FRTB: A Comparative Analysis

FRTB: Egy összehasonlító elemzés

Author: Eszter Hagymási
Actuarial and Financial Mathematics MSc
Quantitative finance major
2018

Supervisor:
Barbara Mária Dömötör, PhD
Corvinus University of Budapest, Department of Finance
## Contents

1. Introduction .......................................................... 1

2. FRTB overview .......................................................... 4
   2.1. Historical Overview ........................................... 4
   2.2. Boundary between the regulatory books ..................... 5
   2.3. Standardised Approach ........................................ 6
      2.3.1. Structure ................................................. 6
      2.3.2. Sensitivities-based Method ............................. 7
      2.3.3. Default Risk Charge ..................................... 10
      2.3.4. Residual Risk Add-On .................................. 10
   2.4. Internal Models Approach .................................... 11
      2.4.1. Approval process ....................................... 12
      2.4.2. ES vs. VaR .............................................. 16
      2.4.3. Calculation of the capital requirement ................. 18
      2.4.4. Capitalization of non-modellable risk factors ........ 21
      2.4.5. Default risk ............................................ 21
      2.4.6. Stress testing .......................................... 22

3. Implementation ....................................................... 23
   3.1. Portfolio construction ....................................... 24
      3.1.1. Attributes of the IRD portfolio ....................... 24
      3.1.2. Swap portfolio ......................................... 25
      3.1.3. Attributes of the FI portfolio ......................... 26
      3.1.4. Final model portfolio .................................. 27
      3.1.5. Mapping of risk factors ................................ 27
   3.2. Implementation of SA .......................................... 28
3.3. Implementation of IMA ................................. 30

4. Analysis ........................................ 34
   4.1. Standardised Approach results ..................... 34
   4.2. Internal Models Approach results ................. 35
   4.3. Single asset type portfolios ...................... 38
   4.4. Homogenous maturity portfolios .................. 39
   4.5. Analysis of shocks .................................. 41
   4.6. The case of CSR risk .............................. 43
   4.7. Quantitative Impact Study of BCBS ............... 44

5. Concluding remarks ................................ 46

A. Portfolio constituents .............................. 48

Bibliography ........................................ 54
List of Figures

2.1. The structure of the Standardised Approach. Reprinted from Minimal capital requirements for market risk (pp. 3.), BCBS, 2016a. . . . . . . 7

2.2. Approval process of the Internal Models Approach. Reprinted from Minimal capital requirements for market risk (pp. 2.), BCBS, 2016a. 11

4.1. Constrained and Unconstrained elements of IMCC throughout 60-day history . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 36

4.2. Constrained and Unconstrained elements of IMCC throughout 60-day history within the short maturity portfolio . . . . . . . . . . . . . . . . 41
List of Tables

3.1. Absolute net present value of major asset types denominated in euro 25
3.2. Summary of risk factors in portfolio based on liquidity horizon and risk class 28

4.1. Standardised Approach charges of the full portfolio by risk class, corresponding to each correlation scenario in thousand euros. 34
4.2. Scenarios used in the calculation of Expected shortfall for each risk class and liquidity horizon on day 62. 37
4.3. SA and IMA charges of single asset portfolios in thousand euro. 38
4.4. NPV, SA charge and IMA charge of homogeneous maturity portfolios in thousand euro and in percentage ratio of the sum of the portfolios. 40
4.5. Average 10-day variations of GIRR risk factors in the 6 worse scenarios compared to prescribed SA shocks given in percentage. 42

A.1. Attributes of interest rate swaps in model portfolio 48
A.2. Attributes of cross-currency swaps in model portfolio 50
A.3. Attributes of bonds in model portfolio 51
Chapter 1.

Introduction

In January 2016 the Basel Committee on Banking Supervision (BCBS) published the new Minimum capital requirements for market risk, the soon to be implemented framework of the capitalization of the trading book (BCBS (2016a)). But the topic of the regulatory overhaul had been keeping market risk managers and senior management awake at night, since the publication of the Fundamental Review of the Trading Book (FRTB) in 2012 (BCBS (2012)).

Even though the wording and the details of the new regulatory standard had changed during the course of the four-year-long preparation, the incentives of the Basel Committee had been clear from the start. Transparency and consistency across the banking industry, more prudent operations and closer regulatory and supervisory overview was much to be desired, even at a cost of possibly overly burdening capital requirements and a bureaucratical load.

The revision startled the banking industry as a whole as the proposed regulatory changes affect banks irrespective of their size or jurisdiction. For smaller banks with less exposure to market risk that have been capitalized in the previous version of the Standardised Approach (SA), the new framework is worrisome because it inflicts far more operational costs on them as well as higher capital requirement. For bigger banks now there is a real threat of loosing the Internal Models Approach (IMA) accreditation as the SA is to become a credible fallback, while inflicting a more punitive capital charge than before for either part of the portfolio or its entirety.

Beside the need to change their internal processes profoundly, these fears are expected to have an effect on how banks operate in several different markets. Even
though the deadline for the implementation has been pushed, FRTB really is a challenge for the banks today. A plethora of decisions have to be made today for a bank to be able to tackle the FRTB puzzle successfully.

A non-exhaustive list of questions include whether to apply for IMA at all, if so, what kind of a trading desk structure to implement, which desks are to be capitalized in IMA, will they even pass the tests of approval and with what kind of a model set-up are they more likely to succeed. If they really pass, should the bank worry about certain risk factors being deemed non-modellable adding more to the capital requirement or should it stop trading instruments with certain underlyings all together.

As of now most mid-size and larger European banks have assigned these questions to project teams to answer, software companies are in a rush to lead in creating the infrastructure needed for the implementation and consulting businesses are eager to analyze and explain the situation at conferences and webinars. Academia has shown interest in the questions regarding the new risk measure, Expected Shortfall and also particular modelling challenges.

The central question of our research is how much of a difference would a choice between the Internal Models Approach and the Standardised Approach mean to a Dutch bank with regards to its market risk capital charge, and what are the main drivers for such a difference. The bank in question is currently capitalized based on IMA, but the implementation costs outlined by Farag (2017) and Olgerdinger (2017) among others, prompted the senior management to question the profitability of internal model usage within the new framework.

To keep the research computationally sound and simple, we create a model portfolio resembling the bank’s own, but focus mostly on the interest rate risk. Through the capitalization of bond, interest rate swap and cross-currency swap instruments we present how the capital charge is to be calculated in both frameworks according to BCBS (2016a). From the analysis of the results we learn that SA capital charge for the model portfolio is 3.5 times higher than that of the IMA even though optionality is not included.

We present a comprehensive analysis to show how the two approaches differ in terms of applied shocks and correlations and how they are weighting risk classes
differently. We also provide explanations of diversification effects and some observed peculiar behavior.

The rest of this paper is organized as follows: As an introduction in Chapter 2 we provide a historical background for our topic, FRTB. We then turn to the regulation itself, presenting the main changes in detail while showcasing the latest literature concerning these propositions, including the revisions that have been introduced in March 2018. In Chapter 3 we outline the implementation choices we made and give an example on how the ordonnances of Chapter 2 materialize in a stylized case. Following the analysis of our results in Chapter 4, we add some concluding remarks in Chapter 5.
Chapter 2.

FRTB overview

In this Chapter, we provide a comprehensive overview of the 2016 standards and the corresponding academic literature as well as the recently suggested changes in the framework. The Chapter is arranged into four sections in the following order: the historical background of the new regulation, boundary between regulatory books, the revised Standardised Approach and the revised Internal Models Approach.

2.1. Historical Overview

The preceding regulation on the capital requirements for market risk was published in 2004 by the BCBS in the first pillar of the Basel II Accords (BCBS (2004)). Even in the years leading up to the subprime crisis of 2007-2008, the regulation was criticized heavily by the industry for its procyclicality (Gordy & Howells (2006), Repullo et al. (2010)). Although the implementation of these rules was still in progress in US banks in 2008 (Cannata & Quagliariello (2009)), critical voices intensified when evaluating Basel II Accords in hindsight later on (Moosa (2010)).

In response to this, the BCBS started to work on the overhaul of the capital requirements, publishing the first consultative document in 2012 under the title of Fundamental Review of the Trading Book: A revised market risk framework. (BCBS (2012)). The first version of FRTB was followed by two further consultative documents in 2013 and 2014 and an interim impact analysis in 2015 before publishing the - seemingly - final version of the Minimum capital requirements for market risk in 2016 (BCBS (2016a)).
According to the explanatory note of BCBS (2016b), the new set of rules was dedicated to mend the deficiencies of the Basel II framework. The paper divides these flaws into four categories. First is the inadequate boundary specification regarding the trading book, that led to misinterpretations and possible capital arbitrages between books. Second is the caveats of the Value-at-Risk (VaR) measure that fails to capture credit risk exposure, market illiquidity, and in the current framework recognizes too many hedging benefits. Furthermore the paper describes incoherency issues in the current risk measurement. Finally, it outlines the lack of clear links between the Internal Models Approach (IMA) and the Standardised Approach (SA) that holds a message for banks that falling back to the SA is not a likely outcome (BCBS (2016b)).

The deadline for implementing the new framework was 2019, however this agenda has proven to be too challenging. Pressured by both the industry and local regulators, the Committee in December 2017 announced pushing the deadline until 2022 (BCBS (2018b)) . The current nature of the topic is best exemplified by the fact that the BCBS has added two Frequently Asked Questions documents in 2017 and 2018, and two new revisory suggestions, the last being published in March 2018 (BCBS (2017b), BCBS (2018a), BCBS (2017a), BCBS (2018b)).

2.2. Boundary between the regulatory books

The general intention behind the revision of the boundary between the banking and the trading book is to impede any regulatory arbitrage that could be achieved by moving instruments between books. To set clear rules, an articulate definition is provided for *market risk*, *trading desk* and *trading book instruments*. According to the definition of FRTB, any instrument that the bank holds for either ‘short-term resale, profiting from short-term price movements, locking in arbitrage profit or hedging risks that arise from instruments meeting these criteria are to be designated as a trading book instrument’ (BCBS (2016a) pp. 7.).

Only under extraordinary circumstances and after supervisory approval could a bank move instruments between books. If a movement does take place, no capital benefit is allowed, meaning that the total capital charge can not decrease as a result
of the switch. With regards to internal risk transfers, the same principal applies, namely that no capital recognition is to be expected when hedging banking book credit or equity exposures using trading book instruments, unless the hedge is an exact match traded with an eligible third-party protection provider. Additionally, in case of interest rate risk exposure, the risk transfer is to be conducted by a separate designated internal risk transfer (IRT) desk (BCBS (2016a)).

In case of risk transfers between trading desks, regulatory capital recognition can be received (i.e. trading desks can reduce capital charge by hedging each other’s exposure). Exception to this rule is the IRT desk itself which can only receive capital recognition if the same constraints apply as in case of hedging banking book exposure (BCBS (2016a)).

Even though this is the least debated section of FRTB, Orgeldinger (2017) warns that it carries a substantial bureaucracy burden and a motivation to circumvent the regulation via the IRT desk.

2.3. Standardised Approach

For banks that have a smaller market risk exposure, the Standardised Approach was initially ment to ease the computational burden and provide a viable alternative to building costly internal risk models. In the revised framework it is to be calculated for all banks in BCBS jurisdiction.

2.3.1. Structure

The Standardised Approach (SA) has three main components as presented in Figure 1. The most substantial is the Sensitivities-based Method (SbM) which aggregates risk charges of seven risk classes. The Default Risk Charge (DRC) accounts for the calculation of the credit risk similar to that of the banking book, in order to avoid different valuations of similar instruments across the different books. Finally, the Residual Risk Add-On (RRAO) captures additional risk factors (e.g. gap risk, behavioural risk, correlation risk) of non-listed instruments that are not captured in the former two components (BCBS (2016a)).
2.3.2. Sensitivities-based Method

Each of the seven risk classes\(^1\) consists of multiple buckets defined uniquely. For instance, equity risk factors are divided into buckets based on cap size, economy type and sector, whereas interest rate risk buckets represent different currencies.

Three different risk measures are calculated across all risk classes: delta, vega and curvature. Vega and curvature risk is not calculated for instruments whose cash flows can be written as a linear function of the price of the underlying risk factors (instruments without optionality). After carefully mapping the risk factors to the instruments, the aggregation process from asset-level to portfolio-level is the following:

1. Asset-level sensitivities of a risk factor for a certain measure (delta or vega\(^2\)) are multiplied by weights assigned to each risk bucket to get weighted sensitivities.

2. Within each bucket these weighted sensitivities are aggregated using defined correlations ($\rho$) to get the bucket-level risk measure.

3. Within each risk class the bucket-level risk measures are aggregated using defined correlations ($\gamma$) to get the class-level measures.

---

\(^1\) General Interest Rate Risk, Credit Spread Risk (CSR): non-securitisation, CSR: securitisation, CSR: securitisation correlation trading portfolio, Foreign Exchange (FX) Risk, Equity Risk, Commodity Risk

\(^2\) The first 3 steps are done separately for delta and vega measures and are summed up in the 5th step.
4. The sum of the class-level measures (e.g. class deltas) constitute the portfolio-level measure.

5. The sum of the three portfolio-level measures is the portfolio-level risk charge for a certain $\rho$ and $\gamma$ correlation scenario.

6. The above described procedure is repeated twice, using lower correlation measures and higher correlation measures.

7. The final risk charge of the portfolio is the highest of these three different risk charges.

The curvature measure is calculated in a different manner, but aggregated similarly, except that negative curvature is ignored. To get the curvature, downward and upward shocks are to be applied to the underlying risk factor, repricing the instrument each time, deducting the relevant delta value. The curvature risk charge is the more damaging of the two delta-adjusted shocks (BCBS (2016a)).

Farag (2017) recognizes a number of inconsistencies in BCBS (2016a) which he primarily attributes to the wording of the text rather than the theoretical foundation of it. The assignment of risk factors of commodities to certain vertices is problematic in his view when the hedging strategy of the derivative depends not only on the maturity but also on interim points in time. He provides a natural gas swap as an example to show how such handling would result in a high capital charge for a fully hedged deal. In his paper he also suggests possible remedies. In this case either the rewording of the text or the possibility to break down such assets into smaller instruments (e.g. swaplets) could solve the issue (Farag (2017)).

Similar issues arise when we capitalize vega risk in SA. Concerning all risk classes, Farag (2017) argues that Footnote 17 in BCBS (2016) suggests assigning vega to the vertex of the maturity only. In case of a cap example, this again results in the break of a perfect hedge by caplets whose vega risks are associated with their own different maturities. Being the most natural resolution, Farag (2017) advises to simply remove the footnote in question.

\[^{3}\text{Aggregation procedure of Curvature risk is similar to that of delta and vega measures, but it is not described in this section for simplification reasons.}\]
However both this issues reappear in the FAQ document published in March 2018, where the Committee stands by the wording of the text, suggesting that this was a choice rather than a codificational mistake (BCBS (2018b)).

An important discovery by Farag (2017) suggests that SA charges can be materially different for the FX risk class depending on the reporting currency the bank chooses. The root of this issue is that the regulation allows for more favorable treatment of liquid currency pairs (e.g. their risk weights can be divided by square root of 2). His examples account for all three risk types, however he puts an emphasis on the curvature charge as the deviation tends to be highest in that case (Farag (2017)).

This anomaly is addressed as well in the BCBS (2018a) revision, where the combination of selected liquid currency pairs are also acknowledged to be liquid thus resolving this issue. Further amendments are suggested for example the lowering of risk weights and the change of the correlation scenarios such that they do not result in an overly conservative capital charge (BCBS (2018a)).

Practitioners have tried to find reasoning behind the correlation structures suggested in BCBS (2012). Sayah (2015) provides alternative modelling approaches to describe the SbM method. The paper notes that compared to the Standardized Approaches of former Basel Accords, the FRTB pillar weights diversification effects more through the weighting and correlation structure proposed in the Basel Committee’s consultative document. She argues however, that the origin of these prescribed correlations are not documented, hence it is an outstanding question how an internal model could replicate the capital charge output of the Sensitivities - based Method.

Focusing on solely the interest rate risk of bond portfolios, Sayah (2015) concludes that depending on the time horizon of the VaR, and the currency composition of the portfolios, different models are best fit to replicate the SBA charge. Out of GARCH, Primary Component Analysis, Independent Component Analysis and the Dynamic Nelson Siegel model, the charge for more volatile currencies would be best matched with PCA on the short end, while for US and Europe, even the most basic GARCH provided results close to the SbM values.

Acknowledging the complexity of the framework and hurdles of implementation for smaller, less exposed banks, the Committee proposed an alternative SbM calculation framework in BCBS (2017a). Only small banks with a trading book worth less than
€1bn are eligible to choose this option, hence we chose not to discuss it in further detail in this thesis.

### 2.3.3. Default Risk Charge

The standardised Default Risk Charge (DRC) of BCBS (2016a) is calculated for the three Credit Spread Risk (CSR) classes. This is independent of the CSR capital charge and it is intended to capture extreme events of stress (sudden default) that are not captured by credit spread shocks. Although the rules vary across risk classes, generally the aggregation method follows the steps below:

1. Determining gross jump-to-default (JTD) loss amounts for each position (i.e. both long and short positions of the same obligor).
2. Offsetting long and short positions for the same obligor to calculate net JTD.
3. Discount the positions by hedge benefit ratio within buckets.
4. Simple sum of the bucket-level capital charge gives the charge of the risk class.

From a practical angle, Farag (2017) draws attention to the fact that the very different examples provided in the standard could also be accounted for by only one general handling. He suggests that for implementational purposes a rewording would be beneficial.

In a more holistic analysis, Orgeldinger (2017) praises the new framework for moving away from VaR, for its limited capability of capturing high-impact but low-probability events, though he recognizes the threat of data limits in forecasting extreme events. He opposes however, the capital charge inflicted on securitization products and envisions increased transactional costs and reduced liquidity in the markets for securitized instruments.

### 2.3.4. Residual Risk Add-On

The Residual Risk Add-On (RRAO) is a simple sum of weighted gross notional of instruments that bear residual risks (i.e. risks that cannot be captured by delta, vega or curvature). The assigned weight is 1% in case of instruments with an exotic underlying and 0.1% otherwise.
2.4. Internal Models Approach

While the most important change in the revised IMA is the shift from Value-at-Risk (VaR) to Expected Shortfall (ES), the requirements for IMA eligibility are also changing profoundly. This section first summarises the approval process in BCBS (2016a) before describing the calculation of the capital charge.
2.4.1. Approval process

The overall approval process for the IMA consists of three steps: firm-wide model assessment, desk-level model assessment, risk factor analysis. The illustrative summary of these steps are shown in Figure 2.

1. Overall assessment

First step is the assessment of the bank’s risk capital model and organizational infrastructure (including the proposed trading desk structure) based on both qualitative and quantitative aspects. The latter is based on a 99th percentile VaR back-testing applied to the latest 250 days for both the actual and the hypothetical PnL. In this context the actual PnL is the daily mark-to-market PnL of the bank, whereas the hypothetical PnL assumes a constant portfolio, i.e. the positions held the end of last day, revalued with market prices of the end of the current day. An outlier occurs whenever either of these two measures are higher than the 99% VaR value.

The supervisor applies a stoplight approach in the firm-wide assessment, based on the number of outliers. Under 5 outliers it is statistically very unlikely that the model is inadequate, therefore this is the green zone. If the number of exceptions fall between 5 and 9 (yellow zone), the adequacy of the model might be questioned. The penalty for too many outliers is materialised through the risk charge calculation where a multiplicative factor is determined based on the number of outliers. Exceptions must be documented and explained by the bank. If the integrity of the model is questioned, the supervisor might consider to disallow the use of the model. In case of 10 or more outliers (red zone), the supervisor is ‘convinced’ - in a statistical sense - that the model is improper therefore the bank should start improving it immediately. The value of the multiplier automatically increases to the highest possible value.

2. Desk eligibility

In the second step banks must nominate which desks are in-scope for model approval. The rest of the desks and the ones that do not meet the
criteria automatically fall under the SA and stay ineligible for IMA for at least one year. To remain eligible for IMA, at least 10% of the bank’s market risk charges must be capitalised under IMA. It is prohibited to nominate desks to be out-of-scope for the reason that the SA capital charge would be lower.

The requirements for IMA on desk-level are two-folded: desks must pass back-testing and PnL attribution requirements.

**Back-testing requirements**

The back-testing of the desk-level is based on a static VaR for a 1-day holding period, tested on both the 97.5\(^{th}\) and 99\(^{th}\) percentile against actual and hypothetical PnL using the most recent 12 months. More than 30 or 12 outliers on the respective significance level means automatic fallback of the desk into the SA, meaning that the capital charge of the full portfolio of the desk will be calculated based on the Standardised Approach until the number of outliers fall into the threshold again.

**PnL attribution**

The PnL attribution (PLA) requirements intend to evaluate how well the risk management model explains the hypothetical PnL of the desk. The desk’s PnL value estimated by the bank’s pricing models using only the risk factors of the risk management model is called the ‘risk-theoretical’ PnL. This theoretical PnL is compared to the hypothetical PnL monthly, using two measures.

The first measure is the mean unexplained PnL (i.e. the difference of the hypothetical and theoretical PnLs) divided by the standard deviation of the hypothetical PnL. The absolute value of this measure must be lower than 10%, otherwise it is considered to be a breach.

The second measure is the fraction of the variance of the unexplained daily PnL and that of the hypothetical daily PnL, which is supposed to be lower than a 20% threshold.

Four or more breaches over a 12 months period in terms of either of these measures mean an automatic fallback of the desk to the SA. The desk becomes eligible for IMA again once it fulfills both the back-testing and PnL attribution requirements for the most recent 12 months.
The PLA test is by far the most controversial and much discussed innovation of FRTB. In a survey conducted by Risk.net more than half of the included banks presumed that 20% or more of their trading desks are expected to fall out of IMA because of the PLA (Sherif (2016)). In addition, some banks complained that the test is designed such that 'one product can make the whole desk fail' (Sherif (2016) pp.2.).

It further complicates the dilemma of practitioners that there’s a discrepancy between the glossary and the text itself concerning the PnL attribution test according to Wood (2016). The difference between the two versions lies in how the risk-theoretical PnL is calculated: the strong version tells a bank to use its risk models, while the weak version requires a bank to use the front-office model, but applying a more limited set of factors that exist in the risk models (BCBS (2016a)).

Moreover, most practitioners fear that passing the test at a well-hedged desk is almost impossible. Quantifying these fears, Thompson et al. (2016) shows through basic assumptions that even properly modelled desks have a high probability of failing the test. They attribute this finding to the fact that the statistical test is based on too few observations, therefore will not provide robust results. They warn that the PLA test on its own would provide an incentive for banks not to pursue an IMA accreditation as the frequent fall-out of desks would impose a huge cost on them. They also argue, that the length of the fallout period is too punitive and for the sake of continuity and forecastability, they advise the Committee to consider changing it (Thompson et al. (2016)).

Being under continued pressure by the industry lobbyists, the Committee decided to revise the PLA requirement in BCBS (2018a). As banks raised concerns that mere data issues can result in a PLA failure (e.g. data coming from different platforms or time zones), BCBS relaxed the data requirements clarifying how the data input can be modified to remedy this issue (BCBS (2018a)). Following the suggestion of Thompson et al. (2016), the new measure will be based on a longer period of observations.

Second, the regulator decided to change the metric design of the statistic
as well. Instead of evaluating the mean and the variance of the unexplained PnL, the Committee suggests either a Kolmogorov-Smirnov, or a Chi squared test to assess how different the hypothetical and risk theoretical PnL distributions are (BCBS (2018a)).

The fallout of a trading desk from being capitalized in IMA is also redesigned to prevent the capital charge of a certain desk from becoming too volatile. A 'smoother' fallout is provided by a traffic light approach, where desks in the amber zone do not fall out of IMA automatically, but are subject to a punitive surcharge - still smaller than the respective SA charge (BCBS (2018a)).

3. Risk factor analysis

For a risk factor to be admissible (i.e. modellable) in the internal ES model, it must have continuously available 'real' prices. Prices are considered 'real' when it is a price the bank has conducted a transaction at/ it is verifiable for an actual transaction between other arms-length parties/ it is obtained from a committed quote/ it is obtained from a third-party vendor where (i) the transaction has been processed through the vendor; (ii) the vendor provides evidence of the transaction to supervisors upon request; (iii) the price meets the three criteria listed above.

To fulfill the criteria of being 'continuously available', a price must have at least 24 quotes per year, with no more than one month between two observations. Risk factors that are combinations of modellable risk factors are automatically deemed modellable. When data for a modellable risk factor is not available during the period used for stressed calculations, proxy data might be used if the generation of missing data is well-documented and approved of by the supervisor.

Non-modellable risk factors (NMRFs) add further dimensions to the forecastability issues of the IMA charge, as risk factors might be falling in and out of modellability. Prompted by the concern that NMRFs can cause up to 30% of the IMA charge (ISDA (2016)), Obitz (2016) investigates the modellability requirements of IMA. Out of the two expectations (24 real prices...
per year/not more than a month between data points), his hypothesis is that the latter is the more restrictive.

Modelling the trading occurrence with a constant-rate Poisson process, his findings show that the probability of answering the frequency requirement for 24 deals per year is extremely low, between 0.7% and 2.2% depending on the length of the month in the assumptions. To assure a 95% probability of meeting the requirement, one would have to assume around 90 trades happening each year, according to Obitz (2016).

Basel Committee on Banking Supervision however did not find these concerns 'compelling evidence', hence there is no change in the original standard in this matter (BCBS (2018a) pp.9.). However, the Committee suggests that it is open to discussion upon the condition that actual data is presented on risk factors that are perceived as liquid enough during turmoils, yet failing the modellability requirement.

Even if a desk obtains approval to be include in the IMA, the SA capital charge is to be calculated for it at least on a monthly basis. This is to provide a common denominator for the supervisor across banks and to function as a fallback for desks that fail the above described criteria.

2.4.2. ES vs. VaR

As mentioned before, the capital charge will no longer be based on VaR, but an Expected Shortfall (ES) measure at the 97.5\textsuperscript{th} percentile. ES measures the expected loss at the tail of the distribution, above a certain quantile\textsuperscript{l}. The new metric intends to capture tail risk that has not been accounted for by VaR (BCBS (2016a)). Before elaborating further on the calculation methodology prescribed by FRTB, we highlight how the industry turned from VaR to ES long before the regulatory swift, and why this change was much awaited by practitioners.

Artzner et al. (1999) laid out the definition of coherent risk measures, which opened the way for widespread discussion across the industry on whether Value-at-Risk was an adequate measure or not, and even how to define adequacy in case of a risk metric. Their well-known conclusion that VaR lacks the subadditivity property and hence
Chapter 2. FRTB overview

is incoherent generated an academic boom. The paper was followed by a plethora of attempts at creating new risk measures and even new paradigms that differed from the coherence principle. The proposition of expected shortfall from Acerbi & Tasche (2002) emerged from this crowd, when they provided proof that it fulfilled the coherence expectation.

New axiomatic frameworks included but were not limited to: law-invariance by Kusuoka (2001), elicitation by Gneiting (2011) and consistency by Davis (2014). By the time Gneiting (2011) showed that ES was not elicitable (able to minimize a scoring function), most of the industry had already implemented it, and the BCBS was ready to incorporate it in the upcoming regulation. A major concern arose around the regulatory shift, namely the back-testability of ES.

Acerbi & Szekely (2014) show that elicitation is unrelated to back-testability and that multiple non-parametric, model-independent back-testing methodologies are applicable without imposing overly burdensome computational procedures. They argue that the back-testability properties of Expected Shortfall are not inferior to that of VaR. Among others, Nyfeler (2015) and Kratz et al. (2018) also propose ways to back-test ES. Sill - as mentioned in an earlier section - BCBS decided to instead include a VaR-based back-testing framework.

Another notable argument on the ES side is Lazar & Zhang’s (2017), who show evidence that ES based models are less prone to model risk than VaR based ones. For this purpose they calculate the minimal adjustment needed for ES to pass three different back-tests at the same time. These tests cover the number, size, and autocorrelation of exceedances. They find that ES model risk is more than 50% less than for VaR, and it is smallest for GARCH (1, 1) processes, while modelling equities is more exposed to model risk than other risk classes.

Some counterarguments to ES faced upon its establishment as the main risk metric in FRTB. Lichtner (2017) shows that ES has a far greater exposure to the return modelling choice of a bank than VaR, as different return models can generate materially different capital charge estimates. He also notes that FRTB lacks any prescription regarding this choice, aggravating the issue.

Following the criticisms of ES, the industry started to yet again look for alternatives. A particularly interesting contribution is that of Kou, Peng & Heyde (2013), who
drew the attention to the difference between internal and external risk measures. Notably, they focus on establishing expectations towards external risk measures, used by regulators, rather than within the bank for risk managing purposes and senior management.

They use the insurance risk measure definition from actuarial literature and the theory of law-invariant coherent risk measures (Kusuoka (2001)) to create a new class of measures through relaxation of the additivity assumptions. They further narrow the class to statistics that are robust to both model misspecifications and data input changes, hence are applicable for regulatory purposes (Kou, Peng & Heyde (2013)).

Finally, following Basel Accord practices they incorporate scenario analysis into their empirical analysis. Based on their results they suggest that Median Shortfall could be a robust alternative of expected shortfall. Another advantage of this class is that it enables for the correction of the procyclicality concerns about the current VaR framework that Gordy & Howells (2006) had raised (Kou, Peng & Heyde (2013)).

### 2.4.3. Calculation of the capital requirement

Next to introducing an Expected Shortfall-based capital charge, another major change is related to the liquidity horizon. While in the VaR framework a 1-day VaR was scaled up to 10 days in case of each risk factor, the base liquidity horizon for ES is 10 days, and the scaling up differs across risk factors. The argumentation outlined by the Committee is based on the fact that in stressed periods unexpected illiquidity can affect instruments differently, given that they are subject to different risk factors. The liquidity horizons used in the new framework are 10, 20, 40, 60, and 120 days (BCBS (2016a)).

To determine the capital charge at the firm-level, the following steps should be followed:

1. Calculate the ES for a certain **risk class** for each of its respective **liquidity horizons**. In each case this means shocking only the risk factors that have at least the liquidity horizon in question.

Orgeldinger (2017) is critical concerning the bucketing for liquidity horizons. He draws attention to the correlation structure being tilted by the unjustifiable
segregation of risk factors, and the fact that the method is not sensitive to
bid-ask spreads. He also argues that this kind of approach in regulation could
cause a decrease in liquidity of particular markets.

2. The **ES of a risk class** will be given by Equation (1), incorporating the scaling
up by liquidity horizons.

\[
ES_i = \sqrt{\left(ES_T(P)\right)^2 + \sum_{j \geq 2} \left(ES_T(P, j) \cdot \sqrt{\left(\frac{LH_j - LH_j-1}{T}\right)}\right)^2}
\] (2.1)

3. To get the **stressed ES**, this calculation is to be repeated for a stressed period
with a possibly reduced set of variables\(^5\), and for the recent period with the
reduced set of variables.

Farag (2017) mentions that the choice of risk factors based on which this stress
period is chosen is at the bank’s discretion according to BCBS (2016a). Laurent
& Omidi Firouzi (2017) criticize the endogenously defined stress period of the
framework and adds that it is not only dependent on the risk factor basket but
also on the model choice, thus making way for manipulation, and dishonest
tailoring of the modelling approach.

4. The **stressed ES (Constrained) of a risk class** is the ES of the stressed
period multiplied by the fraction of the current ES calculated on the full set of
risk factors divided by current ES on the reduced set of risk factors.

\[
ES_i = ES_{R,S,i} \cdot \frac{ES_{F,C,i}}{ES_{R,C,i}}
\] (2.2)

5. These calculations are to be repeated using the full set of risk classes to get
the **Unconstrained stressed ES** \((ES_U)^6\)

6. The **Internal Models Capital Charge** (IMCC) is the weighted average of
the unconstrained ES and the sum of \(R\) constrained ESs, where the weight is

---

\(^5\)The reduced set is required to explain 75% of the full model’s variation over the preceding 12
weeks.

\(^6\)Note that this notation is different from that of the original BCBS document.
set at \( \rho = 0.5 \).

\[
IMCC = \rho (ES_U) + (1 - \rho) \left( \sum_{i=1}^{R} ES_i \right)
\]  

(2.3)

7. The **capital requirement on desk-level** for a certain day is the higher of its IMCC of the previous day plus the capitalization of non-modellable risk factors, or the average IMCC of the last 60 days scaled up by a multiplier \( m_c \)\(^7 \) plus the average non-modellable risk charge.

\[
C_A = \max \{ IMCC_{t-1} + SES_{t-1}; m_c \cdot IMCC_{avg} + SES_{avg} \}
\]  

(2.4)

Orgeldinger (2017) warns, that the ES 'may prove to be too volatile' (Orgeldinger (2017) pp. 11.). In contrast, by taking the maximum, Laurent & Omidi Firouzi (2017) argues that we often choose the average that is multiplied by a number between 1.5 and 2, hence making the ES measure more or less constant over time. While they acclaim that the procyclicality of the capital charge is reduced compared to the previous regulatory framework, they also warn that this could cause complete acyclicality instead.

8. The **aggregate capital charge of a desk** is the sum of the capital charge for modellable risk factors, the capital charge for non-modellable risk factors, and the Default Risk Charge.

As computational complexity increases due to the introduction of FRTB, historical simulation is expected to be the typical choice of simulation method among banks (Laurent & Omidi Firouzi (2017)). Laurent & Omidi Firouzi (2017) reflect on the variability of capital charge estimates across historical simulation models that pass the prescribed back-tests. While they acknowledge that sources of the dispersion are varied, they focus on the weighting of simulated scenarios. They outline the notion that while a decrease in the decay factor is a powerful tool in increasing the resilience of the model, there is an incentive for banks not to use it as it increases the ES substantially. Their fears appear to be well-founded. According to a McKinsey&Company (2012) study, only 15% of historical simulation using banks apply any sort of weighting.

\(^7\)Defined as per the aforementioned stoplight approach.
2.4.4. Capitalization of non-modellable risk factors

Risk factors that have been deemed non-modellable must be capitalised using stress scenarios. The confidence threshold of these calibrations should be at least 97.5%. The liquidity horizon of the scenario is the higher of the liquidity horizon of the risk factor and the largest time interval between two consecutive price observations over the preceding year. For idiosyncratic credit spread risk factors, it is allowed to use the same stress scenario. If it is properly demonstrated to be applicable, the bank may use zero correlation assumptions.

Even though Appendix B III. suggests that exceedance of the daily VaR caused by NMRF capitalization could be disregarded, Farag (2017) shows that this is not a possible use-case at a desk level.

2.4.5. Default risk

Similar to the Standardised Approach, a Default Risk Charge (DRC) is to be calculated also in the Internal Models Approach. Although the bank has discretion about the form of its model, there are standard requirements the models must fulfill. To calculate default risk, a weekly one-tail 99.9 percentile VaR should be applied with a one-year liquidity horizon. Correlations must be based on credit spreads or listed equity prices obtained from a period of 10 years, including a period of stress.

Same way as in case of the capital requirement, the DRC itself is also the greater of the most recent value and the average of the last 60 trading days. The regulation requires the bank to measure default risk for each obligor, but the probability of default can not be less than 0.03%. Netting long and short exposures in case of the same obligor is permitted, but across obligors it needs to be explicitly included in the model.

Since standard back-testing methods are not applicable at the one-year horizon, indirect methods must be used to assess the model’s efficacy. Desks with default risk and credit spread risk exposure must be individually approved, otherwise they are to be ineligible for IMA and capitalized based on the Standardised Approach. There are strict requirements fo both probability of default and loss-given-default measures used for calibrations. A hierarchy of sources where PDs and LGDs are obtained from, must be established by the bank beforehand (BCBS (2016a)).
2.4.6. Stress testing

Banks eligible for IMA must have both trading desk-level and firm-wide stress testing processes. The stress scenarios should cover low probability events in all major types of risks and should incorporate market and liquidity risk as well. The supervisor requires the bank to provide further details of stress testing in three areas upon request. In the first case, no simulation is required, the bank only provides information on its largest losses that occurred during the course of the reporting period. The second area covers stress scenarios of either past disturbances (e.g. 2007-08 subprime crisis) or of assumption violation simulations (e.g. volatilities or correlations). These two are prescribed by the authorities, however as a third exercise, the bank must develop its own stress tests that reflect the unique portfolio characteristics and exposures of the bank (BCBS (2016a)).
Chapter 3.

Implementation

How much of a difference would a choice between the Internal Models Approach and the Standardised Approach mean to a Dutch bank with regards to its market risk capital charge? To address our research question, we applied a number of relaxations and assumptions that are described in this Chapter. The timeframe of our analysis is set in 2017. The changes proposed in BCBS (2018a) are not incorporated in the implementation.

First of all, we only compare the SbM to ES hence deeming the Default Risk Charge and Residual Risk Add-On out of scope. As described above, both measures are to be calculated at trading desk level if a bank opts for the use of IMA and receives regulatory permission. The reasoning is two-folded, on the one hand in case the bank would lose the IMA accreditation at the bank, or at the desk level, the infrastructure to calculate the SA should be in place as an alternative. On the other hand, typically not all trading desks will be eligible to use IMA.

According to the Quantitative Impact Study of BCBS (2015), around 60% of trading desks fail the PLA test, meaning that these will be capitalized on SA. It is important to note that these results are based on the previously set PLA metrics that are out of scope since the publication of BCBS (2018a).

For this reason, we chose to ignore the PLA or the desk structure requirements in their current form throughout the implementation, but instead assume the following. An SA charge will always be higher at a desk level than the IMA charge. This means that by not taking into account the possibility of a trading desk fallout and capitalizing the whole portfolio based on IMA, we can only derive a theoretical
maximum concerning the difference to the SA charge.

A further relaxation is the choice of excluding non-modellable risk factors and the corresponding stressed capital add-on all together, as data limitations would have caused the stress scenario design and implementation requirement extremely challenging to fulfill.

We calculated the capital charge for a model portfolio, consisting of instruments considered typical of the trading activity of the bank. The construction of this portfolio is detailed in the following section.

3.1. Portfolio construction

To analyze the various effects of FRTB on the capital requirement calculation of the bank, we need a stylized portfolio to model the changes. Constructing such a portfolio is burdened with the trade-off between relevance and modellability. A portfolio that mirrors the real trading positions of the bank would be too complex to implement, but conclusions drawn from a too simple example could easily lose relevance. In this section we describe the series of decisions made to keep a healthy balance between these two perspectives.

As of 10th March 2017, the Value-at-Risk of the fixed-income (FI) and interest rate derivatives (IRD) portfolio constitutes almost 80% of the full portfolio’s VaR. As a first consideration we decide to focus on the interest rate risk since it accounts for the vast majority of the bank’s risk exposure. Furthermore, excluding other asset types substantially decreases the computational hardship, so it appears to be a practical restriction.

As 95% of the IRD and 88% of the bond positions’ value is denominated in euro, we exclude any positions traded in other currencies. Although we later find that the total exclusion of the FX risk class is not possible, this exclusion still makes the calculations notably easier.

3.1.1. Attributes of the IRD portfolio

To further explore the composition of the IRD portfolio, we look at the absolute mark-to-market values of each product type, compared to the full portfolio. We
Table 3.1.: Absolute net present value of major asset types denominated in euro

<table>
<thead>
<tr>
<th>Asset type</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coupon bonds</td>
<td>3,298,125,567</td>
</tr>
<tr>
<td>Zero Coupon bonds</td>
<td>1,294,864,506</td>
</tr>
<tr>
<td>Swaps</td>
<td>1,274,852,394</td>
</tr>
<tr>
<td>Swaptions</td>
<td>413,390,828</td>
</tr>
<tr>
<td>Loan/Borrow swap cash flows</td>
<td>148,111,474</td>
</tr>
<tr>
<td>Caps &amp; Floors</td>
<td>72,196,107</td>
</tr>
<tr>
<td>Inflation products</td>
<td>1,902,029</td>
</tr>
<tr>
<td>FRA</td>
<td>72,504</td>
</tr>
</tbody>
</table>

find that swaps (interest rate and cross-currency) and swaptions cover 88% of the derivatives portfolio, hence we decide to exclude other product types such as FRAs, inflation products, caps, floors and loan/borrow swap cash flows. Swaptions are excluded at a later stage, because the volatility surfaces needed in their pricing would have introduced NMRFs into the IMA calculations.

3.1.2. Swap portfolio

Within the class of swaps, vanilla interest rate swaps (IRS) and cross-currency swaps (CCS) contribute 51% and 11% to the IRD portfolio respectively, while averaging, callable and constant maturity swaps make up less than 1%. Therefore we conclude that modeling the swap portfolio with CCSs and vanilla IRSs is a reasonable choice. The inclusion of CCS means that the FX risk class is also to be computed in the Standardised Approach.

With regards to the composition of the euro IRS portfolio, we note that 93% of the outstanding notional is built of swaps with a tenor less than 30 years, and 80% with less than 20. 95% of notional associated with the fixed legs of the swaps is payed annually, while approximately the same ratio of the floating legs is payed either every 6 or 3 months, 6 month being the majority. All floating legs are based on the respective vertex of the Euribor curve.

Although the CCS portfolio includes legs of 7 different currencies, as EUR, USD and NOK covers 90% of the sum of notionals, we only include these in the stylized portfolio, such that one leg is always denominated in the reporting currency, hence euro. 88% of the notional corresponds to floating legs, thus we decide to include only
floating-floating swaps. As a result the number of possible variations decreases to four, since one leg is always in euro. 93% of floating legs is payed quarterly, so in the exercise we apply this as a default payment frequency for all cross-currency swaps. As both legs of the positions are floating rates, we can treat the swaps later as long and short floating rate bonds.

As to maturities, we include every year until 2023, and an additional point in 2025, representing the ratio of CCSs maturing between 2024 and 2026. This way we manage to cover 94% of the notional of the CCS portfolio. As there are no swaps denominated in NOK after 2020, that leaves us with a total of 24 cross-currency swaps in the model portfolio including both EUR paying and recieving swaps.

3.1.3. Attributes of the FI portfolio

Conducting a similar drill-down analysis, we take the maturities, issuers, coupon types and countries of origin into consideration when exploring the FI portfolio. With regards to issuer, we find that more than 99% of the bond portfolio’s value is issued by governments, and the following four countries cover 85% of that value: France, Netherlands, Belgium and Germany. As for maturities, only 7% of bonds have a maturity over 10 years, so we only focus on smaller than 10-year horizons. While 26% of the FI portfolio consists of zero coupon bonds, 34% accounts for coupon bonds, 95% of which is payed annually. Other constituents of the FI portfolio are various money market instruments.

Examining the directions of the trades we notice that the ratio of short positions within the absolute value of the bond portfolio is different across both dimensions: country of origin and maturity. While only 9% of Belgian bond positions are short, that of French bonds is 47%. In case of Dutch and German bonds, the ratio is 18% and 26% respectively. With regards to maturity horizons, the typical short ratio is between 30-35% in half of the buckets, however there are 2 notable outliers: among bonds maturing in the following 6 months, only 2.6% is short, while between 3 to 5 years, the ratio is 49%.

Beside bonds, the amount of money market instruments is substantial (23%). Since these are mostly certificates of deposit (CD) that - from a risk perspective - behave very similarly to a zero coupon bond, we only use the latter in the model portfolio,
but representing the ratio of CDs as well.

### 3.1.4. Final model portfolio

The final stylized portfolio consists of bonds, interest rate swaps and cross-currency swaps. All instruments are imaginary, constructed based on weighted averages of the characteristics of the real portfolio (e.g. average coupon value of German bonds of a certain maturity bucket is represented in one bond). There is a total of 63 government bonds that reflect the different maturities, issuers, coupon types and the sum of short/long positions.

The IRS portfolio is based on payment frequency (3 or 6 months), maturity and the direction of the position, with an overall of 48 swap trades. Cross-currency swaps reflect different maturities and currencies of the second leg (either USD or NOK). In all 24 cases both legs are floating rates, and the euro rate is paid in 12 cases.

### 3.1.5. Mapping of risk factors

For the investment grade credit instruments only the issuer specific curves are relevant risk factors. All later calculations include the bootstrapped curves that normally enter the pricing calibrations of the bank. The credit curves of the four countries (Belgium, Germany, the Netherlands and France) are typically stored on 17 vertices and are derived from respective zero-coupon bonds. The interpolation methodology used is always linear.

The interest rate swaps’ floating legs are derived from and hence are exposed to the Euribor 3 month and 6 month curves respective of their payment frequency. For the discounting of the fixed leg, the OIS Euro discount curve is used thus it is a risk factor for all IRS instruments.

In the pricing of cross currency swaps the EURUSD and EURNOK rates enter the calculations as well as the reference curves of the floating legs. Basis curves between USD and the respective currency - in this case euro and norwegian krone - are used for discounting. This practice is due to the fact that the pricing conventionally happens against USD, however the bank’s reporting currency is euro.
3.2. Implementation of SA

The final portfolio is exposed to GIRR, FX and CSR risk classes as seen in Table 3.2. Since we did not include any optionality in the portfolio, only the delta risk charge is computed for the Sensitivities-based Method. This is done by aggregating the asset level sensitivities to bucket and then risk class level, applying the prescribed correlations. A simple sum is taken of the risk class charges to determine the charge of the correlation scenario. The aggregation is repeated two more times using upward and downward adjusted correlation structures at both asset and bucket level, and out of the three charges the highest is the SA capital requirement.

The GIRR (General Interest Rate Risk) risk class in our case is partitioned into three currency buckets: EUR, USD and NOK. For each curve ten vertices are the prescribed risk factors\(^1\). Unlike other risk classes, for GIRR the bucketing does not define the weights applied to the sensitivities but instead the vertices do. Weights associated with certain currencies (that are assumed to be more liquid than others) can be divided by the square root of 2 according to paragraph 4.75. (b), which

\(^{1}\text{The vertices are 3M, 6M, 1Y, 2Y, 3Y, 5Y, 10Y, 15Y, 20Y, 30Y.}\)
was applied in our case for all USD and EUR denominated curves. The original weights range from 1.5\% to 2.4\% the highest term having the smallest weight. For cross-currency basis risk a term structure-independent weight is defined at 2.25\%. Correlations are based on curve type, bucket and vertex and are floored at 40\%. Between-currency correlations are constant 50\% (BCBS (2016a)).

The GIRR deltas are calculated for all three types of products. An IRS for instance will have an exposure to two curves, hence 20 vertices. These are calculated based on an absolute shock of one basis point, analogous to a PV01 measure, keeping the credit spread (if present e.g. for bonds) constant (see Equation (5) where $V_i(\cdot)$ is the value function of the instrument dependent of the given risk factor). For CCS, the cross-currency basis curve’s 10 vertices are also risk factors.

$$GIRR_{\text{delta}}_{k,r_t} = \frac{V_i(r_t + 0.0001, cs_t) - V_i(r_t, cs_t)}{0.0001}$$ (3.1)

CSR (Credit Spread Risk: non-securitisation) risk factors are five vertices\(^2\) of the credit spread curves, while the corresponding sensitivities are calculated in a similar vein as the GIRR. Since the original term structure of the bank did not include a 6-month pillar which is to be shocked in the SA framework, we flat extrapolated the one-year pillar. To preserve consistency, we use the same extrapolated curves for IMA calculations as well.

In general CSR-NS risk factors are segregated into sixteen buckets based on sector and credit quality, but in our working example all issuers fall into the investment grade sovereigns category, hence bucket number 1. This means that we do not need across-bucket aggregation for the CSR risk class, the bucket level risk charge will be the class-level charge as well.

The risk weight for this bucket is the lowest possible as one would expect: 0.5\%. Correlations are ranging from 0.227 to 1 based on tenor, issuer name and basis curve.

Unlike CSR and GIRR, FX delta sensitivity is defined as a relative shock of 1\% rather than an absolute one (see Equation (6)).

$$FX_{\text{delta}}_k = \frac{V_i(1.01FX_k) - V_i(FX_k)}{0.01}$$ (3.2)

\(^2\)The vertices are 6M, 1Y, 3Y, 5Y, 10Y.
Each currency pair forms a separate bucket hence there is no need for intra-bucket correlations. A uniform weight is set at 30% having the possibility of reduction much like in the GIRR case. The correlation between buckets is 60% in all cases.

Liquidity horizons do not enter the delta calculations, hence they are not needed in our example.

In practice, all $V_i(\cdot)$ values were calculated using the bank’s own pricing methodologies, which typically means using linearly interpolated curves that are more granular than the risk factor vertices of BCBS (2016a). The deltas are assigned to the vertices also linearly while the sensitivity itself is kept constant. Both swap-type instruments are priced by separate legs and cross-currency swaps assume a notional exchange at maturity, constituting material FX risk.

Since the bucketing structure of the revised Standardised Approach requires the banks to store new sorts of terms and conditions data (e.g. issuer types, liquidity horizons, curve types) for their risk models, it also brings around operational challenges in the implementation. In our example we chose to calculate the sensitivities in MatLab using the bank’s own pricing models, however to store the tnc data a seven-table database was built in MySQL. The aggregation of the sensitivities was implemented through stored procedures for each risk class separately.

### 3.3. Implementation of IMA

In the implementation of IMA most modelling choices are to be made at the bank’s discretion. The standard does not specify any directives other than the quantitative requirements of the backtests and some qualitative expectations concerning the processes.

Banks are free to choose from historical or Monte Carlo type distribution generation. We chose to conduct a historical simulation since this approach is in line with the bank’s current regulatory VaR modelling methodologies, and as described in McKinsey & Company (2012) it is also standard across the banking industry.

The IMA charge for a fully varied portfolio (unlike the one in our example) would require the calculation of up to 120 different ES metrics. (For each of the 7 risk classes plus the Unconstrained version one has to calculate an ES for each of the
5 liquidity horizons and then repeat these 40 calculations on the stressed period and the recent period with a reduced set of risk factors.) It is important to note that Monte Carlo type model usage will most probably decrease due to this level of complexity as the computational time\(^3\) for bigger portfolios could multiply as highlighted by Laurent & Omidi Firouzi (2017).

Instead of introducing any kind of weighting methodology, we followed the current practice of the bank and applied an equally weighted ES calculation. A viable alternative could have been the use of 0.94 as a decay factor, an exponential weighting, or the volatility weighted methodology suggested by Laurent & Omidi Firouzi (2017).

For each risk factor we chose the shock type such that it matches the current treatment. This means that for all interest rate curves (BOR types, cross-currency basis and credit spread) we apply absolute shocks while for exchange rate relative shocks. Not surprisingly this is exactly in line with the shocking methodology of the Sensitivities-based Method Delta calculations.

Once shocks are applied to the risk factors, the instruments in the portfolio are fully revalued rather than applying a Taylor-expansion approach. The repricing of instruments is somewhat more computation-intensive especially for instruments with optionality, but it is also better at capturing exposures. In the lack of optionality in the portfolio, this trade-off is almost non-existent, making this choice evident.

As mentioned before, a recalculation of the Expected Shortfall is necessary with a reduced set of risk factors for a stressed period and the recent period (See Equation (2)). In fact this means that the final ES is the upscaled version of the stressed period, taking into account that not all current risk factors were available during the stressed period.

The stressed period must be the length of 12 months representing the largest loss over the observation horizon dating back to at least 2007. This period by regulatory demand must be weighted equally when used for scenario generation. An update is required at least monthly and on specific occasions when the exposure of the bank changes materially (BCBS(2016a)).

Being limited by data availability we chose to use the period of the current Stressed VaR calculations instead of searching for the most damaging period under

\(^3\)Even though our stylized portfolio is not exposed to all liquidity horizons let alone all risk classes, even the historical simulation approach took around 30 minutes to run in MatLab.
ES. Therefore we also ignore the monthly update requirement, however it does not seem to be a material relaxation. During the two-month window of our test case we assume the portfolio and hence the risk factor exposure to be constant and note that no regime change occurred during that time, prompting us to believe that the 12 most damaging months remained constant.

The constant stress period assumption and the simplified nature of the model portfolio allows for further relaxations. Since our current risk factors were also available during the stressed period, the reduced set in our example equals the full set, hence the two further ES calculations in Equation (2) become unnecessary. This simplification however could rarely be made in case of real life portfolios, for instance when it contains any equity that had its IPO later than the stressed period, not all risk factors will be available for the stressed period.

\[ ES_i = ES_{R,S,i} \cdot \frac{ES_{F,C,i}}{ES_{R,C,i}} \]

\[ F = R \]

\[ ES_i = ES_{F,S,i} \cdot \frac{ES_{F,C,i}}{ES_{F,C,i}} \]

\[ ES_i = ES_{F,S,i} \cdot 1 \]

Another issue arises from data limitations. The bank stores only a 251-day history of the risk factors in the stressed period. FRTB however requires the bank to calculate historical shocks of ten days rather than upscaling one-day shocks to a ten-day horizon. This means that to calculate the ES for the standard 250 days, we would need 260 days of history, of which we were ten days short. In the absence of proper risk factor vectors we chose to work with 240 scenarios instead.

Once we have the PnL vector of the historically simulated scenarios, the 97.5% ES is calculated as the average of the 2.5% worst cases. Since we are using a 240-long PnL vector, it is exactly 6 PnLs making further interpolation choices unnecessary. We note that for a 250-long scenario vector this would be 6.25 which is typically solved by adding the fourth of the 7th vector element to the averaging.

In the model portfolio as seen in Table 3.2 we have 10-day and 20-day liquidity horizon risk factors and three risk classes. With the inclusion of the Unconstrained
scenario, 8 ESs are to be calculated. For example a GIRR Expected Shortfall at the
10-day liquidity horizon includes only GIRR risk factors, while at the 20-day horizon
only GIRR risk factors with 20-day or longer horizon. The Unconstrained scenarios
are fairly similar except that all risk factors are involved irrespective of their risk
class.

Equation (1) for the two liquidity horizons simplifies to Equation (7) as the scaling
factor under the square root equals 1 and the summations runs up to j = 2. Hence
for each risk class the IMCC is calculated following Equation (7):

\[ IMCC_{i} = \sqrt{(ES_{10}(P))^{2} + (ES_{10}(P, 2)\sqrt{(LH_{2} - LH_{1})/10})^{2}} \]  \hspace{1cm} (3.3)

where \( LH_{2} = 20 \), \( LH_{1} = 10 \), \( ES_{10} \) is the 10-day Expected Shortfall including all
risk factors and \( ES_{10}(P, 2) \) is the 10-day Expected Shortfall including all risk factors
of 20-day or longer liquidity horizon.

The daily IMCC value for the full portfolio was computed based on Equation (3) as
the weighted average of the four \( IMCC_{i} \) values. To obtain the portfolio level capital
requirement in the absence of a Stressed ES charge (needed for non-modellable risk
factors only) we still need a 60-day history of IMCC values to determine the average
of such. For this reason our analysis includes 60 trading dates from 1st March 2017
until 31st May 2017. As outlined before, during this period we assume the portfolio
to be constant. Note however that a material sum of short term bonds mature in
April during the course of these 60 days.

As for IMA no further data storage was necessary, hence the implementation in
a whole was done in MatLab. Since no PLA was assumed, no desk structure was
introduced either, meaning that the whole portfolio was capitalized as if it was held
by one trading desk.
Chapter 4.

Analysis

Because of the high dimensionality of the FRTB puzzle, solving it is only possible through comprehensive analysis of the difference between the two computational methods. In the following sections, we analyze and compare them, presenting additional insight into their differences.

4.1. Standardised Approach results

The overall Standardised Approach capital charge is computed of risk class charges by simple summation. This means, that diversification across risk classes is not acknowledged in this approach. A possible capital charge is associated with all three correlation scenarios (see 3.2.2, FRTB overview), out of which the greatest will be the market risk capital requirement.

Table 4.1.: Standardised Approach charges of the full portfolio by risk class, corresponding to each correlation scenario in thousand euros.

<table>
<thead>
<tr>
<th>Risk class</th>
<th>Default scenario</th>
<th>High correlation scenario</th>
<th>Low correlation scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td>GIRR</td>
<td>162 694</td>
<td>166 633</td>
<td>142 405</td>
</tr>
<tr>
<td>CSR</td>
<td>10 351</td>
<td>11 256</td>
<td>9 359</td>
</tr>
<tr>
<td>FX</td>
<td>10 311</td>
<td>10 784</td>
<td>9 816</td>
</tr>
</tbody>
</table>

As can be seen in Table 4.1, in our working example the upward shocked correlation structure results in the highest capital charge, approximately €188.67 million. Compared to the other two correlation scenarios, this is 2.9% and 16.8% higher than that of the default, and the downward shocked correlation scenarios respectively.
This indicates that the increased correlation of risk factors could be demaging to the portfolio, while the decrease in correlation would pose materially less risk according to the standard. The comparison of correlation structures in the two approaches are revisited later.

Within the relevant charge, the vast majority, 88.32% of capital is inflicted by GIRR, while the CSR and FX charges construct 5.97% and 5.72% of the overall result respectively. The class level charges would normally come from the summation of the three components (delta, vega, curvature), however there is no optionality present in the portfolio, hence only delta charges are calculated, neither vega, nor curvature.

In case of CSR, there is only one bucket charge (only investment grade sovereigns), whereas for GIRR interest curves for each currency (EUR, USD, NOK) constitute a bucket. The ratio of bucket level charge for EUR among all three is 98.7%. This is expected since USD and NOK only effects one leg of each cross-currency swap.

### 4.2. Internal Models Approach results

The capital charge based on the Internal Models Approach is €53.76 million, only 28.5% of the SA charge. This value is the average of the previous 60 days’ value multiplied by 1.5, calculated according to Equation (4). This is assuming, that the bank passes the overall 10-day 99 % VaR backtesting requirement with 4 or less exceptions per year, otherwise a higher multiplicative factor could be inflicted.

Important to note that we assumed a constant portfolio over the 60 days including some bonds that reached the maturity during this window, such that they properly reflect the short-term fixed-income exposure of the bank. For this reason we can see a downward slope in Figure 4.1 which would not be the case in a real world example.

As opposed to SA, the IMA acclaims some diversification effect. The risk class charges of the Standardised Approach can be matched with the constrained IMA IMCC values, as these are charges only associated with one sole risk class. Beside these, the IMA also takes into account an unconstrained version (meaning that diversification across all risk classes is possible). This results in half of the diversification effect
The sum of constrained risk charges is 159% of the Unconstrained (diversified) charge, suggesting that there is substantial diversification present across risk classes in the model portfolio. As noted before, this is completely disregarded in case of the SA. Note, that the diversified charge is even smaller than the GIRR. To give an explanation to this phenomenon and as a sanity check, we present the scenarios that we average for each ES variation based on risk class and liquidity horizon in Table 4.2 below.

It is visible from the scenario indices of day 62, that at the 10-day liquidity horizon, there is almost no difference between the PnL values used for the calculation of the GIRR ES and the Unconstrained (i.e. diversified) ES. For the 20-day horizon however, these are totally different, but the same as used in the 20-day ES of the CSR risk. This means that among the 10-day horizon risk factors, it is the GIRR risk that drives the diversified ES whereas for the 20-day horizon, it is the Credit Spread Risk.

\[ IMCC = 0.5(IMCC(U)) + 0.5\left(\sum_{i=1}^{R} IMCC(C_i)\right) \]
Table 4.2: Scenarios used in the calculation of Expected shortfall for each risk class and liquidity horizon on day 62.

<table>
<thead>
<tr>
<th></th>
<th>10-day Liquidity Horizon</th>
<th>20-day Liquidity Horizon</th>
</tr>
</thead>
<tbody>
<tr>
<td>GIRR</td>
<td>54, 49, 50, 18, 53, 51</td>
<td>144, 145, 143, 148, 149, 146</td>
</tr>
<tr>
<td>CSR</td>
<td>207, 208, 176, 211, 177, 206</td>
<td>207, 208, 176, 211, 177, 206</td>
</tr>
<tr>
<td>FX</td>
<td>187, 186, 190, 188, 191, 189</td>
<td>181, 190, 192, 189, 146, 147</td>
</tr>
<tr>
<td>Unconstrained</td>
<td>54, 18, 50, 49, 1, 53</td>
<td>176, 207, 177, 208, 206, 211</td>
</tr>
</tbody>
</table>

Diversification can be detected in both cases when we compare the Unconstrained ES to the respective Constrained ES where the scenario indices match, and in both cases the Unconstrained ES is lower. However we can not argue that the differing scenarios cause the difference between the GIRR and Unconstrained results, because the latter is higher for the 20-day liquidity horizon.

Instead we note that as expected the 10-day horizon ES measures are higher as more risk factors are shocked in this case. For GIRR the difference is of factor of 58 providing evidence that this component is the stronger driver. In essence, the Unconstrained IMCC can be lower than the GIRR itself, because for the 10-day horizon the diversification effect is high when FX risk is included in the estimate.

On the undiversified risk class level there is a notable difference between the proportion of class charges in SA and IMA. Within the constrained IMCCs, the ratio of GIRR risk charge is only 63.2%, 25 percentage points lower than in case of SA. While both FX and CSR risk charges are higher than in case of SA, CSR stands out with its 27.45%, four times higher ratio than in SA.

Examining the level of risk class charges might appear less practical since the IMA values go through a number of alterations at later stages (weighted summation, averaging, multiplicator, maximum), but the difference of ratios is informative. We see that while SA is higher by a factor of 6 in case of GIRR, and a factor of 2.7 for FX, the CSR SA charge is slightly lower. The reason for this is to be explained below in a later section.

So far, based on the risk class charges and their differences, we can already outline
some initial observations. First of all, the SA charge is higher than the IMA charge by a factor of 3.5. The root of this is two-folded. The sum of undiversified charges is higher in SA, and also diversification does not play a role in SA. An interesting outlier in this context is the CSR class, where the corresponding IMA charge is slightly higher than the SA. To explore further differences, we break up the portfolio into homogenous sub-portfolios, based on asset type and maturity.

4.3. Single asset type portfolios

We create three different portfolios containing the three asset types and compare the SA and IMA charges of these portfolios. The capital charges associated with each portfolio in SA and IMA can be seen in Table 4.3.

<table>
<thead>
<tr>
<th></th>
<th>Interest-rate swap</th>
<th>Bond</th>
<th>Cross-currency swap</th>
</tr>
</thead>
<tbody>
<tr>
<td>SA</td>
<td>129783</td>
<td>46879</td>
<td>12798</td>
</tr>
<tr>
<td>IMA</td>
<td>23778</td>
<td>29311</td>
<td>7321</td>
</tr>
</tbody>
</table>

Since the IRS portfolio is denominated in euro, it is only exposed to 10-day liquidity horizon GIRR risk. We have seen already, that the interest rate risk is higher weighted in the standardised calculations. In this case, the SA charge (€130 million) is 5.46 times higher than the final IMA charge (€23.8 million). There is no possible diversification effect, hence the difference is caused by either or all of the following three factors: difference in aggregation, applied shocks or the correlation structure.

While the nature of the shocks is fairly easy to examine, the other two are somewhat more challenging. Later on we show how the difference in applied shocks materialize in case of an only-IRS portfolio.

With regards to the only-bond portfolio, the difference between the overall charge is the smallest but the SA charge is 160% of the IMA. Again, comparison between the risk class charges of SA and unconstrained IMCC values of IMA can be made. Interest rate risk constitutes 76% of the SA charge, while only 50.4% of the IMA charge.
The diversification effect across risk classes is slightly higher than in case of the full portfolio: the sum of the Constrained IMCCs is 164.8% of the Unconstrained charge. The same ratio for the portfolio containing only cross-currency swaps is 109.8%, meaning that the diversification between credit spreads and interest rate curves is more substantial than between FX and interest rate curves. This finding is in line with our previous observation made at the full portfolio level.

Within the SA charge of the CCS-only portfolio, only 15.7% is associated with GIRR risk, while in IMA the corresponding ratio is 19.7%. Overall, the SA inflicts a charge that is 175% of that of the IMA, with FX risk being the majority in both cases. Interestingly, the bucket level charges of GIRR risk are highest in case of the downward shocked correlation scenario, however at this level this does not mean any change to the final risk measure, only the upward shocked correlation scenario contributes. Out of these bucket level charges, the highest is the interest rate risk corresponding to the USD curves. The ratio of USD inflicted bucket charge among all three charges is 86.45%, whereas NOK causes the smallest charge, 5.04%.

Comparing the sum of these sub-portfolios to the full portfolio can draw a picture on the diversification effects across different asset types. With regards to SA, the sum of the charges of the single-asset portfolios is only 1% higher than the charge of the overall portfolio, meaning, that there is almost no diversification. This is a sensible result, since only the GIRR risks could offset each other in this case. Nonetheless, there is a 12% difference between the sum of IMA subportfolio charges and the full portfolio capital requirement. That is because the diversification can work between risk classes as well.

### 4.4. Homogenous maturity portfolios

To see whether time horizon effects SA and IMA differently, we created sub-portfolios based on the maturity of products. Assets maturing within 1 year, between 1 year and 5 years and over 5 years constitute the short, medium and long portfolios respectively. The ratios of these sub-portfolios based on net present value are 23.9%, 25.5% and 50.6% in maturity order. The results are contained in Table 4.4.

In comparison, aggregated separately via IMA and then simply summed, the ratios
Table 4.4.: NPV, SA charge and IMA charge of homogeneus maturity portfolios in thousand euro and in percentage ratio of the sum of the portfolios.

<table>
<thead>
<tr>
<th></th>
<th>Net Present Value</th>
<th>SA charge</th>
<th>IMA charge</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Value</td>
<td>Value</td>
<td>Value</td>
</tr>
<tr>
<td>Short</td>
<td>559 317</td>
<td>9 314</td>
<td>5 544</td>
</tr>
<tr>
<td></td>
<td>23.92%</td>
<td>4.70%</td>
<td>9.21%</td>
</tr>
<tr>
<td>Medium</td>
<td>595 655</td>
<td>35 068</td>
<td>16 313</td>
</tr>
<tr>
<td></td>
<td>25.47%</td>
<td>17.69%</td>
<td>27.11%</td>
</tr>
<tr>
<td>Long</td>
<td>1 183 306</td>
<td>153 817</td>
<td>38 326</td>
</tr>
<tr>
<td></td>
<td>50.61%</td>
<td>77.61%</td>
<td>63.68%</td>
</tr>
</tbody>
</table>

they constitute are 9.2%, 27.1% and 63.7%. This is in line with our expectations, since the risk of the long portfolio is over- while the risk of the short portfolio is underrepresented compared to the NPV ratios. The SA difference is even more visible. Within the sum, the long portfolio gives 77.6% of risk and only 4.7% is inflicted by the short bucket.

Similar to the previous settings, SA is higher than IMA in all cases, and is always based on the higher correlation scenario. The greatest difference is in case of the long portfolio, where the factor of difference is 4, while the lowest is in case of the short portfolio, 1.68.

This result suggests that SA weights long-term risk comparatively higher than IMA. We should take into account however that as we have seen already, SA overrates GIRR risk. Since the longest maturity instruments are mainly interest rate swaps, this could lead to false causality inference. Nevertheless we learn in a later section that indeed SA shocks are more damaging in the longer end of the curve.

Diversification across maturity buckets is again higher for IMA. Comparing the sum of the homogeneous maturity portfolios’ capital charges to the full portfolio’s, we find that it is 12% and 5% higher in case of IMA and SA respectively. Diversification within buckets (e.g. across risk classes) is only present for IMA and is highest in case of the medium maturity portfolio (sum is 193% of diversified), and lowest within the short-term bucket (120.6%).

Looking at the constrained risk class measures, we can see that the GIRR has always more weight within SA regardless of the maturity bucket, while CSR is overrepresented in IMA. FX has a peak contribution to the short-term portfolio, as Figure 4.2 shows. This is presumably due to three conditions. First of all the short term maturity means that the GIRR risk is inherently smaller, and secondly the fact that the ratio of plain interest rate swaps within the short bucket is only 1% has a
similar influence. Finally, the notional exchange at the maturity of the cross-currency swaps on its own poses a large FX risk.

Figure 4.2: Constrained and Unconstrained elements of IMCC throughout 60-day history within the short maturity portfolio

The negative slope of the GIRR and CSR risk in Figure 4.2 shows how the risk exposure decreases proportionally to the time to maturity, as the portfolio itself remains constant.

4.5. Analysis of shocks

The differences between SA and IMA charges, as stated before can be due to differing shocks, correlation structure between risk factors and the aggregation method applied. Out of these three, the shocks can be easily described.

In practical sense SA shocks are first order numerical Taylor-expansions since the delta is computed as the price change as a result of a one-basispoint pointwise shock to a certain curve. This is then multiplied by the weights, that are comparable to the 10-day shocks of the same vertices in the IMA framework. The latter however follows a full revaluation methodology rather than Taylor-expansion. Assuming that the pricing functions are linear, this effect can be disregarded.

Without non-modellable risk factors we do not have to work with the reduced set
Chapter 4. Analysis

of risk factors and full set separately, hence the only shocks we need to look at are the shocks in the stressed period. This makes the comparison of SA and IMA shocks more straightforward.

To compare the shocks IMA was calculated on, we use the case of the only-IRS portfolio first, since it is only exposed to 10-day horizon GIRR risk factors, thus we do not need to disentangle the various ingredients of the IMCC charge. A key difference between SA and IMA in shock handling is that IMA inherently always incorporates all shocks on the curve (i.e. 45 vertices in our case), while SA only contains 10.

Furthermore, of all simulated scenarios it is enough to detect the six most damaging in IMA to compare them to the prescribed SA shocks. The average of the shocks incorporated in the ES calculations for the SA vertices for each curve used in the IRS pricing is presented in Table 4.5. For comparison, SA weights are also included.

Table 4.5.: Average 10-day variations of GIRR risk factors in the 6 worse scenarios compared to prescribed SA shocks given in percentage.

<table>
<thead>
<tr>
<th></th>
<th>3M</th>
<th>6M</th>
<th>1Y</th>
<th>2Y</th>
<th>3Y</th>
<th>5Y</th>
<th>10Y</th>
<th>15Y</th>
<th>20Y</th>
<th>30Y</th>
</tr>
</thead>
<tbody>
<tr>
<td>Discount Curve</td>
<td>0.13</td>
<td>0.20</td>
<td>0.32</td>
<td>0.45</td>
<td>0.49</td>
<td>0.45</td>
<td>0.22</td>
<td>0.06</td>
<td>-0.01</td>
<td>-0.07</td>
</tr>
<tr>
<td>Euribor 3M</td>
<td>0.24</td>
<td>0.24</td>
<td>0.37</td>
<td>0.51</td>
<td>0.54</td>
<td>0.46</td>
<td>0.22</td>
<td>0.09</td>
<td>0.01</td>
<td>-0.09</td>
</tr>
<tr>
<td>Euribor 6M</td>
<td>0.20</td>
<td>0.20</td>
<td>0.35</td>
<td>0.50</td>
<td>0.53</td>
<td>0.43</td>
<td>0.19</td>
<td>0.07</td>
<td>-0.01</td>
<td>-0.07</td>
</tr>
<tr>
<td>SA shocks</td>
<td>1.70</td>
<td>1.70</td>
<td>1.59</td>
<td>1.33</td>
<td>1.22</td>
<td>1.06</td>
<td>1.06</td>
<td>1.06</td>
<td>1.06</td>
<td>1.06</td>
</tr>
</tbody>
</table>

From Table 4.5 it is evidentiary that the SA shocks are overly burdening compared to the IMA shocks in case of GIRR risk. Even the smallest difference in shocks is more than a factor of two. This provides a reasonable explanation as to why risk class ratios are so different for SA and why the SA capital charge of an only-IRS portfolio is 5.46 times higher.

We can also see that on average in the six worst PnL scenarios the three curves were almost 'humping' as they produced a downward movement on the long end. This is again very different from what the SA shocks would suggest, and also explains why the longer maturity portfolio (containing mostly IRSs) would produce a proportionally higher SA (4 times larger than IMA) than the full portfolio (3.5 times larger than IMA).

2As all three are euro curves, the weights are divided by √2 at the bank’s discretion
Chapter 4. Analysis

Not unexpectedly in BCBS (2018a) the Committee suggested to lower the original weights by 20-40% at each vertex, however the final decision is yet to be made.

4.6. The case of CSR risk

An important discovery of the previous analysis showed that while we expect SA to be higher not only at the portfolio level but also at each risk class level, for Credit Spread Risk in our example it is not the case. Similar to the previous example, the applied shocks can be shown in both methodologies.

Unlike GIRR, CSR risk can not be detached from other risk classes as we do not have an instrument exposed to only CSR risk factors. However we might argue that the Constrained \( IMCC_{CSR} \) is perfectly enough to be compared to the SA CSR charge since neither of them assumes any diversification effect. In that case it is also true that the \( ES_{10}(CSR) \) is the same as \( ES_{20}(CSR) \)\(^3\), hence the ES metric is yet again based on only six scenarios, rather than twelve or more.

To be able to look into the correlations this time, we reduce the portfolio to Dutch bonds only. The SA CSR charge for the portfolio consisting of 21 Dutch bonds is €5.49 million (again the upward shocked correlation structure results in the highest charge). The IMCC charge for only CSR risk is €5.53 million, slightly higher than the SA charge. As noted above, we attribute the difference to either the different shock sizes, correlation structures, or the aggregation.

To distill the aggregation’s effect on the charges one would have to assume the same correlation structure and shock sizes for both SA and IMA calculations. We however deemed this experiment to be out of scope and is left for later research. Instead we describe the other two factors in detail below.

The IMA 10-day shocks of the six most severe scenarios are well below 0.5%, the maximum shocks fall between 0.37% and 0.46% whereas the averages are between 0.13% and 0.37%. This means that based on solely the shock size, we would expect the SA charge to be higher.

We also assess the correlation structures. In the SA framework as only one curve is considered, all correlations are 0.65\(^4\). In IMA we only take into consideration the

\[^3\]There are no 10-day liquidity horizon CSR risk factors in our portfolio.
\[^4\]\( \rho_{kl} = \rho_{kl}^{(name)} \cdot \rho_{kl}^{(tenor)} \cdot \rho_{kl}^{(basis)} = 1 \cdot 0.65 \cdot 1 \) according to BCBS (2016a)
six relevant scenarios, and only 4 vertices as the 6-month pillar was flat extrapolated hence it won’t give a meaningful correlation in any case.

The correlation of the 1-year pillar with any given pillar is negative, while the long end of the curve (i.e. 5-year and 10-year pillars) is strongly correlated. This suggests that the portfolio is worst affected by a steepening curve. This however is not represented in the SA framework. We conclude that this difference is material enough to result in the SA charge being lower than its IMA counterpart in this example.

In the original BCBS (2012) proposal it is mentioned that the bucket weights and correlations of the Standardised approach were designed to match the 97.5% ES of the worst stress period of the available history. However it is also noted that major differences between the final IMA and SA inputs are to be expected as it is rarely the case that the most stressed period for the full portfolio (for IMA) is the same as the Committee detected for a certain risk class (for SA). This mismatch in both the correlations and the shocks is visible in the example of the Dutch bonds, paradoxically however it results in more similar charges in this case.

4.7. Quantitative Impact Study of BCBS

In 2015 the Basel Committee on Banking Supervision conducted a Quantitative Impact Study (QIS) based on the provided trading books of 44 banks (BCBS (2015)). It is important to note that the study was conducted based on the initial proposal which has undergone a number of major changes since.

For instance CSR weights were mapped not only based on bucket but also based on the maturity of the cash flows, the GIRR risk weights were notably higher and the multiplicative factor applied in the IMA charge calculation was set at 1. As a result the average ratio between the two proposed frameworks fell in the ballpark of 9 (SA being the higher), prompting the Committee to recalibrate most of the prescribed parameters.

As a final note we show that at a risk class level however, we can see high level similarities to our working example. According to Table 4 in BCBS (2015) the median difference between the SA and IMA charge for risk classes (ignoring the Default Risk Charge and NMRFs) was highest for GIRR class (1024%) and lowest for the CSR
class (335%). FX had a slightly higher median ratio in their study, 364%. (BCBS (2015) pp.12.). This is comparable to the case of our model portfolio where these ratios are 615%, 96% and 269% respectively.
Chapter 5.

Concluding remarks

FRTB challenges the banking industry in several different ways. Our research focused on understanding the quantitative requirements of the implementation and through a model portfolio showcasing the most vital question of a bank: Which approach to choose? Even though we do not intend to give a final answer to that exact question, we highlight some important factors that need to be taken into consideration.

In estimating the difference between the capital charge inflicted by the Standardised Approach and the Internal Models Approach we applied a number of relaxations. Given that the future of the current PnL Attribution test has recently been called into question (BCBS (2018a)), we chose to ignore both the trading desk structure and the IMA admissibility of the desks. By capitalizing the full portfolio using IMA, we estimated the maximum possible capital gain the bank could achieve by implementing internal models.

The capital requirement value for the real portfolio could change however in the presence of optionality and non-modellable risk factors that are expected to drive a material sum within the IMA framework according to ISDA (2016). In our working example we found that for a portfolio consisting of simple linear instruments exposed to only three risk classes, the SA charge is already 3.5 times higher than the IMA charge.

We attributed this to four main differences: the possible diversification effect, the shocks applied in each approach, the implied correlation structure and the aggregation procedure. We learned through different arrangements of the stylized portfolio that the interest rate risk is overrepresented in the SA charge through higher shocks, the
non-diversification feature and possibly the prescribed correlation structure. For SA, always the highest correlation structure prevailed out of the prescribed three.

We showed the diversification effects and the lack thereof in different partitions of the portfolio. Even though IMA assumes only half of the diversification across risk classes, it appears to be a significant difference to SA even for a simple portfolio. This holds a message that the desk structure has a material impact for when a desk falls out of IMA, the overall capital charge is bloated by the loss of the diversificational gain as well.

With regards to time horizons we found that the longer the exposure is, the higher the difference is between SA and IMA. It is both due to the fact that the GIRR exposure was higher in longer portfolios, and the fact that the SA shocks on the long end of the curve were on average 50 to 100 times bigger than the shocks incorporated in IMA through the most damaging scenarios of the stress period.

In the example of Dutch bonds we showed how the relation between IMA and SA might change due to the correlation assumptions in SA that disregards the burdening nature of a steepening curve to the portfolio. Even though this difference was detected at the risk class - level charge for a homogeneus portfolio exposed to only one CSR curve, for the full bond portfolio, the SA charge turned out to be approximately 160% of the IMA capital requirement.

We acknowledge that multiple aspects have been ignored during our implementation, however it is exactly the Catch 22 of FRTB: the need to implement IMA to be able to decide whether it is worth implementing it. Natural extension to our research would be the inclusion of optionality, NMRFs and once the final version is published, the PLA test to be able to optimize the trading desk structure accordingly.
## Appendix A.

### Portfolio constituents

<table>
<thead>
<tr>
<th>Asset id</th>
<th>Maturity</th>
<th>Long/short</th>
<th>Frequency</th>
<th>Fixed coupon</th>
<th>Notional</th>
</tr>
</thead>
<tbody>
<tr>
<td>irs1</td>
<td>31-8-2017</td>
<td>Long</td>
<td>6 months</td>
<td>4.08</td>
<td>1,537,005,047</td>
</tr>
<tr>
<td>irs2</td>
<td>31-8-2017</td>
<td>Short</td>
<td>6 months</td>
<td>3.86</td>
<td>1,537,005,047</td>
</tr>
<tr>
<td>irs3</td>
<td>31-8-2017</td>
<td>Long</td>
<td>3 months</td>
<td>4.18</td>
<td>597,724,185</td>
</tr>
<tr>
<td>irs4</td>
<td>31-8-2017</td>
<td>Short</td>
<td>3 months</td>
<td>3.51</td>
<td>597,724,185</td>
</tr>
<tr>
<td>irs5</td>
<td>31-8-2018</td>
<td>Long</td>
<td>6 months</td>
<td>3.58</td>
<td>2,396,330,668</td>
</tr>
<tr>
<td>irs6</td>
<td>31-8-2018</td>
<td>Short</td>
<td>6 months</td>
<td>2.41</td>
<td>2,396,330,668</td>
</tr>
<tr>
<td>irs7</td>
<td>31-8-2018</td>
<td>Long</td>
<td>3 months</td>
<td>4.11</td>
<td>931,906,371</td>
</tr>
<tr>
<td>irs8</td>
<td>31-8-2018</td>
<td>Short</td>
<td>3 months</td>
<td>3.63</td>
<td>931,906,371</td>
</tr>
<tr>
<td>irs9</td>
<td>31-8-2019</td>
<td>Long</td>
<td>6 months</td>
<td>2.9</td>
<td>1,926,912,129</td>
</tr>
<tr>
<td>irs10</td>
<td>31-8-2019</td>
<td>Short</td>
<td>6 months</td>
<td>2.8</td>
<td>1,926,912,129</td>
</tr>
<tr>
<td>irs11</td>
<td>31-8-2019</td>
<td>Long</td>
<td>3 months</td>
<td>3.94</td>
<td>749,354,717</td>
</tr>
<tr>
<td>irs12</td>
<td>31-8-2019</td>
<td>Short</td>
<td>3 months</td>
<td>2.7</td>
<td>749,354,717</td>
</tr>
<tr>
<td>irs13</td>
<td>31-8-2020</td>
<td>Long</td>
<td>6 months</td>
<td>2.6</td>
<td>2,832,872,344</td>
</tr>
<tr>
<td>irs14</td>
<td>31-8-2020</td>
<td>Short</td>
<td>6 months</td>
<td>2.23</td>
<td>2,832,872,344</td>
</tr>
<tr>
<td>irs15</td>
<td>31-8-2020</td>
<td>Long</td>
<td>3 months</td>
<td>3.79</td>
<td>1,101,672,578</td>
</tr>
<tr>
<td>irs16</td>
<td>31-8-2020</td>
<td>Short</td>
<td>3 months</td>
<td>2.44</td>
<td>1,101,672,578</td>
</tr>
<tr>
<td>irs17</td>
<td>31-8-2021</td>
<td>Long</td>
<td>6 months</td>
<td>2.78</td>
<td>2,568,059,204</td>
</tr>
<tr>
<td>irs18</td>
<td>31-8-2021</td>
<td>Short</td>
<td>6 months</td>
<td>2.55</td>
<td>2,568,059,204</td>
</tr>
<tr>
<td>irs19</td>
<td>31-8-2021</td>
<td>Long</td>
<td>3 months</td>
<td>3.2</td>
<td>998,689,690</td>
</tr>
</tbody>
</table>

Continued on next page
### Table A.1 – continued from previous page

<table>
<thead>
<tr>
<th>Asset id</th>
<th>Maturity</th>
<th>Issuer</th>
<th>Coupon</th>
<th>Notional</th>
</tr>
</thead>
<tbody>
<tr>
<td>irs20</td>
<td>31-8-2021</td>
<td>Short</td>
<td>3 months</td>
<td>2.62</td>
</tr>
<tr>
<td>irs21</td>
<td>31-8-2022</td>
<td>Long</td>
<td>6 months</td>
<td>3.43</td>
</tr>
<tr>
<td>irs22</td>
<td>31-8-2022</td>
<td>Short</td>
<td>6 months</td>
<td>2.57</td>
</tr>
<tr>
<td>irs23</td>
<td>31-8-2022</td>
<td>Long</td>
<td>3 months</td>
<td>3.88</td>
</tr>
<tr>
<td>irs24</td>
<td>31-8-2022</td>
<td>Short</td>
<td>3 months</td>
<td>2.57</td>
</tr>
<tr>
<td>irs25</td>
<td>31-8-2023</td>
<td>Long</td>
<td>6 months</td>
<td>3.04</td>
</tr>
<tr>
<td>irs26</td>
<td>31-8-2023</td>
<td>Short</td>
<td>6 months</td>
<td>2.87</td>
</tr>
<tr>
<td>irs27</td>
<td>31-8-2023</td>
<td>Long</td>
<td>3 months</td>
<td>4.2</td>
</tr>
<tr>
<td>irs28</td>
<td>31-8-2023</td>
<td>Short</td>
<td>3 months</td>
<td>2.66</td>
</tr>
<tr>
<td>irs29</td>
<td>31-8-2024</td>
<td>Long</td>
<td>6 months</td>
<td>3.23</td>
</tr>
<tr>
<td>irs30</td>
<td>31-8-2024</td>
<td>Short</td>
<td>6 months</td>
<td>2.74</td>
</tr>
<tr>
<td>irs31</td>
<td>31-8-2024</td>
<td>Long</td>
<td>3 months</td>
<td>4.32</td>
</tr>
<tr>
<td>irs32</td>
<td>31-8-2024</td>
<td>Short</td>
<td>3 months</td>
<td>2.8</td>
</tr>
<tr>
<td>irs33</td>
<td>31-8-2025</td>
<td>Long</td>
<td>6 months</td>
<td>3.12</td>
</tr>
<tr>
<td>irs34</td>
<td>31-8-2025</td>
<td>Short</td>
<td>6 months</td>
<td>2.49</td>
</tr>
<tr>
<td>irs35</td>
<td>31-8-2025</td>
<td>Long</td>
<td>3 months</td>
<td>4.7</td>
</tr>
<tr>
<td>irs36</td>
<td>31-8-2025</td>
<td>Short</td>
<td>3 months</td>
<td>2.55</td>
</tr>
<tr>
<td>irs37</td>
<td>31-8-2026</td>
<td>Long</td>
<td>6 months</td>
<td>3.21</td>
</tr>
<tr>
<td>irs38</td>
<td>31-8-2026</td>
<td>Short</td>
<td>6 months</td>
<td>3.86</td>
</tr>
<tr>
<td>irs39</td>
<td>31-8-2026</td>
<td>Long</td>
<td>3 months</td>
<td>3.57</td>
</tr>
<tr>
<td>irs40</td>
<td>31-8-2026</td>
<td>Short</td>
<td>3 months</td>
<td>2.2</td>
</tr>
<tr>
<td>irs41</td>
<td>31-8-2029</td>
<td>Long</td>
<td>6 months</td>
<td>2.99</td>
</tr>
<tr>
<td>irs42</td>
<td>31-8-2029</td>
<td>Short</td>
<td>6 months</td>
<td>2.35</td>
</tr>
<tr>
<td>irs43</td>
<td>31-8-2029</td>
<td>Long</td>
<td>3 months</td>
<td>4.73</td>
</tr>
<tr>
<td>irs44</td>
<td>31-8-2029</td>
<td>Short</td>
<td>3 months</td>
<td>3.11</td>
</tr>
<tr>
<td>irs45</td>
<td>31-8-2034</td>
<td>Long</td>
<td>6 months</td>
<td>1.026</td>
</tr>
<tr>
<td>irs46</td>
<td>31-8-2034</td>
<td>Short</td>
<td>6 months</td>
<td>1.176</td>
</tr>
<tr>
<td>irs47</td>
<td>31-8-2034</td>
<td>Long</td>
<td>3 months</td>
<td>3.89</td>
</tr>
<tr>
<td>irs48</td>
<td>31-8-2034</td>
<td>Short</td>
<td>3 months</td>
<td>3.65</td>
</tr>
</tbody>
</table>
## Appendix A. Portfolio constituents

Table A.2:

<table>
<thead>
<tr>
<th>Asset id</th>
<th>Maturity</th>
<th>Currency</th>
<th>EUR leg</th>
<th>Notional</th>
</tr>
</thead>
<tbody>
<tr>
<td>ccs1</td>
<td>31-8-2017</td>
<td>USD</td>
<td>Payed</td>
<td>1,624,910,483</td>
</tr>
<tr>
<td>ccs2</td>
<td>31-8-2017</td>
<td>NOK</td>
<td>Payed</td>
<td>580,781,069</td>
</tr>
<tr>
<td>ccs3</td>
<td>31-8-2018</td>
<td>USD</td>
<td>Payed</td>
<td>1,895,024,610</td>
</tr>
<tr>
<td>ccs4</td>
<td>31-8-2018</td>
<td>NOK</td>
<td>Payed</td>
<td>645,312,298</td>
</tr>
<tr>
<td>ccs5</td>
<td>31-8-2019</td>
<td>USD</td>
<td>Payed</td>
<td>876,828,908</td>
</tr>
<tr>
<td>ccs6</td>
<td>31-8-2019</td>
<td>NOK</td>
<td>Payed</td>
<td>742,109,143</td>
</tr>
<tr>
<td>ccs7</td>
<td>31-8-2020</td>
<td>USD</td>
<td>Payed</td>
<td>1,171,800,737</td>
</tr>
<tr>
<td>ccs8</td>
<td>31-8-2020</td>
<td>NOK</td>
<td>Payed</td>
<td>593,687,315</td>
</tr>
<tr>
<td>ccs9</td>
<td>31-8-2021</td>
<td>USD</td>
<td>Payed</td>
<td>842,173,890</td>
</tr>
<tr>
<td>ccs10</td>
<td>31-8-2022</td>
<td>USD</td>
<td>Payed</td>
<td>431,456,448</td>
</tr>
<tr>
<td>ccs11</td>
<td>31-8-2023</td>
<td>USD</td>
<td>Payed</td>
<td>673,597,908</td>
</tr>
<tr>
<td>ccs12</td>
<td>31-8-2025</td>
<td>USD</td>
<td>Payed</td>
<td>1,545,487,785</td>
</tr>
<tr>
<td>ccs13</td>
<td>31-8-2017</td>
<td>USD</td>
<td>Received</td>
<td>1,342,213,961</td>
</tr>
<tr>
<td>ccs14</td>
<td>31-8-2017</td>
<td>NOK</td>
<td>Received</td>
<td>483,984,224</td>
</tr>
<tr>
<td>ccs15</td>
<td>31-8-2018</td>
<td>USD</td>
<td>Received</td>
<td>1,926,949,098</td>
</tr>
<tr>
<td>ccs16</td>
<td>31-8-2018</td>
<td>NOK</td>
<td>Received</td>
<td>838,905,988</td>
</tr>
<tr>
<td>ccs17</td>
<td>31-8-2019</td>
<td>USD</td>
<td>Received</td>
<td>783,267,226</td>
</tr>
<tr>
<td>ccs18</td>
<td>31-8-2019</td>
<td>NOK</td>
<td>Received</td>
<td>516,249,839</td>
</tr>
<tr>
<td>ccs19</td>
<td>31-8-2020</td>
<td>USD</td>
<td>Received</td>
<td>889,051,774</td>
</tr>
<tr>
<td>ccs20</td>
<td>31-8-2020</td>
<td>NOK</td>
<td>Received</td>
<td>513,668,590</td>
</tr>
<tr>
<td>ccs21</td>
<td>31-8-2021</td>
<td>USD</td>
<td>Received</td>
<td>972,433,456</td>
</tr>
<tr>
<td>ccs22</td>
<td>31-8-2022</td>
<td>USD</td>
<td>Received</td>
<td>305,782,323</td>
</tr>
<tr>
<td>ccs23</td>
<td>31-8-2023</td>
<td>USD</td>
<td>Received</td>
<td>802,994,862</td>
</tr>
<tr>
<td>ccs24</td>
<td>31-8-2025</td>
<td>USD</td>
<td>Received</td>
<td>1,752,008,693</td>
</tr>
</tbody>
</table>
Appendix A. Portfolio constituents

Table A.3.:  

<table>
<thead>
<tr>
<th>Asset id</th>
<th>Maturity</th>
<th>Issuer</th>
<th>Coupon</th>
<th>Notional</th>
</tr>
</thead>
<tbody>
<tr>
<td>bond1</td>
<td>15-4-2017</td>
<td>Kingdom of Belgium</td>
<td>0.0</td>
<td>77,396,949</td>
</tr>
<tr>
<td>bond2</td>
<td>15-7-2017</td>
<td>Kingdom of Belgium</td>
<td>0.0</td>
<td>93,884,958</td>
</tr>
<tr>
<td>bond3</td>
<td>30-11-2017</td>
<td>Kingdom of Belgium</td>
<td>0.0</td>
<td>3,683,486</td>
</tr>
<tr>
<td>bond4</td>
<td>28-2-2021</td>
<td>Kingdom of Belgium</td>
<td>0.0</td>
<td>1,298,242</td>
</tr>
<tr>
<td>bond5</td>
<td>31-8-2024</td>
<td>Kingdom of Belgium</td>
<td>0.0</td>
<td>992,586</td>
</tr>
<tr>
<td>bond6</td>
<td>15-4-2017</td>
<td>Kingdom of Belgium</td>
<td>4.0</td>
<td>141,523</td>
</tr>
<tr>
<td>bond7</td>
<td>31-8-2018</td>
<td>Kingdom of Belgium</td>
<td>2.3</td>
<td>1,464,859</td>
</tr>
<tr>
<td>bond8</td>
<td>31-8-2019</td>
<td>Kingdom of Belgium</td>
<td>3.5</td>
<td>814,762</td>
</tr>
<tr>
<td>bond9</td>
<td>28-2-2021</td>
<td>Kingdom of Belgium</td>
<td>1.0</td>
<td>144,042</td>
</tr>
<tr>
<td>bond10</td>
<td>31-8-2024</td>
<td>Kingdom of Belgium</td>
<td>1.4</td>
<td>12,189,687</td>
</tr>
<tr>
<td>bond11</td>
<td>28-2-2021</td>
<td>Kingdom of Belgium</td>
<td>0.3</td>
<td>-1,869,585</td>
</tr>
<tr>
<td>bond12</td>
<td>31-8-2024</td>
<td>Kingdom of Belgium</td>
<td>1.6</td>
<td>-14,242,117</td>
</tr>
<tr>
<td>bond13</td>
<td>15-7-2017</td>
<td>Federal Republic of Germany</td>
<td>0.0</td>
<td>5,646,557</td>
</tr>
<tr>
<td>bond14</td>
<td>28-2-2021</td>
<td>Federal Republic of Germany</td>
<td>0.0</td>
<td>18,035,835</td>
</tr>
<tr>
<td>bond15</td>
<td>31-8-2024</td>
<td>Federal Republic of Germany</td>
<td>0.0</td>
<td>10,390,709</td>
</tr>
<tr>
<td>bond16</td>
<td>31-8-2018</td>
<td>Federal Republic of Germany</td>
<td>1.5</td>
<td>38,240,913</td>
</tr>
<tr>
<td>bond17</td>
<td>31-8-2019</td>
<td>Federal Republic of Germany</td>
<td>1.5</td>
<td>27,105,501</td>
</tr>
<tr>
<td>bond18</td>
<td>28-2-2021</td>
<td>Federal Republic of Germany</td>
<td>1.5</td>
<td>15,396,560</td>
</tr>
<tr>
<td>bond19</td>
<td>31-8-2024</td>
<td>Federal Republic of Germany</td>
<td>1.1</td>
<td>17,101,159</td>
</tr>
<tr>
<td>bond20</td>
<td>31-8-2018</td>
<td>Federal Republic of Germany</td>
<td>0.0</td>
<td>-14,336,858</td>
</tr>
<tr>
<td>bond21</td>
<td>28-2-2021</td>
<td>Federal Republic of Germany</td>
<td>0.0</td>
<td>-6,675,900</td>
</tr>
<tr>
<td>bond22</td>
<td>31-8-2024</td>
<td>Federal Republic of Germany</td>
<td>0.0</td>
<td>-557,064</td>
</tr>
<tr>
<td>bond24</td>
<td>31-8-2019</td>
<td>Federal Republic of Germany</td>
<td>2.1</td>
<td>-1,204,186</td>
</tr>
<tr>
<td>bond25</td>
<td>28-2-2021</td>
<td>Federal Republic of Germany</td>
<td>2.4</td>
<td>-10,413,934</td>
</tr>
<tr>
<td>bond26</td>
<td>31-8-2024</td>
<td>Federal Republic of Germany</td>
<td>1.1</td>
<td>-6,515,181</td>
</tr>
<tr>
<td>bond27</td>
<td>15-4-2017</td>
<td>Kingdom of Netherlands</td>
<td>0.0</td>
<td>27,265,555</td>
</tr>
<tr>
<td>bond28</td>
<td>15-7-2017</td>
<td>Kingdom of Netherlands</td>
<td>0.0</td>
<td>36,775</td>
</tr>
</tbody>
</table>

Continued on next page
Table A.3 – continued from previous page

<table>
<thead>
<tr>
<th>Asset id</th>
<th>Maturity</th>
<th>Issuer</th>
<th>Coupon</th>
<th>Notional</th>
</tr>
</thead>
<tbody>
<tr>
<td>bond29</td>
<td>31-8-2019</td>
<td>Kingdom of Netherlands</td>
<td>0.0</td>
<td>339,915</td>
</tr>
<tr>
<td>bond30</td>
<td>28-2-2021</td>
<td>Kingdom of Netherlands</td>
<td>0.0</td>
<td>23,855,016</td>
</tr>
<tr>
<td>bond31</td>
<td>31-8-2024</td>
<td>Kingdom of Netherlands</td>
<td>0.0</td>
<td>14,263,665</td>
</tr>
<tr>
<td>bond32</td>
<td>15-4-2017</td>
<td>Kingdom of Netherlands</td>
<td>0.5</td>
<td>28</td>
</tr>
<tr>
<td>bond33</td>
<td>15-7-2017</td>
<td>Kingdom of Netherlands</td>
<td>3.2</td>
<td>31,583,908</td>
</tr>
<tr>
<td>bond34</td>
<td>30-11-2017</td>
<td>Kingdom of Netherlands</td>
<td>1.6</td>
<td>32,896,079</td>
</tr>
<tr>
<td>bond35</td>
<td>31-8-2018</td>
<td>Kingdom of Netherlands</td>
<td>3.0</td>
<td>11,830,339</td>
</tr>
<tr>
<td>bond36</td>
<td>31-8-2019</td>
<td>Kingdom of Netherlands</td>
<td>2.5</td>
<td>12,051,725</td>
</tr>
<tr>
<td>bond37</td>
<td>28-2-2021</td>
<td>Kingdom of Netherlands</td>
<td>1.8</td>
<td>19,016,827</td>
</tr>
<tr>
<td>bond38</td>
<td>31-8-2024</td>
<td>Kingdom of Netherlands</td>
<td>1.4</td>
<td>46,332,626</td>
</tr>
<tr>
<td>bond39</td>
<td>31-8-2018</td>
<td>Kingdom of Netherlands</td>
<td>0.0</td>
<td>-6,713,028</td>
</tr>
<tr>
<td>bond40</td>
<td>28-2-2021</td>
<td>Kingdom of Netherlands</td>
<td>0.0</td>
<td>-2,900,520</td>
</tr>
<tr>
<td>bond41</td>
<td>15-4-2017</td>
<td>Kingdom of Netherlands</td>
<td>4.3</td>
<td>-1,072,032</td>
</tr>
<tr>
<td>bond42</td>
<td>15-7-2017</td>
<td>Kingdom of Netherlands</td>
<td>3.0</td>
<td>-2,920,148</td>
</tr>
<tr>
<td>bond43</td>
<td>30-11-2017</td>
<td>Kingdom of Netherlands</td>
<td>4.4</td>
<td>-976,305</td>
</tr>
<tr>
<td>bond44</td>
<td>31-8-2018</td>
<td>Kingdom of Netherlands</td>
<td>1.1</td>
<td>-290,353</td>
</tr>
<tr>
<td>bond45</td>
<td>31-8-2019</td>
<td>Kingdom of Netherlands</td>
<td>4.0</td>
<td>-2,549,214</td>
</tr>
<tr>
<td>bond46</td>
<td>28-2-2021</td>
<td>Kingdom of Netherlands</td>
<td>3.4</td>
<td>-7,598,943</td>
</tr>
<tr>
<td>bond47</td>
<td>31-8-2024</td>
<td>Kingdom of Netherlands</td>
<td>1.5</td>
<td>-42,179,339</td>
</tr>
<tr>
<td>bond48</td>
<td>15-4-2017</td>
<td>French Republic</td>
<td>3.6</td>
<td>354,835</td>
</tr>
<tr>
<td>bond49</td>
<td>15-7-2017</td>
<td>French Republic</td>
<td>4.9</td>
<td>163,073</td>
</tr>
<tr>
<td>bond50</td>
<td>30-11-2017</td>
<td>French Republic</td>
<td>4.5</td>
<td>1,209,681</td>
</tr>
<tr>
<td>bond51</td>
<td>31-8-2018</td>
<td>French Republic</td>
<td>3.5</td>
<td>6,944,235</td>
</tr>
<tr>
<td>bond52</td>
<td>31-8-2019</td>
<td>French Republic</td>
<td>2.8</td>
<td>630,756</td>
</tr>
<tr>
<td>bond53</td>
<td>28-2-2021</td>
<td>French Republic</td>
<td>2.0</td>
<td>22,537,430</td>
</tr>
<tr>
<td>bond54</td>
<td>31-8-2024</td>
<td>French Republic</td>
<td>2.0</td>
<td>94,072,406</td>
</tr>
<tr>
<td>bond55</td>
<td>28-2-2021</td>
<td>French Republic</td>
<td>0.0</td>
<td>-10,129,572</td>
</tr>
<tr>
<td>bond56</td>
<td>31-8-2024</td>
<td>French Republic</td>
<td>0.0</td>
<td>-13,249,676</td>
</tr>
<tr>
<td>bond57</td>
<td>15-4-2017</td>
<td>French Republic</td>
<td>2.1</td>
<td>-2,577,400</td>
</tr>
</tbody>
</table>

Continued on next page
Appendix A. Portfolio constituents

Table A.3 – continued from previous page

<table>
<thead>
<tr>
<th>Asset id</th>
<th>Maturity</th>
<th>Issuer</th>
<th>Coupon</th>
<th>Notional</th>
</tr>
</thead>
<tbody>
<tr>
<td>bond58</td>
<td>15-7-2017</td>
<td>French Republic</td>
<td>5.4</td>
<td>-143,681</td>
</tr>
<tr>
<td>bond59</td>
<td>30-11-2017</td>
<td>French Republic</td>
<td>4.1</td>
<td>-1,730,914</td>
</tr>
<tr>
<td>bond60</td>
<td>31-8-2018</td>
<td>French Republic</td>
<td>2.3</td>
<td>-9,760,544</td>
</tr>
<tr>
<td>bond61</td>
<td>31-8-2019</td>
<td>French Republic</td>
<td>0.3</td>
<td>-2,761,417</td>
</tr>
<tr>
<td>bond62</td>
<td>28-2-2021</td>
<td>French Republic</td>
<td>2.4</td>
<td>-18,445,928</td>
</tr>
<tr>
<td>bond63</td>
<td>31-8-2024</td>
<td>French Republic</td>
<td>1.6</td>
<td>-51,605,546</td>
</tr>
</tbody>
</table>
Bibliography


Cannata, F., & Quagliariello, M. (2009). The role of Basel II in the subprime financial crisis: Guilty or not guilty?


Statutory Declaration

I declare that I have authored this thesis independently, that I have not used other than the declared sources/resources, and that I have explicitly marked all material which has been quoted either literally or by content from the used sources.

Budapest, ___________________________    ___________________________
Date                                           Signature
Nyilatkozat saját munkáról

Név: __________________________________________

E-mail cím: _______________________________________

NEPTUN-kód: ______________________________________

A szakdolgozat címe magyarul:
____________________________________________________________________

____________________________________________________________________

A szakdolgozat címe angolul:
____________________________________________________________________

____________________________________________________________________

Szakszemináriumvezető (vagy konzulens) neve: ____________________________

Alulírott Hagymási Eszter igazolom, hogy a szakdolgozatom saját munka eredménye.
Bizonyos gondolatok, érvek, logikai és matematikai összefüggések más tanulmányokból
való átvétele során a hivatkozásra vonatkozó szabályokat teljes mértékben betartottam.

Budapest, ____________________________

Dátum ____________________________ Hallgató aláírása
DECLARATION

Name (in block letters):

Bachelor    Master    Other form of study

I hereby declare that the selected access regulation applies to the publicity level of the electronic version of my thesis (PDF format: the view, save and print functions are allowed, edit function is not allowed) given the following alternatives:

☐ FULL PUBLICITY
Accessible from all over the world in PDF format through the University Library website in the Corvinus Theses and Outstanding Student Papers archive (http://szd.lib.uni-corvinus.hu/).

☐ RESTRICTED PUBLICITY
Accessible only from within the Corvinus University network in PDF format through the University Library website in the Corvinus Theses and Outstanding Student Papers archive (http://szd.lib.uni-corvinus.hu/).

☐ NO PUBLICITY
The thesis will not be recorded by the University Library either in its catalogue or in its archives.

Budapest, ..................

..........................................................
Signature of the author