}$$

1.3. Equity spot

$$s_k = \frac{V_i(1.01\, EQ_k) - V_i(EQ_k)}{0.01} \tag{4}$$

Where:

- k is a given equity;
- EQ is the market value of equity k;
- V_i is the market value of the instrument i as a function of the price of equity k.

1.4. Commodity

$$s_k = \frac{V_i(1.01\, CTY_k) - V_i(CTY_k)}{0.01} \tag{5}$$

Where:

- k is a given commodity;
- CTY_k is the market value of commodity k;
- V_i is the market value of the instrument i as a function of the spot price of commodity k.

1.5. FX

$$s_k = \frac{V_i(1.01\, FX_k) - V_i(FX_k)}{0.01} \tag{6}$$

Where:

- k is a given currency;
- FX_k is the exchange rate between a given currency and a bank's reporting currency or base currency, where the FX spot rate is the current market price of one unit of another currency expressed in the units of the bank's reporting currency or base currency;
- V_i is the market value of the instrument i as a function of the exchange rate k.

2. Vega risk charge

The vega risk sensitivity to a given risk factor is determined by the following formula:

$$s_k = vega \times implied\ volatility \tag{7}$$

Where:

- $vega\ \frac{\partial v_i}{\partial \sigma_i}$ is defined as the change in the market value of the option V_i as a result of a small amount of change to the implied volatility σ_i.

3. Risk weighting for delta and vega risks

Sensitivities to the same risk factor shall be aggregated to give a net sensitivity s_k for all instruments in the portfolio to each risk factor k. The weighted sensitivity WS_k is the product of the net sensitivity s_k and the corresponding risk weight RW_k. All risk weights prescribed by FRTB are described in Appendices 4 and 6.

$$WS_k = RW_k s_k \tag{8}$$

4. Aggregation within buckets

The K_b weighted sensitivities are cumulated within each bucket b using the ρ_{kl} correlations prescribed by the FRTB regulation. All correlations prescribed by FRTB are described in *Appendix 5* for delta and *Appendix 6* for vega.

$$K_b = \sqrt{\max\left(0, \sum_k WS_k^2 + \sum_k \sum_{k \neq l} \rho_{kl}\, WS_k WS_l\right)} \tag{9}$$

5. Aggregation across buckets

The resulting capital charges at bucket-level are then aggregated using a similar methodology to the previous step to determine the capital charge at risk class-level, using the correlations γ_{bc} prescribed by FRTB.

$$Delta\ or\ Vega = \sqrt{\sum_b K_b^2 + \sum_b \sum_{c \neq b} \gamma_{bc} S_b S_c} \qquad (10)$$

Where:

- $S_b = \sum_k WS_k$ represents all risk factors in bucket b;
- $S_c = \sum_k WS_k$ in bucket c.

If $S_b$et S_c values make $\sum_b K_b^2 + \sum_b \sum_{c \neq b} \gamma_{bc} S_b S_c$ negative, then the bank must calculate the delta or vega risk capital requirement according to another formula described by FRTB:

$S_b = \max\ [\min\ (\sum_k WS_k, K_b), -K_b]$ for all risk factors in bucket b

$S_c = \max\ [\min\ (\sum_k WS_k, K_c), -K_c]$ for all risk factors in bucket c

6. Curvature risk charge

In the SA, the computation of the curvature risk measure is based on two stress scenarios involving an upward shock and a downward shock to each regulatory risk factor k. In the case of an instrument dependent on several risk factors, the curvature risk must be computed independently for each risk factor. To determine the net curvature risk capital requirement, the values of CVR_k^+ and CVR_k^-must be determined using the following formulae:

$$CVR_k^+ = -\left\{\sum_i \left\{V_i\left(x_k^{RW(Curvature)^+}\right) - V(x_k) + RW_k^{Curvature} \times s_{ik}\right\}\right. \qquad (11)$$

$$CVR_k^- = -\left\{\sum_i \left\{V_i\left(x_k^{RW(Curvature)^-}\right) - V(x_k) + RW_k^{Curvature} \times s_{ik}\right\}\right. \qquad (12)$$

Where:

- i is an instrument subject to curvature risk associated with risk factor k;
- x_k is the current level of risk factor k;
- $V_i\ (x_k)$ is the price of instrument i at the current level of risk factor k;
- $V_i\left(x_k^{RW(Curvature)^+}\right)$ and $V_i\left(x_k^{RW(Curvature)^-}\right)$ are the price of instrument i after x_k is shifted upward and downward respectively;

- $RW_k^{Curvature}$ is the risk weight for curvature risk factor k for instrument i;
- s_{ik} is the delta sensitivity of instrument i with respect to the delta risk factor that corresponds to curvature risk factor k, where:
  - For the FX and equity risk classes, s_{ik} is the delta sensitivity of instrument i;
  - For the GIRR, CSR and commodity risk classes, s_{ik} is the sum of delta sensitivities to all tenors of the relevant curve of instrument i with respect to curvature risk factor k.

For each bucket, the results must then be aggregated using the corresponding prescribed correlation ρ_{kl} (see *Appendix 7*) and thus determine the bucket level capital requirement K_b. The following formula is used:

$$K_b = max(K_b^+, K_b^-) \qquad (13)$$

$$where \begin{cases} K_b^+ = \sqrt{\max\left(0, \sum_k \max(CVR_k^+, 0)^2 + \sum_{l \neq k} \sum_k \rho_{kl}\, CVR_k^+ CVR_l^+ \psi\,(CVR_k^+, CVR_l^+)\right)} \\ K_b^- = \sqrt{\max\left(0, \sum_k \max(CVR_k^-, 0)^2 + \sum_{l \neq k} \sum_k \rho_{kl}\, CVR_k^- CVR_l^- \psi\,(CVR_k^-, CVR_l^-)\right)} \end{cases} \qquad (14)$$

Curvature risk positions must then be aggregated across buckets within each risk class, using the corresponding prescribed correlations γ_{bc} thanks to the following formula:

$$Curvature\ risk = \sqrt{max(0, \sum_b K_b^2 + \sum_{c \neq b} \sum_b \gamma_{bc} S_b S_c\, \psi\,(S_b, S_c))} \qquad (15)$$

Where:

- $S_b = \sum_k CVR_k^+$ for all risk factors in bucket b when the upward scenario has been selected for bucket b or $S_b = \sum_k CVR_k^-$ otherwise;
- $\psi(S_b, S_c)$ takes the value 0 if S_b and S_c both have negative signs and 1 otherwise.

7. Final aggregation

For each correlation scenario, the bank must add together the delta, vega and curvature capital requirements calculated separately for all risk classes to determine the overall capital requirement for that scenario.

The level of correlations prescribed by FRTB between these elements could increase or decrease depending on the stress the market may experience. Consequently, the regulation foresees three different scenarios for the correlation ρ_{kl} between the risk factors in a bucket and the correlation γ_{bc} between the buckets in a risk class.

- Under the "high correlations" scenario, the correlation ρ_{kl} and γ_{bc} are uniformly multiplied by 1.25.
- Under the "low correlations" scenario, the correlation ρ_{kl} and γ_{bc} are replaced by

$$\rho_{kl}^{low} = \max(2 \times \rho_{kl} - 100\%; 75\% \times \rho_{kl}) \quad (16)$$

$$\gamma_{bc}^{low} = \max(2 \times \gamma_{bc} - 100\%; 75\% \times \gamma_{bc}) \quad (17)$$

- Under the "medium correlations" scenario, the prescribed parameters are applied.

The scenario resulting in the highest capital requirements is the one adopted.

Default risk capital requirement

Only three types of instruments are concerned by the calculation of the DRC.

- Non-securitization portfolios;
- Securitization portfolios (non-CTP);
- Securitization portfolios (CTP).

In SA, DRC attempts to capture the Jump-To-Default (JTD) risk. It is the risk "that a financial product, whose value directly depends on the credit quality of one or more entities, may experience sudden price changes due to an unexpected default of one of these entities" (BCBS, 2016, p.11).

The steps for determining the DRC charge are similar for these three types of financial instruments. This master's thesis only describes in detail those concerning non-securitizations because it is the only instrument sensitive to credit spread that makes up the trading portfolio analyzed in the practical part.

To determine the DRC charge, it is necessary to follow the steps described below.

1. Gross JTD risk positions

The gross JTD risk position is computed on an exposure basis. In other words, if a bank has a long position on a bond issued by a company, and another short position on a bond issued by the same company, two separate JTD exposures will be computed. A long exposure is defined as "a credit exposure that results in a loss in the case of a default" (BCBS, 2019, p.5).

The JTD risks are determined using the following formulas:

$$JTD\ (long) = \max(LGD \times notional + P\&L, 0) \tag{18}$$

$$JTD\ (short) = \min(LGD \times notional + P\&L, 0) \tag{19}$$

Where :

- LGD is the loss given default;
- $notional$ is the bond-equivalent notional amount of the position;
- $P\&L$ is the cumulative mark-to-market loss or gain already taken on the exposure.

LGD is defined as "the amount of money a bank or other financial institution loses when a borrower defaults on a loan, depicted as a percentage of total exposure at the time of default" (Tuovila, 2020, p.1).

BCBS (2019) determines the LGD as follows:

- 100% for equity instruments and non-senior debt instruments;
- 75% for senior debt instruments;
- 25% for covered bonds;
- 0% when the price of the instrument is not linked to the recovery rate of the defaulter.

2. Net JTD risk positions

If a bank holds instruments issued by the same obligor, the gross JTD risk positions can be decreased. This is the case only if the short exposure of an instrument has the same or lower seniority relative to the long exposure (Sharma & Beckwith, 2018).

To compute the default risk of non-securitizations, FRTB describes three different buckets:

- Corporates;
- Sovereigns;
- Local governments and municipalities.

To cover potential correlation between net long and net short positions within a bucket, a Hedge Benefit Ratio (HBR) has to be determined:

$$HBR = \frac{\sum net\ JTD_{long}}{\sum net\ JTD_{long} + \sum |netJTD_{short}|} \tag{20}$$

3. DRC charge

The following formula is used to compute the DRC capital requirement for each bucket b:

$$DRC_b = \max\left[\left(\sum_{i \in long} RW_i \cdot net\ JTD_i\right) - HBR \cdot \left(\sum_{i \in short} RW_i \cdot |net\ JTD_i|\right); 0\right] \quad (21)$$

The corresponding risk weight RW_i is determined by FRTB based on the credit quality for the three buckets (see *Appendix 8*).

Residual risk add-on

Although it is broader and more risk-sensitive than the SA described under Basel 2.5, FRTB SA will not capture the underlying risks of all types of instruments and asset classes, especially those that are non-linear. These are the risks of correlation (multi-product equity options or spread options where correlation is a significant risk factor) and early redemption. SA also does not fully capture the risks of exotic options, such as Asian and Bermudan options. Non-vanilla instruments such as barriers have complex risk profiles, and the sensitivity-based capital charge may not capture their underlying risks. In addition, non-standard risk factors such as weather-related instruments are not assigned risk weights and sensitivities cannot be computed (Sharma & Beckwith, 2018).

The SA described under FRTB takes these shortcomings into account by prescribing an additional capital charge factor: the residual risk add-on. This is a flat, notional-based add-on capital charge that will be applied for non-vanilla instruments. RRAO is to be computed as the simple sum of an instrument's notional amount times a prescribed risk weight at 1% or 0.1%, depending upon whether the instrument's underlying risk classification is deemed to be "exotic" or "other" (Khwaja, 2016).

Internal Model Approach

FRTB's IMA addresses the weaknesses of Basel 2.5 framework across two main aspects. On the one hand, it is designed to capture tail risk thanks to the expected shortfall methodology. FRTB also prescribes differentiated liquidity horizons for risk factors. These are categorized on the basis of the most unfavorable estimates in order to liquidate or hedge them without influencing market prices. On the other hand, FRTB describes a significantly more rigorous and periodic model approval process at the RTD level, with more consistent identification and capitalization of material risk factors (BCBS, 2016).

An IMA-based capital charge has three components: the Internally Modelled Capital Charge (IMCC), the DRC and the Non-Modellable Risk Factors (NMRF). This section describes the qualitative and quantitative criteria to be met by each RTD wishing to apply the IMA as well as the steps to be taken to determine the three capital sub-charges.

Qualitative criteria

Bank should assure bank supervisors that RTDs under IMA have conceptually sound risk management systems that are implemented with integrity. To achieve that, FRTB prescribes that IMA RTDs and banks should have established independent risk control units that are responsible for the design and implementation of the bank's risk management systems. (BCBS, 2019).

A bank's senior management and board directors must be involved in the risk control process and pay attention to dedicating significant resources to the risk control function. Within senior management governance, FRTB also prescribes that daily and other periodic reports produced by the independent risk control units be reviewed by "level of management with sufficient seniority and authority to enforce risk reduction at position, RTD and bank levels" (BCBS, 2016, p.55). They have to create a comprehensive risk management system with detailed explanation of empirical techniques for measuring market risk.

FRTB prescribes that validation for internal models should be conducted on an annual basis. Furthermore, the new regulation requires a periodic and rigorous stress-testing and assessment program with senior management review on a monthly basis. Each significant change to models that have been approved by the bank's supervisor must be submitted for approval before being implemented and operationalized (BCBS, 2019).

Finally, under FRTB, an independent review, internal or external, of a bank's risk measurement system has to be considered at least annually. This review should include the activities of both the trading desks and independent risk control units (Sharma & Beckwith, 2018). The minimum scope the review should cover is described in *Appendix 9*.

Quantitative standards

FRTB imposes strict conditions for availability of historical date for each risk factor for it to be considered modellable with capital charge multipliers for breaches. For a risk factor to be deemed modellable and pass the Risk Factor Eligibility Test (RFET), there must be continuously available "real" prices for a sufficient set of representative transactions. A price will be 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 arm's-length parties;
- Or it is obtained from a committed quote or a third party-vendor.

Furthermore, a risk factor must have either:

- At least 24 observable "real" prices per year with a maximum period of one month between two consecutive observations. Moreover, during the previous year, a minimum of four real price observations must be identified per 90-day period, with a maximum of one real price observation per day. This last criterion is to be checked on a monthly basis.
- At least 100 real price observations over the previous year, with a maximum of one real price observation per day.

These two criteria must be checked on a quarterly basis (BCBS, 2019).

Specification of liquidity horizons

The existing IMA framework under Basel 2.5 assumes a fixed liquidity horizon (LH) of 10 days across all risk factors. This is a simplistic approach with an underlying assumption that this period is sufficiently long to adjust, close out or hedge trades/risk positions irrespective of their characteristics, size or market depth. However, as became harshly evident during the GFC, complex and bespoke instruments as well as their derivatives become less liquid during crisis periods. This decline is generally a function of market depth for individual asset/instrument classes and their complexity (Deloitte, 2019).

Considering this reality, FRTB has prescribed LHs ranging from 10 days to 120 days depending on instrument type and risk factors (see *Appendix 10*). Each liquidity horizon corresponds to one risk factor category. A bank may increase the LH at the RTD level above the prescribed values from the prescribed floor values within the specified ranges, subject to the approval of the banking authority (BCBS, 2019).

Calculation of expected shortfall

ES has to be computed over a 10-day base horizon for each RTD at a one-tailed 97.5% confidence level. The process for computing LH-adjusted ES has the following steps (BCBS, 2019):

- For individual RTDs, compute ES for all risk factors over a 10-day base horizon - ES_1.
- Exclude risk factors that have prescribed a LH of 10 days and recalculate and scale-up ES with LHs of 20 days or greater using 10-day shocks. Subsequently, ES is calculated for 10-day changes in all risk factors in categories 2-5, with risk factors in category 1 being kept constant - ES_2 ... ES_5.
- This process is continued until ES_5 is calculated.

The general expression for liquidity adjusted ES is:

$$ES = \sqrt{\left(ES(P)\right)^2 + \sum_{j \geq 2} \left(ES_T(P,j) \sqrt{\frac{\left(LH_j - LH_{j-1}\right)}{T}} \right)^2} \quad (22)$$

Where:

- ES is the liquidity-adjusted expected shortfall;
- LH_j is the liquidity horizon for category j liquidity horizon;
- T is the length of the base horizon (from 10 to 120 days);
- $ES_T(P)$ is the expected shortfall 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;
- $ES_T(P,j)$ is the expected shortfall 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;
- ES at horizon $T - ES_T(P)$ has to be calculated for changes in the risk factors, and $ES_T(P,j)$ for changes in the relevant subset $Q(p_i, j)$ of risk factors, over the time interval T without scaling from a shorter horizon;
- $Q(p_i, j)$ is the subset of risk factors for which liquidity horizons are at least as long as LH_j.

FRTB requires that ES for the current portfolio at the RTD level be calibrated to a stressed market environment for the underlying risk factors. To compute stressed ES, banks have to identify the 12-month period of market stress over the historical observation period during which the portfolio would have experienced the largest loss. The observation horizon to determine the most stressful 12 months must, at a minimum, go back and include 2007 (Sharma & Beckwith, 2018).

The challenge of this approach is the calibration of risk factors that did not exist during the referenced stress period. FRTB addresses this by prescribing that the calibration be based on an indirect approach using a reduced set of risk factors. In this approach, from the full set of applicable risk factors to their current trade portfolios, banks are to extract a reduced set of risk factors for which there is a sufficiently long history of observations during the stress period. The identified reduced set of risk factors must be able to explain a minimum of 75% of the variation of the full ES model and is subject to supervisory approval (BCBS, 2019).

Finally, the ES for market risk capital purposes is expressed thanks to the following formula:

$$ES = ES_{R,S} \cdot \frac{ES_{F,C}}{ES_{R,C}} \quad (23)$$

Where:

- $ES_{R,S}$ is the expected shortfall based on a stressed observation period using a reduced set of risk factors;
- $ES_{F,C}$ is the expected shortfall based on the current (most recent) 12-month observation period with a full set of risk factors;
- $ES_{R,C}$ is the expected shortfall based on the current period with a reduced set of risk factors;
- The ratio $\frac{ES_{F,C}}{ES_{R,C}}$ is floored at 1.

Calculation of capital requirement for Internal Modellable Risk Factors

For modellable risk factors, the ES and associated capital charge is calculated at the bank-wide level. Partial ES and associated capital charge are to be calculated individually for each broad FRTB risk class when all other risk factors are shocked, and the sum of partial ES will always be greater than that of the overall portfolio. These partial ES values $IMCC(C_i)$ are summed to provide the aggregated risk class ES (BCBS, 2019).

The aggregate capital charge for modellable risk factors $IMCC$ is then computed following this formula:

$$IMCC = \rho\big(IMCC(C)\big) + (1-\rho)\left(\sum_{i=1}^{B} IMCC(C_i)\right) \quad (24)$$

Where:

- $IMCC(C) = ES_{R,S} \times \frac{ES_{F,C}}{ES_{R,C}}$;
- $IMCC(C_i) = ES_{R,S,i} \times \frac{ES_{F,C,i}}{ES_{R,C,i}}$;
- ρ is the relative weight assigned to the firm's internal model (0.5 for equal weighting).

The stress period used in the risk class-level $ES_{R,S,i}$ should be the same as that used to calculate the portfolio-wide $ES_{R,S}$.

Calculation of default risk capital requirement

FRTB prescribes that banks should have a separate internal model to measure the DRC. It has to be measured by a VaR model. It must be done weekly and based on a one-year time horizon at a one-tail, 99.9% confidence level. The IMA-DRC charge is to be included in the overall capital charge as the greater of either the average of the DRC model measures over the previous 12 weeks or the most recent DRC model measure (BCBS, 2019).

Calculation of capital requirement for Non-Modellable Risk Factors

FRTB distinguishes two types of risk factors: modellable and non-modellable. If these do not meet the quantitative criteria described above, they are classified as non-modellable. These are therefore risk factors that have fewer than 24 observable real prices within a year or there is more than a month between two observations (Slime, 2019).

Each NMRF is to be capitalized using a stress scenario that is calibrated to be at least as severe as the ES calibration used for modellable risk factors. For each NMRF, the specified LH of the stress scenario must be the greater of the longest time interval between two consecutive price observations over the prior year and the LH assigned to the risk factor in *Appendix 10*. FRTB does not allow correlation or diversification effect across NMRFs (BCBS, 2019).

The aggregate regulatory capital measure is given by the following formula:

$$SES = \sqrt{\sum_{i=1}^{I} ISES_{NM,i}^{2}} + \sqrt{\sum_{j=1}^{J} ISES_{NM,j}^{2}} + \sqrt{\left(\rho * \sum_{k=1}^{K} SES_{NM,k}\right)^{2} + (1-\rho^{2}) * \sum_{k=1}^{K} SES^{2}{}_{NM,k}} \quad (25)$$

Where:

- $ISES_{NM,i}$ is the stress scenario capital charge for idiosyncratic credit spread non-modellable risk i from the I risk factors aggregated with zero correlation;
- $ISES_{NM,j}$ is the stress scenario capital charge for idiosyncratic equity non-modellable risk j from the J risk factors aggregated with zero correlation;
- $SES_{NM,k}$ is the stress scenario capital charge for non-modellable risk k from K risk factors;
- ρ is equal to 0.6.

Aggregation of capital requirements

The aggregated IMA capital charge associated with approved RTDs (C_A) is the maximum of the most recent observation and scaled by a multiplier:

$$C_A = max\{IMCC_{t-1} + SES_{t-1}; m_c \cdot IMCC_{avg} + SES_{avg}\} \quad (26)$$

Where:

- SES is the aggregate regulatory capital measure for K risk factors in model-eligible desks that are non-modellable;
- $IMCC_{t-1}$is the internal model capital charge for the previous day;
- $IMCC_{avg}$ is the weighted average of the previous 60 days;
- m_c is the regulator prescribed scaling multiplier.

The multiplication factor m_c will be 1.5 or higher to be set by individual supervisory authorities based on their assessment of the quality of the bank's risk management systems (BCBS, 2019).

The previously calculated DRC is added to C_A to obtain the aggregate capital requirement for approved and eligible trading desks.

Recent stress market periods

FRTB requires that ES be calibrated to a stressed market environment for the underlying risk factors. For computing stressed ES, banks have to identify the 12-month period of market stress over the historical observation period during which the portfolio would have experienced the largest loss. As specified before, the observation horizon for determining the most stressful 12 months must, at a minimum, go back to 2007 (BCBS, 2016).

It is a reasonable assumption that for most if not all markets and banks, the referenced stress period would be across the GFC (Sharma & Beckwith, 2018). However, the COVID-19 crisis has placed considerable stress on global markets. Recent sharp declines in interest rates and high volatility in securities and currency prices increase banks' market risk, which can lead to losses (Deloitte, 2020). COVID-19 crisis' effects may lead to "regular" VaR being higher than stressed VaR. A re-assessment of the stressed period window could be required (KPMG, 2020).

GFC is the result of endogenous dysfunctions in the US mortgage market. As credit standards were lowered, risk accumulated to form a bubble that eventually burst. The world then faced a massive credit crisis, causing financial markets to freeze, liquidity to dry up, and a recession. Faced with this situation, central banks decided to lower interest rates to stimulate growth. (Duncan, 2020).

The COVID-19 crisis has its origin in an exogenous shock to the market. The pandemic caused a global collapse of supply and demand due to a closure of international borders. As a result, financial stability prior to this crisis was stronger than in 2007-2008. It was also reinforced by lessons learned from the GFC, which led to a greater proportion of risky loans being guaranteed by non-bank players, thereby reducing their exposure. To date, the credit market has been largely stable, thanks to considerable efforts by individual central banks (Duncan, 2020).

Commodities were under stress during these two crises. Following the collapse of the housing bubble, the price of oil almost tripled from $50 to $147 from early 2007 to 2008, before plummeting when the financial crisis began to take hold in late 2008 (Conway, 2008). At the peak of the COVID-19 pandemic, global demand for oil plunged, leading to an unprecedented storage level. On April 21, 2020, the reference price of a barrel of West Texas Intermediate (WTI) was even traded at a negative price for the first time in its history (Pemberton 2019).

These two periods of crisis have also put a lot of stress on the stock markets. Global equity markets were under severe stress during GFC. The stock market return for 2008 was 40% negative, the lowest in the 126 years of stock market returns recorded (Bishop, 2011). According to the OECD (2020), the global spread of COVID-19 increased market risk aversion as during GFC. Stock markets fell by more than 30% while the implied volatilities of equities reached crisis levels.

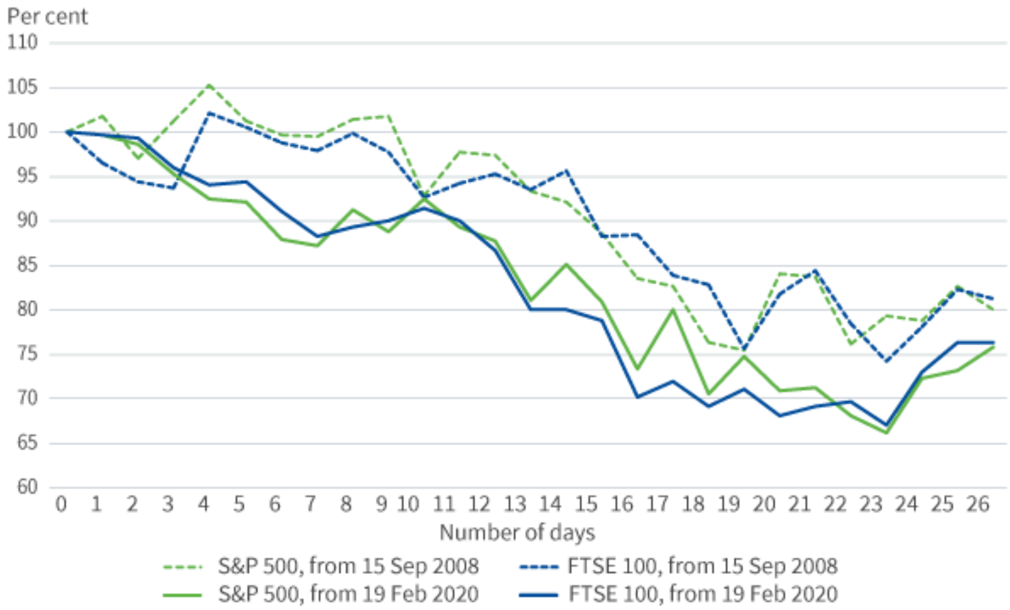

Figure 4: Market response to COVID-19 (Q1 2020) vs Lehman's collapse (Q3 2008) (Nunan, 2020)

Credit spreads have widened significantly during the GFC as a result of increased uncertainty and growing concerns about the ability of businesses (and other private borrowers) to service their debt because of deteriorating economic conditions. The COVID-19 pandemic, for its part, led to a high level of redemption by investors. Funds were forced to sell off corporate debt quickly, particularly high-yield bonds and leveraged loans. This undermined market liquidity, increasing the price of traded debt and the cost of corporate financing (Pemberton, 2019).

The foreign exchange market was not spared during these two crises. In August 2017, when the subprime crisis first hit equity and fixed income portfolios, portfolio managers liquidated all their winning positions, including currency positions. The collapse of Lehman then led to unprecedented volatility in exchange rates and transaction costs in the foreign exchange market increased drastically. The bid-ask spread has increased considerably (see *Appendix 11*). Indeed, by providing liquidity to the market, market makers were holding inventories of currencies that were increasingly risky to hold because of this high volatility (Melvin & Taylor, 2009).

These pressures on exchange rates were also observed during the COVID-19 crisis. Policymakers reacted quickly with strong measures such as central bank swap lines and an increase of resources for international financial institutions. The objective was to stabilize reserve currencies such as the dollar or the euro. However, the currencies of many emerging markets and energy exporters fell sharply against these reserve currencies. As the *figure 5* shows, countries with large net energy exports (over 20 million tons of oil equivalent in 2018) have experienced sharp downward movements in their currencies against the US dollar (Collins & Gagnon, 2020).

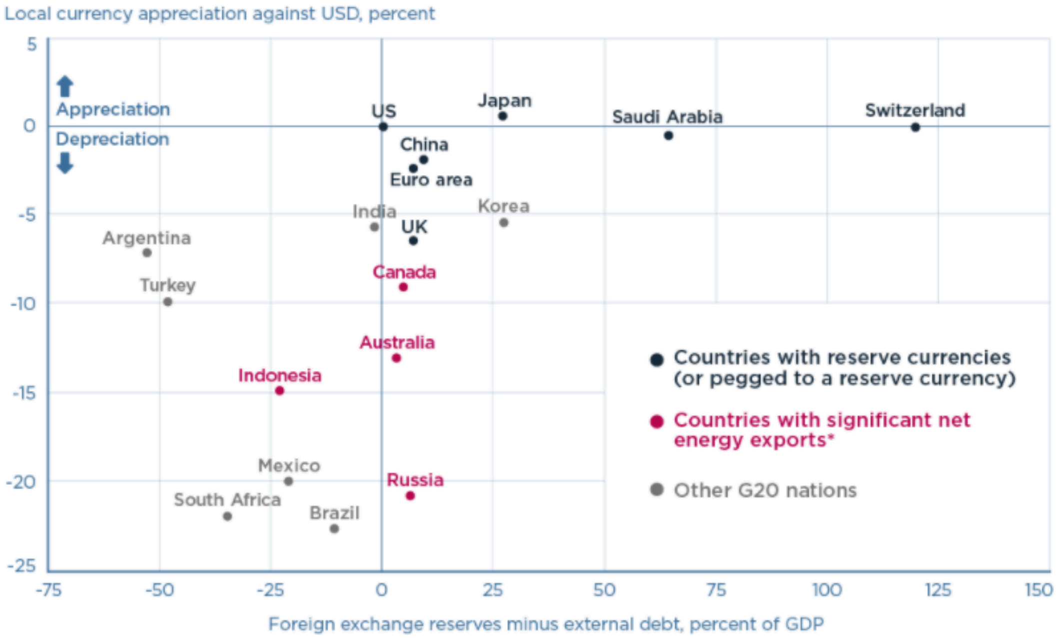

Figure 5: Currency changes on December 31, 2019 vs on March 31, 2020 (PIIE, 2020)

To sum up, the Global Financial and COVID-19 crises have severely disrupted all financial markets. That is why the supervisory body of the Basel Committee, the Group of Central Bank Governors and Heads of Supervision (GHOS), has decided to help banks deal with this period and to postpone the implementation of the FRTB until January 2023 (BIS, 2020).

Assessment of FRTB's impacts

Since the start of work on FRTB at the end of 2011, numerous consultations have been held with banking industry players in order to develop the regulation that is best suited to everyone's needs. As changes have been made to the text, Quantitative Impact Studies (QIS) have made it possible to assess the effects of the regulation. The Basel Committee carried out three large-scale studies.

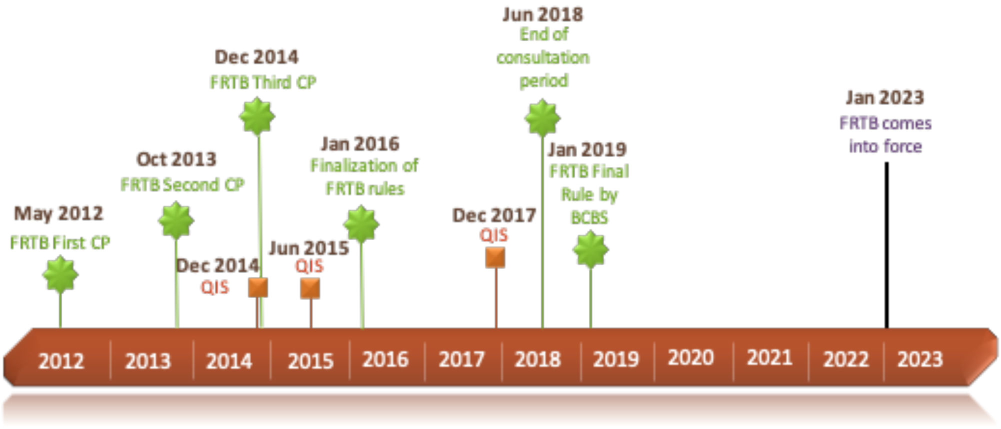

Figure 6: FRTB development timeline (KPMG, 2019, p.1)

The first one was carried out in December 2014, based on a first version of FRTB. It dealt for the first time with the effects of the new features described under FRTB: expected shortfall, default risk charge and capital charge for non-modellable risk factors. The study was based on data as at December 31, 2014, provided by 78 banks from 26 different jurisdictions (see composition by nationality in *Appendix 13*) (BCBS, 2015).

The findings of this study were numerous and important for the adaptation of FRTB in its final version. The application of SA compared to IMA required almost 9 times more capital. The main risk classes impacted are interest rate risk and equity risk, while the effect is less for credit spread, commodity and FX risks.

In per cent	**Simple mean**	**Min**	**25th percentile**	**Median**	**75th percentile**	**Max**	**StDev**	**Sample size**
Interest rate risk	1579	-70	611	**1024**	1755	8322	1901	22
Credit spread risk	414	-73	133	**335**	685	1070	344	14
Equity risk	3735	134	499	**837**	2616	25269	6708	19
Commodity risk	1219	-67	330	**579**	1127	7668	1957	15
FX risk	937	-97	148	**364**	1164	4650	1298	16

Table 1: Change in capital charge from IMA to SA under first version of FRTB (BCBS, 2015, p.9)

Based on the first final version published in 2016, the Basel Committee described different impacts of FRTB in its explanatory note (BCBS, 2016). These were based on data collected in June 2015.

Revised SA/IMA	**25th percentile**	**Median**	**75th percentile**	**StDev**	**Sample size**
Interest rate risk	0.8	**1.3**	2.6	3.9	16
Credit spread risk	0.7	**1.2**	2.6	1.7	14
Equity risk	0.6	**1.2**	3.0	3.9	15
Commodity risk	1.0	**1.5**	2.2	1.2	12
FX risk	0.9	**1.4**	2.6	2.1	10
Total	0.9	**1.4**	3.0	1.9	16

Table 2: Change in capital charge from IMA to SA under 2016 FRTB version (BCBS, 2016, p.11)

These results have been reinforced by a QIS carried out by the Global Financial Markets Association (GFMA), the International Swaps and Derivatives Association (ISDA) and the Institute of International Finance (IIF) in June 2017. It put forward results based on data from 30 banks. Comparing SA and IMA, the results were as follows:

Revised SA / Revised IMA	**Median**
Interest rate risk	3.7
Credit spread risk	1.6
Equity risk	3.8
Commodity risk	3.3
FX risk	5.3

Table 3: Change in capital charge from IMA to SA (ISDA, GFMA & IIF, 2017, p.1)

To date, the only QIS based on the final version of the FRTB that indicates the effects of the choice of approach on capital requirements was published in 2019 by the Basel Committee. This is the last QIS published publicly and, like the previous ones, it highlights higher capital requirements under SA than under IMA.

Revised SA / Revised IMA	**Median**	**Sample size**
General interest rate risk	1.5	31
Credit spread risk: non-securitizations	1.1	24
Equity risk	3.8	24
Commodity risk	1.6	22
FX risk	2.2	31

Table 4: Estimated capital requirements under the FRTB-SA relative to capital requirements under the FRT-IMA (BCBS, 2019, p.15)

Conclusion

On the basis of the literature review, several research hypotheses can be put forward.

Firstly, the objective of FRTB with the revised SA is to provide a credible fallback solution for banks that would not be able to authorize the internal methodology. The available QISs, sometimes based on older versions of FRTBs, each indicates a significant increase in capital requirements if SA is applied rather than IMA. On the basis of the regulation's final version, the first hypothesis that this master's thesis will address is:
H1*: The IMA described in the FRTB final version implies lower capital requirements for each risk class than if the choice of SA is made by a bank.*

As mentioned in the literature review, an important aspect of the transition from Basel 2.5 to FRTB involves the switch from stressed Value-at-Risk (sVaR) to Expected Shortfall (ES) as risk measure under IMA. This change would definitely have impacts on capital requirements. The second hypothesis therefore involves comparing two simulations of the FRTB implementation. The first would use ES as prescribed, while the second would assume that the Basel Committee has kept VaR as the baseline measure of market risk. The second assumption is therefore the following:
H2*: The shift from 99% stressed Value-at-Risk to 97.5% Expected Shortfall leads to higher capital requirements for banks under FRTB-IMA.*

The recent financial context due to the COVID-19 pandemic has resulted in a period of stressed markets which could have a similar impact on the level of capital requirements as the Global Financial Crisis. FRTB imposes in its final version to confront the IMA risk models to the stressed market conditions of GFC. The third hypothesis to which this master's thesis will focus is the following:
H3*: The market during the COVID-19 lockdown was more stressed than during the GFC for the instruments analyzed and will therefore become a key period for back-testing.*

Finally, although FRTB will come into force on January 2023, it could be interesting to simulate its effects on the stress period the world has just experienced. In this way, it will be possible to assess the impacts of FRTB on capital requirements in a context other than GFC.
H4*: The change in methodology under FRTB to determine the capital requirements of banks covering their market risk has the same consequences if the stress period analyzed is the COVID-19 pandemic.*

Problematic

From January 2023, banks will therefore be faced with a choice: either to continue with the approach they applied under Basel 2.5 if they meet the criteria prescribed by FRTB, or to switch to another approach. These choices will have consequences in financial, organizational, data management and strategic terms.

This master's thesis focuses on the financial aspect and more particularly on the level of capital requirements implied by the choice between the two main approaches described under FRTB: Internal Model Approach (IMA) and Standardized Approach (SA).

This financial dimension appears to be a determining factor that will guide the choice to be made by the decision-makers. The interest of this master's thesis lies essentially in the lack of relevant impact studies available in the literature to help these decision-makers. At the time of writing, few impact studies based on the FRTB final version have been undertaken by the Basel Committee.

Furthermore, the global economic context has recently been disrupted by the COVID-19 crisis. Markets have experienced instabilities such as those observed during the 2007-2008 Global Financial Crisis. Under IMA, FRTB requires banks to compare the models developed to GFC period if historical data exists. The last few months the world has been going through an unprecedented situation which could have been just as stressful as GFC. This master's thesis takes this opportunity to analyze FRTB through the prism of another crisis to determine its relevance.

The aim of this master's thesis will therefore be to answer the following research question which can be subdivided into four questions:

What impacts will the Fundamental Review of the Trading Book have on banks' capital requirements in a post-COVID-19 context?

- What will be the impacts of FRTB on the capital requirements according to the approach applied (SA or IMA)?
- What will be the impacts on capital requirements of the Expected Shortfall (ES) as the referential market risk measure?
- What will be the impacts of the COVID-19 crisis on the market risk charge's determination?
- What is the relevance of FRTB, and therefore of ES, in a crisis context other than GFC?

Methodology

In order to shed light on these impacts, this practical part will be based on an empirical approach and thus on several hypotheses developed through the literature analysis. A simulation will then be applied to an investment portfolio made up of various international financial instruments representative of the main risk classes described under FRTB. The results and their interpretation will allow to affirm or invalidate the hypotheses made. They will be compared to the results of the Quantitative Impact Studies (QIS) already carried out and which have been analyzed in the literature review. The other results will be discussed with market risk professionals to gather their opinions, will be enriched by other professionals or professors' comments and will be confronted to the literature review. Remaining questions and limitations of this master's thesis will also be addressed, taking into account the assumptions made and the more detailed lines of thought that could be analyzed in the future. In conclusion, this work will analyze the extent to which FRTB meets its objectives and is part of a broader dynamic.

Quantitative approach

To answer the research question and determine whether these hypotheses are true, this master's thesis develops a quantitative approach based on a representative portfolio. The choice of a quantitative approach was motivated by several factors.

Firstly, at the time of starting this work in 2019, national and supranational banking authorities remained skeptical and cautious about the implementation of FRTB. Following the 2015 QIS, it became apparent that the requirements set by the Basel Committee were too strict and forced banks to overcapitalize. Faced with this situation, the European Banking Authority (EBA) had already authorized a progressive implementation of FRTB for European banks by allowing them to capitalize only 65% of the requirements during the first three years (EBA, 2019). In the United States, President Donald Trump summoned the Department of Treasury to analyze the impacts of future banking regulations on the competitiveness of American banks. In 2018, the experts decided to postpone the implementation of FRTBs as long as possible (Wood, 2018). In the United Kingdom, a transition period was also under consideration (Morzaria, 2019). The majority of banks in the world therefore did not know when and how FRTB would be implemented and to what extent. In this context, I decided to opt for a quantitative approach to address my problematic. This choice allowed me to work on context-independent data. It ensures the relevance of this master's thesis since the final version of FRTB published in

February 2019 is the one to be adopted sooner or later. In 2020, the COVID-19 crisis added to this already unclear international context and thus reinforced my choice to work on a quantitative approach.

This quantitative method also makes it possible to use a verifiable and more particularly descriptive path according to Jacquemin (2017). Indeed, this master's thesis will describe a representative example of the impacts that FRTB will have in terms of capital requirements for banks. These objective results can be used by all banks interested in the implementation of FRTB around the world, independently of their competent banking authority.

In summary, this quantitative approach makes this master's thesis relevant whatever the spatial and temporal constraints before the next regulation.

Portfolio Description

This portfolio will be held by a bank reporting its activities in USD. The dollar is the main international currency and the most used in cross-border transactions. Some 90 countries around the world use a currency that is explicitly or implicitly pegged to the dollar (Auboin, 2012). Taking this and market-driven currency co-movements into account, Ito et al. (2015) estimate that the USD zone could account for more than half of global GDP. More specifically, the dollar continues to dominate international financial transactions despite the introduction of the euro. In 2017, the dollar was used in 40% of transactions. The euro has seen its importance grow in international financial transactions, but its use remains largely confined to euro area countries (OECD, 2018).

This portfolio is composed of financial instruments representative of the various asset classes described under FRTB. The only exception concerns securitizations (CTP and non-CTP). This master's thesis will not analyze these categories because they are almost identical to non-securitizations in terms of capital charge’s computations. Moreover, they are only rarely found in the classic portfolios of banks (Sharma & Beckwith, 2018). Only a single question in the last FAQ is related to CTPs and non-CTPs (BCBS, 2017).

This portfolio therefore focuses on the typical risk factors of a trading portfolio (interest rate, equity price, volatility, foreign exchange, credit spread, commodity price). In this way, the analysis will be able to determine effects of the liquidity horizons extension prescribed by FRTB. Indeed, some of these risk factors are characterized by a liquidity horizon of 10 days, as is the case in the current regulation, and others by a liquidity horizon of up to 120 days as prescribed by FRTB. The comparison between the application of FRTB during the GFC and during the COVID-19 crisis will also be relevant in addressing all these risk factors.

In concrete terms, the portfolio of $1 million USD is made up of the following financial instruments:

Asset	Asset Class	Position	Current Value	Weight
Share Westpac (WBK)	Equity	5595	$ 12.51	7%
Share Solvay (SOLB)	Equity	874	€ 71.26 € 1 = $ 1.1233	7%
Call Option Microsoft (MSFT) Strike: $195 - 18/06/2021 Quarterly dividends	Equity	2378	$ 33.64	8%
Cash Position in Costa Rican Colón (CRC)	Foreign Exchange	80 000	$ 1 = 579.78 CRC	8%
Bond Boeing (BA) 8.75% - 15/08/2021	CSR non-securitization	6195	$ 108.14	67%
Crude Oil OK WTI	Commodity	764	$ 39.27	3%

Table 5: Composition of the trading portfolio analyzed as part of this master's thesis

The weight given to each asset class is based on an example of allocation published by the Basel Committee (2005).

The risk measures are determined on the basis of historical data since this is the most widely used method and it encompasses all sources of risk as specified in the literature review. All data are taken from Bloomberg, Investing.com, Optionsedeucation.org and the US Department of Treasury.

The reference date for the portfolio value as well as for all risk measures relevant for SA is 06/30/2020. Concerning IMA, two periods are analyzed. The first one extends over the past year, from 07/01/2019 to 06/30/2020 and covers the shock observed on the markets due to the COVID-19 pandemic. The second period has to be a proven stressed market period according to FRTB. This master's thesis assumes that each instrument observed was the most stressed from 01/01/2008 to 12/31/2008, during the GFC.

The following sections describe each instrument and the rational reasons for their presence in the portfolio. On a more personal note, all of these instruments have a connection with the experiences that the International Business Program has given me the chance to live over the last two years.

Westpac Bank Corporation Share

There are several reasons for choosing to consider Westpac (WBK) in the portfolio. It is an Australian bank listed on the New York Stock Exchange (NYSE), the world's largest stock exchange in terms of market capitalization. With $44.29B of market capitalization, Westpac is a "large cap" company as described in FRTB (market capitalization higher than $2B). Since it is listed on NYSE, this equity asset is classified as an "advanced economy". A bank is obviously part of the "financial" sector.

During the GFC, the global banking sector was particularly affected. U.S. banks have seen their share price fall. This was the case for Westpac, whose share price fell by 58% in 2008 (Bloomberg, 2020). It therefore seems wise to include this company in the portfolio in order to respond to the hypotheses. First of all, it will be possible to analyze the sensitivities linked to equity risk. Secondly, as 2008 was a stressful year, differences between VaR and ES risk measures could be highlighted. Finally, in recent months, the WBK share price has also been strongly disrupted by the COVID-19 crisis (-36%) (Bloomberg, 2020). It will therefore be relevant to compare these two periods of stress.

Solvay SA Share

Solvay is a Belgian flagship of the chemical industry. There are a number of reasons for choosing to include it in this portfolio. Firstly, it is a company classified in a different bucket according to FRTB since its sector of activity is not financial. This master's thesis will therefore cover all the new aggregation formulas described by FRTB and will highlight the differences between these two buckets.

In addition, being listed on the BEL 20, the shares are expressed in euro. This therefore adds an additional risk factor, by integrating the USD/EUR volatility.

Finally, the share price has been highly stressed during the GFC as well as during the COVID-19 pandemic (*Appendix 14*). This will contribute to the reflection on the last three hypotheses.

Microsoft Call Option

Another financial instrument sensitive to equity risk makes up the portfolio. It is a call option on Microsoft shares (MSFT). Considering an option here allows to include a financial instrument sensitive to equity risk but also to implied volatility. The described vega and curvature risks will therefore be calculated.

Under FRTB, Microsoft is also considered as a large cap company ($1.62T), in an advanced economy (USA), in the technology sector which is associated with the financial sector. The equity risk of Westpac and Microsoft are therefore comparable under the new regulation.

Finally, 2008 corresponds to a stressed period in the market as the price fell by 48% (Bloomberg, 2020). During the COVID-19 pandemic, the share price was supported by the development of the Teams tool. It is therefore interesting to observe the effects of this period on equity risk compared to Westpac.

Crude Oil

Through the literature review, it was specified that the price of oil was significantly disrupted during the GFC and the COVID-19 pandemic. It may therefore be interesting to analyze the WTI barrel of crude oil as a commodity.

Moreover, this choice allows to take into account an instrument included in the commodity risk class under FRTB. The weighting rates as well as the specificities linked to this risk category can therefore be analyzed.

Costa Rican Colón

Including a cash position in this portfolio allows to trade an instrument sensitive to FX rate risk. By choosing the Costa Rican Colón, this master's thesis will analyze a currency that is not referenced under FRTB as being specific. The risk weights and liquidity horizons will therefore be different than in the case of euro for SOLB shares. Moreover, this currency was severely disrupted during the two crises analyzed, as shown in *Appendix 14*.

Boeing Bond

Finally, the portfolio is mainly made up of a bond position. This allows to analyze two different risk classes under IMA: GIRR and CSR non-securitization. Indeed, a bond issued by a company is subject to the interest rate as well as the credit spread curves.

During GFC, corporate bond spreads increased significantly before central bank intervention (Dewachter et al., 2018). One can assume that Boeing has not been an exception. On the other hand, the airline sector was particularly affected by the global lockdown. This weakened Boeing's financial health, certainly increasing the company's bond credit spread. Interest rates were also severely disrupted during these crises, with central banks intervening to inject liquidity into the market.

Regarding SA, considering a non-securitization is relevant in order to cover the computation of the new DRC capital charge described under FRTB.

Focus on IMA computations for Boeing bond and Microsoft call option

Both of these instruments require further explanation. Indeed, they ask to simulate historical data since they did not exist during the year 2008.

BA bonds are sensitive to five risk factors: the 1-month US risk-free rate, the 6-month US risk-free rate, the 1-year US risk-free rate, the 2-year risk-free rate and the Boeing credit spread. The US risk-free rates are available on the Federal Reserve Bank of New York website[1]. To determine the credit spread, the following formula was used:

$$Credit\ Spread = Corporate\ Bond\ Yield - Treasury\ Bond\ Yield \qquad (27)$$

The Treasury Bond Yield data comes from the US Department of the Treasury website[2].To estimate Boeing's corporate bond yield in 2008, this paper assumes that it is similar to the corporate bond yield of all US companies with the same credit quality in 2008 (A+). These data were found on the website of the Federal Reserve Bank of Saint-Louis[3].

[1] www.newyorkfed.org
[2] www.treasury.gov
[3] www.fred.stlouisfed.org

For each of risk factors, it is necessary to simulate approximately 250 scenarios (average number of trading days). Based on these results, a historical daily value of the current bond in 2008 can be determined. It is then possible to determine a 10-D P&L distribution and calculate the 10-D Expected Shortfall by taking the average of the largest losses at a level of 97.5%. *Appendix 15* presents the Excel spreadsheets that made these calculations possible.

Regarding the MSFT call options, these are sensitive to two risk factors: the value of the MSFT stock and the implied volatility of the option for the same day. To determine the ES under FRTB, it is necessary to know the 10-day P&L distribution. The challenge is therefore to simulate the historical values of today's option in 2008, corresponding by assumption to the most stressed year.

For this purpose, it is useful to apply a Black-Sholes model as follows:

$$C = S_t N(d_1) - K\, e^{-rt} N(d_2) \tag{27}$$

Where:

- $d_1 = \frac{\ln\frac{S_t}{K} + \left(r + \frac{\sigma_v^2}{2}\right) t}{\sigma_s \sqrt{t}}$;
- $d_2 = d1 - \sigma_s \sqrt{t}$;
- C is the option price;
- S is the current stock (or other underlying) price;
- K is the strike price;
- r is the risk-free interest rate;
- σ is the volatility of the asset's return;
- t is the time to maturity;
- N is the a normal distribution.

As part of this analysis to determine C in 2008:

- S is the current MSFT stock price multiplied by the daily historical price variance;
- K is set at $195 USD;
- r is set by assumption at the risk-free interest rate of 06/30/2020;
- σ is set at the 2008 implied volatility (30.01%);
- t is the time to maturity of the current contract.

This scenario must be repeated for all trading days in 2008. It was done by running a VBA macro. It is then possible to calculate the 10-D Expected Shortfall as described above. *Appendix 16* presents the VBA code that made these calculations possible.

Analysis

Hypothesis 1

***H1**: The IMA described in the FRTB final version implies lower capital requirements for each risk class than if the choice of SA is made by a bank.*

In order to answer the first hypothesis, it is necessary to simulate the application of SA and IMA described under FRTB to the portfolio. This section describes the results obtained for these two approaches.

Standardized Approach

As specified in the literature review, the SA capital charge is made up of three main elements: Sensitivities-based Method charge (SbM), Default Risk Capital charge (DRC) and Residual Risk Add-On charge (RRAO). For the purposes of this analysis, we assume that the RRAOs are equal to 0.

Sensitivities-based Method Charge

To determine this component, the delta risk charge must be calculated for each risk factor to which the financial instruments are sensitive. In addition, for those meeting the criteria defined in the theory, the vega and curvature risk charges must also be determined. This table is a summary of these precepts as applied to the portfolio's instruments.

<table>
<tr><th>Asset</th><th>Risk Factor</th><th>Delta Risk</th><th>Vega Risk</th><th>Curvature Risk</th><th>Risk Class</th></tr>
<tr><td rowspan="2">Bond BA
8.75% - 15/08/2021</td><td>Interest Rate</td><td>✓</td><td>-</td><td>-</td><td>GIRR</td></tr>
<tr><td>Credit Spread</td><td>✓</td><td>-</td><td>-</td><td>CSR</td></tr>
<tr><td>Share WBK</td><td>Equity Price</td><td>✓</td><td>-</td><td>-</td><td rowspan="4">Equity</td></tr>
<tr><td rowspan="2">Call Option MSFT
$195 - 18/06/2021</td><td>Equity Price</td><td rowspan="2">✓</td><td rowspan="2">✓</td><td rowspan="2">✓</td></tr>
<tr><td>Implied Volatility</td></tr>
<tr><td rowspan="2">Share SOLB</td><td>Equity Price</td><td>✓</td><td>-</td><td>-</td></tr>
<tr><td>FX Rate</td><td>✓</td><td>-</td><td>-</td><td rowspan="2">FX</td></tr>
<tr><td>Cash Position CRC</td><td>FX Rate</td><td>✓</td><td>-</td><td>-</td></tr>
<tr><td>Crude Oil OK WTI</td><td>Commodity Price</td><td>✓</td><td>-</td><td>-</td><td>Commodity</td></tr>
</table>

Table 6: Summary of SbM theoretical principles applied to the portfolio's instrument

The following pages will retrace the seven steps described in the section "Set the frame - SA" to determine the SbM charge.

1. Delta risk charge

   1.1. GIRR

As specified in the final version of FRTB, where market data permits, a financial instrument sensitive to interest rate and credit spread should require the calculation of two capital charges: one from the GIRR class and the other from the CSR non-securitization class (BCBS, 2019). The capital requirements from this position in bonds therefore result from two separate calculations. The first one concerns interest rate sensitivity and involves the following delta charge according to formula (2):

Asset	Risk Class	Delta Charge
Bond BA **8.75% - 08/15/2021**	GIRR	$ 714,587.06

Table 7: Delta risk charge under SA for the instrument subject to the GIRR

The delta charge is here the sum of the delta charge calculated for the tenor 0.25Y, 0.5Y and 1Y.

   1.2. Credit spread risk: Non-securitization

The second calculation concerns the capital charge related to the CSR sensitivity. In order to find Boeing's credit spread at 30/06/2020, the same Goal Seek function was used as described in the methodology (*Appendix 14*). The amount of the delta charge is, according to formula (3):

Asset	Risk Class	Delta Charge
Bond BA **8.75% - 08/15/2021**	CSR	$ 714,587.06

Table 8: Delta risk charge under SA for the instrument subject to the CSR

1.3. Equity risk

On the basis of formula (4), the delta charge linked to the holding of WBK and SOLB shares and MSFT call options is as follows:

Asset	Risk Class	Delta Charge
Share WBK	EQUITY	$ 69,993.45
Share SOLB		$ 69,993.45
Call Option MSFT		$ 95,120.00

Table 9: Delta risk charge under SA for instruments subject to the equity risk

1.4. Commodity risk

Formula (5) is used to determine the delta capital charge for commodity price sensitive instruments. This is the case for crude oil in the portfolio, the results of which are as follows:

Asset	Risk Class	Delta Charge
Crude Oil OK WTI	COMMODITY	$ 30,002.28

Table 10: Delta risk charge under SA for the instrument subject to the commodity risk

1.5. FX risk

Finally, in the portfolio analyzed, two instruments are sensitive to FX Risk. These are the cash position in Costa Rican Colón and SOLB shares, denominated in Euro. Thanks to formula (6), the results are:

Asset	Risk Class	Delta Charge
Share SOLB	FX	$ 69,955.34
Cash Position CRC		$ 80,000,00

Table 11: Delta risk charge under SA for instruments subject to the FX risk

2. Vega risk charge

The only instrument concerned by the vega risk charge is the MSFT call option. It is indeed sensitive to an additional risk factor: implied volatility. To determine this amount, formula (7) indicates that a shock (equal to that applied in the case of delta, i.e. 1% in this case) must be applied to the price of the underlying. Changes in the option price must be observed. This result must then be multiplied by the implied volatility which was 31% on 06/30/2020.

This simulation was possible thanks to an online pricer[4]. Thanks to this tool, the vega risk charge for the MSFT call option is:

Asset	Risk Class	Vega Charge
Call Option MSFT	EQUITY	$ 2948,72

Table 12: Vega risk charge under SA for the MSFT call option subject to implied volatility changes

3. Risk weighting for delta and vega risks

The third step is to weigh the gross delta and vega risk charges found previously according to the levels specified by FRTB (*see Appendices 4 & 6*). Here is a summary of the risk weights to be applied for the instruments in this portfolio.

Asset	Risk Class	Delta Risk Weight			Vega Risk Weight
Bond BA	GIRR	*Tenor 0.25Y*	*Tenor 0.5Y*	*Tenor 1Y*	-
		1.20%	1.20%	1.13%	
	CSR	3%			-
Call Option MSFT	EQUITY	50%			77.78%
Share WBK		50%			-
Share SOLB		40%			-
	FX	11%			-
Cash Position CRC		15%			-
Crude Oil OK WTI	COMMODITY	35%			-

Table 13: Summary of delta and vega weights to be applied to portfolio instruments

The delta and vega risk weighted charges are therefore as follows (formula (8)).

Asset	Risk Class	Delta Risk Weighted	Vega Risk Weighted
Bond BA	GIRR	$ 14,291.74	-
			-
	CSR	$ 21,437.61	-
Call Option MSFT	EQUITY	$ 47,560.00	$ 2293.57
Share WBK		$ 34,996.73	-
Share SOLB		$ 27,982.14	-
	FX	$ 7,419,88	-
Cash Position CRC		$ 12,000.00	-
Crude Oil OK WTI	COMMODITY	$ 10,500.80	-

Table 14: Instruments' weighted delta and vega risk charges

[4] www.optionseducation.org

4. Aggregation within buckets

The two instruments concerned by this step are the WBK share and the MSFT call option since FRTB classifies them both in bucket 8, i.e. "large cap" companies listed on an "advanced" market and active in the financial or technological sectors (see *Appendix 3*). Applying formula (9) with the correlation rate described in *Appendix 5*, a cumulative and weighted delta charge (K_b) of $ 41,278.36 is computed for bucket 8.

5. Aggregation across buckets

With regard to aggregation across buckets within the same risk class, all instruments sensitive to equity risk and FX risk are included in this analysis. The results are obtained using formula (10).

Risk Class	Delta risk charge across bucket
Equity Risk	$ 70,446.85
FX Risk	$ 27.426,62

Table 15: Delta charge aggregated at risk class-level for Equity and FX risk classes

6. Curvature risk charge

For the MSFT call option, it is necessary to determine a curvature risk charge as specified in the "Setting the frame" section. Positive and negative shocks are applied to the underlying price (50% in this case). The curvature risk charge in this case is $ 47,466.61 by applying formulas (11), (12), (13) and (14).

7. Final aggregation

Before adding up each result, the final version of FRTB describes three correlation scenarios as specified in theory (formulas (16) and (17)). In this case, correlation parameters were used previously for Equity and FX classes. The modified correlation parameters are as follows.

Scenario	Equity delta capital charge		FX delta capital charge
	ρ	γ	γ
High Correlations	31.25%	18.75%	75%
Medium Correlations	25%	15%	60%
Low Correlations	18.75%	11.25%	45%

Table 16: Modified correlation parameters (ρ and γ) according to the SA-stressed scenario described under FRTB

The impact on capital requirements is as follows. Only scenarios leading to the highest level of capital requirements are kept.

Scenario	Equity delta capital charge	FX delta capital charge
High Correlations	$ 71,666.01	$ 28,371.69
Medium Correlations	$ 70,446.85	$ 27.426.62
Low Correlations	$ 69,206.21	$ 26,353.92

Table 17: Delta capital charge under three SA-stressed scenarios as described by FRTB

In summary, here are all the values to be aggregated and the total of the SbM capital charge.

Risk Class	Delta Risk Charge	Vega Risk Charge	Curvature Risk Charge	TOTAL
GIRR	$ 14,291.74	-	-	**$ 14,291.74**
CSR	$ 21,437.61	-	-	**$ 21,437.61**
Equity	$ 71,666.01	$ 2,293.57	$ 47,466.61	**$ 121,426.19**
FX	$ 28,371.69	-	-	**$ 28,371.69**
Commodity	$ 10,500.80	-		**$ 10,500.80**
TOTAL	**$ 146,267.85**	**$ 2,293.57**	**$ 47,466.61**	**$ 196,028.03**

Table 18: SbM capital charge of the portfolio and its components

The following table presents each risk class' charges in relation to their portfolio positions.

Risk Class	Capital requirements	Portfolio position	Percentage compared to portfolio position
GIRR	$ 14,291.74	$ 670,000.00	**2.14%**
CSR	$ 21,437.61	$ 670,000.00	**3.20%**
Equity	$ 121,426.19	$ 220,000.00	**55.19%**
FX	$ 28,371.69	$ 150,000.00	**18.91%**
Commodity	$ 10,500.80	$ 30,000.00	**35.00%**
TOTAL	**$ 196,028.03**	**$ 1,000,000.00**	**19.60%**

Table 19: SbM capital charge's components compare to their portfolio positions

Table 20 shows the proportion of each component of the SbM and its weight in relation to the total SbM charge and the portfolio value at 06/30/2020.

Risk Charge	Capital Charge	Percentage on SbM capital requirements	Percentage on portfolio value
Delta	$ 146,267.85	74.62 %	**14.63%**
Vega	$ 2,293.57	1.17%	**0.23%**
Curvature	$ 47,466.61	24.21%	**4.75%**
SbM Capital Charge	**$ 196,028.03**	**100 %**	**19.60%**

Table 20: Proportion of each SbM's component and its weight in relation to the total SbM charge and the portfolio value at 06/30/2020

Default Risk Capital Charge

The only instrument subject to the calculation of a DRC charge is the BA bond because it is a non-securitization according to FRTB. The following page will retrace the three steps described in the section "Set the frame - SA" to determine the DRC charge.

1. Gross JTD risk position

According to the definition specified in the literature, the bank has a long position on the BA bond. Formula (18) therefore finds the gross JTD risk position. LGD is equal to 75% according to the regulation. The gross JTD risk position equals $ 515,052.30.

2. Net JTD risk position

Since there is only this long position, no hedge benefit ratio needs to be calculated. The net JTD value is therefore equal to the gross value.

3. DRC charge

Boeing's credit quality according to Fitch has recently been downgraded to BBB (Kilgore, 2020). As a result, its weighting level is 6% (*see Appendix 8*). Using formula (21), the DRC bond charge equals $ 30,903.14.

Capital charge under SA

The table below summarizes all the results found as well as the weight of each charge in relation to the total capital requirement and to the value of the portfolio as of 06/30/2020.

	Capital requirements	Percentage on SA capital requirements	Percentage on portfolio value
SbM	$ 196,028.03	86.38%	19.60%
DRC	$ 30,903.14	13.62%	3.09%
SA Capital Requirements	**$ 226,931.17**	**100 %**	**22.69%**

Table 21: Detail of the SA-charge required to cover the market risk of the portfolio

Internal Model Approach

This section presents the results of applying the FRTB-IMA to the same portfolio. As specified in the literature review, the IMA capital charge is made up of three main elements: Internal Modellable Risk Factors (IMCC) charge, Default Risk Capital charge (DRC) and Non-Modellable Risk Factors (NMRF) charge. For the purposes of this analysis, all risk factors were assumed to be modellable. Therefore, the NMRFs are equal to 0.

Internal Modellable Risk Factors Charge

As a reminder, the most stressful 12-month period for the portfolio must be chosen as the reference period for the calculation of the ES. This paper assumes that it is the year 2008 for each instrument in the portfolio. In most of the cases, historical values are available on Investing.com. In case historical values were not available, they were simulated using a Black-Sholes model or a Goal Seek function as explained in the methodology. The following pages will retrace the steps described in the section "Set the frame - IMA" to determine the IMA charge.

As specified in the literature review, ES has to be computed over a 10-day base horizon at a one-tailed 97.5% confidence level. FRTB allows to use overlapping observations to build the time series of changes in risk factors.

The first step was to consider the daily value of the portfolio taking into account changes in all risk factors. From this, it was possible to determine the 10-day P&L distribution to calculate the ES. The values should be ranked from the largest loss to the largest positive change. Since

ES must be calculated at a confidence interval of 97.5%, only the 6 most stressful observations will be considered. Indeed, the tail risk of the P&L distribution corresponds to 2.5% of the 250 values on average observed in 2008 (average number of trading days per year).

FRTB, with formula (22), prescribes a liquidity adjustment. Four risk factors in this portfolio have a liquidity horizon different from 10 days in this portfolio (*see Appendix 17*). It is therefore necessary to compute two more ES by fixing positions with risk factors determined at 10 days and then at 20 days.

The table below shows the results of the ES taking into account the liquidity adjustment.

	Capital Requirements	**Percentage on portfolio value**
10-day ES 97.5%	$ 42,344.91	4.23%
10-day liquidity-adjusted ES 97.5%	$ 67,691.68	6.77%

Table 22: Results of the different ES based on the portfolio

Due to the restrictive structure of this portfolio, it has been assumed that the full set of risk factors coincides with a reduced set. Therefore, this does not imply any change with respect to formula (23).

In order to calculate the IMCC, FRTB prescribes formula (24). The unconstrained and constrained ES must be averaged. The latter does not consider any diversification effect and is therefore the simple sum of the ES in each risk class. The previous steps are therefore repeated for each broad risk class as defined by FRTB (GIRR, CSR, Equity, Commodity, FX,).

	Capital Requirements	**Value**
$\textbf{IMCC}_{\textbf{unconstrained}}$	$ 67,691.68	6.77%
$\textbf{IMCC}_{\textbf{constrained}}$	$ 92,554.39	9.26%
IMCC	**$ 80,123.04**	**8.01%**

Table 23: IMCC amount and its decomposition between constrained and unconstrained IMCCs

The following table shows the decomposition of the constrained IMCC by risk class.

Risk Class	Capital requirements	Percentage compared to portfolio position
GIRR	$ 10,999.26	1.64%
CSR	$ 20,238.16	3.02%
Equity	$ 42,902.44	19.50%
Commodity	$ 8,189.00	27.30%
FX	$ 10,225.53	6.82%
$IMCC_{constrained}$	$ 92,554.39	9.26%

Table 24: Constrained IMCC's components compared to their portfolio position

Default Risk Capital Charge

This paper assumes that DRC under IMA are identical to those under SA. It results in an overestimation of the IMA-DRC.

Capital charge under IMA

The table below summarizes all the results found as well as the weight of each charge in relation to the total capital requirement and to the original value of the portfolio.

	Capital requirements	Percentage on IMA capital requirements	Percentage on portfolio value
IMCC	$ 80,123.04	72.17%	8.01%
DRC	$ 30,903.14	27.83%	3.09%
IMA Capital Requirements	**$ 111,026.18**	**100 %**	**11.10%**

Table 25: Detail of the IMA-charge required to cover the portfolio's market risk

Comparison of capital requirements under FRTB-SA and FRTB-IMA

In order to answer hypothesis 1, it is necessary to compare the capital requirements according to the approach applied.

Approach	Capital requirements	Percentage on portfolio value	SA/IMA ratio
SA	$ 226,931.17	22.69 %	2.04
IMA	$ 111,026.18	11.10%	

Table 26: Comparison of SA and IMA capital requirements under FRTB

The following table presents the same results with the DRC capital charge, neglecting the DRC capital charge in order to make the ratio even more relevant given the assumption used to calculate the DRC capital charge.

Component	Capital requirements	Percentage on portfolio value	SA/IMA ratio
SbM	$ 196,028.03	19.60%	2.45
IMCC	$ 80,123.04	8.01%	

Table 27: Comparison of SbM and IMCC capital requirements under FRTB

The following table compares the capital requirements under SA and IMA by risk class, neglecting DRC. Under SA, the portfolio chosen did not allow the consideration of hedging positions that could have reduced the total SA-capital requirements. No diversification effect was taken into account and therefore the following table will compare the ES constrained with the SA.

Risk Class	SbM capital requirements	IMCC capital requirements	SbM/IMCC ratio
GIRR	$ 14,291.74	$ 10,999.26	1.3
CSR	$ 21,437.61	$ 20,238.16	1.06
Equity	$ 121,426.19	$ 42,902.44	2.83
Commodity	$ 10,500.80	$ 8,189.00	1.28
FX	$ 28,371.69	$ 10,225.53	2.77

Table 28: Comparison of SbM and IMCC capital requirements under FRTB by risk class

Hypothesis 2

***H2**: The shift from 99% stressed Value-at-Risk to 97.5% Expected Shortfall leads to higher capital requirements for banks under FRTB-IMA.*

In other words, what would have been the impact on capital requirements if regulators had prescribed the use of 99% VaR rather than the 97.5% ES for FRTB? To reach a conclusion, it is necessary to compare ES and VaR by varying their parameters. As specified in the literature review, these risk measures are defined according to the confidence interval and the holding period.

The first comparison sets the methodology for the holding period at that prescribed by FRTB. The second comparison focuses on the second parameter and highlights the differences between ES as prescribed under FRTB and the daily VaR scaled at 10 days under Basel 2.5.

Capital requirements according to 10-day ES 97.5%

As a reminder, the ES is based on the average of the losses located in its tail distribution fixed at 2.5% under FRTB. The new regulation introduces the notion of overlapping time periods for the calculation of ES when historical simulation is used. ES is therefore calculated directly from the 10-day P&L distribution. *Table 29* presents the capital requirements for the portfolio.

Risk Class	Associated capital charge	Percentage compared to portfolio position
Diversified	$ 67,700.00	6.77%
GIRR	$ 10,999.26	1.64%
CSR	$ 20,238.16	3.02%
Equity	$ 42,902.44	19.50%
Commodity	$ 8,189.00	27.30%
FX	$ 10,225.53	6.82%
IMCC	**$ 80,121.82**	**8.01%**

Table 29: IMCC and its components determined according to the liquidity-adjusted 10-day ES 97.5%

Capital requirements according to 10-day VaR 99%

VaR is similar to a threshold above which all tail observations are found. The current regulation requires a VaR calculated at a 99% confidence interval. For one year (250 trading days on average), the VaR is therefore the third biggest loss (2.5 tail observations per year). By calculating the 99% VaR from the 10-day P&L according to the FRTB methodology, the results obtained are as follows.

Risk Class	Associated capital charge	Percentage compared to portfolio position
Diversified	$ 64,500.00	6.45%
GIRR	$ 10,184.41	1.52%
CSR	$ 19,564.49	2.92%
Equity	$ 40,714.00	18.51%
Commodity	$ 7,785.71	25.95%
FX	$ 9,593.01	6.40%
IMCC	**$ 76,170.81**	**7.40%**

Table 30: IMCCs determined according to liquidity-adjusted 10-day VaR 99%

Comparison of capital requirements according to 10-day ES 97.5% and 10-day VaR 99%

The following table presents the ratios between IMCC according to the risk measure used.

Risk Class	Associated capital charge (L-A 10-day ES 97.5%)	Associated capital charge (L-A 10-day VaR 99%)	$\frac{IMCC_{ES}}{IMCC_{VaR}}$
Diversified	$ 67,700.00	$ 64,500.00	1.05
GIRR	$ 10,999.26	$ 10,184.41	1.08
CSR	$ 20,238.16	$ 19,564.49	1.03
Equity	$ 42,902.44	$ 40,714.00	1.05
Commodity	$ 8,189.00	$ 7,785.71	1.05
FX	$ 10,225.53	$ 9,593.01	1.07
IMCC	**$ 80,121.82**	**$ 76,170.81**	**1.05**

Table 31: Comparison of IMCC based on liquidity-adjusted 10-day ES 97.5% and VaR 99%

Capital requirements according to daily VaR 99% scaled

As specified in the literature, Basel 2.5 allowed the deduction of VaR at a horizon of 10 days from the daily VaR. To move from one value to another, banks could multiply the daily value by the square root of 10. The table presents the capital requirements in the event that FRTB would have allowed this methodology to be used to calculate ES and IMCC.

Risk Class	Associated capital charge	Percentage compared to portfolio position
Diversified	$ 68,700.00	6.87%
GIRR	$ 15,511.67	2.64%
CSR	$ 28,073.78	4.19%
Equity	$ 61,310.91	27.87%
Commodity	$ 9,936.50	33.12%
FX	$ 8,696.92	5.80%
IMCC	**$ 97,203.51**	**7.40%**

Table 32: IMCC and its components determined according to the liquidity-adjusted daily VaR 99% scaled to 10-day holding period

Comparison of capital requirements according to 10-day ES 97.5% and daily VaR 99% scaled

The following table presents the ratios between IMCC according to the risk measure used.

Risk Class	Associated capital charge (L-A 10-day ES 97.5%)	Associated capital charge (Daily VaR 99% scaled)	$\frac{IMCC_{ES}}{IMCC_{VaR}}$
Diversified	$ 67,700.00	$ 68,700.00	0.99
GIRR	$ 10,999.26	$ 15,511.67	0.62
CSR	$ 20,238.16	$ 21,611.01	0.72
Equity	$ 42,902.44	$ 61,310.91	0.70
Commodity	$ 8,189.00	$ 9,936.50	0.82
FX	$ 10,225.53	$ 13,889.68	1.18
IMCC	**$ 80,121.82**	**$ 97,203.51**	**0.82**

Table 33: Comparison of capital requirements from 10-day ES 97.5% and daily VaR 99% scaled

Hypothesis 3

***H3**: The market period during the COVID-19 crisis was more stressed than during GFC and could be used as the 12-month referential period for the computation of market risk charge under FRTB-IMA.*

In order to determine whether the period of financial stress the world has just experienced has been as stressful as the GFC period, it is necessary to determine the levels of capital required under FRTB for the past year, from 07/01/2019 to 06/30/2020. This section presents these results and compares them to the results based on the year 2008. For the sake of consistency, the same assumptions are respected.

Capital requirements under FRTB based on 2019/2020 data

Following the same steps and assumptions as above, here are the results of the ES calculations for each instrument when data from 07/01/2019 to 06/30/2020 are taken into account.

Risk Class	Associated capital charge	Percentage compared to portfolio position
Diversified	$ 179,300.00	17.93%
GIRR	$ 12,595.88	1.88%
CSR	$ 52,461.82	7.83%
Equity	$ 87,948.71	39.98%
Commodity	$ 30,365.77	101.22%
FX	$ 8,580.51	5.72%
IMCC	**$ 185,626.35**	**18.56%**

Table 34: IMCC charge and its components based on 2019/2020 data

Comparison of the two periods

Stress Period	Capital Charge	Percentage on portfolio value	$\frac{IMCC_{COVID-19}}{IMCC_{GFC}}$
$IMCC_{COVID-19}$	$ 185,626.35	18.56%	2.32
$IMCC_{GFC}$	$ 80,121.82	8.01%	

Table 35: Comparison of IMCC from GFC and COVID-19 periods

The following table compares the IMCC requirements during COVID-19 and GFC stress periods by risk class.

Risk Class	$IMCC_{COVID-19}$	$IMCC_{GFC}$	$\frac{IMCC_{COVID-19}}{IMCC_{GFC}}$
Diversified	$ 179,300.00	$ 67,700.00	2.65
GIRR	$ 12,595.88	$ 10,999.26	1.15
CSR	$ 52,461.82	$ 20,238.16	2.59
Equity	$ 87,948.71	$ 42,902.44	2.05
Commodity	$ 30,365.77	$ 8,189.00	3.71
FX	$ 8,580.51	$ 10,225.53	0.84

Table 36: Comparison of IMCC's components during GFC and COVID-19 periods by risk class

Hypothesis 4

H4*: The change in methodology under FRTB to determine the capital requirements of banks covering their market risk has the same consequences if the stress period analyzed is the COVID-19 pandemic.*

The purpose of this hypothesis is to determine whether the simulation of FRTB at the time of the COVID-19 pandemic can lead to the same conclusions as hypothesis 2, where the stress period analyzed was the GFC period. To do so, the same analysis structure was applied to the data for the period from 07/01/2019 to 06/30/2020.

Capital requirements according to 10-day VaR 99%

The following table presents the capital charges for each IMCC's component according to the liquidity-adjusted 10-day VaR 99%.

Risk Class	Associated capital charge	Percentage compared to portfolio position
Diversified	$ 184,500.00	18.45%
GIRR	$ 11,925.43	1.78%
CSR	$ 29,278.98	4.37%
Equity	$ 85,992.01	39.09%
Commodity	$ 18,644.86	62.15%
FX	$ 5,730.78	3.82%
IMCC	**$ 168,036.03**	**16.80%**

Table 37: IMCC and its components determined according to liquidity-adjusted 10-day VaR 99%

Comparison of capital requirements according to 10-day ES 97.5% and 10-day VaR 99%

The following table presents the ratios between IMCC according to the risk measure used.

Risk Class	Associated capital charge (L-A 10-day ES 97.5%)	Associated capital charge (L-A 10-day VaR 99%)	$\frac{IMCC_{ES}}{IMCC_{VaR}}$
Diversified	$ 179,300.00	$ 184,500.00	0.97
GIRR	$ 12,595.88	$ 11,925.43	1.06
CSR	$ 52,461.82	$ 29,278.98	1.78
Equity	$ 87,948.71	$ 85,992.01	1.02
Commodity	$ 30,365.77	$ 18,644.86	1.63
FX	$ 8,580.51	$ 5,730.78	1.49
IMCC	**$ 185,626.35**	**$ 168,036.03**	**1.10**

Table 38: Comparison of IMCC based on liquidity-adjusted 10-day ES 97.5% and VaR 99%

Capital requirements according to daily VaR 99% scaled

The following table presents the capital charges for each IMCC's component according to daily VaR 99% scaled to 10 days by the square root rule.

Risk Class	Associated capital charge	Percentage compared to portfolio position
Diversified	$ 310,420.00	31.42%
GIRR	$ 10,876.88	1.09%
CSR	$ 36,314.98	5.42%
Equity	$ 195,808.80	89.00%
Commodity	$ 23,267.42	77.56%
FX	$ 7,331.20	4.89%
IMCC	**$ 292,009.60**	**29.20%**

Table 39: IMCC and its components determined according to the daily VaR 99% scaled to 10-day holding period

Comparison of capital requirements according to 10-day ES 97.5% and daily VaR 99% scaled

The following table presents the ratios between IMCC according to the risk measure used.

Risk Class	Associated capital charge (L-A 10-day ES 97.5%)	Associated capital charge (L-A daily VaR 99%)	$\frac{IMCC_{ES}}{IMCC_{VaR}}$
Diversified	$ 179,300.00	$ 310,420.00	0.58
GIRR	$ 10,876.88	$ 11,522.96	0.94
CSR	$ 52,461.82	$ 36,314.98	1.45
Equity	$ 87,948.71	$ 195,808.80	0.45
Commodity	$ 30,365.77	$ 23,267.42	1.31
FX	$ 8,580.51	$ 7,331.20	1.17
IMCC	**$ 185,626.35**	**$ 292,009.60**	**0.64**

Table 40: Comparison of capital requirements from 10-day ES 97.5% and daily VaR 99% scaled

Comparison between IMCC based on COVID-19 period and SA-SbM capital requirements

Finally, *Table 41* compares the SA-SbM from hypothesis 1 and the $IMCC_{COVID-19}$ capital requirements.

Risk Class	SbM capital requirements	$IMCC_{COVID-19}$ capital requirements	SbM/IMCC ratio
GIRR	$ 14,291.74	$ 12,595.88	1.13
CSR	$ 21,437.61	$ 52,461.82	0.41
Equity	$ 121,426.19	$ 87,948.71	1.38
Commodity	$ 10,500.80	$ 30,365.77	0.35
FX	$ 28,371.69	$ 8,580.51	3.31
TOTAL	**$ 196,028.03**	**$ 185,626.35**	**1.06**

Table 41: Comparison of SbM and $IMCC_{COVID-19}$ capital requirements

Discussion

Hypothesis 1

***H1**: The IMA described in the FRTB final version implies lower capital requirements for each risk class than if the choice of SA is made by a bank.*

The results do show that SA requires more capital than IMA to cover the market risk of this portfolio. Indeed, as *Table 26* shows, the SA as described under FRTB would require the bank to capitalize 2.04 times more than if the IMA were applied.

This conclusion is also valid when the DRCs are neglected. Given that these charges were determined according to the SA methodology, it is more relevant to analyze the SbM and IMCC charges as in *Table 27*. In this case, the hypothesis is met again with a SA/IMA charge ratio of 2.45.

These results are consistent with the latest QIS conducted by the Basel Committee. They are also relevant compared to the other initiatives launched by, for example, the ISDA, GFMA and IIF as specified in the literature review, or the research carried out by Hortin (2016), Orgeldinger (2018) as well as Pederzoli and Torricelli (2019). Indeed, all these studies highlight more substantial capital requirements under SA than under IMA, with the ratio varying between 2 and 3. The first hypothesis is even fully verified since each risk class requires more capital under SA than under IMA.

Under SA, the level of capital requirements reflects the intrinsic risk of each instrument. The instruments that make up the equity risk class are highly volatile, with maximum losses on equities averaging up to 50%. In the case of commodities, they can lose up to 75% of their value (Lombard Odier, 2015). Regulators have obviously taken into account these instruments' inherent volatilities to determine the risk weights and correlation parameters. It therefore seems appropriate that *Table 19* shows higher levels of capital requirements for these two risk classes in relation to their portfolio position.

Table 20 highlights the allocation of the three SA risk charges. The curvature risk charge arises solely from the call option position and yet appears to be a very significant component. It reflects the Basel Committee's objective that SA captures the gamma risk and hedge banks against the high volatility of derivatives. Banks are therefore punished if they hold risky positions as in this example. The call option position represents only 8% of the portfolio value while 24.21% of SbM's capital requirements come from the curvature risk charge.

This new obligation for banks to calculate a curvature risk charge when they hold optional products represents significant financial stakes, given the place of derivatives in trading portfolios. This is one of the reasons that prompted the Basel Committee to reopen consultation with banks and other stakeholders in March 2018, but the basic functional form remains unchanged. As a result, curvature risk charges can always be really sensitive to changes in portfolio composition (Rokob, 2019).

The only result of this analysis that appears questionable concerns the BA bond position. Bonds issued and guaranteed by private companies are also volatile financial instruments, their value potentially losing up to 60% annually (Lombard Odier, 2015). However, the proportion of SbM capital charge linked to GIRR and CSR risk classes only represents 5.34% of the total amount while the bond position represents 67% of the total portfolio value. This demonstrates the importance of the DRC charge, which reinforces the capital provisions for this position (*Table 21*). FRTB could have required the calculation of curvature risk charges for holding bond position, as there is a non-linear relationship of bond prices and yields (P. Franks, survey response, August 4, 2020).

These theoretical volatility levels, on which SA is based, is confirmed by the application of the IMA method. Indeed, based on 2008 market data, it shows a similar distribution of capital requirements between each risk class. The most significant amounts to be provisioned are those related to equity and commodity risk classes (*Table 24*).

SA remains however more conservative than IMA and requires more capital for positions that are effectively riskier. Overall, SA may therefore appear to be a consistent fallback solution for banks that do not meet the eligibility criteria for applying IMA. However, this conclusion must be nuanced. Thanks to *Table 28*, we can see that the ratio varies between each risk class.

SA requires much higher capital provisions for the FX risk class than IMA. This observation was also made in the last Basel Committee's QIS (ratio of 2.2). This can be explained by the lack of granularity offered by FRTB. Indeed, as specified in the literature, the FX delta charges are all weighted at 15%, and around 11% for the specified currency pairs. While exchange rates, even for specified currencies, can be extremely stressful, such as the Russian ruble falling by more than 50% against the US dollar in 2014, it was not the case for the EUR/USD rate in 2008 .

Extreme volatilities are generally more observed for emerging currencies. Although the Costa Rican colón (CRC) is one of them, its case is quite particular. From 2006 to 2015, the National Bank of Costa Rica has set up a crawling peg system of the colón against the US dollar. The colón could therefore only fluctuate very little in relation to the US dollar, which explains the small variations observed (-4.55%) during GFC. Furthermore, Costa Rica was running fiscal and balance of payments surpluses at that time, which made it a very safe place for money to be. There was therefore a massive flow of capital out of the developed world to places like Costa Rica (A. Trejos, email, August 9, 2020). 2008 was therefore a stressful time for CRC if we go back to the GFC as prescribed by the FRTB but it has not been like other emerging currencies. Risk weightings would therefore be more effective if done on a currency-by-currency (J. Clarke, survey response, August 6, 2020).

The SbM/IMCC ratio of the equity risk class is 2.83 for the instruments analyzed in this paper, which reflects the conservatism of SA regarding volatile products. This ratio, although lower, is similar to that predicted by the Basel Committee's QIS. This difference can be explained by the portfolio composition which presents only an optional instrument. As specified in the literature review, options and other derivatives have been an important part of banks' trading strategy since the 1990s. Given the observed influence of the curvature risk charge in the total amount of capital requirements, it seems logical that the last QIS, the largest and most representative impact study to date, will involve even more capital requirements under SA for this risk class.

Regarding the commodity risk class, the hypothesis is again true since the crude oil barrel position requires 1.28 times more capital according to SA than according to IMA. This ratio is lower than the one reported in the 2018 QIS (1.6) for two main reasons. On the one hand, oil is one of the most tradable commodities on the market, along with precious metals such as gold and silver. The delta risk weight suggested by FRTB is therefore relatively low (35%) compared to other commodities. On the other hand, the majority of the financial instruments that banks generally hold and that are classified in the commodity risk class are derivatives: options and other contracts whose underlying instrument is a commodity (Lombard Odier, 2015). For these instruments, the calculation of vega and curvature risk is mandatory, which may explain the higher ratio reported in the 2018 QIS. The vega and curvature risk charges could have been mandatory for any type of commodity position. These underlying assets are highly volatile and could have justified additional and systematic stress exposure under SA.

Finally, the GIRR and CSR risk classes show results that are completely in line with those observed in the QIS. SA leads to conservative capital requirements for the GIRR risk class while the differences are less pronounced for the CSR risk class. The QIS results were also presented by neglecting the DRC charges.

The observations concerning the CSR risk class therefore highlight a first weakness of SA. In the event of a more stressful period than GFC, the SA capital requirements would be more advantageous than those determined according to IMA, which might not allow banks to cover their market risk. As mentioned above, requiring the calculation of a curvature risk charge for corporate bonds would make sense.

In conclusion, the results of this analysis are consistent with those observed in the latest Basel Committee QIS as described in the literature review. The objective of the Basel Committee to offer a credible fallback solution to banks with a standardized method is therefore fulfilled. However, a few weaknesses have been highlighted and comparing these results under another period of stress will allow to confirm them.

Hypothesis 2

***H2**: The shift from 99% stressed Value-at-Risk to 97.5% Expected Shortfall leads to higher capital requirements for banks under FRTB-IMA.*

This hypothesis needs to be analyzed and interpreted at several levels. The first comparison (*Table 31*) highlights the capital amounts in the case where FRTB required to calculate them from a 99% VaR based on the 10-day profit and loss (P&L) distribution. It indicates that in each case, the capital requirements based on the 10-day ES 97.5% are higher. These results clearly demonstrate the conservatism of ES, which succeeds each time in better capturing the tail risks of the 10-day P&L distribution. The hypothesis is therefore verified at this stage.

The following graph shows, as an example, the sorted 10-day P&L distribution of the diversified portfolio and the amounts to be capitalized by the bank. The amounts are obviously positive, but their inverse is represented for the sake of clarity in relation to the largest loss observed.

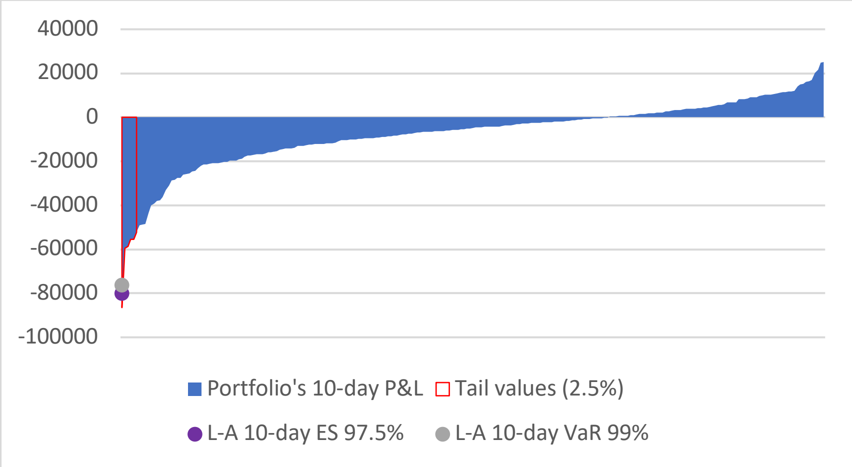

Figure 7: Portfolio's sorted 10-day P&L distribution with the related capital requirements according to ES and VaR

Table 33 then compares these ES results with the methodology currently in place, i.e. daily VaR 99% scaled over a 10-day horizon by the square root rule. With a ratio of 0.82, the conclusion is unequivocal: the current method requires more capital provisions than that prescribed by FRTB. The comparison for each risk class should be observed in order to draw nuanced conclusions.

Firstly, the scaled VaR method requires the provisioning of much more capital when the daily VaR 99% value is high. Applying the square root rule was a general rule and encompassed all situations, regardless of the 10-day tail values or the instrument's liquidity. The amounts of capital to be provisioned were therefore not always consistent with the risk actually incurred. In this analysis, it is the case for GIRR and equity risk classes for which the daily VaR 99% value is high and for which the liquidity risk is considered low by FRTB. The bank is therefore currently required to capitalize a significant amount that is not justified.

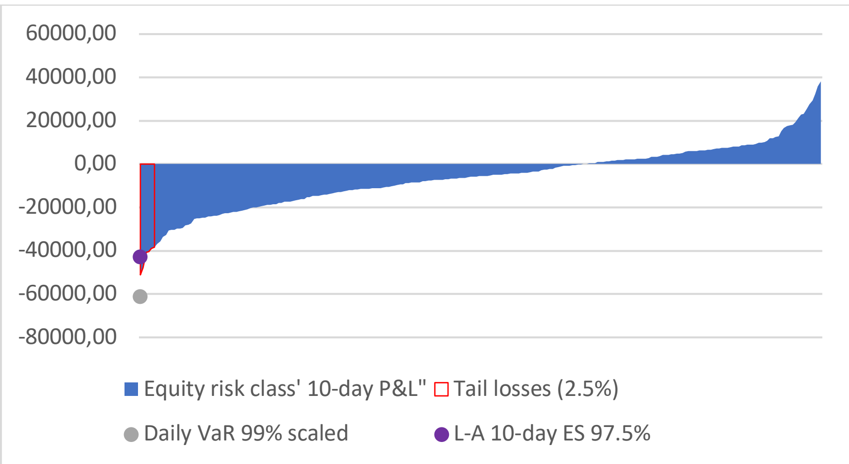

Figure 8: Example of the equity' sorted 10-day P&L distribution with the related capital requirements according to ES and VaR

When the more illiquid risk factors are concerned, the conclusions are less categorical. Although the scaled VaR method still requires more capital, the ratio is closer to 1 for the CSR and commodity risk classes. Their 10-day tail values are homogeneous and close to those observed on a daily basis. The reduction in the differences observed is therefore due to the liquidity-adjustment prescribed by FRTB. It is not harshly perceived, as these instruments are still considered liquid within their risk class. The credit spread risk factor linked to the bond BA is 40 days, whereas those linked to this risk class can extend from 20 to 120 days. Crude oil is considered as "Energy" and therefore corresponds to the most liquid commodities with a 20-day liquidity horizon, whereas they can extend up to 120 days. The observed ratios are therefore closer to 1 while remaining lower.

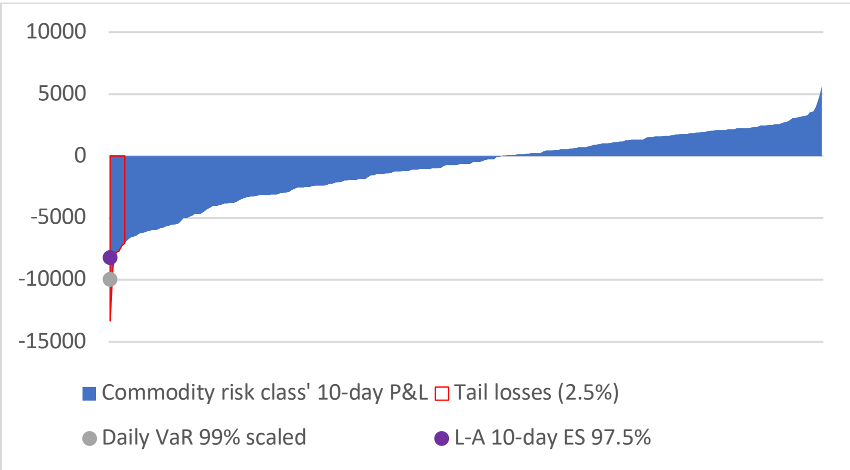

Figure 9: Example of the commodity' sorted 10-day distribution with the related capital requirements according to ES and VaR

The case of the FX risk class is particular since daily volatilities are really low. On the contrary, over a 10-day horizon, losses can be substantial as shown in the graph below. The daily VaR 99% value, even when scaled to 10 days, therefore does not reach the ES level. It is reinforced by the liquidity-adjustment of the ES over a 20-day liquidity horizon because of the CRC position.

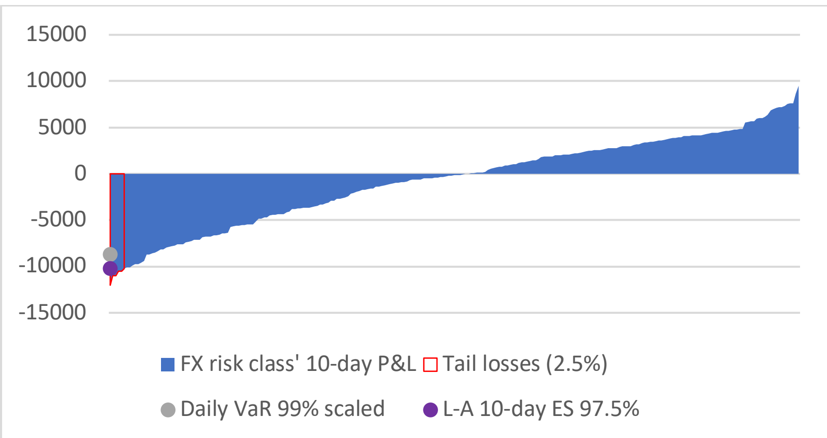

Figure 10: FX' sorted 10-day P&L distribution with the related capital requirements according to ES and VaR

Finally, when the diversified ES is considered, the conclusions drawn above are synthesized. Its 10-day P&L distribution has high tail values unlike the daily distribution, leading to a high ES compared to the daily VaR 99% value. However, the majority of the portfolio's instruments are liquid according to FRTB. It is therefore logical that the observed ratio is very close to 1 (0.99).

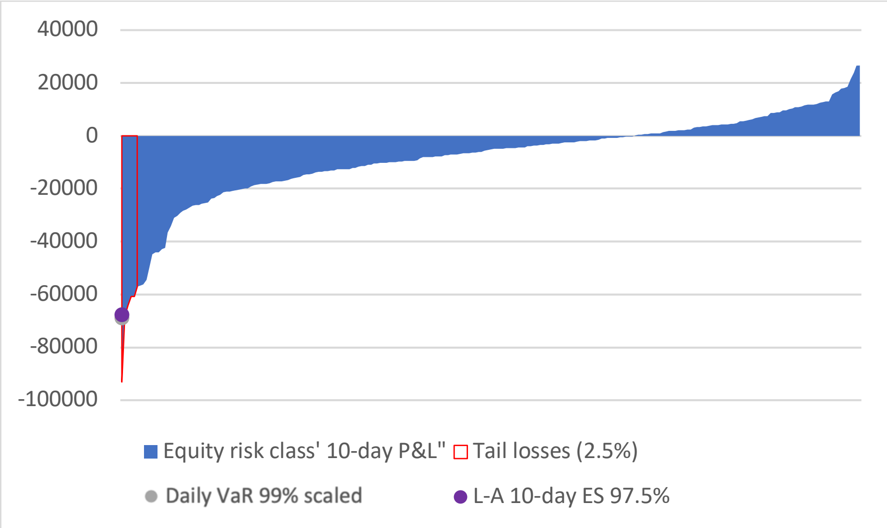

Figure 11: Diversified portfolio' sorted 10-day P&L distribution with related capital requirements according to ES and VaR

To summarize, in relation to the current methodology, this analyze shows that under FRTB:

- Liquid positions with low 10-day tail risks require lower capital requirements;
- Illiquid positions with a low tail risk require higher capital requirements in this case but still lower than the current methodology;
- Illiquid positions with a high tail risk compared to the daily P&L distribution require higher capital requirements;
- Liquid positions with high tail risks compared to the daily P&L distribution require similar capital requirements.

In conclusion, the answer to this hypothesis is nuanced. By prescribing ES as the baseline measure for market risk as well as a liquidity adjustment, FRTB punishes banks that hold excessively risky and illiquid positions by demanding higher levels of provisions (P. Franks, survey response, August 4, 2020). When tail or liquidity risks are not high, FRTB will require similar or lower levels than at present. This was one of the objectives of the Basel Committee which, on the basis of this analysis, seems to have been met. This analysis proves that FRTB does not simply aim at requiring banks to make a higher level of capital provision, but rather at enabling them to better spread their provisions in order to cope with the real market risk. The level of capital requirements takes into account diversity and is better adapted to the liquidity as well as tail risks incurred by the bank under FRTB, which was not the case under the current methodology as the level of capital requirements was disproportionate or too low.

Hypothesis 3

***H3**: The market during the COVID-19 lockdown was more stressed than during the GFC. This period could therefore be used as the 12-month referential period for the computation of market risk charge under FRTB-IMA.*

As *Table 35* shows, the period from 07/01/2019 to 06/30/2020 was generally more stressful for the instruments analyzed in this portfolio. As in the discussion of hypothesis 2, these results should be analyzed at the risk class level in order to be more precise in our conclusions.

As specified in the literature review, equity markets were significantly stressed during the global lockdown. Due to its exogenous cause to the banking system as specified in the literature, COVID-19 struck quickly and has already been nicknamed the "Great Compression" (Harvey, 2020). According to Professor Mikaël Petitjean (2020), this is the fastest stock market correction of more than 20% since the beginning of the last century. This is verified for companies linked to instruments in this risk class.

On April 24, 2000, the value of Microsoft shares fell by 15.6% due to the internet bubble crisis. The share dropped 14.74% on March 16, 2020, compared to a maximum of 7.96% during 2008. The same day in 2020 was synonymous with a 16.24% loss in the WBK share price, whereas the largest negative variation recorded in 2008 was 15.25%. For Solvay, its share price dropped by 14.93% on March 12, 2020, compared to a maximum daily loss of 8.71% in 2008. 10-day losses were also greater during the COVID-19 period than during GFC.

Regarding the GIRR risk class, U.S. interest rates also experienced record stress levels. To face the economic cataclysm that threatened the US, the FED implemented an aggressive strategy by buying back a historic number of bonds on March 13, 2020 for $37 billion. *"…At this rate, the New York FED will have bought more bonds and offered more money to borrowers in one month than it did during the whole GFC"* (Potter, para. 1). In this way, the central bank has injected new reserves into the banking system. As a result, bank liquidity has increased but the federal funds rate fell. They are currently hovering between 0 and 0.25% compared to 1.6% before the lockdown. This is a carbon copy of the strategy applied during the GFC by the USA according to Roger Montgomery (2020).

The second factor to which the BA bond price is sensitive is the credit spread linked to the Boeing company. The rating agencies have recently decided to lower the aircraft manufacturer's credit quality rating to BBB. Air traffic was paralyzed during the global lockdown causing 96% drop in air travel within US. This obviously had disastrous consequences for Boeing, which announced a loss of $2.4bn as well as a 25% drop in revenue to $11.8bn for the second quarter (Rao, 2020). 6,770 staff were laid off and 5,520 left voluntarily the company in May (The Guardian, 2020). The credit spread has therefore risen sharply while the company had weathered GFC rather well. At that time, Fitch saw in Boeing a company that could take over GFC. The U.S. company had an A+ credit rating prior to GFC, which was maintained on April 30, 2020 and June 3, 2010 (Fitch, 2020). This time, beyond the magnitude of the crisis, it is the future of global aviation that is at stake.

In conclusion, the two factors influencing the BA bond price were under severe stress during COVID-19. However, they have opposite effects. On the one hand, the fall in interest rates positively influences the price while the increase in the credit spread reduces the price. Therefore, similar strategies during GFC and COVID-19 to lower interest rates did not stress the bank's BA bond position. The amounts to be capitalized from these risk factors are small and similar (ratio of 1.15). On the other hand, the downgrade of the credit rating to BBB caused an explosion in credit spreads leading to a fall in the bond BA price. It was not on this scale in 2008. The ratio of 2.59 for this risk class therefore appears to be consistent.

It should be noted that, in the context of a trading portfolio analysis, the bank's objective was not to hold the bond to maturity but to speculate on the price of the bond. The yield, which is inversely linked to the price of the bond, was therefore not taken into account in this reflection.

Unsurprisingly, crude oil experienced a more stressful period during the COVID-19 crisis than it did during GFC. Negative barrel prices led to huge losses, constituting significant tails risks. Taking the average of these, the ES has therefore exploded (101.22%).

The FX risk class is the only exception that appears to be more stressed during GFC than during COVID-19. This can be explained by the euro which lost much more value in 2008 against the US dollar than during the COVID-19 period. This difference can be explained by the speed with which this time, unlike in 2008, the European Central Bank (ECB) reacted to the crisis compared to the FED. Brender et al. (2009) demonstrate that the global risk aversion triggered by the collapse of Lehman Brothers has disrupted the EUR/USD price in 2008.

This event suddenly increased investors' risk aversion. It pushed high interest rate currencies down against low interest rate currencies. This was the case for the euro against the U.S. dollar, as the FED had injected liquidity into its economy by buying back bonds long before the ECB.

Regarding the CRC position, although the BCBR has opted for a floating strategy of CRC's exchange rate against the US dollar since 2015, the CRC/USD exchange rate was less stressed. Costa Rica was hit hard by the COVID-19 crisis, as its economy was mainly based on tourism. Initial estimates show a drop of 1 billion in revenue and the loss of 150,000 jobs (Dieryck, 2019). The government, which is one of few economic agents that mostly spends CRC, received much more foreign financing than usual, and then put it back on the market in order to stabilize the economy as well as the currency. Very small variations have so far been observed, but this situation may change at any time (A. Trejos, email, August 9, 2020). It seems consistent, therefore, that the stress associated with GFC was more consequential than that associated with the global lockdown and therefore that the capital requirements under FRTB in 2008 were higher.

To sum up, the recent period has been more stressful for all the instruments analyzed in this paper, with the exception of the FX risk class. This year could therefore be considered as a reference year for testing risk models in the future for these instruments. This discussion also highlighted one of the properties that makes ES a consistent measure of risk. Indeed, as specified in the literature review, monotonicity implies that a more stressed portfolio leads to more capital requirements than a less stressed portfolio. Therefore, it is logical that this portfolio during the COVID-19 period leads to higher capital requirements than during the GFC.

Hypothesis 4

H4*: The change in methodology under FRTB to determine the capital requirements of banks covering their market risk has the same consequences if the stress period analyzed is the COVID-19 pandemic.*

Since hypothesis 3 is verified for the majority of the instruments in the portfolio under analysis, hypothesis 4 makes even more sense. The conclusions of hypothesis 1 and 2 will be confronted with an even more stressful situation and the FRTB' contributions will be put forward even more.

When the 99% VaR is calculated from the 10-day P&L distribution, the same conclusions are drawn, since once again ES proves its conservatism and its ability to better capture tail risks (*Table 38*). The only exception is when the diversified portfolio is concerned. This result is not consistent according to Artzner et al. (1999) as specified in the literature review. Indeed, *Table 37* shows higher capital requirements for the diversified portfolio than for the portfolio taking into account the sum of the ES of each major risk class. This lack of subadditivity of VaR as discussed in the literature review is therefore clearly highlighted in this example. The comparison between the capital requirements of the two periods is therefore not relevant when considering the diversified portfolio.

Regarding the comparison with the scaled VaR (*Table 40*), more risk classes require higher provisions of capital according to FRTB. CSR and commodity risk classes, which require a more severe liquidity adjustment (40 and 20 days respectively), lead to higher capital provisions under the methodology prescribed by FRTB. As determined in the previous hypothesis, since the COVID-19 period is more stressful for the BA bond and the crude oil positions, their tail risks and therefore their ES are greater. Once again, capital requirements based on the daily scaled VaR appear to be irrelevant, not reflecting or by chance the real level of market risk.

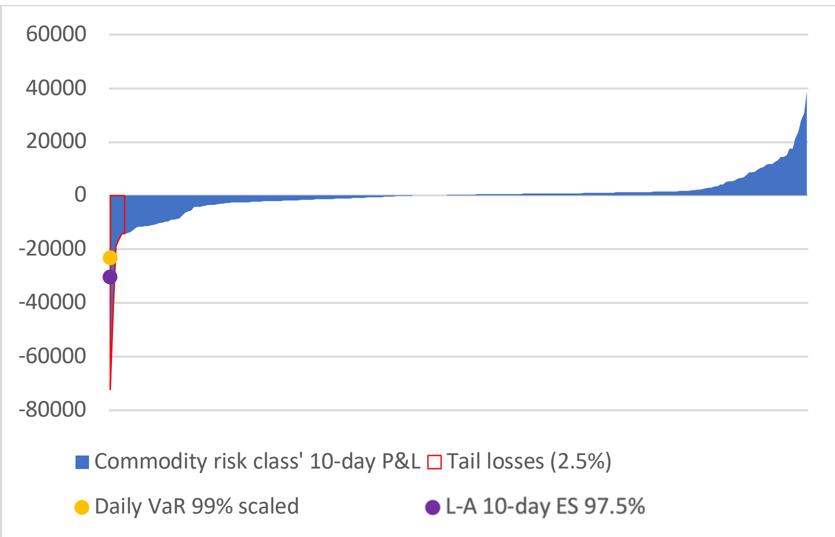

Figure 12: Example of the commodity risk class' sorted 10-day P&L distribution based on the COVID-19 period with related capital requirements according to ES and VaR

The conclusions for the equity risk class are similar to those drawn previously. The COVID-19 period was synonymous with very high market speculation, leading to high daily volatilities. But when we look at the 10-day results, the variations wear off. The daily VaR 99% value is therefore closer to the ES value, which makes the scaled VaR explode.

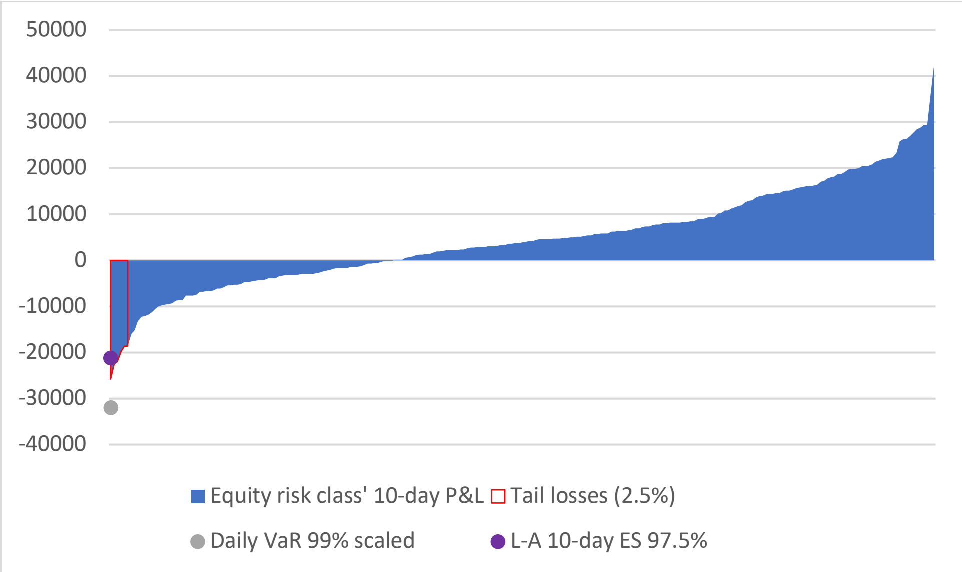

Figure 13: Example of the equity risk class' sorted 10-day P&L distribution based on the COVID-19 period with related capital requirements according to ES and VaR

By performing the same analysis over a more stressful period than GFC, the benefits of FRTB are brought into sharper focus. The COVID-19 period reinforced the tail risk for the less liquid instruments analyzed and the conclusions are clear. The new regulation will require banks to provide more capital for less liquid instruments when their tail risk is high. Banks will capitalize in a much more accurate manner in relation to the reality of market risk, avoiding situations such as those observed under the equity risk class, where currently a bank was paying the price for high daily volatilities without this translating into greater market risk over a 10-day horizon.

The last point of analysis, which completes the loop, concerns the results found under SA compared to those found under IMA over the period of COVID-19. *Table 41* corroborates the weaknesses that had been identified in the discussion of hypothesis 1. During a more stressful period, SA was unable to provide a credible fallback solution for the commodity and CSR risk classes. The risk weights did not capture huge shifts in unstable market. In order to achieve the FRTB's objective of stabilizing the banking system, the Basel Committee could impose the application of IMA to top tier banks (P. Franks, survey response, August 4, 2020).

Remaining questions and limitations

First of all, the composition of this portfolio makes it irrelevant to generalize the conclusions of each hypothesis. This portfolio does not highlight all the weaknesses of SA. Other positions could lead to lower capital requirements under SA than under IMA. Regarding the second hypothesis, the results are limited since this portfolio is mainly made up of instruments with risk factors deemed liquid by FRTB. Finally, the COVID-19 period appears to be stressed for the majority of these instruments, but others may not have been stressed.

Beyond the intrinsic composition of the portfolio, several analysis criteria chosen scrupulously for this master's thesis lead to results that are sometimes caricatural or conservative. Integrating RRAO and NMRF charges would have an impact on the results of hypothesis 1. Furthermore, DRCs for both approaches calculated according to SA lead to more conservative levels than if the IMA methodology had been followed. The assumption for the second hypothesis that 2008 was the most stressed year for each instrument is strong. For example, the disruption to MSFT's share price in 2013 was greater than in 2008. All periods of stress experienced by the instruments concerned should therefore be considered in order to really judge the intensity of the COVID-19 crisis.

Finally, this paper is limited to a study of the FRTB's impacts on the capital requirements issue. As specified by Hortin (2016), the strategic choice of banks will not only be made on the capital requirements question. Other issues will be critical, such as data management, IT or organizational issues. IMA involves heavy calculations, as this portfolio, although simplified, already shows. Banks already possess this data but given the complexity of certain internal processes, they could prove difficult to obtain it quickly. Systems that feed directly into the regulatory capital calculation tool but also other upstream systems such as risk management systems may need to be modified. Finally, IMA, as specified in the literature review, will require organizational transformations given the qualitative criteria prescribed by FRTB. All these changes could have a significant cost or simply could not be in place by January 2023. This master's thesis therefore does not answer this question of which approach to choose but offers elements that will potentially help decision-makers in their reflection.

Conclusion

On January 1, 2023, banks must be ready to implement this far-reaching new regulation. FRTB, as its name suggests, will have fundamental consequences on the required capital levels that banks will have to provide, but also in other areas such as data management and organization. This revolution was expected and necessary, since the weaknesses of the current system had been highlighted during the Global Financial Crisis.

After this event, the last few years have been marked by a wave of regulations that continues to arrive (DAC 6, Beps, etc.). According to Patrick Wagenaar, ex-head of private banking at Degroof Petercam Luxembourg, all these regulations pursue two major objectives: to protect the investor and to offer greater transparency for the financial authorities of different countries (as cited in Renauld, 2020).

The objectives of FRTB are similar. This master's thesis addressed several questions about FRTB in the turbulent context of another major crisis that will forever mark contemporary societies. The results of this paper show that establishing consistent and reliable regulations takes time. FRTB-IMA could have the means to stabilize the banking sector as it considers liquidity at a more granular level and penalize banks that take too risky positions. The move to ES as the measure of market risk is a step forward that will allow banks to capitalize in a consistent manner, as tail risks will be taken into account. The analysis based on the COVID-19 period tested FRTB in an inherently different stress environment for these instruments and demonstrated the robustness of IMA. However, the choice of SA will not necessarily lead to higher levels of capital than IMA and thus to amounts adapted to stress peaks. The Basel Committee's objective of providing banks with a credible fallback solution if they fail to implement the IMA is therefore not achieved with certainty. This approach will not yet fully stabilize the banking sector and reassure the investor.

Finally, like other regulations, the introduction of FRTB will further exacerbate a labor market reality: the essential need for banks to recruit risk management professionals. Faced with an increasingly heavy regulatory burden, banks will have to strengthen their middle-office teams. The risk professions, like compliance or audit, are becoming increasingly important sources of competitive advantage for banks. FRTB is therefore part of an economic, strategic, financial and human upheaval for banks that is already underway.

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Appendices

Appendix 1: New concepts introduced, and old concepts redefined in FRTB regulation

New concepts	Old concepts redefined
Regulatory trading desk (RTD)	Trading book
Operating sub-desks (OSD)	Trading instruments
Internal risk transfer desk	Trading purpose
Liquidity horizons (LHs)	Mandatory banking book
Non-modellable risk factors (NMRF)	Mandatory trading book
P&L attribution (PLA)	Granular regulation and SA application
Equity jump-to-default (EJTD)	Commodity risks in the banking book (CRBB)
Instrument illiquidity	FX risk in the banking book (FXRBB)
Actionable and observable prices	Interest rate risk in the banking book (IRRBB)

Appendix 2: Hurdles and costs of movements across the boundary

<table>
<tr><th>Hurdles</th><th>Costs</th></tr>
<tr><td>Regulatory pre-approval</td><td>No capital relief allowed</td></tr>
<tr><td>Regulatory arbitrage strictly prohibited</td><td rowspan="3">Pillar 1 capital surcharge for any benefit:
• Supervisor-agreed roll-off; and
• No market revaluation</td></tr>
<tr><td>Internal bank approvals documented:
• From senior management;
• In compliance with policies; and
Publicly disclosed</td></tr>
<tr><td>Decision is irrevocable</td></tr>
<tr><td colspan="2">Related bank policies requirements:
• Minimum annual update that incorporates extraordinary events over previous 12 months;
• Changes highlighted and distributed to appropriate supervisors;
• Clear articulation of re-designation restrictions and description of potentially appropriate extraordinary circumstances;
• Clear articulation of process for obtaining senior management and regulatory approval;
• Public disclosure at earliest reporting date.</td></tr>
</table>

Appendix 3: Buckets of each asset class

GIRR

Each currency is a separate GIRR bucket.

CSR non-securitization

Bucket number	Credit quality	Sector
1	Investment Grade (IG)	Sovereigns including central banks, multilateral development banks
2		Local government, government-backed non-financials, education, public administration
3		Financials including government-backed financials
4		Basic materials, energy, industrials, agriculture, manufacturing, mining and quarrying
5		Consumer goods and services, transportation and storage, administrative and support service activities
6		Technology, telecommunications
7		Health care, utilities, professional and technical activities
8		Covered bonds
9	High yield (HY) & non-rated (NR)	Sovereigns including central banks, multilateral development banks
10		Local government, government-backed non-financials, education, public administration
11		Financials including government-backed financials
12		Basic materials, energy, industrials, agriculture, manufacturing, mining and quarrying
13		Consumer goods and services, transportation and storage, administrative and support service activities
14		Technology, telecommunications
15		Health care, utilities, professional and technical activities
16	Other sector	
17	IG indices	
18	HY indices	

Equity

Bucket number	**Market cap**	**Economy**	**Sector**
1	Large	Emerging market economy	Consumer goods and services, transportation and storage, administrative and support service activities, healthcare, utilities
2			Telecommunications, industrials
3			Basic materials, energy, agriculture, manufacturing, mining and quarrying
4			Financials including government-backed financials, real estate activities, technology
5		Advanced economy	Consumer goods and services, transportation and storage, administrative and support service activities, healthcare, utilities
6			Telecommunications, industrials
7			Basic materials, energy, agriculture, manufacturing, mining and quarrying
8			Financials including government-backed financials, real estate activities, technology
9	Small	Emerging market economy	All sectors described under bucket numbers 1, 2, 3 and 4
10		Advanced economy	All sectors described under bucket numbers 5, 6, 7 and 8
11	Other sector		
12	Large market cap, advanced economy equity indices (non-sector specific)		
13	Other equity indices (non-sector specific)		

Commodity

Bucket number	Commodity bucket	Examples of commodities allocated to each commodity bucket (non-exhaustive)
1	Energy – solid combustibles	Coal, charcoal, wood pellets, uranium…
2	Energy – liquid combustibles	Light-sweet crude oil, heavy crude oil, WTI…
3	Energy – electricity and carbon trading	Spot electricity, day-ahead electricity, peak electricity, renewable energy certificates…
4	Freight	Capesize, Panamax, Suezmax…
5	Metals – non-precious	Aluminum, copper, lead, nickel…
6	Gaseous combustibles	Natural gas, liquified natural gas
7	Precious metals (including gold)	Gold, silver, platinum, palladium…
8	Grains and oilseed	Com, wheat, soybean seed, soybean oil, rice…
9	Livestock and dairy	Live cattle, feeder cattle, cheese…
10	Softs and other agriculturals	Cocoa, arabica coffee, cotton, lumber, pulp…
11	Other commodity	Potash, fertilizer, rare earths, flat glass, phosphate rocks…

FX

An FX risk bucket is set for each exchange rate between the currency in which an instrument is denominated and the reporting currency.

Appendix 4: Delta risk weights

GIRR

Tenor	0.25 year	0.5 year	1 year	2 year	3 year	5 year	10 year	15 year	20 year	30 year
Risk weight	1.7%	1.7%	1.6%	1.3%	1.2%	1.1%	1.1%	1.1%	1.1%	1.1%

CSR non-securitization

Bucket number	Risk weight
1	0.5%
2	1.0%
3	5.0%
4	3.0%
5	3.0%
6	2.0%
7	1.5%
8	2.5%
9	2.0%
10	4.0%
11	12.0%
12	7.0%
13	8.5%
14	5.5%
15	5.0%
16	12.0%
17	1.5%
18	5.0%

Equity

Bucket number	Risk weight
1	55%
2	60%
3	45%
4	55%
5	30%
6	35%
7	40%
8	50%
9	70%
10	50%
11	70%
12	15%
13	25%

Commodity

Bucket number	Risk weight
1	30%
2	35%
3	60%
4	80%
5	40%
6	45%
7	20%
8	35%
9	25%
10	35%
11	50%

FX

A unique relative risk weight equal to 15% applies to all the FX sensitivities. However, for the specified currency pairs by the Basel Committee and for currency pairs forming first-order crosses across the specified currency pairs, the above risk weight may at the discretion of the bank be divided by the square root of 2. (USD/EUR, USD/JPY, USD/GBP, USD/AUD, USD/CAD, USD/CHF, USD/MXN, USD/CNY, USD/NZD, USD/RUB, USD/HKD, USD/SGD, USD/TRY, USD/KRW, USD/SEK, USD/ZAR, USD/INR, USD/NOK, USD/BRL)

Appendix 5: Delta correlations

GIRR

Within bucket

	0.25 year	**0.5 year**	**1 year**	**2 year**	**3 year**	**5 year**	**10 year**	**15 year**	**20 year**	**30 year**
0.25 year	100%	97%	91.4%	81.1%	71.99%	56.6%	40%	40%	40%	40%
0.5 year	97%	100%	97%	91.4%	86.1%	76.3%	65.7%	41.9%	40%	40%
1 year	91.4%	97%	100%	97%	94.2%	88.7%	76.3%	65.7%	56.6%	41.9%
2 year	81.1%	91.4%	97%	100%	98.5%	95.6%	88.7%	82.3%	76.3%	65.7%
3 year	71.9%	86.1%	94.2%	98.5%	100%	98%	93.2%	88.7%	84.4%	76.3%
5 year	56.6%	76.3%	88.7%	95.6%	98%	100%	97%	94.2%	91.4%	86.1%
10 year	40%	56.6%	76.3%	88.7%	93.2%	97%	100%	98.5%	97%	94.2%
15 year	40%	41.9%	65.7%	82.3%	88.7%	94.2%	98.5%	100%	99%	97%
20 year	40%	40%	56.6%	76.3%	84.4%	91.4%	97%	99%	100%	98.5%
30 year	40%	40%	41.9%	65.7%	76.3%	86.1%	94.2%	97%	98.5%	100%

Between two weighted sensitivities within the same bucket with different tenor and different curves, the correlation is equal to the correlation parameter described above multiplied by 99.9%.

Between two weighted sensitivities within the same bucket with same tenor and different curves, the correlation is set at 99.9%.

Between a weighted sensitivity to the inflation curve and a weighted sensitivity to a given tenor of the relevant yield curve, the correlation is set at 40%.

Between a weighted sensitivity to a cross-currency basis curve and a weighted sensitivity to each of the following curves is 0%:

- a given tenor of the relevant yield curve;
- the inflation curve;
- another cross-currency basis curve.

Across buckets

For aggregating GIRR risk positions across different buckets (ie different currencies), the parameter is set at 50%.

CSR non-securitization

Within bucket

For buckets 1 to 15, for aggregating delta CSR non-securitizations risk positions within a bucket, the correlation parameter between two weighted sensitivities within the same bucket, is set as follows:

$$\rho_{kl} = \rho_{kl}^{(name)} \cdot \rho_{kl}^{(tenor)} \cdot \rho_{kl}^{(basis)}$$

Where:

- $\rho_{kl}^{(name)}$ is equal to 1 where the two names of sensitivities k and l are identical, and 35% otherwise;
- $\rho_{kl}^{(tenor)}$ is equal to 1 if the two tenors of the sensitivities k and l are identical, and to 65% otherwise;
- $\rho_{kl}^{(basis)}$ is equal to 1 if the two sensitivities are related to same curves, and 99.90% otherwise.

For buckets 17 and 18, for aggregating delta CSR non-securitisations risk positions within a bucket, the correlation parameter between two weighted sensitivities within the same bucket is set as follows:

$$\rho_{kl} = \rho_{kl}^{(name)} \cdot \rho_{kl}^{(tenor)} \cdot \rho_{kl}^{(basis)}$$

Where:

- $\rho_{kl}^{(name)}$ is equal to 1 where the two names of sensitivities k and l are identical, and 80% otherwise;
- $\rho_{kl}^{(tenor)}$ is equal to 1 if the two tenors of the sensitivities k and l are identical, and to 65% otherwise;
- $\rho_{kl}^{(basis)}$ is equal to 1 if the two sensitivities are related to same curves, and 99.90% otherwise.

Across buckets

For aggregating delta CSR non-securitisation risk positions across buckets 1 to 16, the correlation parameter is set as follows:

$$\gamma_{bc} = \gamma_{bc}^{(rating)} \cdot \gamma_{bc}^{(sector)}$$

Where:

- $\gamma_{bc}^{(rating)}$ is equal to 50% where the two buckets b and c are both in buckets 1 to 15 and have a different rating category (either IG or HY/NR), and 1 otherwise;
- $\gamma_{bc}^{(sector)}$ is equal to 1 if the two buckets belong to the same sector, and to the specified numbers in following table otherwise.

Bucket	1/9	2/10	3/11	4/12	5/13	6/14	7/15	8	16	17	18
1/9		75%	10%	20%	25%	20%	15%	10%	0%	45%	45%
2/10			5%	15%	20%	15%	10%	10%	0%	45%	45%
3/11				5%	15%	20%	5%	20%	0%	45%	45%
4/12					20%	25%	5%	5%	0%	45%	45%
5/13						25%	5%	15%	0%	45%	45%
6/14							5%	20%	0%	45%	45%
7/15								5%	0%	45%	45%
8									0%	45%	45%
16										0%	0%
17											75%
18											

Equity

Within bucket

For aggregating delta equity risk positions within a bucket, the correlation parameter between two sensitivities to equity price within the same bucket is set at:

- 15% between two sensitivities within the same bucket that fall under large market cap, emerging market economy (1, 2, 3, 4)
- 25% between two sensitivities within the same bucket that fall under large market cap, advanced economy (5, 6, 7, 8)
- 7.5% between two sensitivities within the same bucket that fall under small market cap, emerging market economy (9)
- 12.5% between two sensitivities within the same bucket that fall under small market cap, advanced economy (10)
- 80% between two sensitivities within the same bucket that fall under either index bucket (12, 13)

Across buckets

For aggregating delta equity risk positions across buckets 1 to 13, the correlation parameter is set at:

- 15% if bucket b and bucket c fall within bucket numbers 1 to 10;
- 0% if either of bucket b and bucket c is bucket 11;
- 75% if bucket b and bucket c are bucket numbers 12 and 13;
- 45% otherwise.

Commodity

Within bucket

For the purpose of aggregating commodity risk positions within a bucket using a correlation parameter, the correlation parameter between two sensitivities within the same bucket, is set as follows:

$$\rho_{kl} = \rho_{kl}^{(cty)} \cdot \rho_{kl}^{(tenor)} \cdot \rho_{kl}^{(basis)}$$

Where:

- $\rho_{kl}^{(cty)}$ is equal to 1 where the two commodities of sensitivities k and l are identical, and to the intra-bucket correlations otherwise;
- $\rho_{kl}^{(tenor)}$ is equal to 1 if the two tenors of the sensitivities k and l are identical, and to 99% otherwise;
- $\rho_{kl}^{(basis)}$ is equal to 1 if the two sensitivities are identical in the delivery location of a commodity, and 99.90% otherwise.

Bucket number	Commodity bucket	Correlation $\rho_{kl}^{(cty)}$
1	Energy – solid combustibles	55%
2	Energy – liquid combustibles	95%
3	Energy – electricity and carbon trading	40%
4	Freight	80%
5	Metals – non-precious	60%
6	Gaseous combustibles	65%
7	Precious metals (including gold)	55%
8	Grains and oilseed	45%
9	Livestock and dairy	15%
10	Softs and other agriculturals	40%
11	Other commodity	15%

Across buckets

For aggregating delta commodity risk positions across buckets, the correlation parameter is set at:

- 20% if bucket b and bucket c fall within bucket numbers 1 to 10;
- 0% if either bucket b or bucket c is bucket number 11.

FX

Across buckets

For aggregating delta FX risk positions across buckets, the correlation parameter is uniformly set to 60%.

Appendix 6: Vega risk weights and correlations

Risk class	$LH_{risk\ class}$	**Risk weights**
GIRR	60	100%
CSR non-securitizations	120	100%
Equity (large cap and indices)	20	77.78%
Equity (small cap and other sector)	60	100%
Commodity	120	100%
FX	40	100%

Within bucket

For aggregating vega GIRR risk positions within a bucket, the correlation parameter is set as follows:

$$\rho_{kl} = \min\left[\rho_{kl}^{(option\ maturity)} \cdot \rho_{kl}^{(underlying)}; 1\right]$$

Where:

- $\rho_{kl}^{(option\ maturity)}$ is equal to $e^{-\alpha \frac{|T_k - T_l|}{\min\{T_k; T_l\}}}$ where:
  - α is set at 1%;
  - T_k(respectively T_l is the maturity of the option from which the vega sensitivity VR_k (VR_l) is derived, expressed as a number of years.
- $\rho_{kl}^{(underlying\ maturity)}$is equal to $e^{-\alpha \frac{|T_k^U - T_l^U|}{\min\{|T_k^U; T_l^U\}}}$ where:
  - α is set at 1%;
  - T_k^U (respectively T_l^U) is the maturity of the underlying of the option from which the sensitivity VR_k (VR_l)is derived, expressed as a number of years after the maturity of the option.

For aggregating vega risk positions within a bucket of the other risk classes (ie non-GIRR), the correlation parameter is set as follows:

$$\rho_{kl} = \min\left[\rho_{kl}^{(delta)} \cdot \rho_{kl}^{(option\ maturity)}; 1\right]$$

Across buckets

For aggregating vega risk positions across different buckets within a risk class (GIRR and non-GIRR), the delta correlation parameters are to be used for the aggregation of vega risks.

Appendix 7: Curvature correlations

For calculating the net curvature risk capital requirement for risk factor k for FX and equity risk classes, the curvature risk weight, which is the size of a shock to the given risk factor, is a relative shift equal to the respective delta risk weight.

For FX curvature, for options that do not reference a bank's reporting currency, net curvature risk charges may be divided by a scalar of 1.5. Alternatively, and subject to supervisory approval, a bank may apply the scalar of 1.5 consistently to all FX instruments provided curvature sensitivities are calculated for all currencies, including sensitivities determined by shocking the reporting currency (or base currency where used) relative to all other currencies.

For calculating the net curvature risk capital requirement for curvature risk factor k for GIRR, CSR and commodity risk classes, the curvature risk weight is the parallel shift of all the tenors for each curve based on the highest prescribed delta risk weight for each risk class.

For aggregating curvature risk positions within a bucket, the curvature risk correlations are determined by squaring the corresponding delta correlation parameters except for CSR non-securitizations.

For CSR non-securitizations, only correlation parameter applies between two weighted sensitivities within the same bucket. This correlation parameter should be squared.

For aggregating curvature risk positions across buckets, the curvature risk correlations are determined by squaring the corresponding delta correlation parameters.

Appendix 8: Default risk weights for non-securitizations by credit quality category

Credit quality category	Default risk weight
AAA	0.5%
AA	2%
A	3%
BBB	6%
BB	15%
B	30%
CCC	50%
Unrated	15%
Defaulted	100%

Appendix 9: Minimum scope reviewed by an independent risk control unit under FRTB-IMA

The minimum scope the review should cover is prescribed as:

- Organization of the independent risk control unit;
- Adequacy of risk measurement system and process;
- Accuracy and appropriateness of risk management system – this can be assumed to imply testing of model results against challenger models, review of the applicability of the models and their tractability;
- Verification of the consistency, timeliness independence and reliability of market data sources used for models;
- Approval process for risk pricing and valuation models across all functions;
- Scope of market risks captured by the models;
- Integrity of management information systems;
- Accuracy and completeness of position data, validity and correlation assumptions, and valuation and risk transformation calculations;
- Periodic back testing and PLA.

Appendix 10: LH prescription by type of risk factor

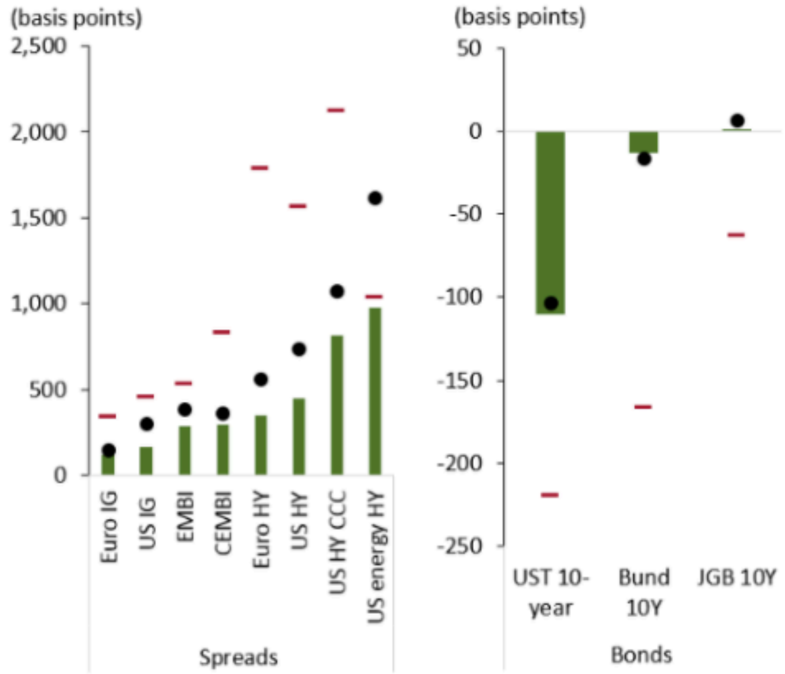
Risk factor category	LH (days)	Risk factor category	LH (days)
Interest rate: specified currencies - €, US$, £, A$, ¥, Skr, C$ and domestic currency of a bank	10	Equity price (small cap): volatility	60
Interest rate: unspecified currencies	20	Equity: other types	60
Interest rate: volatility	60	FX rate: specified currency pairs	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

Appendix 11: FX bid-ask spreads for $50 million in pips

	Pre-crisis (2007)		**Post-Lehman Crisis Period spot (2008)**	
Currencies	*Spot*	*3-M swap*	*Spot*	*3-M swap*
EUR-USD	1	0.2	5	10
GBP-USD	3	0.3	12	12
USD-JPY	3	0.2	12	10
USD-CHF	4	0.4	16	15
AUD-USD	4	0.4	20	20
USD-CAD	4	0.3	20	30
NZD-USD	8	0.5	40	10

Source: Bloomberg

Appendix 12: Asset prices during GFC and COVID-19 pandemic



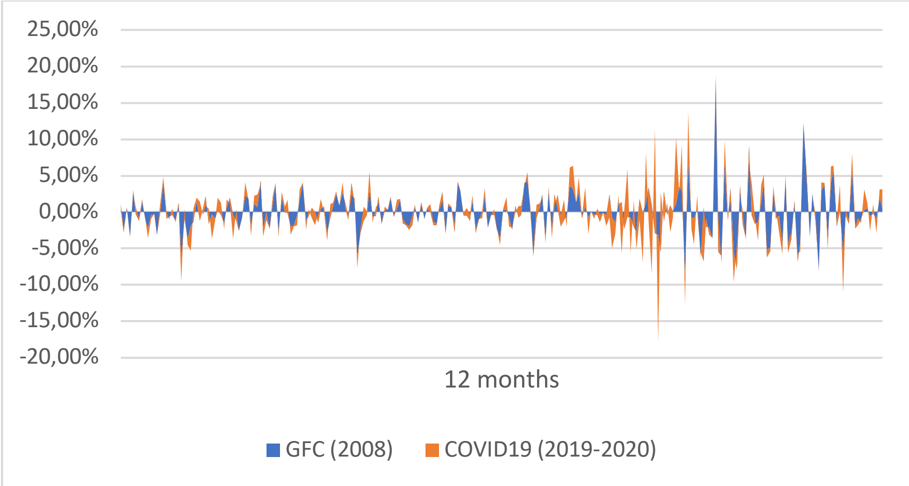
Source: Adrian & Natalucci, 2020

Appendix 13: Number of banks in the sample reporting data for the trading book

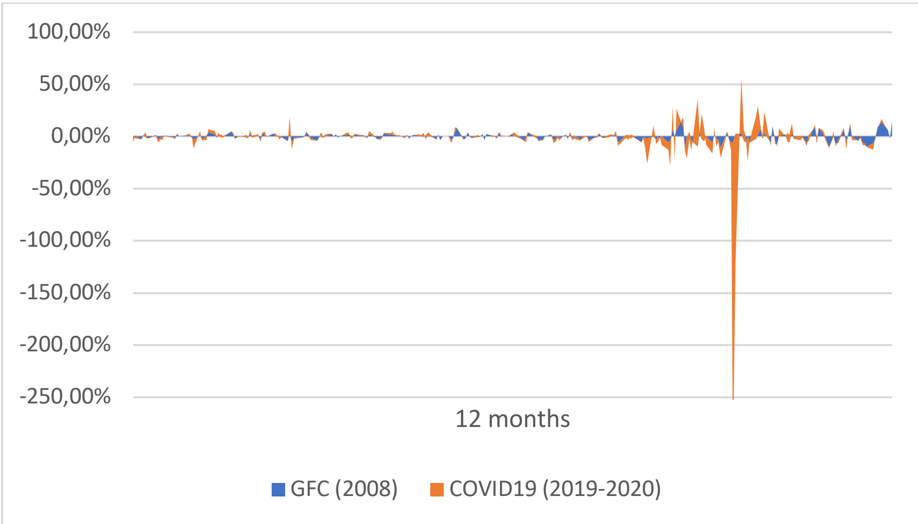
Country's name	Group 1	Group 2
Argentina	0	0
Australia	2	0
Belgium	2	1
Brazil	4	0
Canada	6	0
China	0	0
France	5	1
Germany	6	2
India	1	0
Indonesia	0	0
Italy	2	0
Japan	9	0
Korea	0	0
Luxembourg	0	0
Mexico	0	0
Netherlands	3	5
Russia	1	0
Saudi Arabia	0	0
Singapore	3	0
South Africa	3	1
Spain	0	0
Sweden	3	0
Switzerland	2	2
Turkey	1	0
United Kingdom	4	0
United States	9	0
Total	**66**	**12**

Source: BCBS QIS, 2018

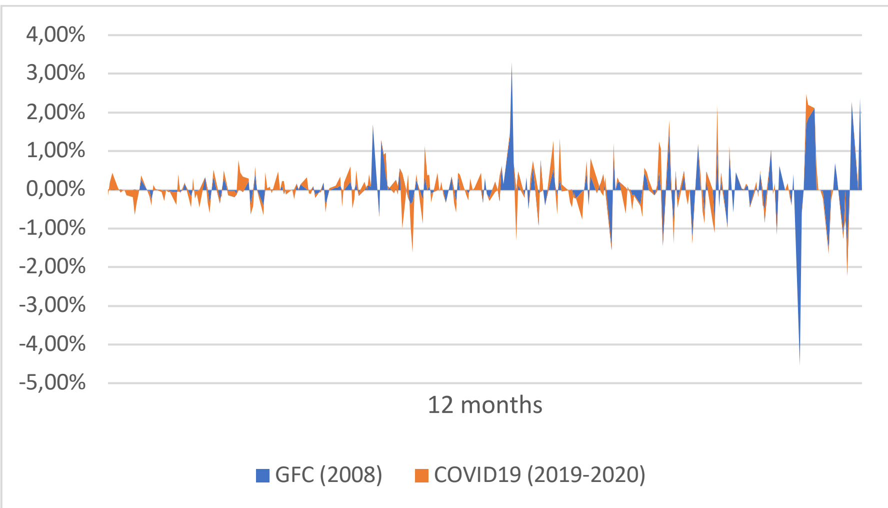
Appendix 14: Volatilities of the instruments in the portfolio



Source: Bloomberg, MSFT



Source: Bloomberg, WTI OK



Source: Bloomberg, CRC

Appendix 15: Excel spreadsheets and VBA code to simulate the P&L distribution of the BA Bond

0,085	coupon				4,25	4,25	4,25	4,25	4,25	104,25
100	notional	cf								
		t			0,4	0,9	1,4	1,9	2,4	2,9
				18/07/2020	12/12/2020	12/06/2021	12/12/2021	12/06/2022	12/12/2022	12/06/2023
		y=r+cs								
		r	from us gov	0,02%	0,05%	0,10%	0,20%	0,50%	0,75%	1%
		cs		4,70%	4,70%	4,70%	4,70%	4,70%	4,70%	4,70%
		continuous comp.	df		0,9811599	0,9576771	0,9336353	0,9058386	0,8772889	0,8475175
		6 month comp								
		108,1400029	present value		4,1699296	4,0701277	3,96795	3,8498139	3,7284777	88,353704

```
Sub Macro1()
'
Dim i As Integer
'
For i = 2 To 263

Sheets("BA 2008").Cells(7, 32).Value = Sheets("BA 2008").Cells(i, 9).Value
Sheets("BA 2008").Cells(7, 33).Value = Sheets("BA 2008").Cells(i, 9).Value
Sheets("BA 2008").Cells(7, 34).Value = Sheets("BA 2008").Cells(i, 10).Value
Sheets("BA 2008").Cells(7, 35).Value = Sheets("BA 2008").Cells(i, 11).Value
Sheets("BA 2008").Cells(7, 36).Value = Sheets("BA 2008").Cells(i, 11).Value
Sheets("BA 2008").Cells(7, 37).Value = Sheets("BA 2008").Cells(i, 12).Value

Sheets("BA 2008").Cells(8, 32).Value = Sheets("BA 2008").Cells(i, 8).Value
Sheets("BA 2008").Cells(8, 33).Value = Sheets("BA 2008").Cells(i, 8).Value
Sheets("BA 2008").Cells(8, 34).Value = Sheets("BA 2008").Cells(i, 8).Value
Sheets("BA 2008").Cells(8, 35).Value = Sheets("BA 2008").Cells(i, 8).Value
Sheets("BA 2008").Cells(8, 36).Value = Sheets("BA 2008").Cells(i, 8).Value
Sheets("BA 2008").Cells(8, 37).Value = Sheets("BA 2008").Cells(i, 8).Value


   Cells(i, 13) = Range("AB12").Value

 Next i

End Sub
```

Appendix 16: VBA code to simulate the P&L distribution of the MSFT Call Option

```
Sub BlackSholes2008()
'
Dim i As Integer
'
For i = 2 To 254

    Sheets("Black-Sholes 2008").Cells(1, 2).Value = Sheets("data 2008").Cells(i, 2).Value

    Sheets("Black-Sholes 2008").Cells(3, 2).Value = Sheets("data 2008").Cells(i, 1).Value

    Sheets("Black-Sholes 2008").Cells(6, 2).Value = Sheets("data 2008").Cells(i, 4).Value

    Sheets("Black-Sholes 2008").Cells(15, 2).GoalSeek _
    Goal:=Sheets("data 2008").Cells(i, 3).Value, _
    ChangingCell:=Sheets("Black-Sholes 2008").Range("B5")

    Sheets("data 2008").Cells(i, 5) = Sheets("Black-Sholes 2008").Range("B5").Value

 Next i

End Sub
```

Appendix 17: Liquidity horizon of the portfolio's risk factos

Risk factor	LH (days)
Interest rate: specified	10
Equity price (large cap)	10
Equity price (large cap): volatility	20
Energy and carbon emissions trading price	20
Credit spread: corporate (IG)	40
FX rate: specified currency pairs	10
FX rate: currency pairs	20

Appendix 18: Email from Professor Albert Trejos

Re: Request for contribution to a master's thesis

Alberto Trejos <alberto.trejos@incae.edu>
Dim 09/08/2020 00:34
À : Louis Renauld <louis.renauld@student.uclouvain.be>

Hi Louis. Of course I remember you.

First a little bit of history. The profound financial crisis that we went through in 1980-82 was caused by a variety of reasons, ranging from completely unsustainable public finances (quick growth of debt, very large deficits) to an unsustainably strong currency that led to a big loss in competitiveness. By the time the crisis exploded, imports were twice exports, interest payments were huge and the current account deficit was nearly 10% of GDP.

At the time, the exchange rate was fixed by the Central Bank, and of course as it ran out of reserves it was forced to remove the exchange rate peg, but meanwhile keeping a number of controls that meant, in practice, multiple exchange rates. The "purchasing" rate at which importers bought spiraled as far as a 400% depreciation over a couple of years.

In the mid 1980s, there was an effort to put the system in order, including a single exchange rate at which anybody could freely buy and sell. The Central Bank continued fixing the exchange rate (had a put and call at the same price), but slowly adjusting the rate daily by minute amounts to ensure that depreciation compensated inflation differentials.

That system was in place between the mid 80s to the mid 00s, over 20 years. It allowed an environment where people and firms had to concern little about exchange rate risk in their planning, and where we remained cost-competitive as the Costa Rican "export miracle" happened.

The problem with that system was that, in order to maintain control of the price, the CB had to do each day massive transactions in one direction or the other, and thus had to employ all its monetary instruments simply sterilizing the liquidity effects of those transactions. As it usually happens globally, with the growth of the economy the currency market expands more than proportionally, and this problem therefore was nearly unmanageable around 2006.

Hence the change that year to a band system, where the CB would set a floor price at which it was willing to buy any currency surplus, and a ceiling price at which it was also willing to sell. That way, when the price went up to ceiling or down to floor the CB would have to intervene, but when the price was in the middle it would not. Later on it also allowed the band to get really wide, so days of intervention became few and far between. And finally, in 2016 it eliminated the bands altogether.

Sadly, during that period the CB was run by politicians (always a problem) who intervened in the market aggressively to keep the exchange rate from going up, due to political considerations. That has passed now, and since last year it has been running a much more neutral and responsible policy.

You mention that in 2008-09 the exchange rate barely reacted. The reason is simple: we were running fiscal and balance of payments surpluses in that period, became a very safe place for money to be, so there was a massive flow of capital fleeing the developed world and into places like Costa Rica. The colon appreciated, making us the very expensive country that unfortunately we are, and you experiened. In fact, if it had not been for the band system, the colon would have kept appreciating further, but the floor kept it from moving.

Of course, we are now in a different position, with large deficits and very exposed to oscillating market valuations and to currency risk. Furthermore, as you saw when you were here, Costa Ricans very easily switch between colones and dollars, accept both and hold both. It is not uncommon that many firms and individuals hold assets and liabilities in both currencies, and have revenues and expenses in both. Therefore, if one is not careful, one may be unhedged, with a different currency composition in different sides of the balance of the P&L, and therefore with one´s equity and profitability being too exposed to currency oscillation.

Still, the currency has not yet oscillated too much in this period. I blame the fact that the government has had, during COVID, to rely on much larger-than-usual funding from abroad, that it then puts back on the market as the gov is one of few economic agents that actually mostly spends colones. I do not need to tell you that this situation can flip in a moment.

Hope that addresses your points, and let me know if I left anything untouched.

AT

Appendix 19: Survey responses

H1: The IMA described in the FRTB final version implies lower capital requirements for each risk class than if the choice of SA is made by a bank.

In your opinion, are the delta risk weights prescribed under the FRTB-SA adapted to the reality of the market? Why?

Une réponse

The risk weights represent a realistic market on average but if we compare the risk weights against the shifts for some illiquid GIRR currencies during the stressed period, then I would say the risk weights are much lower and does not consider any stressed spikes. That's why SA could be favourable for GIRR

Does the FRTB-SA requirement to calculate a curvature risk charge for optional instruments seem justified to you? Why?

Une réponse

Yes, it effectively captures the gamma risks.

H2: The shift from 99% stressed Value-at-Risk to 97.5% Expected Shortfall leads to higher capital requirements for banks under FRTB-IMA.

What do you see as the issues and improvements related to this change in market risk measurement?

Une réponse

The 97.5% percentile stressed period for illiquid FRTB currencies can be a lot higher, as the ES and SES needs to be calculated. Allowing for further diversification in the SES would be more realistic.

What do you think of this liquidity adjustment required by FRTB, which was not present under Basel 2.5? Do all these prescribed liquidity horizons seem justified to you?

Une réponse

The liquidity adjustments are justified theoretically.

H4: The change in methodology under FRTB to determine the capital requirements of banks covering their market risk has the same consequences if the stress period analysed is the COVID-19 pandemic.

In your opinion, will FRTB succeed in stabilising the banking system in future crises?

Une réponse

The FRTB IMA could have the means to as it considers liquidity at a more granular level and punishes banks for taking high exposure risks. However I do not think the FRTB-SA can effectively stabilise the banking system, as the risk weights will not capture huge shifts in unstable market. The regulators should force top tier banks to implement the FRTB-IMA.

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