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Bonds Portfolio liquidity risk under stress

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Abstract

The focus of this thesis is to study and model the capacity of the bank to trade on the bonds market under normal and stressed conditions. This capacity is related to the liquidity of bonds market (ie, the ability to trade) and bank's trading desks capacity to trade. All banks have different models but all are subject to the validation of the bank in a first place and the EU Central Bank afterward. Thereby, this study handles different internal and external recommendations. The study takes also into account market data in order to check out the global liquidity of the bond market.

Such a study is important for two reasons. First, it gives a time horizon on the bond's liquidation process. It provides an estimation of the time that the bank needs to get rid of its bond's positions. Secondly, it analyses liquidity for different pool of bonds. Thereby, bank can group its bonds by rational liquidity categories and study the liquidity of these groups instead of thousands of products.

This information is used by the bank to evaluate the cash that can be raised from bond's positions in order to get funding. Thus, the cash required for liquidity purpose will decrease if the liquidation process of bonds speed up. The model helps the bank to level out its balance sheet at all time.

The research approach is based on several liquidity measures that have been computed on internal data and help to observe trends and periodicity. Then appropriate models are described based on two measures: the daily volume of sells, and the turnover.

The main conclusion drawn by the thesis display that bond's products can be pooled per type (defined in 3.1.2). Indeed, the liquidity between those types is similar and can be compared. The model chosen depends on the stress scenario. Under normal condition the turnover is preferred and under stress the daily volume has been chosen.

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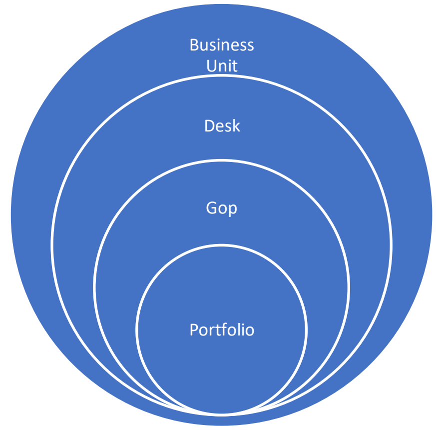
Lexique :

- Business Unit: “A business unit is a fully-functional unit of a business that has its own vision and direction. Typically, a strategic business unit operates as a separate unit, but it is also an important part of the company” (The Times Group, 2020).
- Desk of trading: Specific trading activity of a business unit.
- Gop: Set of portfolio trade in a same purpose.
- Portfolio: Set of same type’s assets.



- Bid-Ask Spread: “A bid-ask spread is the amount by which the ask price exceeds the bid price for an asset in the market. The bid-ask spread is essentially the difference between the highest price that a buyer is willing to pay for an asset and the lowest price that a seller is willing to accept.” (Dotdash, 2020)
- Repo : “A repurchase agreement (repo) is a form of short-term borrowing for dealers in government securities. In the case of a repo, a dealer sells government securities to investors, usually on an overnight basis, and buys them back the following day at a slightly higher price.” (Dotdash, 2020)

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Part 1 Introduction

1.1 Context

Banks and more broadly financial institution provide liquidity to both depositors and creditors by providing them, on demand, cash. In this scheme liquidity risk comes from the possible bank runs of depositors caused by the lost faith in financial system and consequently withdraw of their savings. This risk has been managed by imposing reserve requirement tied to deposits.

But in 2007-2008 liquidity risk came from the exposure to various financial arrangements as repurchased agreement, margin calls, ... combined with the bursting of the housing bubble which led to funding liquidity issues. As bank's balance deteriorated, they had to reduce their exposure by selling asset and hoarding cash. This strategy was common to everyone as it was the best way to minimize the counter party exposure, but it put a stress on the whole funding market. Indeed, wholesale deposits, repurchase agreement (called repos) rarefy during the crisis and the banks faced the choice of selling their assets into a bear market or looking at new expensive sources of credit.

This crisis raised reflection about the impact that liquidity could have and the emergency for bank regulator to improve the requirement in order that financial institutions better assess this risk.

Within Market activities banks have dedicated teams who are in charge of the management of the liquidity risk. Liquidity means an immediate capacity to meet one's financial commitments. The degree of liquidity depends upon the relationship between a company's cash assets plus, those assets which can be quickly turned into cash, and the liabilities awaiting payments could be met immediately (Settlement Bank For International, 2008).

Thus, the liquidity risk can be described as the difference between the future financing needs to maintain its activity and the financing achieved. The future financing needs correspond to the projected differences between assets and liability by time buckets;

1.2 Target Group

This study is addressed to all people interesting by the management of liquidity risk in banks and specifically the liquidity on bonds market. All concepts, measures for which additional background theories is needed, are explained in the part “background theory” (see Part 3).

1.3 Purpose and delimitation

This thesis aims to investigate how the liquidity on bonds market and to model the capacity of the bank to liquidate its bond position and estimate the time period over which these sales occurs under normal market conditions and stressed market conditions. As each position is sold, the proceeds from the sales provides the Bank with additional liquidity and reduces its funding needs. The bank aims to proposed robust and accurate model which are not designed to be re-calibrate more than once a year. The model proposed should also be easily understandable from the regulator.

In this thesis several delimitations are made in order to match the bank's criteria. Firstly, the data used comes from one single bank so the resulting model will be related to this specific bank and could not be generalized to other banks. Secondly, confidential agreement signed with the company imply that results, figures, charts, etc won't contain the unit of the numbers presented. Finally, the data used for the model will be mainly issued by the bank and so the calibration found cannot be publicly communicate in this paper but the whole process will be described.

1.4 Research question

Our study has been carried out in order to respond to the regulator's question:

How fast and in which proportion can bonds' long and short positions can be liquidated in order to reduce bank's funding needs under normal and stressed conditions?

1.5 Motivation and Innovation

The project has interested me for both its financial and mathematical modelling aspects. From one hand the understanding of the bond market and the process to trade on this market is essential to get an overview of this problem. From another hand the liquidity has an important mathematical background so the modelling aspect is major.
The understanding of banking environment is also essential for the interaction with other people and to draw an implementable model.

The project is based on previous models which have been developed in the same purpose but with limited data. The innovation comes from the enhancement of: the transaction's data, the trading process and the categorization studies. The main idea is to develop a robust and reliable model with a simple implementation procedure and easily explainable.

1.6 Structure of report

To answer this question the study will be presented in a specific order. The second chapter presents an overview of financial market and the activities of these market. It also introduces the liquidity and the liquidity scenario of the bank. Then the third chapter aims at describing all the theorical background that the reader needs to understand the document. Chapter 4 detailed previous relevant studies made on the same subject to compare external and internal data. The chapter 5 presents the modelling process used to respond to the research question. So, this part displays the methodology used to get the results which are analyzed in chapter 7. But before the chapter 6 describe how the data used in our study have been compiled and which retreatment have been done and why. Then chapter 7 presents the results and gives a brief discussion on direct observation made. A further discussion is given in chapter 8, the results of the analysis conducted in chapter 7 and from external sources results (from part 4) are pooled and explained. This part responds to the research question and propose the calibrations of the model and the process of implementation. Then a back test has been carried out in chapter 9 to validate our model and assess its robustness. Finally, an appendix gathers all relevant analysis and results up. This part is frequently quoted in the main document frame.

Part 2 Liquidity in market activities

2.1 Financial Market

Finance markets play a crucial role in capitalist world. Their functions could be described as: "Creators of financial products (Bonds, stock, commodities, derivatives) that are drawn to provide a return for those who have excess cash (called Investors/lenders), making these funds available (by lending or buying products) to those who need additional money (borrowers)" (Dotdash, 2020). Thus, their put in relation lender and borrower which determine together the market price of products exchanged. Main activities are :

- Easy mobilize savings and invest them in a productive use.
- Determine securities prices (not always based on rational knowledges)
- Provide liquidity by enabling securities owners to sell their assets in exchange of cash
- Borrowers don't need any more to spend time and resources to find investors.

(John C. Hull, 2003)

The below scheme resumes the interaction between all participants in a capitalist economy:

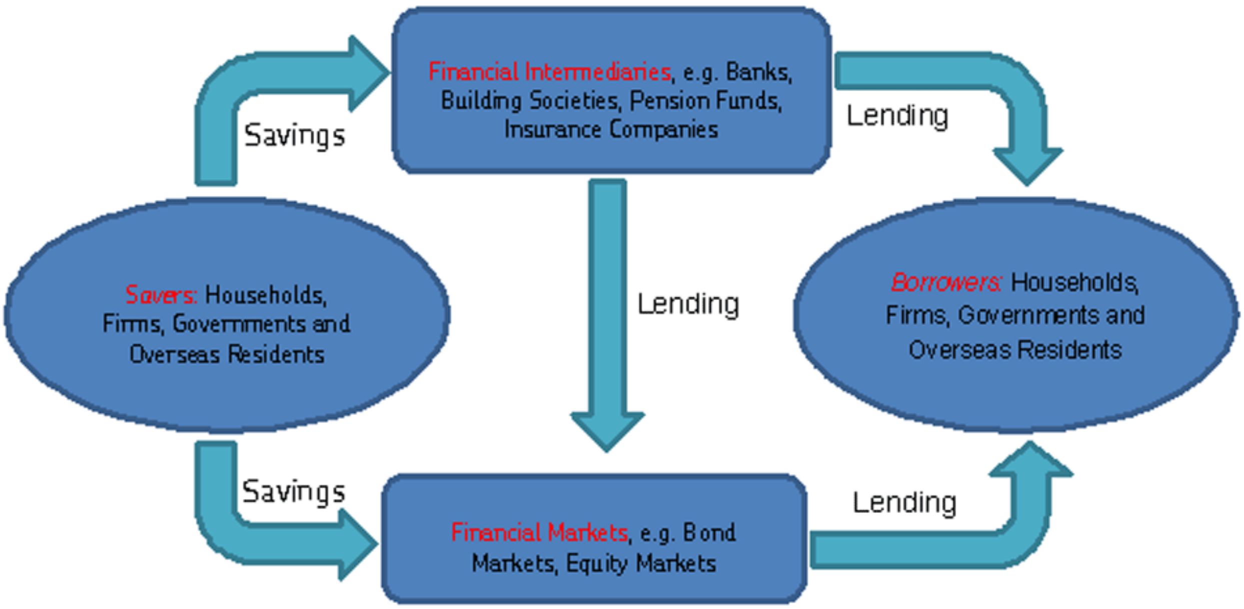

FIGURE 2-1: FINANCIAL MARKET PROCESS

HTTPS://WWW.AQA.ORG.UK/RESOURCES/ECONOMICS/AS-AND-A-LEVEL/ECONOMICS

The "savers" inject their savings into financial intermediaries such as banks, pension funds or insurance compagnies or directly into the financial market. Then Intermediaries or financial market invest into different markets in function of their needs

Bank act as intermediary, their make profit by providing servicing in order to responds to client demands. However, institution, corporation and governments have different risk appetite, return expectation, investment style. The role of the investment bank is then to facilitate the deals between all the market participants. This intermediary role exposes the bank to various risk such as credit risk (risk that the counterparty default), operational risk (human or technical mistake), market risk (market variations) and liquidity risk. The latter has been highlighted during the 2008 crisis and will be subject to further investigation in the following.

2.2 Type of Markets

There are different types of market (according to (John C. Hull, 2003)) in order to respond to both investor's and borrower's needs. Some markets are related to each other's. This part aims at describing most of the market and the relation between each market.

Markets are distinguished in function of 4 characteristics:

- The nature of the claim: debt or stock
- Maturity of the claim: less or more to 1 year
- Timing for delivery: real time or future delivery
- By organization structure: organized or unorganized market place

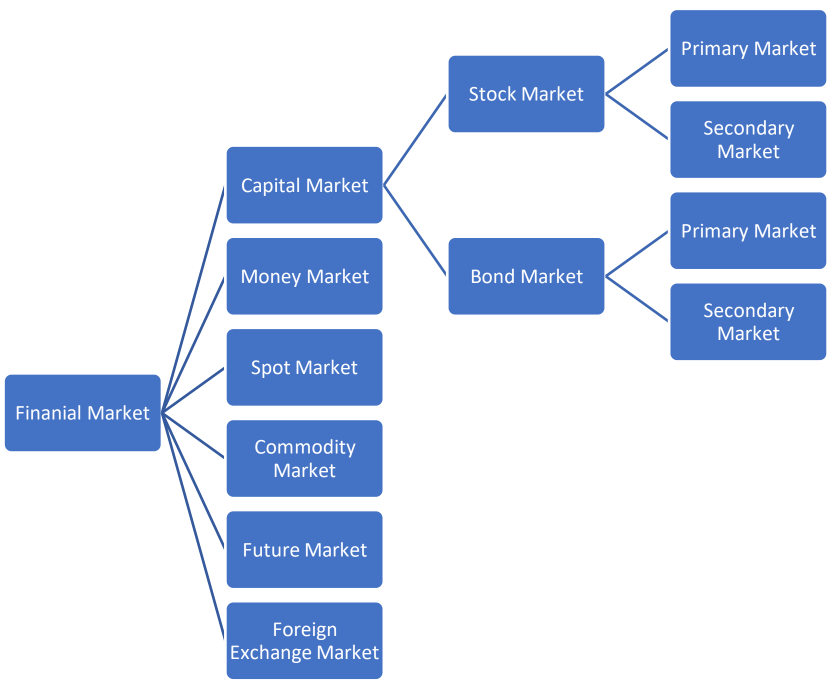

FIGURE 2-2 : TYPE OF FINANCIAL MARKET

HTTPS://WWW.AQA.ORG.UK/RESOURCES/ECONOMICS/AS-AND-A-LEVEL/ECONOMICS

2.2.1 Money Market

Money market is mostly designed for short term investment (refinancing purpose), with a maturity less than 1 year. Different types of instrument are dealt in this market: Treasury Bills, Commercial Paper, Certificate of Deposit, …. (these bonds are described in 3.1.2). It is mostly used by corporations and government to stabilize their flow. And investor could use this market for small and fast profit.

2.2.2 Capital Market

This market enables compagnies to raise capital by selling different securities: stock and bonds. Thereby, capital market is composed of both stock and bond markets. The process of emission of securities give also 2 other markets: the primary and secondary markets. These 4 markets are presented below.

2.2.2.1 Primary Market

Primary financial markets are markets in which firms raise funds by selling financial assets such as shares or debentures to investors. Secondary financial markets are markets in which investors trade financial assets such as shares or debentures with other investors.

2.2.2.2 Secondary Market

Secondary financial is used after than the corporation, governments, … have issued securities in the primary market. It enables all investors to exchange them without any relation with the issuer.

A bond (with maturity 10Y) issued by Ericson in 2008 is bought by investor A in 2008 and sold in 2010 to investor B. The interest payment after this date will be made by the issuer (Ericson) to the current bond's holder (investor B).

2.2.2.3 Stock Market

The stock market is a market where investors can buy and sell companies shares. The shares issued by the company represent a fraction of the company's capital. Thus, shareholder become associate to the company and take the decision with the board (with a pro-rata in function of its participation in the company). The shareholder also receives potential dividend decided by the board. It is composed of both primary and secondary market.

Shares can be traded on both organized market (see 2.2.3.4.2) for large companies listed on the stock exchange (NYSE, CAC40, S&P500, etc) or over-the-counter market (see 2.2.3.4.1) for un-listed companies.

2.2.2.4 Bonds market

The bond market is a market in which companies or government can raise capital through debt instrument: bond. The bond gives the right to the bond holder to interest payment and principal payment at the maturity.

This life cycle:

The below chart displays the typical life cycle of a bond:

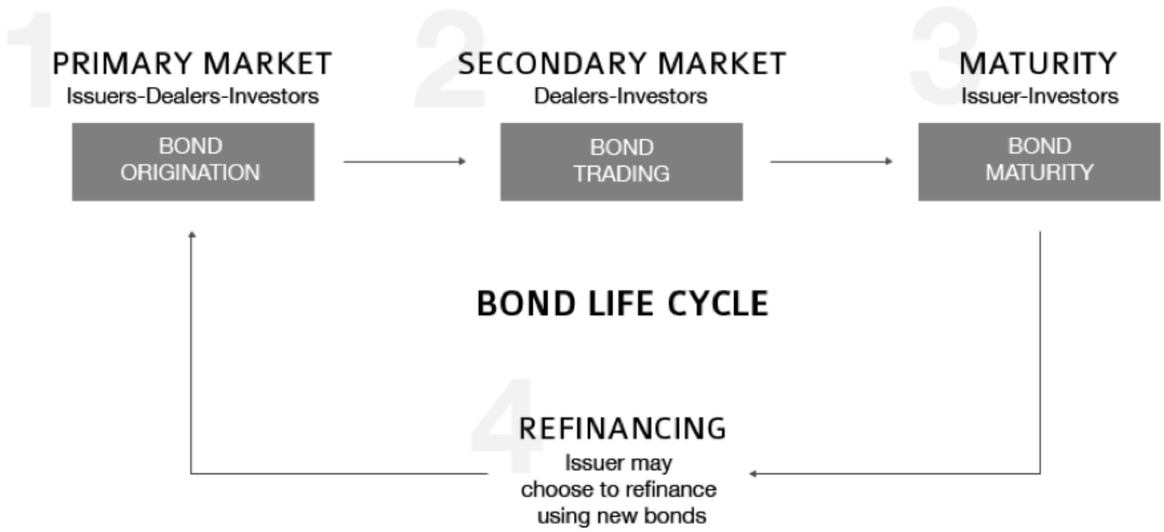

FIGURE 2-3 : BONDS LIFE CYCLE

HTTPS://WWW.OVERBOND.COM/ACADEMY/FIXED-INCOME-MARKET/BOND-LIFE-CYLE/OVERVIEW

This life cycle can be divided in three:

- Primary market: bonds are issued in this market by issuers and dealers/investors buy these bonds (Bough a deal, Bond auction).
- Secondary Market: Bonds owner can sell their bonds and investor/dealers can buy. This market doesn't affect the issuer directly. The owner of the bond got the interest payment made by the issuer
- Maturity: At maturity the issuer pays the bonds owner.
- Refinancing: Issuer can decide to issue new bonds in order to pay the bonds at maturity.

Key Participants:

There is different type of participant on the bond market:

- Issuer: The issuer raise money by proposing bonds or other debt instrument in order to invest in its projects. Issuer are mainly governments and compagnies. Governments use the funds raised for public needs.
- Investor: Investors can be individual or institution (financial institution, governments, corporations, mutual funds, pensions, hedge funds) who decide to provide capital to the issuers in order to generating return on their capital through interest payment.
- Dealer: Dealer are financial institution (often investment banks) provide advisory to the issuers when they want to raise funds (editing legal document, marketing). Often issuers choose specific dealers: known as primary dealers for the first issuance in order to distribute the risk exposure to a bunch of dealers. Dealers also provide trading/structuring and sales to both investors and issuers.

Where Bond market take place?

Due to the large number of different types of debt bonds are mostly traded on the over-the-counter market (see 2.2.3.4.1).

2.2.3 Other Markets

There are other type of market depending of the type of claim defined above. This part aims at explaining these markets briefly.

2.2.3.1 Interbank Market

The Interbank market is the market used by financial institutions to trade between themselves. It is mainly used to adjust their own accounts. Banks borrow short term funds from others having excess of liquidity (Dotdash, 2020).

2.2.3.2 Derivative Market

Derivative are securities with a value related to an underlying asset or group of assets. The main underlying assets are stocks, bonds, currencies, commodities, interest rates and indexes. There are mainly traded over the counter (Dotdash, 2020).
The derivative market is the market where all derivatives (such as future contracts) are traded.

2.2.3.3 Commodity Market

The commodities market is where traders and investors buy and sell natural resources or commodities such as corn, oil, meat, and gold (Dotdash, 2020).

2.2.3.4 By organization structure of the claim

2.2.3.4.1 OVER-THE-COUNTER MARKET

An over the counter market (OTC) is a decentralized market where trade occurs directly between two counterparties. Thus, there is not physical location for this market. The OTC markets are less transparent due to the difficulty to get financial data and confidential data (Nystedt Jens, 2004).
This market carries the counterparties risk (default of one of the counterparties).

2.2.3.4.2 EXCHANGE TRADED MARKET

Exchange-traded markets are financial markets in which a central source is used to route all transactions. So, a single party (as warehouse) is the intermediary that connects buyers and sellers. The drawbacks of this kind of market is that the intermediary shape the market. The advantage is that it standardizes products and which increase the trading frequency and it enhances security measures. (Nystedt Jens, 2004).

2.2.3.4.3 COMPARISON

The table summarize the two above markets (Nystedt Jens, 2004):

Exchange Trade Market	Over The Counter Market
Organized centralized exchange	Privately negotiated (between two counterparties) and have don't have any centralized trading facility
Exchange is the counterparty of all trades	The parties involved in negotiations or the trading firms are the counter parties
Highly regulated implying less counterparty risk	Unregulated and involves potential counter party risk
Exchange encourages heavy competition between the counterparties which tend to lower transaction execution costs	OTC involves less price competition and hence higher transaction execution cost for the trading

FIGURE 2-4 : ORGANIZATION MARKET COMPARISON

(HTTP://JAIARTHAVIDHYA.BLOGSPOT.COM/2011/01/EXCHANGE-TRADED-MARKET-VS-OVER-COUNTER.HTML)

2.2.3.5 Foreign Exchange Market

Foreign exchange market is an OTC market which trade currencies. It set the exchange rates between all currency pairs such as EUR/USD. It is one of the biggest market with more than 6 trillion US $ traded each day (Dotdash, 2020).
There are three types of contracts on this market:

- Spot market (see 2.2.3.6.1): currency price is taken the time of the trade
- Forward/Future market (see 2.2.3.6.2): it is an agreement to exchange a given amount of currencies at a fixed price in a coming date.
- Swap: Combination of spot and forward, dealer buy at spot price and sell the same amount in the forward market.

2.2.3.6 Timing for delivery the claim

2.2.3.6.1 SPOT MARKET

The spot market is a market where securities are traded for immediate delivery. All transactions are settled within two business days

2.2.3.6.2 FUTURE MARKET

On the other hand, future market transaction has a price fixed upon today with a future delivery date.

2.3 Market-Making

This part aims at defining the market making activity which trade actively on bonds market (Ingo Fender, 2015). Indeed, bonds are mostly traded over-the-counter (OTC) markets due to:

- the large number of different bonds issued involved low probability of finding matches in investor supply and demand for any given bond
- the fixed maturity of bonds which enable the strategy of buying and holding the bonds without trading it on the secondary market in order to recoup its investment.

The major drawback of OTC markets is the illiquidity of the market. Indeed, the probability that seller and buyer reach a consensus is low. However, bonds investors desired to trade their bond (sell and buy) immediately. This problem is partially absorbed by the market maker.

The market makers act as liquidity provider by matching existing demand and supply or acting as counterparty by using their own balance sheet capacity known as principal trading. Consequently, the positions of market makers are not designed to be held and risk-taking is an important part of the activity and have to be managed.

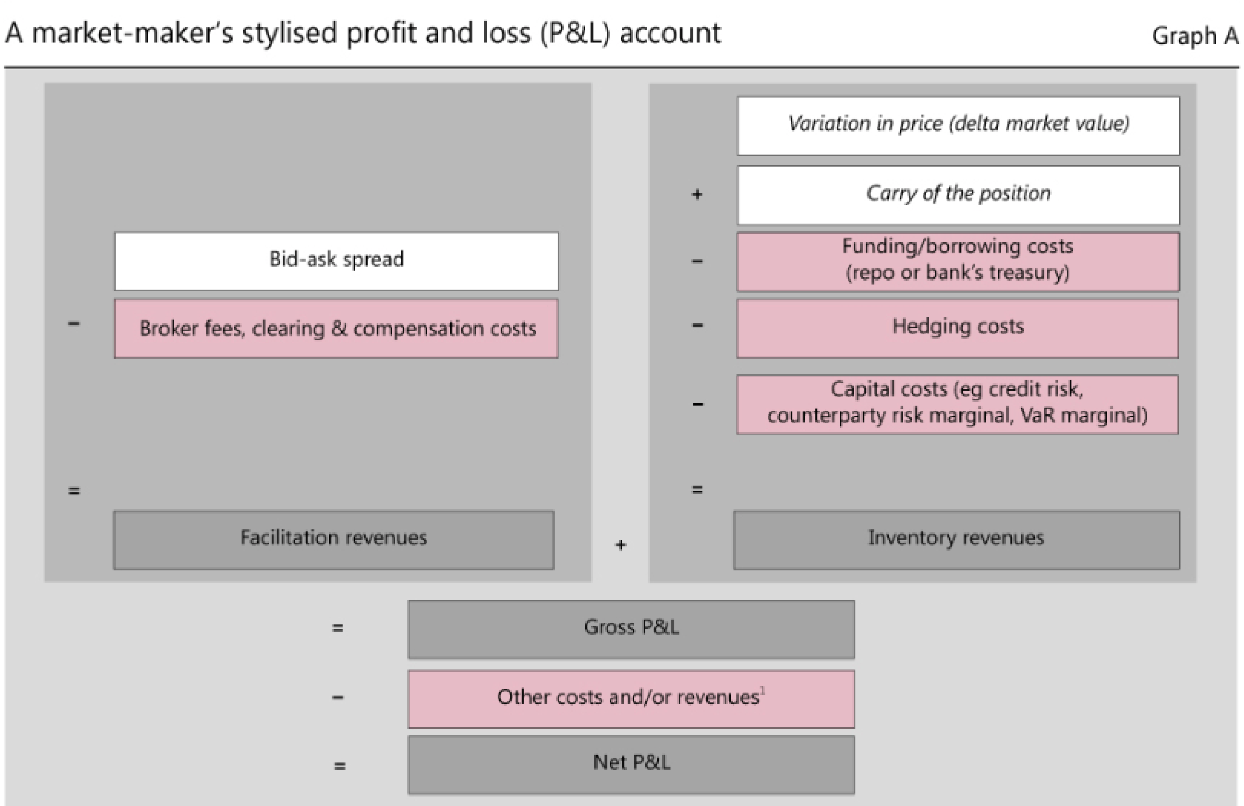

FIGURE 2-5 : MARKET MAKING PROCESS (INGO FENDER, 2015)

The business model of market making activity is standardized and resumed in the below figure 2.5. One part of the revenue if the facilitation revenues which comes from the bid-ask spread (i.e., the difference between the prices of market-makers to buy and to sell an assets) and subtracting the cost of trading. The second is the inventory revenues which represent the changes in the asset's values held in the inventory diminish by hedging costs and funding costs. The market makers set the spread depending on the projected hedging and funding costs.

2.4 Funding needs

Funding needs come from the difference between the valuation of assets and liabilities in the balance sheet generate by the market activities.
The trading of securities and specifically bonds impact the balance sheet. The buy and sell positions are on the balance sheet, long positions on the assets side and short position on the liability side. The net position is the result of all buy and sell transactions that have already been dealt. However, these positions a defined economic purpose and come from market making or hedging activity. All buys and sells positions have a contractual maturity. This maturity is either the maturity of the security, mainly for Bonds, or the maturity of the derivative they hedge, mainly for equities. The liquidity risk come from the future positive difference between the asset side and liability side. Thus, the bank could not meet its commitment.

To avoid this risk, the bank estimates its future funding needs. This funding needs come from the future outflows of assets which need to be model in function of projection/scenario: liquidity scenario.

2.5 Liquidity Scenario

Liquidity scenario are designed to describe the outflow of assets to compute the future funding needs.
There are two main liquidity scenarios: the first one is called BAU (business as Usual) and the second CMB (Combined Stressed Scenario). The rest of this section aims at describing them and explaining their underlying assumption.

2.5.1 Normal environment scenario (BAU)

The static gap retains the future evolution of outstanding transactions stock (operations already committed or present in the balance sheet) according to their contractual or modelized amortization based on some assumptions:

- Normal behavior of market participants
- Melting of balance sheet or cessation of activity or liquidation of existing Portfolio
- No new production (product emission).

The end of new production implies the limitation to the bank activity to the daily management of already subscribed products. This static gap, unlike the contractual gap, integrates the customer behaviour but in a non-stressed environment, then called "Business As Usual" (BAU).
This static liquidity gap measures the structural risk associated with past operations.

2.5.2 Stressed Scenario (CMB)

The “CoMBined” (CMB) scenario reflects the effects of a specific adverse event for the bank combined with a market-wide stress. The consequences for the bank are the following:

- Bank's long-term credit rating downgraded by three-notches at day 1
- Decrease of its short-term credit rating to A2/P2 at day 1
- Market shock followed by a long-term recession similar to the 2008 global financial crisis
- Asset value changes associated with the macroeconomic environment are accelerated to day 1.

For market activities the scenario should impact the manoeuvrability of these activities by limited their processing capacity.

Idiosyncratic Stress:

This assumption attempts to capture a firm-specific crisis triggered by:

- Material losses
- reputation damages
- Litigations
- Executive departures
- Other firms’ specific event

This stress assumes severe constraints on its funding activities as a result of a downgrade. Counterparties refuse to lend and limited issuance of short and medium term financial instrument. In addition, the downgrade has triggered an increase in margin and collateral calls.

Market Stress:

The actual context of very low levels of interest rates (especially on the long end if the yield curve) could, in a context of crisis, cause a violent market move driving most assets down. This crisis would be characterized by:

- significant increase of interest rate and credit spread
- A decline of all assets including those considered as safe-haven

This hypothetical scenario known as HYPO34 is called Asset drop. This scenario would increase of funding costs, cause a global decline in assets prices and increased volatility. This scenario has a major impact on equities, interest rate, credit spreads, illiquidity of various assets ... Despite this scenario and the fact that market participants are cutting back their exposure in all market compartment, we assume that a few sovereign issuers with very good creditworthiness would experience an increase in demand for their debt. The US and Japan would see their sovereign credit spread tightening. In Europe, best countries as France, Germany, Netherlands would see their sovereign credit spread tightening. The most badly affected country will be the PIIGS (Portugal, Ireland, Italy, Greece, Spain). Thus, a specific will be provide to these countries. Government Bonds National-issued government bonds (or Treasuries) entice buyers by paying out the face value listed on the bond certificate, on the agreed maturity date, while also issuing periodic interest payments along the way. This characteristic makes government bonds attractive to conservative investors.

Part 3 Background Theory

This part aims at describing all theories required to understand the following parts of the thesis (especially the "modelling part")

3.1 Product definition

3.1.1 What's a bond ?

Bonds are investment securities between an investor who lends money to a bond issuer (companies, governments) for a given period of time. In exchange of this lend, the issuer pays to the investor regular interest payments. At bond's maturity, the issuer returns the investor's money. Bonds investment is known as Fixed income as the investment makes fixed payments during the life of the bond (Dotdash, 2020).

<u>What's the financial purpose of Bonds?</u>

- Companies can decide to sell bonds in order to finance ongoing operations, new projects or acquisitions.
- Governments sell bonds for public funding purposes.

<u>Purpose of Bonds?</u>

Most bonds are viewed as lower risk investment, compared with equities. Thus, it can hedge risky, volatile investments like stocks and provide a steady source of income for long term management purpose as trust fund, life insurance.

3.1.2 Type of bonds

In order to match issuer needs there are plenty of bonds with different maturities, yields, nominal value, …

3.1.2.1 Corporate Bonds

Corporate bonds are issued by compagnies which can be large institution (such as investment banks), small corporation, start-up, in the purpose of raising money for their needs.
There are different types of corporate bonds:

- EO: "European Obligation" are bonds issued by EU corporations
- O: "Obligation" are bonds issued by "non-EU" corporations
- CD: "Certificate of deposit' is a saving product in which the customer accepts to leave a deposit in exchange of what he/she receive an interest rate premium. It's comparable to classical bank saving account.
- OI: "Obligation inflation-indexed" is a bond that guarantees a return higher than the rate of inflation if it is held to maturity. Inflation-indexed bond link their capital appreciation, or coupon payments, to inflation rates
- OC: "Obligation convertible" is a corporate bond that yield interest payment but it can be converted into stock(s) at specific times.
- PERBO: "Perpetual Bond" is a bond with no maturity date. It can be compared to equity. They cannot be redeemed but they payed stable interest rate forever.
- TSR: "Redeemable subordinated note" is bond with a maturity and a risky profile. In case default bondholder is compensated only after all other bondholders.

- TSDI: “Perpetual subordinated note” is bond with no maturity and a risky profile. In case default bondholder is compensated only after all other bondholders.

3.1.2.2 Governmental Bonds

Governmental bonds are used to finance country’s needs. They usually issued their bonds in local currency but to avoid the currency they can choose to issue their bonds in US dollar (or any strong currency). Governmental bonds (govies) are considered to be less risky than corporate bonds.
Govies are different names depending on their maturities:

- “Bills” for maturities less than 1 year (usually zero coupon)
- “Notes” for maturities of 2 to 10 years
- “Bonds” for maturities superior to 10 years
- “Inflation-indexed Bond” is bond with a return indexed on inflation/deflation. They are used to hedge the inflation of a specific country
- “Strip bond” is bond in which the principal (nominal amount) and the coupon (regular payments) are sold separately.

Bonds have specific names depending on the issuer country and their maturity. For instance, German 2Y bond is called BOBL and German 5Y bond is called Schatzt.

3.1.2.3 Municipal Bonds

Municipal bonds are issued by a local government to finance local project or investment (plan work, bridge, …). They are called: “MUNI”

3.1.2.4 Agencies Bonds

There are various governmental association that specializes in securitizing pools of mortgage into structured bonds. Their role is to securities pool of mortgages or loans and sell them in bonds after trenching the pool into different categories according to their credit exposure.

3.1.3 Key characteristics

Bonds can be characterized by several factors (Lionel Martellinei, 2003):

- Maturity: The date on which the bond issuer returns the money lent to them by bond investors. Bonds have short, medium or long maturities.
- Face value: Also known as par value, face value is the amount bond will be worth at maturity. A bond's face value is also the basis for calculating interest payments due to bondholders.
- Yield: The rate of return on the bond. While coupon is fixed, yield is variable and depends on a bond's price in the secondary market and other factors.
- Price: Many if not most bonds are traded after they've been issued. In the market, bonds have two prices: bid and ask. The bid price is the highest amount a buyer is willing to pay for a bond, while ask price is the lowest price ordered by a seller.
- Rating: Rating agencies assign ratings to bonds and bond issuers, based on their creditworthiness. Bond ratings help investors understand the risk of investing in bonds. Investment-grade bonds have ratings of BBB or better.

3.1.4 Yield Curves

Usually yield curve has positive slope. The investors think that it's riskier to lend money on long term than short term. Thus, they ask higher returns. The curve is often concave to reflect the difference of risk between short maturities and two long maturities for which it is harder to detect.

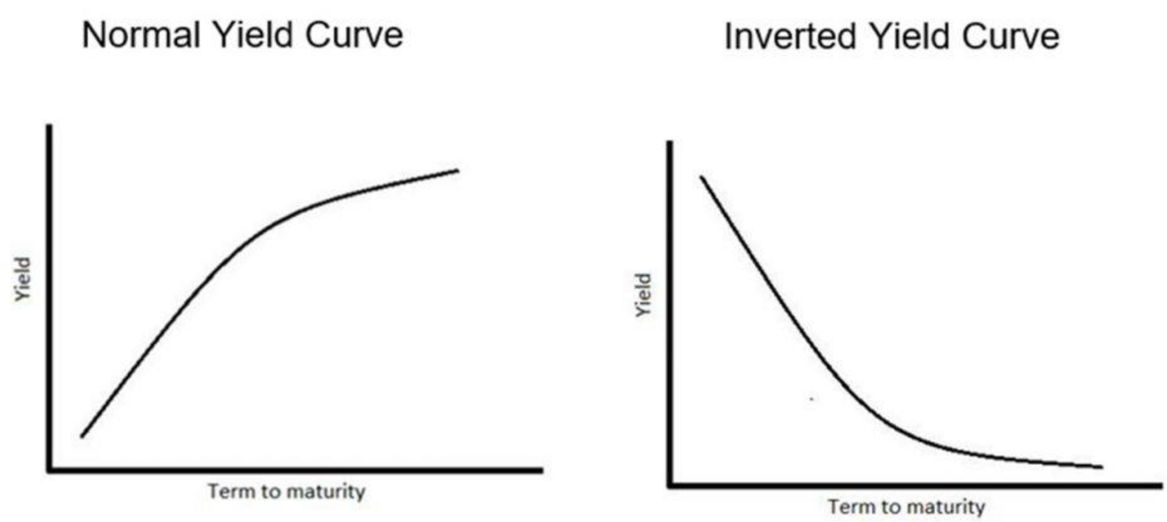

FIGURE 3-1 : YIELD CURVES (SHAH HAMZA, 2020; SANJIV R. DAS, 2003; F. LONGSTAFF, 2002)

An inverted yield curve represents a situation in which short terms yield become higher than long and mid-terms returns. The curve has a negative slop. These phenomena can be caused by:

- Monetary policy imposing high short-term interest rate
- Concerns about a future upcoming recession

3.1.5 Bonds Pricing

The price of bond is equal to the present value of its expected future cash flows. The yield to maturity is the rate of interest used as discount factor for bond's cash. (Lionel Martellinei, 2003)

The formula is:

$$Price = \sum_{i=0}^{T} \frac{Coupon}{(1 + Yield)^i} + \frac{FaceValue}{(1 + Yield)^T}$$

(3-1)

Where yield represents the unique discount rate at which the market price of the bond equals the present value of the bond's cash flows.

Link between price and yield

Due to formula above the price and the yield are negatively correlated.

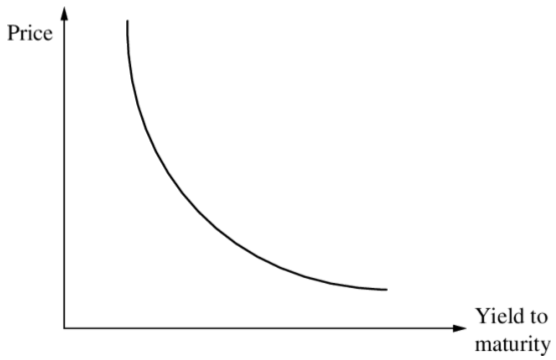

FIGURE 3-2 : PRICE AND YIELD TO MATURITY CURVE (LIONEL MARTELLINEI, 2003)

3.2 Liquidity Measures

Along years one of the main strategies about bonds is: buy and hold. Consequently, the liquidity is essential to evaluate the liquidity premia which represent the cost of trading immediacy.
Liquidity has 5 mains components :

- Transaction cost: captures the price at which one can sell or buy
- Immediacy: captures the ability to trade immediately on the market
- Depth: captures the abundance of orders in a range of price. It reflects the market ability to absorb large order amount.
- Breadth: captures the number of orders realized
- Resiliency: captures the flow of orders which can impact the market

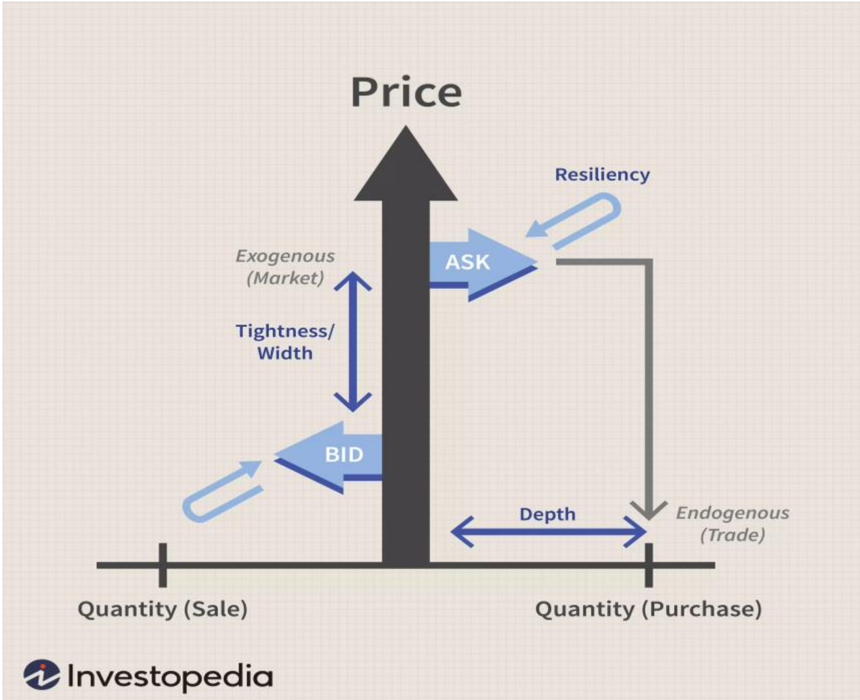

FIGURE 3-3 : LIQUIDITY SUM-UP (DOTDASH, 2020)

3.2.1 Bid Ask Spread

Bid Ask Spread represents the difference between the price quotes at a time t. The security is bought and sold immediately.
This measure has been studied and other related measures have been developed.
(AMF (Financial Market Authority), 2019)

3.2.1.1 Quoted spread

$$Quoted\_Spread = \frac{Ask - Bid}{Mid} \tag{3-2}$$

Where:

- Ask represents the lowest ask
- Bid represents the highest bid

Mid represents the average between Asks and Bids
(AMF (Financial Market Authority), 2019)

3.2.1.2 Effective spread

A more relevant measure use the trade price to evaluate more carefully the price to trade.

$$Effective\_Spread = 2\frac{|TradePrice - Mid|}{Mid}$$

(3-3)

(AMF (Financial Market Authority), 2019)

3.2.1.3 Realized Spread

The quoted and effective spread measure immediacy and cost of asymmetric information (impacting bid or ask) or cost of trading with intermediary.

$$Effective\_Spread_k = 2\frac{|TradePrice_k - Mid_k|}{Mid_k}$$

(3-4)

Where k is the kth trades. After this trade the dealer readjust its quotes by taking the trade into account.
(AMF (Financial Market Authority), 2019)

3.2.1.4 Bid ask proxies

Rolls estimator use correlation in price change to measure the bid-ask spread

$$Roll\_Spread = 2\sqrt{-Cov(\Delta p_t, \Delta p_{t+1})}$$

(3-5)

3.2.1.5 Discussion – Bid Ask Spread

These measures are relevant but the data (price and quote) are hard to access. The internal trades registered don't record the mid-point or other asks and bids. Thus, all measures with trades price cannot be implemented.
External data are expensive, and our analysis is about thousands of different products (isin, mnemonic). Consequently, it will be useless to analyses one specific product and generalize to other.

3.2.2 Zero Trading days

Based on the assumption that the return is equal to 0 when the market is inactive, we compute the frequency of these days to evaluate the liquidity.

$$Zero\_Trading\_Days = \frac{Number\ of\ zero\ return\ days}{number\ of\ day}$$

(3-6)

3.2.3 LOT measure

The LOT (from Lesmond, Ogden, and Trzcinka described in (AMF (Financial Market Authority), 2019)) idea is that return come from the realization of a process. By measuring the frequency table of returns and with returns assumptions for the relation between spread and return we can deduce the spread.

Amihud ratio

This ratio computes the absolute variation of an asset price per daily volume unit. It can be interpreted as the reaction of the market price for 1$ of transaction.

$$Ratio_{Amihud} = \frac{1}{D}\sum_{i}^{D}\frac{|R_i|}{Volume_i} \tag{3-7}$$

Where:

- D = the number of observed days
- R_i = the return of the asset the day I
- $Volume_i$ = the transaction volume of the asset the day i

3.2.4 Volume based measures

Volume based measures are used to get the breadth and depth components of liquidity.

3.2.4.1 Frequency

A large number of trades is a good indicator of the liquidity of a market. Indeed, a high frequency of trading provide continuous information to dealers which assess the equilibrium and the continuity of prices.

3.2.4.2 Traded Volume

Trading volume capture both the number of transactions and the number of participants.

$$Volume\_Traded = \sum Price_i \cdot Quantity_i \tag{3-8}$$

3.2.4.3 Turnover

The turnover ratio provides the information of how often an asset change hand in a given period of times

$$Turnover = \frac{\sum Price_i \cdot Quantity_i}{OutstandingAmount \cdot AveragePrice} \tag{3-9}$$

3.2.4.4 Average trade Size

The average trade size measures the depth of the market by measuring the average size of trades. The size is a reference to the quantity in nominal amount traded

3.2.5 Discussion

As shown in part 3.2.1.5 price-based measure and quoted based measures cannot be used to the large number of bonds in our scope and the difficulty to get data. Thus, our study will focus on volume-based measures. Indeed, volume and frequency provide good proxies of the daily trading activity the bank.

The average trade size is in our case a tricky metric. Easily implementable, the large number of bonds manage in our study makes impossible to compute a relevant trade size which depend on the bonds type. To get a relevant measure we should analysis bonds type one by one which has not been done.

3.3 Inventory Methods

3.3.1 FIFO – First In First Out

FIFO model is used in accountancy for inventory management. It assumes that the first assets buy (so the first asset to go in the inventory) are the first to be sold (to go out the inventory). Basically, FIFO consider that the "company" sell in priority oldest buys.
Simple example:
I bought 20 assets for 100$ in 2019 and 10 others at 120$ in 2020. My total stock is 30 (20+10) assets. In 2021 I sold 21 assets. The 20 first are sold at 100$ (price of the oldest assets) and the last one at 120$.
<u>Advantages</u>:

- Authorize by fiscal institution
- It takes current market price into account
- It reflects the reality of how corporations manage their stocks.

<u>Drawbacks :</u>

- It doesn't take the price variation into account
- It doesn't manage well the inflation (overestimate margin in case of inflation)
- Need to know the prices of assets bought

3.3.2 Other inventory methods

There are several other inventory methods which have not been retained for rational reasons (discussed 3.3.3).

<u>LIFO</u>: "Last In Last Out" follow the same routine than FIFO with the difference that the last buy is the first to be sold. A major drawback is that old buy could not be sold.

<u>The weighted average method:</u> This inventory method valuates stocks by the average trade price. Basically, the unit cost is simply the total cost divided by the number of products.

3.3.3 Discussion

To avoid price fluctuation the study, focus on nominal amount which doesn't vary. Thus, only FIFO and LIFO present are relevant method. From a rational point of view, it seems logical to suppose that same products (sharing the same isin) are interchangeable. Thus, a sell of product A use the oldest buy of product A whether it's the real oldest buy or not.

3.4 Prediction Model – Time series analysis

There are different ways to model times series. From simplest ones, easy to understand and implement to complicated ones, expensive to implement but more accurate in some cases.
This part aims at describing the theory to model time series. For complete explanation on the below theory please refer (Kristina Berndtsson, 2014)

3.4.1 Stationarity

3.4.1.1 Strong stationarity

A time series $\{X_t\}$ is strictly stationary if the distribution of the set $\{X_{t_1}, \ldots, X_{t_k}\}$ is equal to the set $\{X_{t_1+h},\ldots,X_{t_k+h}\}$ for all h (k is a positive integer and $t_1,\ldots,t_k$ a are a collection of positive integers). So, the joint distribution of the set $\{X_{t_1},\ldots,X_{t_k}\}$ is invariant under time variation. (Kristina Berndtsson, 2014)

3.4.1.2 Weak Stationarity

A process $\{X_t\}$ is named weak-sense stationary (WSS) if the expectations $E[X_s]$ and $E[X_{s+t}X_s]$, are well-defined for all s and t and do not depend on the value of s. (Kristina Berndtsson, 2014)

Lag Operator

To easy the notation of time series we used different operators as:

- The backshift operator B are defined as $X_t = B\, X_{t+1}$
- The forward operator, F defined as: $X_{t+1} = F\, X_t$
- The power of the lag operator is : $B^k X_t = X_{t-k}$
- A polynomial of lag operator is written: $\phi(B) = 1 + \sum_{i=1}^{p} \phi_i B^i$
- Difference operator defined as: $\Delta X_t = (1-B)X_t = X_t - X_{t-1}$

3.4.2 Moving Average

The notation MA(q) refers to the moving average model of order q (Jakobsson Andreas, 2015):

$$X_t = \mu + e_t + \sum_{i=0}^{q} \theta_i e_{t-i} \quad \sim \quad X_t = \mu + \sum_{i=0}^{q} \theta_i B^i e_t \tag{3-10}$$

With $e_1, e_2, \ldots e_q$ white noise term, $e_t \sim i.i.d\ N(0, \sigma_e^2)$
Some properties can be deduced from this expression:

- $E(a_t) = E[a_t[a_{t-1,}, a_{t-2}, \ldots] = 0$
- $E\left(a_t\, a_{t-j}\right) = Cov\left(a_t, a_{t-j}\right) = 0$
- $Var(a_t) = Var(a_t | a_{t-1}, a_{t-2}, \ldots) = \sigma_a^2$
-

3.4.3 Autoregressive model

The notation AR(p) refers to the moving average model of order q (Jakobsson Andreas, 2015):

$$X_t = c + e_t + \sum_{i=0}^{p} \phi_i X_{t-i} \quad \sim \quad X_t = c + \sum_{i=0}^{p} \phi_i B^i X_t$$

(3-11)

3.4.4 ARMA

Given this the ARMA(p,q)-model is given by a combination of the MA(q) and AR(p) models (Jakobsson Andreas, 2015):

$$X_t = c + e_t + \sum_{i=0}^{p} \phi_i X_{t-i} + \sum_{i=0}^{q} \theta_i e_{t-i}$$

(3-12)

Or equivalently with lag operators:

$$\left(1 - \sum_{i=1}^{p} \phi_i B^i\right) X_t = \left(1 - \sum_{i=1}^{q} \theta_i B^i\right) e_t$$

(3-13

3.4.5 SARIMA

The SARIMA or seasonal auto-regressive moving average algorithm expands the ARIMA model with seasonal components. The model parameters of a SARIMA(p,d,q,P,D,Q,s) have the following extra elements (Jakobsson Andreas, 2015):

- seasonal_window (or seasonal_periods) models the period (e.g. daily or weekly) for recurring patterns.
- the seasonal_order parameter P,D,Q prescribe how to handle the influence of observations with a lag of one or more seasons.

Parameter	Description
p	Order of the auto-regressive (AR) model
q	Order of the moving-average (MA) model
d	Differencing order (0 for stationary data)
P	Order of the seasonal auto-regressive (AR) part of the model
Q	Order of the seasonal moving-average (MA)
D	Order of seasonal differencing (0 for stationary data)

Below is the example of a $SARIMA(1,0,1)x(1,1,1)^4$ (see (Peter J. Brockwell, 2006))

$$\underbrace{(1-\phi_1 B)}_{\text{Non-seasonal AR(1)}}\ \underbrace{(1-\Phi_1 B^4)}_{\text{Seasonal AR(1)}}\ \underbrace{(1-B)}_{\text{Non-seasonal difference}}\ \underbrace{(1-B^4)}_{\text{Seasonal difference}} y_t \ = \ \underbrace{(1+\theta_1 B)}_{\text{Non-seasonal MA(1)}}\ \underbrace{(1+\Theta_1 B^4)}_{\text{Seasonal MA(1)}} e_t.$$

(3-14)

3.4.6 Selection Criteria :

Two criterias are used two select models (Peter J. Brockwell, 2006) :

- **Akaike's Information Criterion (AIC):** Formally, AIC is defined as $2\log L_k + 2k$

  Where,

  $L_k Lk$ is the maximized log likelihood
  k is the number of parameters in the model.

- **Bayesian Information Criterion (BIC):** $BIC = \ln(n)\, k - 2\ln\,(L)$

For more and complete information on these two criteria please see (Kristina Berndtsson, 2014).

3.4.7 Error indicators

Error indicators measure the accuracy of a forecast: $e_t = y_t - \widetilde{y_t}$, with y_t the observed data and $\widetilde{y_t}$ the prediction

3.4.7.1 MAPE

MAPE is the sum of the individual absolute errors divided by the forecast (each period separately). It is the average of the percentage errors.

$$MAPE = \frac{1}{N}\sum \frac{|e_t|}{\widetilde{y_t}}$$

(3-15)

One of the main drawbacks of this measure is that it cannot be used if the series reach 0. (Forecast KPI: RMSE, MAE, MAPE & Bias, 2019)

3.4.7.2 MAE

The Mean Absolute Error (MAE) is a very good to measure forecast accuracy. As the name implies, it is the mean of the absolute error.

$$MAE = \frac{1}{N}\sum |e_t|$$

(3-16)

(Forecast KPI: RMSE, MAE, MAPE & Bias, 2019)

3.4.7.3 MSE

Actually, many algorithms are based on the Mean Squared Error (MSE) which is easily implementable

$$MSE = \frac{1}{N}\sum e_t^2 \tag{3-17}$$

(Forecast KPI: RMSE, MAE, MAPE & Bias, 2019)

3.4.7.4 RMSE

The Root Mean Squared Error (RMSE) is defined as the square root of the average squared error.

$$RMSE = \sqrt{\frac{1}{N}\sum e_t^2} \tag{3-18}$$

RMSE puts much more importance on the biggest errors whereas MAE gives the same importance to each error.
(Forecast KPI: RMSE, MAE, MAPE & Bias, 2019)

3.5 Statistics measures

In order to analyse data both position and dispersion several positional and dispersion measures have been displayed. The advantage and drawbacks presented only care about our set of data. Thus, this short analysis of these measures cannot be extended to other sets of data without a deeper analysis (Jakobsson Andreas, 2015).

Measure Purpose	Measure Name	Description	Advantages	Drawbacks
Position	Mean	$\tilde{x} = \sum \frac{x}{N}$	Easy to implement	Sensitive to extreme values
	Quartile	Second quartile (50% data set above)	Not sensitive to outlier	X
	Median	Quartiles divide a rank-ordered data set into four equal parts	Not sensitive to outlier	X
	Mode	The data which occurs the more frequently	Not sensitive to outlier	Ignore other potential peaks

Measure Purpose	Measure Name	Description	Advantages	Drawbacks
Dispersion measure	MAD	$mad = \sum \frac{\lvert x - \tilde{x} \rvert}{N}$	Robust estimator	Sensitive to extreme values
	Std	$std = \sqrt{\frac{\sum(x - \tilde{x})^2}{N}}$	Great for gaussian distribution	Sensitive to extreme values
	Coefficient of Variation	$CV = \frac{std}{\tilde{x}}$	Unit independent	Singularity in 0
	Coefficient of variation interquartile	$CV_{IRQ} = \frac{Quantile(0.75) - Quantile(0.25)}{Quantile(0.75) + Quantile(0.25)}$	Not sensitive to outlier	X
	Med_Mad	$med_{mad} = median(\lvert x - median(x) \rvert)$	Not sensitive to outlier	Doesn’t work well on gaussian distribution

TABLEAU 3-1 : DISPERSION AND POSITIONAL MEASURES

Part 4 Benchmark of other studies

4.1 Historical Market Overview

4.1.1 US Market

Since the crisis of 2008, new rules have been set up such as the Volcker rule or the Dodd-Frank Act in 2010. Those rules increased the capital requirements and have raised the costs of market marking for corporate bonds. Consequently, the primary dealers' positions on corporate bonds have shrunk.

The figure 4.1 shows the decreasing of corporate bonds inventory in US market.

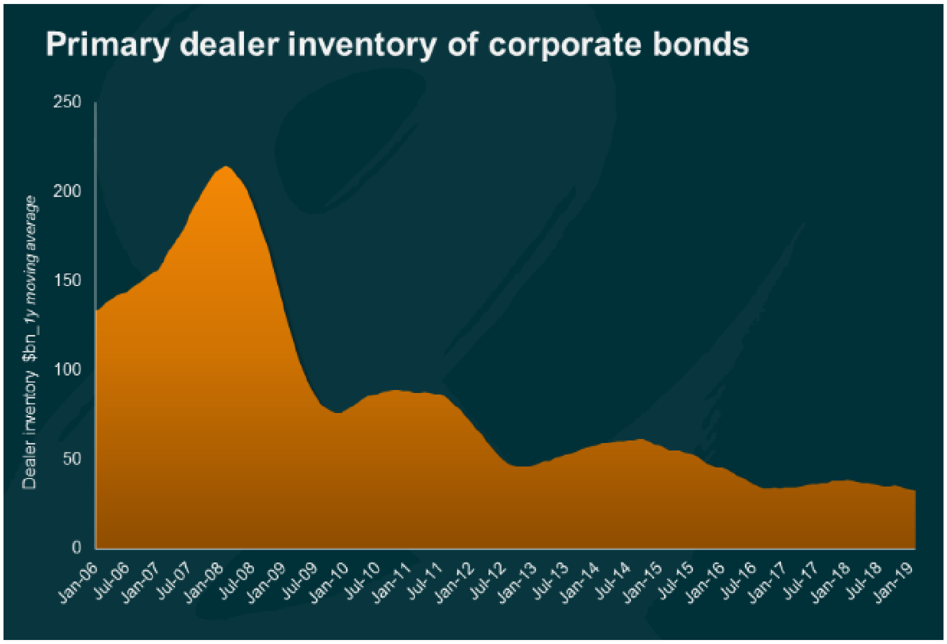

FIGURE 4-1 : INVENTORY US BOND MARKET (WOOLNOUGH RICHARD, 2019)

Those rules implied that the bonds were no longer held in inventories but traded on the market which led to an improvement of the turnover of primary dealers.

The figure 4.2 displays the turnover of corporate US bond market from 2006 to 2019.

FIGURE 4-2 : INVENTORY MANAGEMENT US (WOOLNOUGH RICHARD, 2019)

The charts below display the daily volume (in Bi $) traded is US corporate and governmental market.

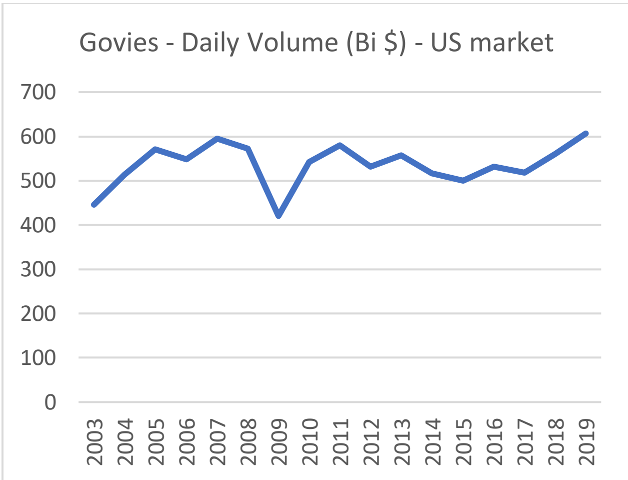

FIGURE 4-3 : GOVIES DAILY TURNOVER US (SECURITIES INDUSTRY AND FINANCIAL MARKETS ASSOCIATION, 2020)

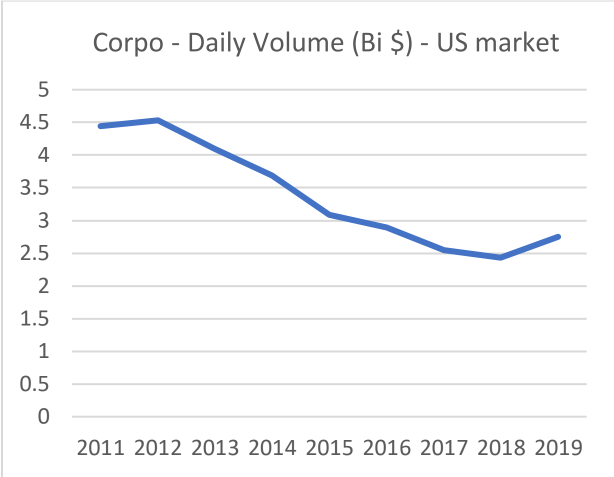

FIGURE 4-4 : CORPORATE DAILY TURNOVER US (SECURITIES INDUSTRY AND FINANCIAL MARKETS ASSOCIATION, 2020)

Based on SIFMA feed by TRACE reporting, the daily Volume of Corporate market slightly decrease from 4.5 Bi $ to 2.8 Bi $. However, the slight decrease seems due to the new regulations that has been setting up in 20010 more than crisis (2012).
The Governmental bonds market is stable since 2004 (between 500-600 bi $) except in 2009 where the volume loses around 20%. Thus, the daily volume in sovereign bonds had been impacted by the 2008 crisis.

4.1.2 EU Market

The charts below display the long-short-net positions of dealers in Europe for Corporate and Governmental Bonds:

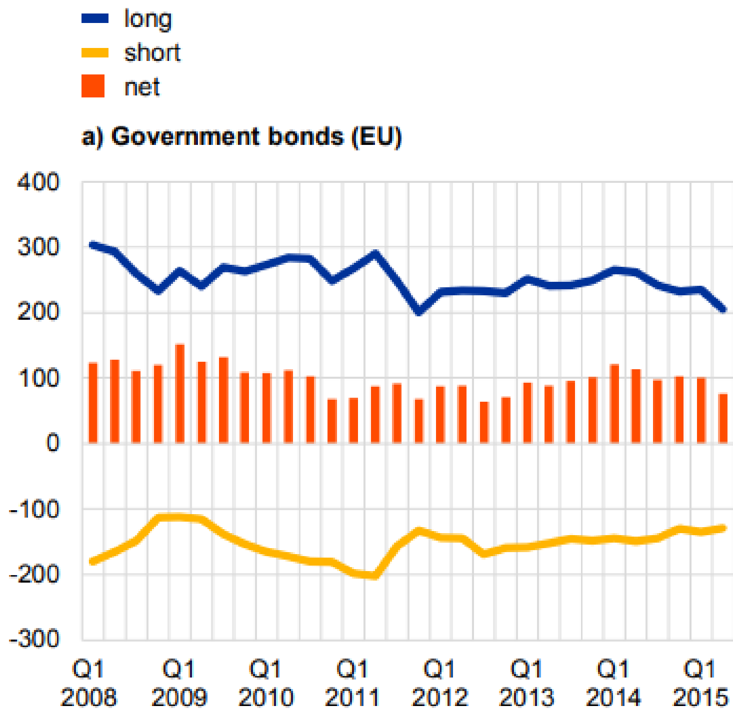

FIGURE 4-5:INVENTORY GOVIES EU MARKET (EUROPEAN SYSTEMIC RISK BOARD, 2020)

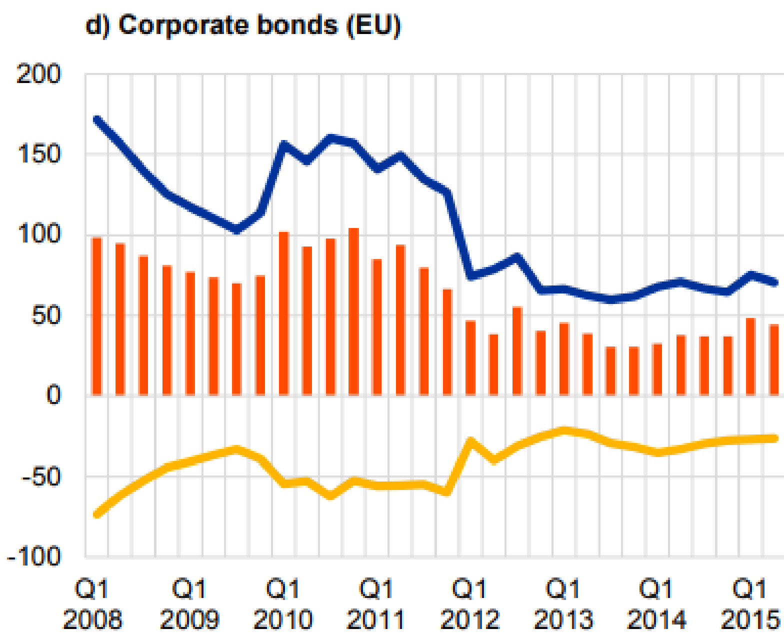

FIGURE 4-6 : INVENTORY CORPORATE EU MARKET (EUROPEAN SYSTEMIC RISK BOARD, 2020)

The governmental bonds inventory remained broadly stable during crisis periods (2008 and 2012). As seen in the US-market part the corporate inventory shrinks after 2008 and 2012. The reason is also the setup of new regulations design to increase the capital requirements.

Benchmark of other studies

The two charts below show the average volume traded variation since 2006 for both corporate and governmental bonds:

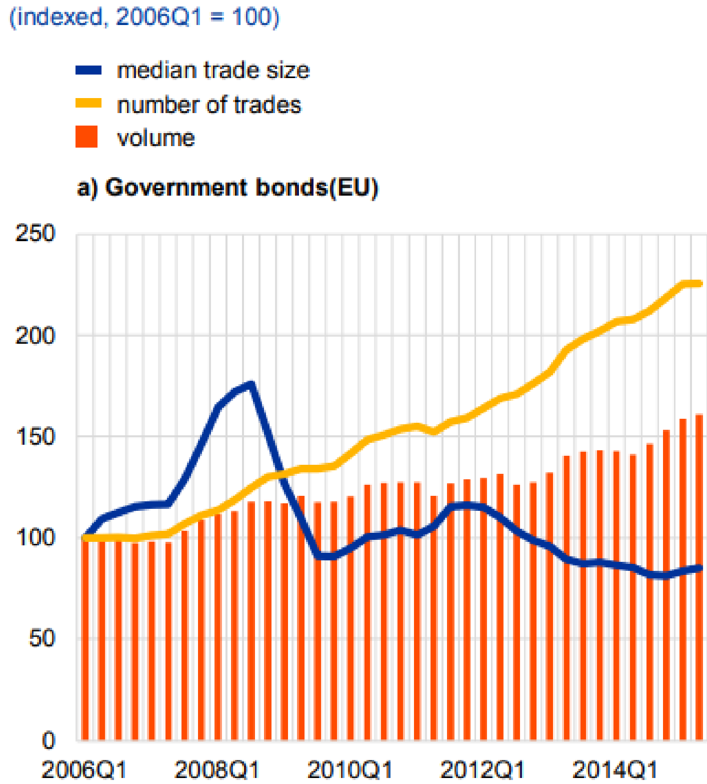

FIGURE 4-7 : GOVIES VOLUME EU MARKET (EUROPEAN SYSTEMIC RISK BOARD, 2020)

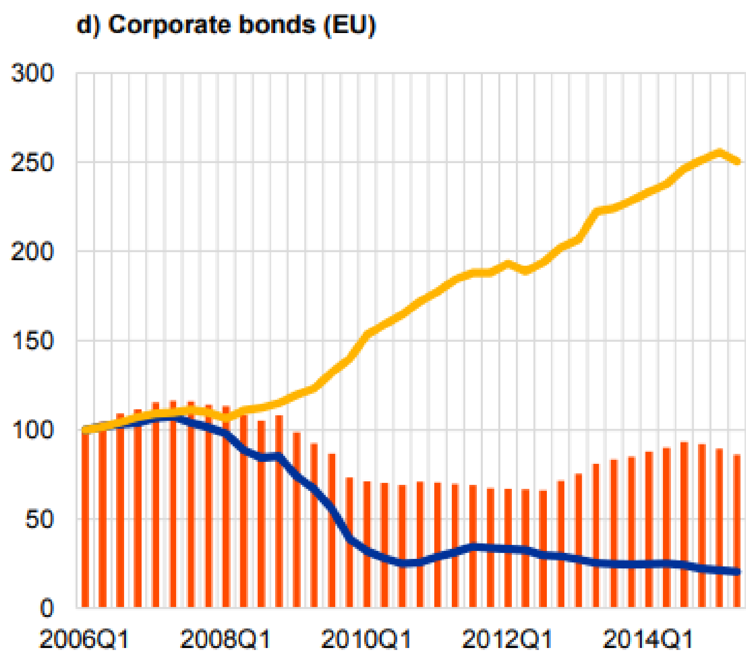

FIGURE 4-8 : CORPORATE VOLUME EU MARKET (EUROPEAN SYSTEMIC RISK BOARD, 2020)

Benchmark of other studies

These two graphs show that volume remain broadly stable since 2006. The number of trades increased as the trade size decreased which cause a stability in the volume.
Crisis (2008-2012) had a weak impact on volume traded on both corporate and governmental bonds.

4.2 Recent market overview

4.2.1 EU Market

The below chart exhibits the average trading volumes in the EU for governmental bond at Q4-2019:

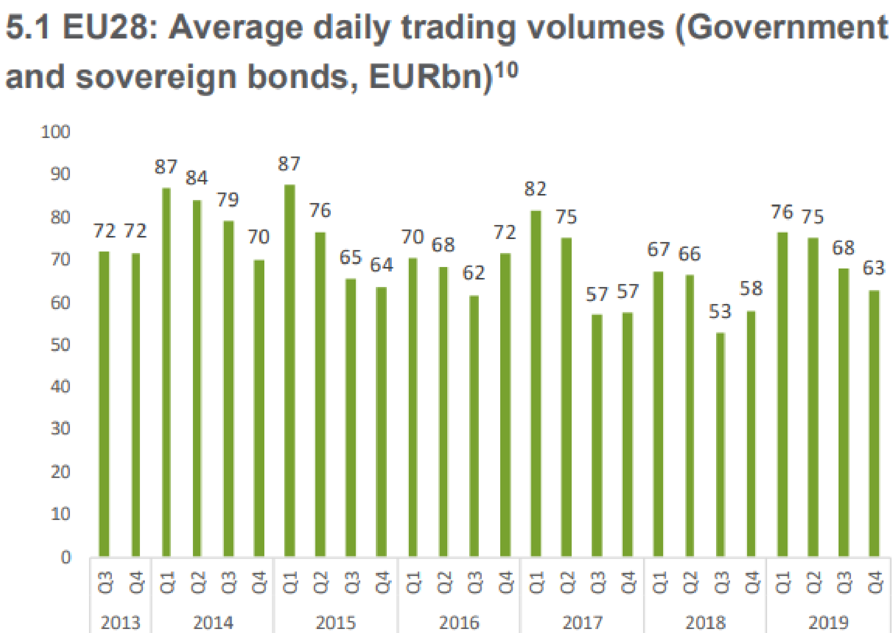

FIGURE 4-9 : DAILY TRADING VOLUME GOVIES EU (AFME (ASSOCIATION FOR FINANCIAL MARKETS IN EUROPE), 2019)

Discussion:
From Afme report the volume traded (daily for afme) is broadly stable and the volumes increase during the COVID-19 crisis, especially on govies.

4.2.2 US Market

The chart below exhibits the Daily trading volume (in Bi $) reported in TRACE.

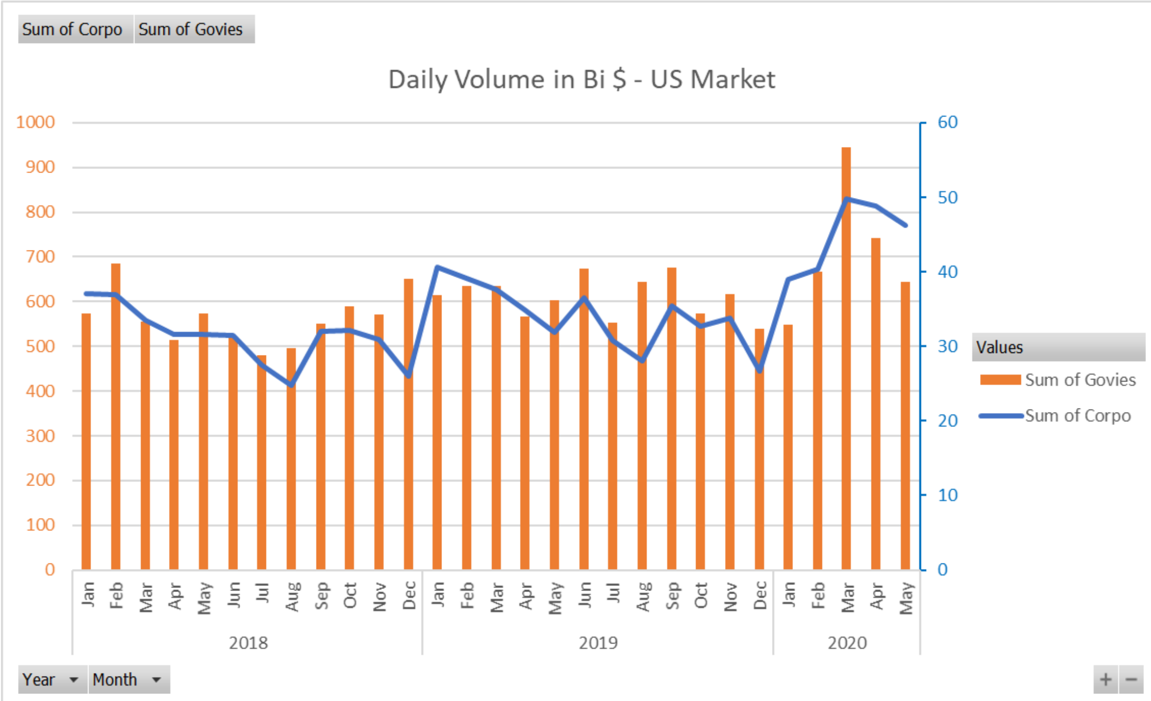

FIGURE 4-10 : DAILY TRADING VOLUME GOVIES US (SECURITIES INDUSTRY AND FINANCIAL MARKETS ASSOCIATION, 2020)

Discussion

The COVID-2019 crisis led to an increase in daily trading volume in US both corporate and governmental bonds.

4.3 Conclusion

Based on historic and recent observations of the market volume for both governmental and corporate bond, we conclude that the bonds market has been impacted by the rules (liquidity requirements) established after the 2008-crisis and 2012. However, no dramatical changes have been observed during these periods. Thus, it seems wise to evaluate the ability to sell/buy bonds on a recent historic rather than an old "crisis" historic in order to reflect the actual bonds market.

4.4 GIIPS Market Analysis

GIIPS represent the Greece, Ireland, Italy, Portugal and Spain. These countries are considered as riskier than other emerging countries such as Germany or US. So, a specific attention is provided to them in order to assess the necessity of specific calibrations.

4.4.1 Outstanding Amount in EU area

This chart displays the outstanding government bonds in Europe in 2020 (Eur tn)

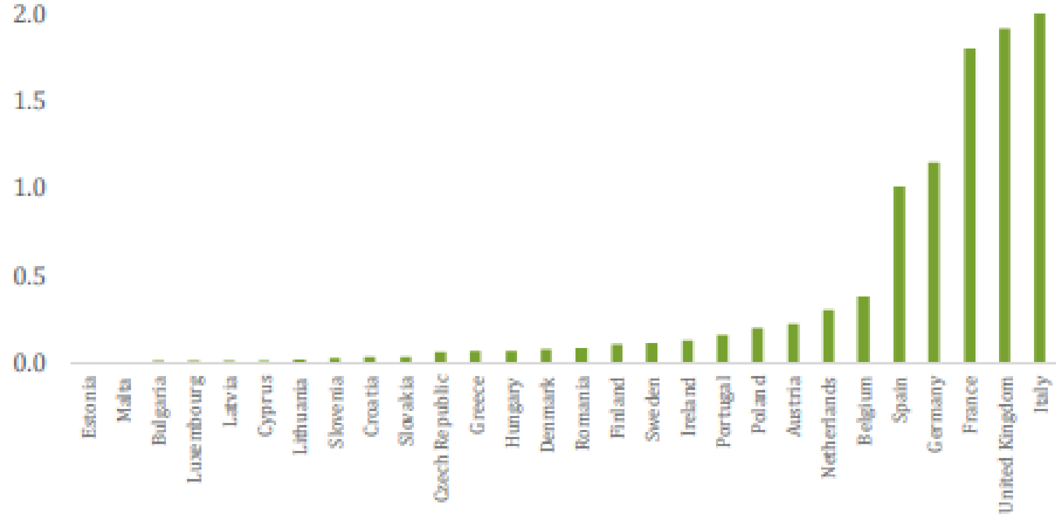

FIGURE 4-11 : OUTSTANDING AMOUNT PER EU COUNTRY (AFME (ASSOCIATION FOR FINANCIAL MARKETS IN EUROPE), 2019)

The chart shows that Italy and Spain have a deep market. And that Portugal and Ireland also have an important governmental market which appear in the top 10 of European countries outstanding debts

4.4.2 Italy - Spain – Portugal – Ireland

The charts below show the average trading volumes (in Bi Eur) and turnovers (in percent) for Ireland, Spain, Portugal and Italy

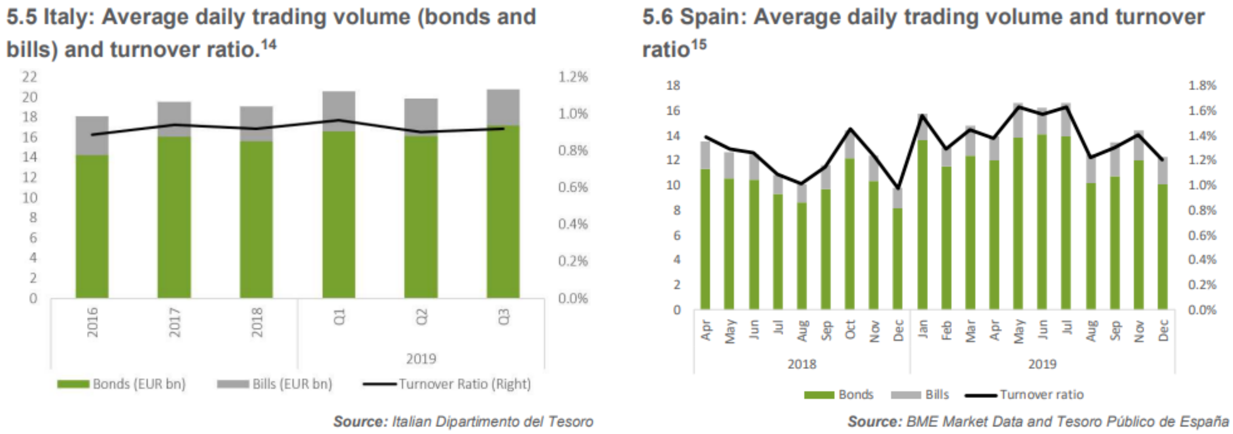

FIGURE 4-12 : SPAIN AND ITALY TRADING VOLUME (AFME (ASSOCIATION FOR FINANCIAL MARKETS IN EUROPE), 2019)

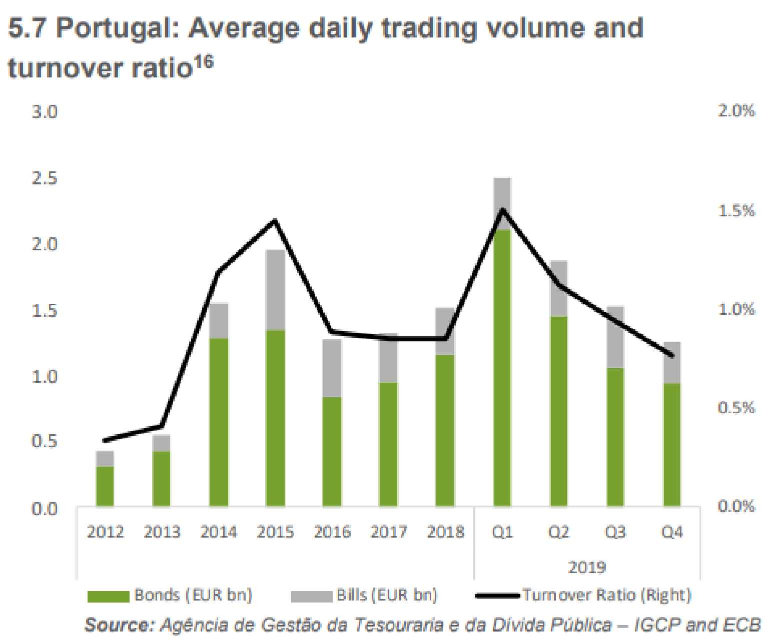

FIGURE 4-13 : PORTUGAL TRADING VOLUME (AFME (ASSOCIATION FOR FINANCIAL MARKETS IN EUROPE), 2019)

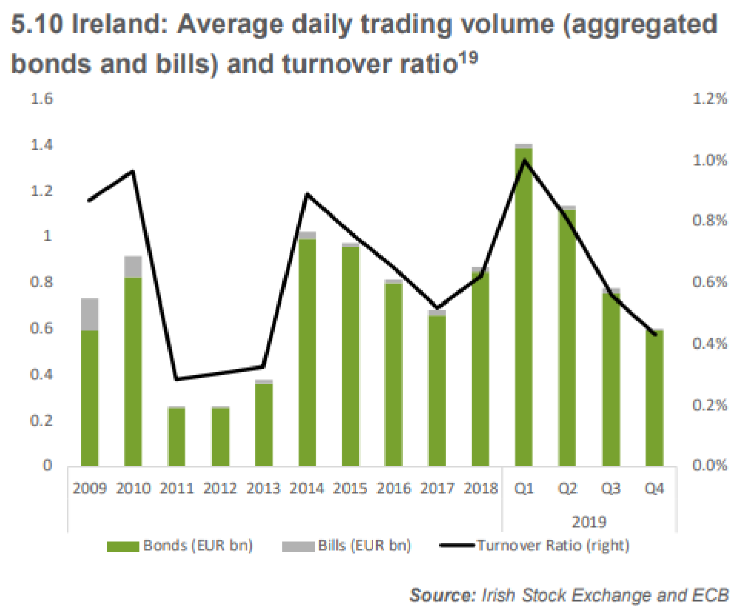

FIGURE 4-14 : IRELAND TRADING VOLUME (AFME (ASSOCIATION FOR FINANCIAL MARKETS IN EUROPE), 2019)

Italy and Spain governmental market is stable in term of volume and turnover. By considering the depth of the market it is not necessary to set a specific calibration/ method for these countries.
For Portugal and Ireland, the daily volume has decreased during stressed period however we do not observe an impact of these periods on the MARK trading capacity cf part **Error! Reference source not found.** .

4.4.3 Greece

The chart below displays the average trading volume and turnover ratio in the Greece governmental bonds market.

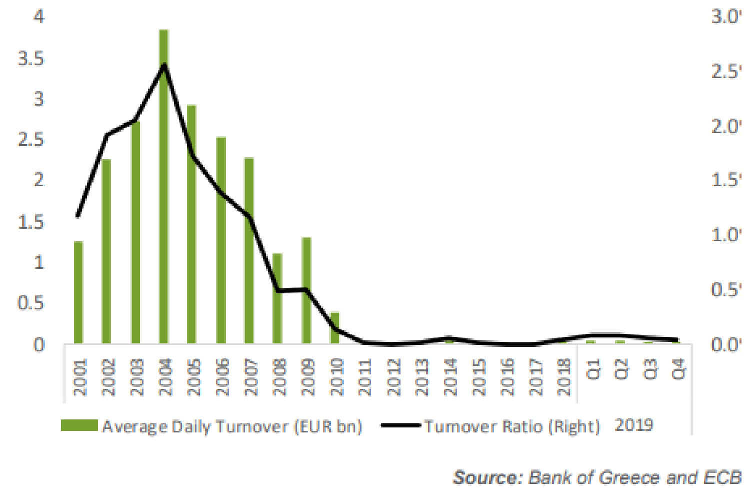

FIGURE 4-15 : GREECE TRADING VOLUME (AFME (ASSOCIATION FOR FINANCIAL MARKETS IN EUROPE), 2019)

Since 2004 the daily volume shrinks and is now very low. Thus, MARK/TRD/SCR proposes to consider that Greek government bonds cannot be sold in stressed scenario. Thus, these bonds are amortized by the contractual model which liquidate bonds at their contractual maturities.

4.4.4 Conclusion

From the above observation it has been decided that only Greece present an irregular activity on bonds market since 2012. Consequently, only this country will receive a specific calibration which is: "under stress it is impossible to trade Greek governmental bonds"

Part 5 Modelling

Purpose: this part aims at defining a process to measure the capacity of trader to sell/buy bonds in order to reduce the bank exposure.
In this purpose several liquidity analyses have been carried out to get an overview of the liquidity on bonds market under both normal and stress conditions.

5.1 Bonds group

Governmental and corporate bonds both represent debts. However, they are different on various point such as:

- Liquidity: corporate are less liquid than govies due to the large number of different products (source: internal documentation)
- Trading activity: Bank trade more govies than corporate (see appendix 10.5)
- Global position: Corporate bonds position contribute to around 1/10th to the global bonds position of the bank (source: internal documentation)

Due to these differences it has been decided to study corporate and governmental bonds separately in order to reflect they real impact on business.

5.2 Process

The purpose of this study is to draw a process to compute the time to liquidate the bank assets under both stressed and non-stressed environment.
Consequently, liquidity proxies (see 3.2) have been studied in order to get a general overview of the bank trading activity and evaluation of liquidity. However, a decision about the calibration proposal under both liquidity scenarios is made in the result part (see Part 7).

5.3 Frequency

5.3.1 Analysis

The frequency represents the number of trade settle per a given time period. Bank registered on a database all trades. From these data we can retrieve the number of trades per day and observe the behaviour of the frequency proxy.
A trivial analysis would say that the liquidity increases with the number of trades. This assumption could be true but further explanation on the result will go deeper and explain the consequence caused by the increase of the number of trades.
The frequency time period is: business day. Thus, the measure isn't spoiled by 0 trade day which are not coherent. To avoid to low frequency due to mistake in the field "date" we also removed the days with less than 500 trades.
To facilitate the reading and the understanding we also compute the rolling mean on 21 business day (1 month), 252 business day (1 year).

5.3.2 Model

The observation of the frequency will be essential to understand the behaviour of the trading activity in the bank. However, the frequency depend on the technology and the increase during these past years cannot be taken has a durable tendency. But the monthly frequency can be modelled in order to observe any abnormal activity during a period.
The idea is to keep the model as simple as possible.

5.3.3 Retreatment

In order to avoid polluting our data with 0 values it has been explained that we keep only business day. However, the python calendar of business day is not always updated and may not correspond to real trading days. Consequently, it has been decided to impose a threshold to our data, data above quantiles 99% and 1% have been set up to these quantiles. Thereby we removed extreme data and kept the length of the time series in order to analyses seasonality and trend.

5.4 Traded Volume

5.4.1 Analysis

The traded volume represents the quantity multiplied by the price. This metrics measures the depth of the market and take into account the frequency. It is also positively correlated with the liquidity but as for frequency a deeper analysis is done further.
The time period chosen is the same that for the frequency for coherence issue and to be able to, if necessary, compare our result on the same time basis.

5.4.2 Model

The observation of the traded volume is an important part of the trading activity in the bank. The bank is interested in knowing the evolution of liquidity. Thereby, it has been decided to develop a SARIMA model described in 3.4.5 in order to get an overview of the tendency of traded volume. The models developed could be different for corporate and govies but the idea is to easy the implementation and to homogenize models if it’s possible and accurate.
The idea is to keep the model as simple as possible.

5.4.3 Retreatment

In order to avoid polluting our data with 0 values it has been explained that we keep only business day. However, the python calendar of business day is not always update and could not correspond to real trading days. Consequently, it has been decided to impose a threshold to our data, data above quantiles 99% and 1% have been set up to these quantiles. Thereby we removed extreme data and kept the length of the time series in order to analyses seasonality and trend.

5.5 Turnover

5.5.1 Methodology

The turnover measures the time to renew its portfolio. Thus, it is based on the sell and buy and the total amount of bonds in our inventory. The idea is to measure the time spend by a product in the bank inventory. Then with the proportion of the time spend in the inventory we can deduce the turnover/the average time to sell/buy the product.
To get this done a clever method is to use an inventory model which help us to identify the outstanding amount and the time spend in the inventory per product.

The inventory model chosen is a FIFO ("First In First Out") defined 3.3.1. However, our idea is not the same that a classical FIFO user who want to evaluate its stock at a specific date time. The value of our stock is in our case useless and we only focus of the time to liquidate our stocks (both long and short). To get rid of the price change and take the quantity into account we use the trade nominal amount which is the multiplication of the quantity traded per the nominal amount (imposed at the bond issuance).

Example

Let's assume that our inventory is on French government bonds (security type OAT).
The daily trading activity (buy and sell) is detailed on the left blue pane.
The Load – Inventory FIFO – DeLoad parts should be observed simultaneously. The load represents the quantity of buy remaining in the inventory. The "DeLoad" record when sell occurs (number of day) and save the quantity. The inventory FIFO parts is an inventory at the time: business day 1, business day 2,….

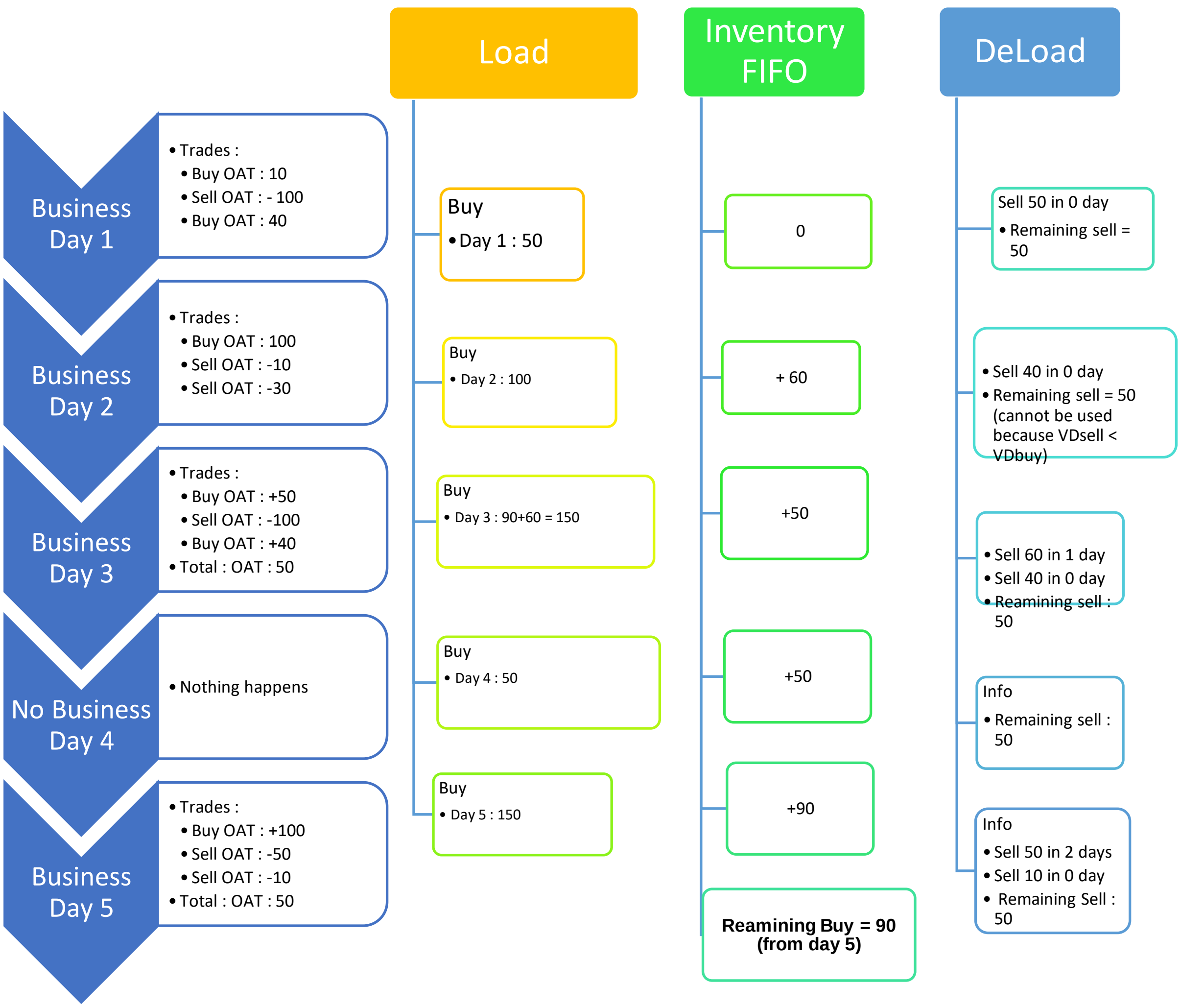

FIGURE 5-1 : FIFO PROCESS EXAMPLE

Note: VD(Buy) < VD(Sell), value date of the buy should be before the value date of the sell to validate the process of deload.

At the end of the FIFO remaining buys (90 in our example) are sold one day after the end of FIFO scope (at day 6) so there are sold in 1day (6-5=1).
From all "Info" present in DeLoad, we choose two categories for the delay to sell: [0 day, 1-2 days]
Then we weight by the quantity the calibration for the selected categories.

Measures / Category	Quantity sum	Percentage	Cumulative calibration
0 Day	40+40+10 = 90	90/290	90/290
1-2 Days	60+50+90 = 200	200/290	200/290+90/290=1
All Category	290	1	x

TABLEAU 5-1 : EXAMPLE FIFO CALIBRATION

The calibrations represent the percentage of long/short position liquidated in a given number of days or category of days.
Example: model sell/buy 30% (90/290) of OAT in 0 day then 70% (200/290) in 1 and 2 days
To easy the understanding it has been decided that outflow in categories are linear. In our example the outflow is:

- Day 0 = 30%
- Day 1 = (100%-30%)/ (2-1) = 70%
- Day 2 = 100%

Thus, to know the quantity left of a given category after *x* days we simply multiply the quantity at t_0 by the calibration of the *x* days.
This methodology presents the advantage of providing a turnover per category and let the choice of the category that can be discussed and challenged.

5.5.2 Product characteristics

As described above a key to implement the FIFO is the characterization of the products. A product is linked to the unique components: Issuance date, currency, bonds type, nominal amount, maturity and issuer. All these parameters are resumed in the isin/ mnemonic. So, there is a bijection between a product and its mnemonic.
However, risk department measure the risk associated to the product exposition and this can be similar between some products sharing certain characteristics.
Consequently, it has been decided that:

- Corporate bonds products are identified through their unique mnemonic
- Governmental Bonds products are identified by products sharing the same:
    - Issuer (France, Sweden …)
    - Security type (OAT, …)
    - Residual Maturity Bucket: 0 year to 2 years; 2years to 11 years; longer than 11 years.
      (Residual maturity = Maturity Date – Trade date)

(The pooling of govies per maturity time is due to the observation that bonds are mainly traded at the beginning of their life time, this assumption is proofed in appendix 10.3)

5.5.3 Granularity

The FIFO described in 5.5.1 referred to "category" which is the mesh to sum our result up. In the example of the methodology of the FIFO used (in 5.5.1) there is only one product with the security type: "OAT". However, plenty of products share this security type. Thus, the weighted result is essential and give different result depending on the granularity chosen.

Example:

Following the FIFO, we get the cumulative percentage spend by categories (1day, 2days in this example per product).

FIFO Table					
Product			Calibration		Nominal Amount traded (in K €)
Isin	Currency	bonds Type	1day	2days	
A	€	SGB	30%	40%	10 K€
B	€	OAT	2%	20%	50 K€
C	€	OAT	99%	100%	100 K€
D	$	TBIL	59%	100%	30 K€
E	$	TBOND	1%	2%	2 K€

TABLEAU 5-2 : FIFO GRANULARITY EXAMPLE 1

Here it is an example of two different granularities: currency and bonds type. The percentage have been weighted by the nominal amount traded.

Result				
Granularity		1day	2days	Nominal Amount traded
Currency	€	64%	71%	160 K€
	$	55%	94%	32 K€
Bonds Type	SGB	30%	40%	10 K€
	OAT	67%	73%	150 K€
	TBIL	59%	100%	30 K€
	TBOND	1%	2%	2 K€

TABLEAU 5-3 : FIFO GRANULARITY EXAMPLE 2

Observation :

From dollar traded products it seems evident that a granularity per currency don't reflect properly the calibration of TBOND which was about 1% and will be about 55% with the granularity per currency.

Issue:

This issue is to find the balance between granularity with too much categories which can cause an overfit result and too few categories which not reflect the reality.

5.5.4 Dispersion and granularity

To manage the issue presented above it has been decided to look at the dispersity of two measures:

- Delay: number of days to sell a buy for a given product
- Nominal x Delay: number of days to sell a buy times the nominal amount in euro

From these observations (given per granularity) we computed statistics to compute the accuracy of the granularity. The purpose of the model is to propose homogenous calibration. To control the homogeneity of the model proposed we check out the dispersion of the two measures (delay and Nominal x delay) with dispersion metrics presented in 3.5.

Example:

- Data from FIFO:

Here is a frequency table/histogram example which display the apparition frequency of delay from 0 to 100 per product characteristics for euro currency and OAT, SGB Security Types in percentage:

Product	Isin	A	B	C	Granularity		
	Currency	€	€	€	Currency	Bonds Type	
	Bonds Type	OAT	OAT	SGB	€	OAT	SGB
Delay	0	25%	26%	16%	23%	26%	16%
	1	30%	9%	9%	18%	22%	9%
	2	10%	22%	24%	17%	14%	24%
	3	5%	11%	12%	9%	7%	12%
	4	5%	9%	9%	7%	6%	9%
	5	11%	2%	8%	8%	7%	8%
	6	6%	9%	5%	6%	7%	5%
	7	4%	2%	2%	3%	3%	2%
	8	4%	4%	2%	3%	4%	2%
	9	1%	4%	0%	1%	2%	0%
	10	0%	1%	5%	2%	0%	5%
	11	0%	0%	1%	0%	0%	1%
	12	0%	1%	0%	0%	0%	0%
	13	0%	2%	8%	3%	1%	8%
	14	0%	0%	1%	0%	0%	1%
	15	1%	0%	0%	0%	0%	0%

TABLEAU 5-4 : FIFO GRANULARITY EXAMPLE 3

The idea is that we want to reduce the number of parameters (from 3 to 1 in our example if we choose the currency granularity or to 2 if we rather the bonds type granularity.

- Analysis:

If we focus on OAT, we want to know which granularity fit the most the frequency of both OAT securities.

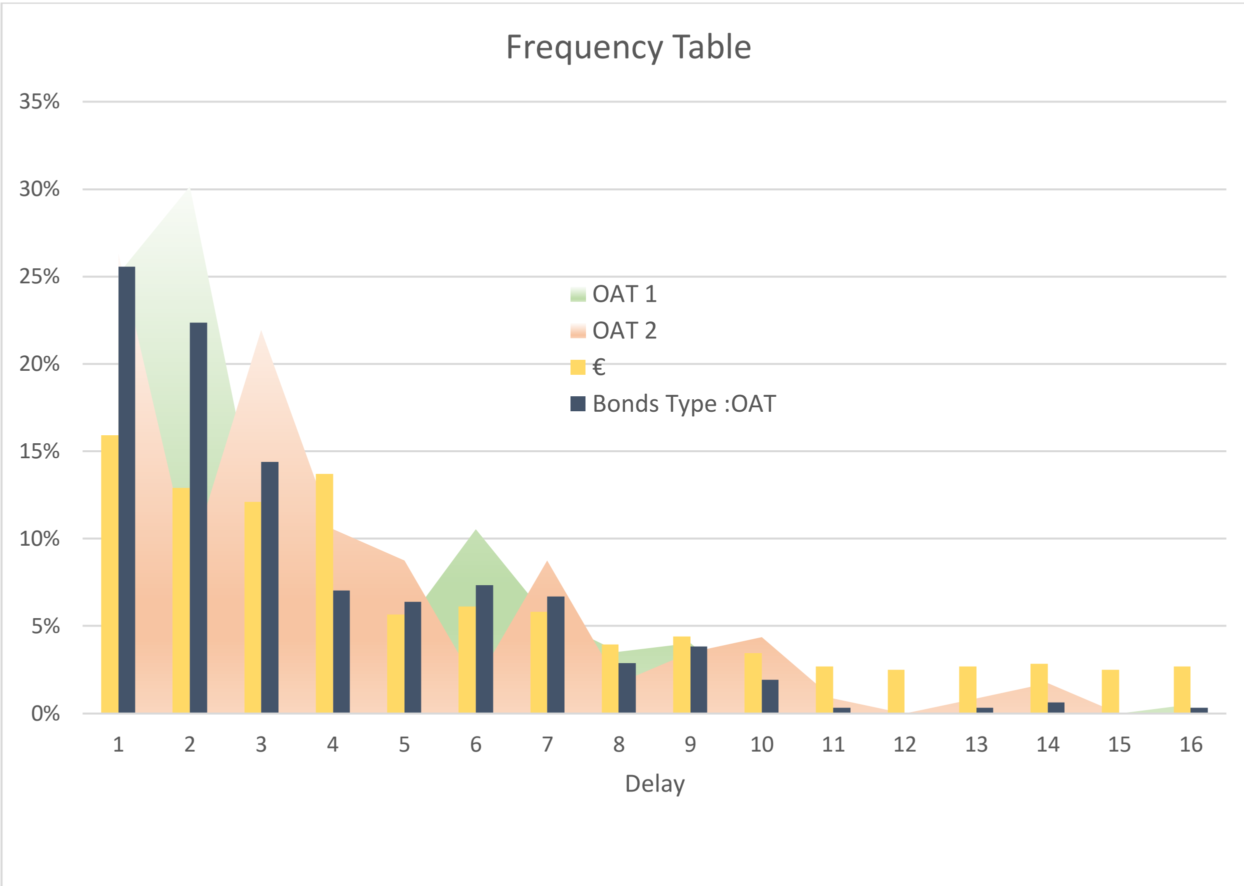

FIGURE 5-2 :GRANULARITY FREQUENCY EXAMPLE

One observes that the bonds type granularity has a better fit than currency granularity. Thus, in this example we would choose Bonds type granularity.

Discussion:
The analysis display as example is relevant but it is not practicable due to the large amount of different bonds and the number of different granularities.
Thus, rather than compare the histogram of the granularity to the products histograms we decided to directly compare dispersion measure from granularity. Thereby granularities are associated to measures of their inherent dispersion.
The lower the dispersion is the more homogenous a granularity is.

Methodology of dispersion measure:

- Firstly, granularities have been selected for rational reasons:

- Security Type : Type of product
- Country Issuer: Type of issuer with the assumption that the liquidity is the same across the same country

- geographic Area x Rating of the issuer country per bucket: Extension of the previous granularity by adding the rating of the country in 3 buckets: Prime, Medium, Speculative. With the assumption that the liquidity is similar across the same geographic area between same rating countries.

- Currency per bucket: Euro, dollar, other currencies. With the assumption that the liquidity is the same for products sharing the same currency.

Secondly, dispersion measures are made on different granularities following the process below:

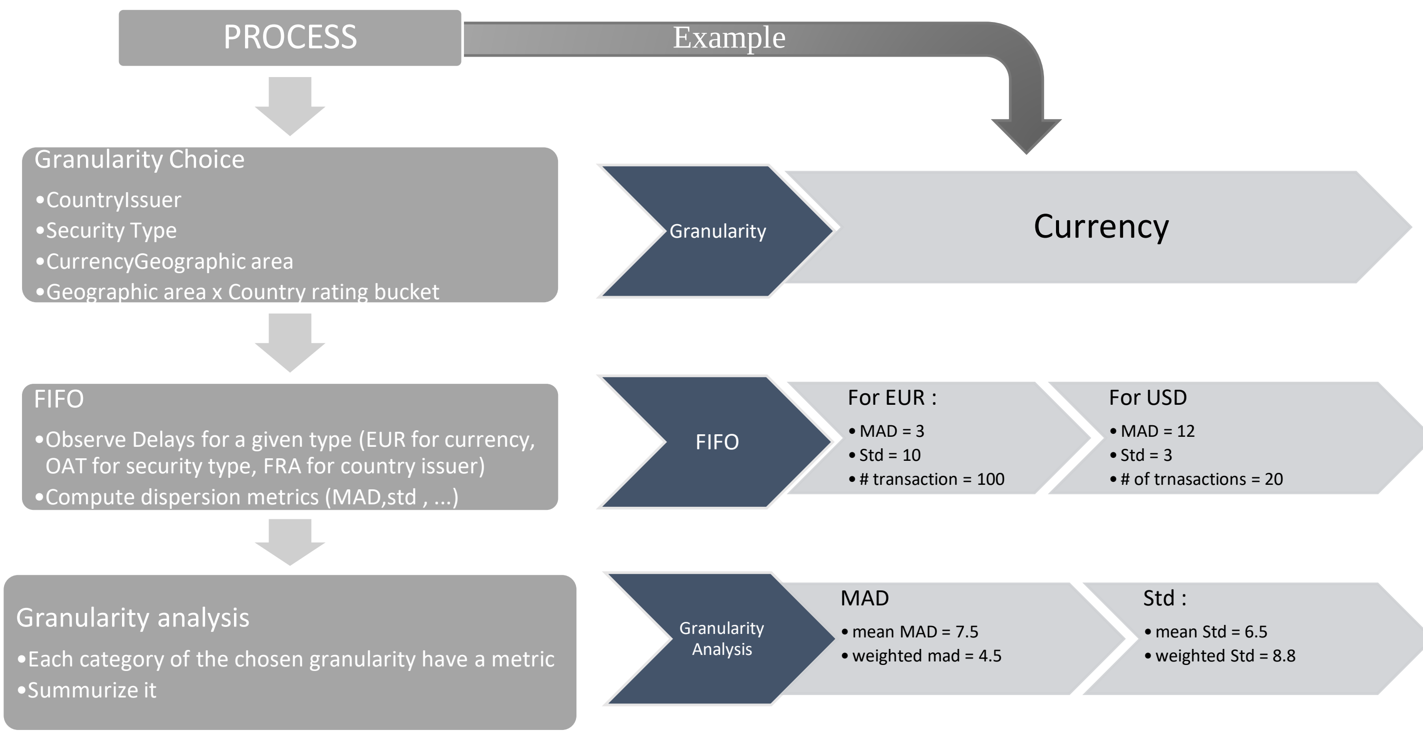

FIGURE 5-3 : DISPERSION MEASURE PROCESS

Dispersion Measures selection:

Dispersion measures are daily reality in data analysis but in our case delay can vary a lot and often have outlier that spoil some dispersion measure like: mean, std, Coefficient of Variation ... Basically, all measures based on mean are overestimated due to these outliers this is due to the sensibility of the mean to outliers.

To solve this issue two possibilities:

- Removing extreme values from our scope. This technique decreases the measures, but the rule is uncertain. Moreover, most measures decrease equally so it’s hard to conclude about the homogeneity of the measure.

- The other possibility is to focus on measures which use quantile rather than mean. Thus, the results shall not be impacted by outliers. We choose the InterQuantile and med_MAD measures to measure dispersion

We combined these two solutions by choosing the dispersion measures: CV_interquartile and med_mad which are not (or less) sensitive to outlier and we removed the top 1% of extreme values to soften the effect of outliers.

Positional measure selection:
In order to compare the granularities, the dispersion measures have to be sum up in one single value. For that we selected three possibilities:
- Taking the mean
- Taking the median (quantile 50%)
- Taking the mean weighted per the number of transactions of the granularity product (example $ for currency granularity)

All these positional measures can be used and have been computed. However, the median seems a better fit to the criteria: “The granularity chosen has to assess a homogenous dispersion for all categories ($, €, other for currency granularity).”. Thereby the positional measure chosen is the median.

Observable measure:
There are two observable measure: the delay and the delay weighted by the nominal. The nominal is an interesting value, but the calibration turnovers don’t take into account the volume. Thus, it has been decided to focus our analysis on the Delay measure

5.6 Calibration

The final purpose of this study is to draw a process to compute the time to liquidate the bank assets under both stressed and non-stressed environment. Thus, a model has to be chosen and calibration must be proposed. All other analysis carried out help us to get a better understanding of the bank activity on bonds market.

Part 6 Data

Our analysis has been carried out based on internal data provided by bank's database

6.1 Data source

The data extracted are formatted and share a given number of fields. Here is displayed a presentation of the different field and the signification.

Fields	Description
SECURITY_SUB_CATEGORY	Bonds Type (OAT, EO, …)
SECURITY_MNEMO	Product identifier
SECURITY_ISIN	Product identifier
SECURITY_ISSUER	Issuer of the bond identifier
SECURITY_NOMINAL_CURRENCY	currency
COUNTERPARTY_MNEMO	Counterparty of the bond identifier
DEAL_REFERENCE	Deal identifier (unique per deal)
FRONT_REFERENCE	Deal identifier
GOP	Who has traded the bond?
TRADE_DATE	Date of trade
VALUE_DATE	Date of assets transaction
DEAL_TYPE	Buy or sell
QUANTITY	quantity of bonds traded
SECURITY_NOMINAL	Nominal amount
TRADE_PRICE	price at trade date
TRADE_NET_SETTLEMENT_AMOUNT	Total price of the transaction
TRADE_NOMINAL_AMOUNT	Nominal amount of the transaction

TABLE 6-1 : DATA FIELDS DESCRIPTION

6.2 Perimeter

Raw data need to be reprocessed in order to get only relevant trade in our analysis. Moreover, data selected depends on the liquidity scenario.

6.2.1 Perimeter in BAU

The BAU model is based on market making activity (see 2.5.1). Thus, the BAU perimeter focus on desks and gops which trade bonds in a market making purpose.
It has been decided to remove:

- Internal counterparties which represent intern deals realized between desks
- Internal issuers which represent intern product, issued by the bank
- Business Units (other than MARK, which represent all market activities of the bank

Then we select desks and gops registered as market maker in FIC market.

6.2.2 Perimeter in CMB

The CMB model is based on the overall bank sell capacity. Thus, all desk belonging to market activity are taking into account. However, some internal deals have been removed such as:

- Internal counterparties which represent intern deals realized between desks
- Internal issuers which represent intern product, issued by the bank

6.3 Delimitation

Data are registered from 2007 up to now. However, the market has suffered crisis and new rules has been set up. Consequently, the market is no longer the same and it is hard to compare pre and post crisis data (2008 and 2012 crisis).
Moreover, old data are less accurate and could had been misfiled or number could be corrupted. Consequently, the calibration of our model is done on a recent basis: 2015 to 2019. 2020 has been rejected from our calibration basis to avoid side effect due to the COVID crisis.

Caution: This analysis is based on internal data and under no circumstances can be generalized to other study with different data set.

Part 7 Result

This part aims at proposing the result of the process described in the Modelling Part. Due to the important number of results, specific discussions will be done briefly at each end of section; and a general discussion is presented in dedicated part.

7.1 Frequency

Based on the process described in the part: 5.3 frequency has been calculated from 2007 up to now. The frequency of buys and sells is similar (see appendix 10.4 for proof) so it has been decided to analyses only the sell side which could be generalized to buy side for this set of data.
Full analysis on frequency forecasting is displayed in the appendix 10.5.

7.1.1 Result

The charts below display: the daily frequency (occurrence of trades per business days), the monthly frequency, the quarterly frequency and the yearly frequency for both corporate and governmental bonds:

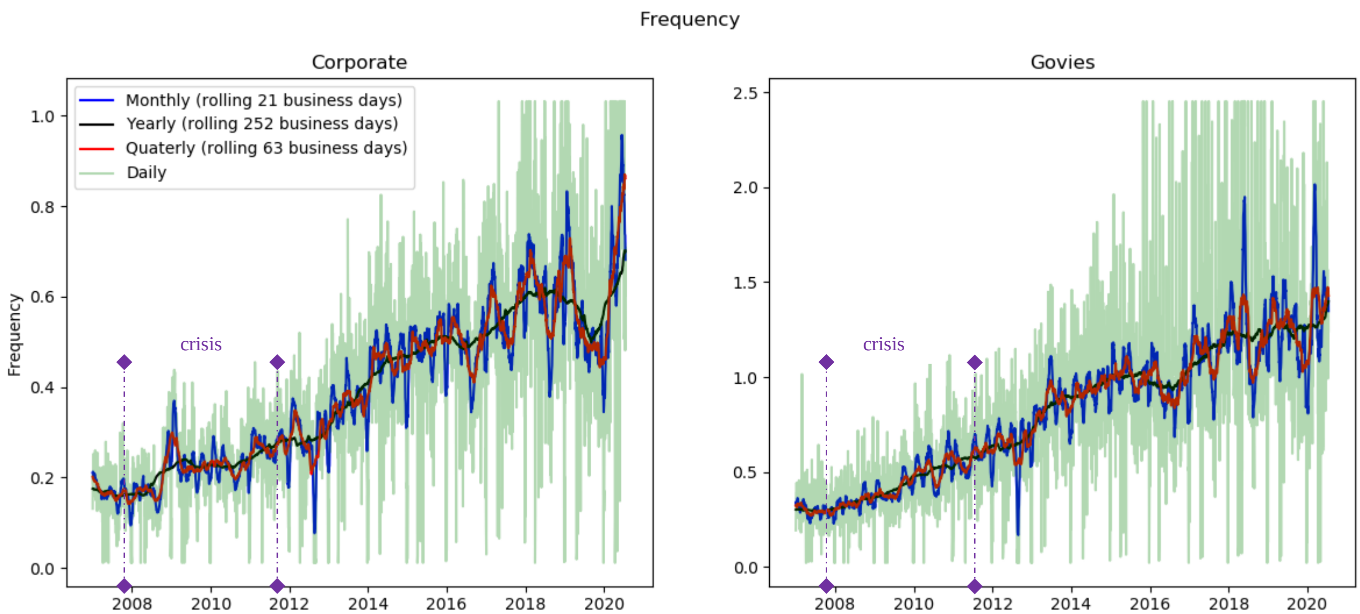

FIGURE 7-1 : FREQUENCY OBSERVATION

The graph below shows both moving average and rolling standard deviation on 252 business days for corporate and govies.

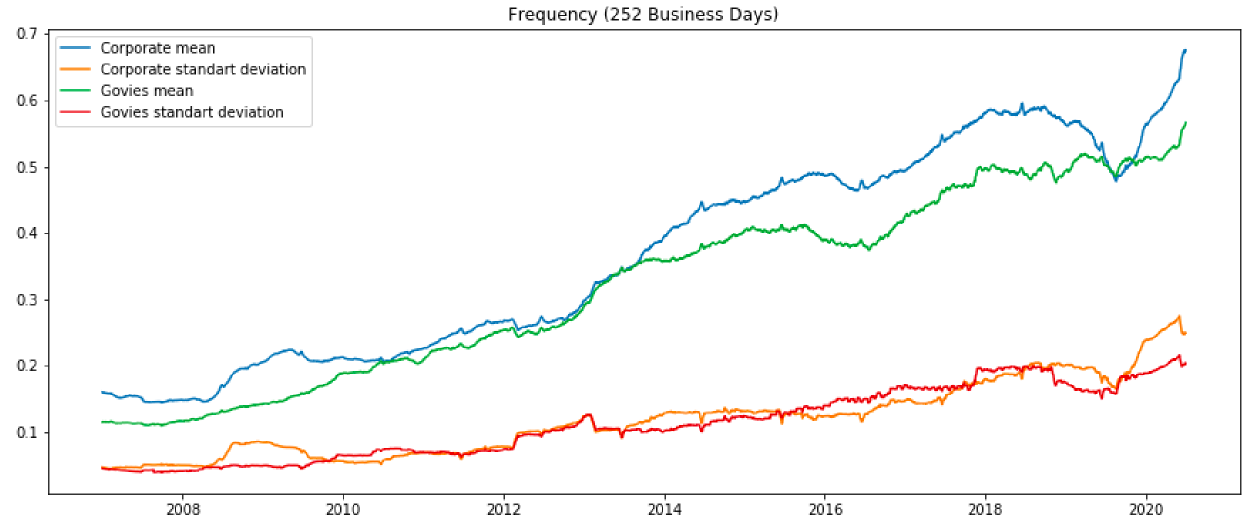

FIGURE 7-2 : MOVING AVERAGE AND STANDART DEVIATION (ON 252 DAYS PERIOD)

The series are clearly not stationary. We differentiate the series and check the stationarity with the AD-fuller test (see 10.5) and get p-values less than 1% for both corporate and govies.

The two differentiate series are correlated as the correlation table show it:

		Frequency	
		Corporate	Govies
Frequency	Corporate	1.000000	0.782043
	Govies	0.782043	1.000000

TABLE 7-1 : CORRELATION FREQUENCY

This correlation should imply similarities between corporate and govies models.

Based on the selection process described in 5.3.2, one selected the following SARIMA model for **monthly** frequency for:

- Govies (see appendix 10.5.2 for more analysis)

	coef	std err	z	P>|z|
ma.L1	-0.8481	0.040	-21.137	0.000
ar.S.L12	1.0127	0.062	16.346	0.000
ma.S.L12	-0.7023	0.145	-4.829	0.000
sigma2	1.2927	0.079	16.415	0.000

TABLE 7-2 : MODEL FREQUENCY COEFFICIENTS GOVIES

- Corporate (see appendix 10.5.1 for more analysis)

	coef	std err	z	P>|z|
ma.L1	-0.3415	0.057	-6.035	0.000
ar.S.L12	1.0105	0.028	36.045	0.000
ma.S.L12	-0.8019	0.082	-9.803	0.000
sigma2	1.2458	0.119	10.449	0.000

TABLE 7-3 : MODEL FREQUENCY COEFFICIENTS CORPORATE

The forecast based on this model is showed below:

- For Govies

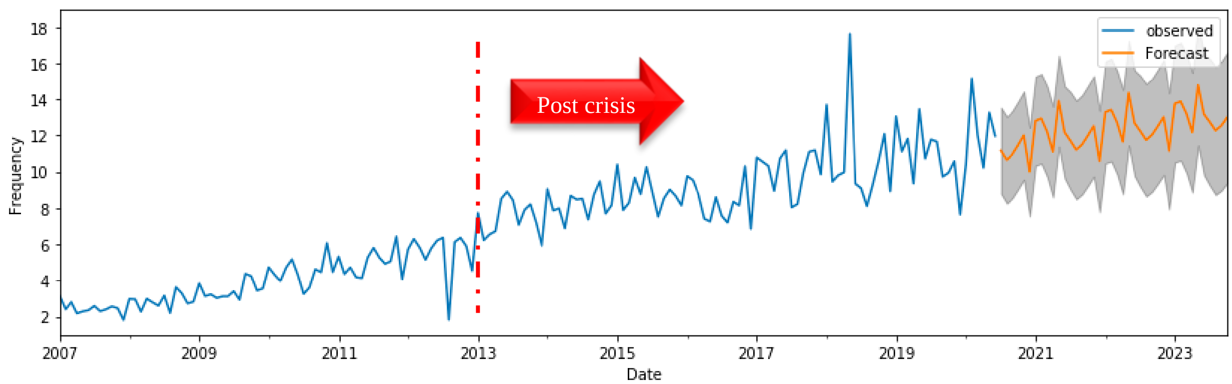

FIGURE 7-3 : FORECAST FREQUENCY GOVIES

- For Corporate

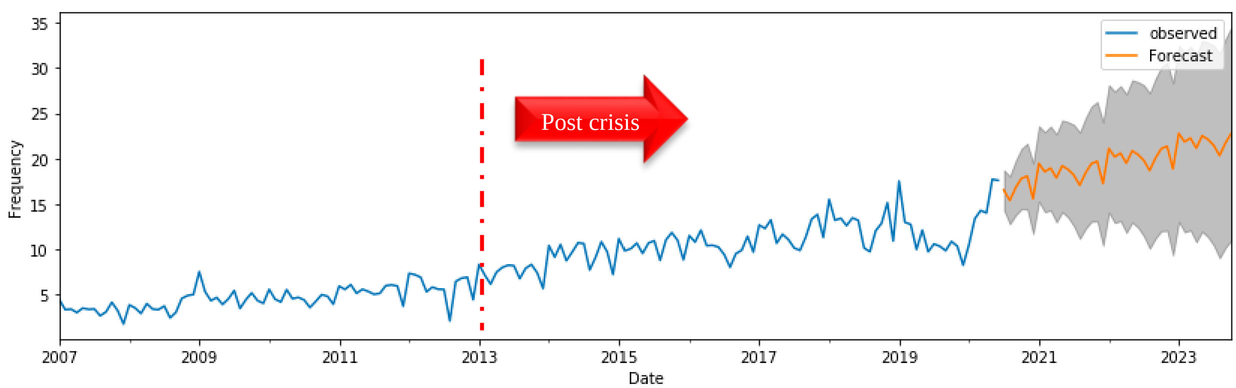

FIGURE 7-4 : FORECAST FREQUENCY CORPORATE

7.1.2 Discussion

For both corporate and govies, the frequency of trades has broadly increased since 2007 with a slight decrease in the 2016 summer and in the summer of 2019 for corporate bonds. Globally the number of transactions has been multiplied per 4. This is mainly due to the automatization of the trading processes which enhances the accessibility to the secondary market.

The projection realized with SARIMA models show that the monthly frequency should continue to increase with a one-year periodicity.

SARIMA models are close except the ma.L1 coefficient (1st coefficient of moving average process). However, the trend observed cannot be projected in the long term due the impact of other parameters independent of liquidity as transaction fees.

7.2 Traded Volume

Based on the process described in the part: 5.4 traded volume has been calculated from 2007 up to now from the field: “TRADE_NOMINAL_AMOUNT”. The traded volume is similar for buy and sell (see appendix 10.4 for proof). Thus, it has been decided to only study the sell side.
Full analysis on frequency forecasting is displayed in the appendix 10.6.

7.2.1 Result

The charts below display: the daily traded volume (occurrence of trades per business days), the monthly traded volume, the quarterly traded volume and the yearly traded volume for both corporate and governmental bonds:

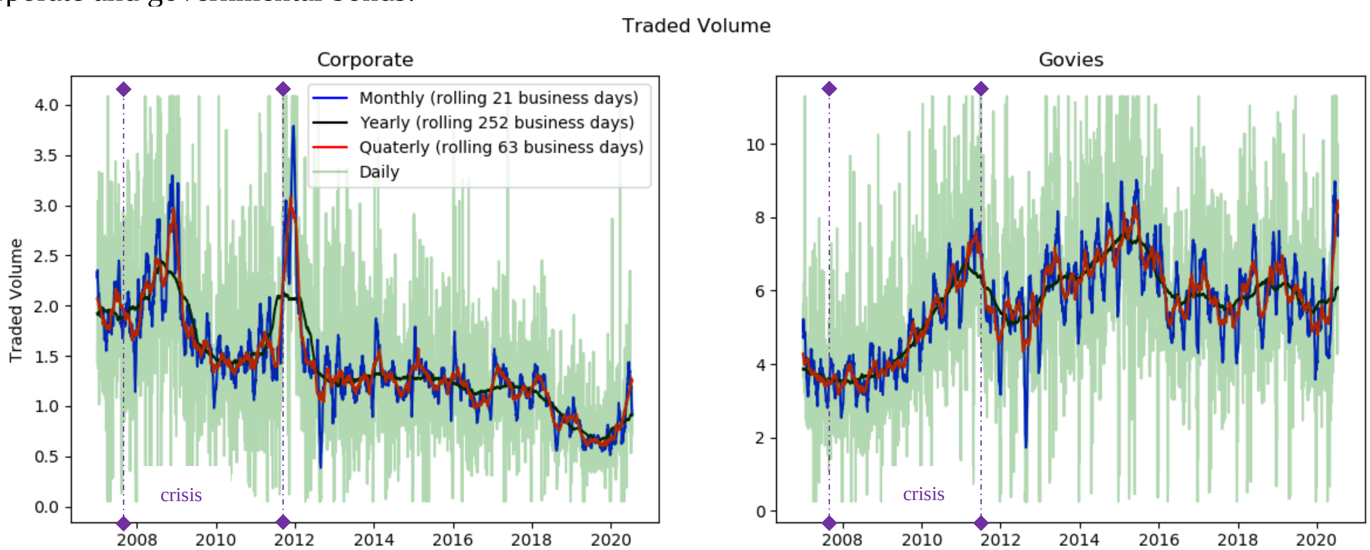

FIGURE 7-5 : TRADED VOLUME OBSERVATION

The graph below shows both moving average and rolling standard deviation on 252 business days for corporate and govies.

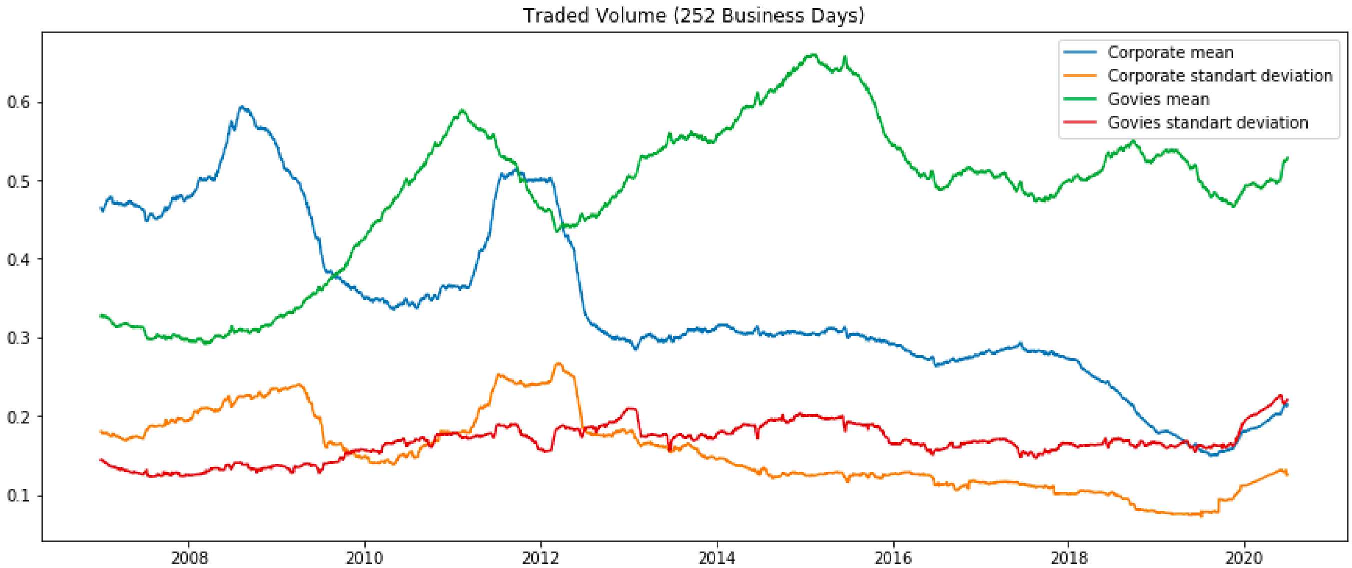

TABLE 7-4 : MOVING AVERAGE AND STANDARD DEVIATION (ON 252 DAYS PERIOD)

The series are clearly not stationary. We differentiate the series and check the stationarity with the AD-fuller test (see 10.5) and get p-values less than 1% for both corporate and govies.

The correlation between differentiate corporate and govies traded volumes is very low:

		Traded Volume	
		Corporate	Govies
Traded Volume	Corporate	1.000000	0.016788
	Govies	0.016788	1.000000

TABLE 7-5 : TRADED VOLUME CORRELATION

Thus, the model should not be the same and the analysis could not be the same.

Based on the selection process described in 5.4, one selected the following SARIMA model for **monthly** traded volume for:

- Govies (see appendix 10.6.2 for more analysis)

	coef	std err	z	P>|z|
ar.L1	-0.5820	0.071	-8.141	0.000
ar.L2	-0.3597	0.073	-4.948	0.000
ma.S.L4	-1.0509	0.066	-15.903	0.000
sigma2	2.3171	0.316	7.324	0.000

TABLE 7-6 : MODEL TRADED VOLUME GOVIES COEFFICIENTS

- Corporate (see appendix 10.6.1 for more analysis)

	coef	std err	z	P>|z|
ar.L1	-0.3600	0.053	-6.819	0.000
ar.L2	-0.2305	0.050	-4.603	0.000
ma.S.L3	-0.9377	0.050	-18.890	0.000
sigma2	2.8442	0.192	14.848	0.000

TABLE 7-7 : MODEL TRADED VOLUME CORPORATE COEFFICIENTS

As expected, the models have different coefficient and the periodicity is not the same: quarterly for corporate bonds and 4-month period for Govies (more information in 10.6)

The forecast based on this model is showed below:

- For Govies

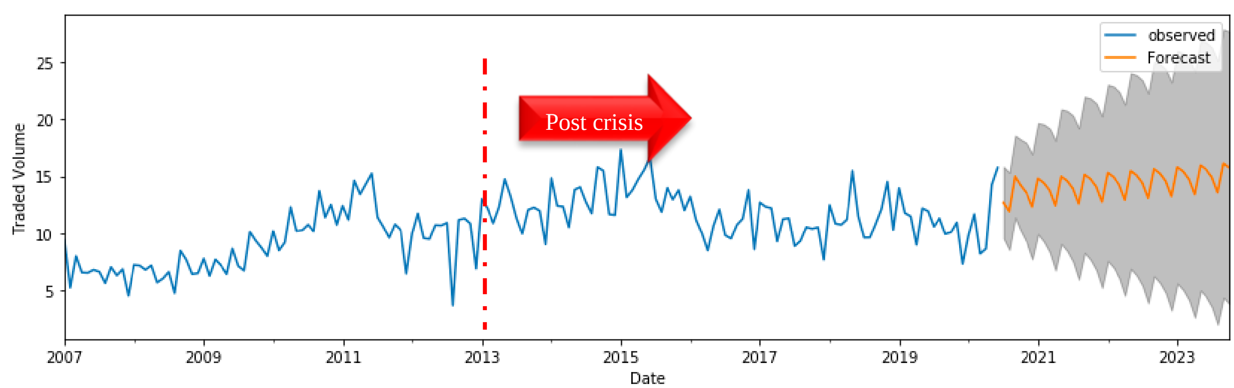

FIGURE 7-6 : FORECAST TRADED VOLUME GOVIES

- For Corporate

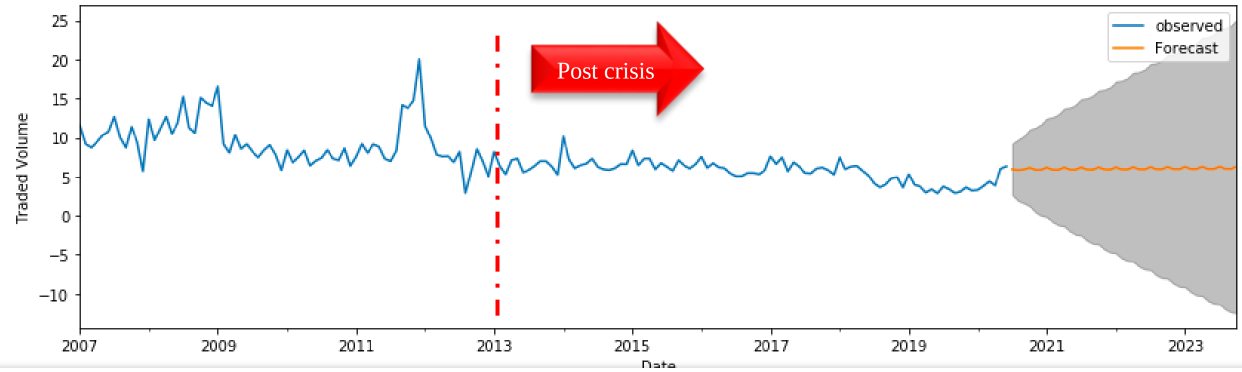

FIGURE 7-7 : FORECAST TRADED VOLUME CORPORATE

7.2.2 Discussion

Corporate bonds traded volume has slightly decreased since 2008 with an upturn in 2012. However, the traded volume remains in the same proportion since 2015. The 2012-upturn can be explained by the 2012 crisis which caused a stress on bonds market. During this period, frequency of trade did not increase so the upturn of traded volume is mainly due to the trade size average which raised (orders became larger in 2012 to respond to the crisis).
Governmental bonds traded volume has slightly increased in the end of 2011 and decreased in the beginning of 2012. Otherwise the traded volume remains steady since 2016. The global tendency seems to be softly bullish but the high volatility and variation due to crisis impact could heavily affect this tendency.

The projections realized with SARIMA models show that the traded volumes for both corporate and govies should remain the same order of magnitude than the current ones.
The two models are similar in their form but vary by the seasonality and the coefficients values. This variation is mainly due to the different trends of govies and corporate bonds.

7.3 Frequency / Traded Volume

In order to get an idea of the relation between frequency and traded volume one computed the correlation between these series:

		Frequency		Traded Volume	
		Corporate	Govies	Corporate	Govies
Frequency	Corporate	1.000000	0.782043	-0.158035	0.511394
	Govies	0.782043	1.000000	-0.247236	0.575517
Traded Volume	Corporate	-0.158035	-0.247236	1.000000	0.016788
	Govies	0.511394	0.575517	0.016788	1.000000

TABLE 7-8 : FREQUENCY AND TRADED VOLUME CORRELATION

The correlation for govies between frequency and traded volume seems significant (correlation value = 0.57) but for corporate bonds the correlation is negative.
Consequently, it has been decided to ignore relation between these two measures and no further calculation has been made to link them.

7.4 Turnover

Based on the methodology described in 5.5.1 turnovers have been computed for different granularities. Results have been anonymized in order to assess an unbiased analysis.

7.4.1 Result

Turnover cannot be display for confidential concerns. This part will only display the dispersion measure and the choice of the granularity. As explained in 5.5.4 we measured the observable "delay" and compute the dispersion measures: 'Coefficient of variation Interquantile' and 'med_mad'. Then we summarize the values with the positional measure: 'median'.
Below are displayed the charts of the observed dispersion measures for both corporate and governmental bonds (full result tables are displayed in appendix 10.1):

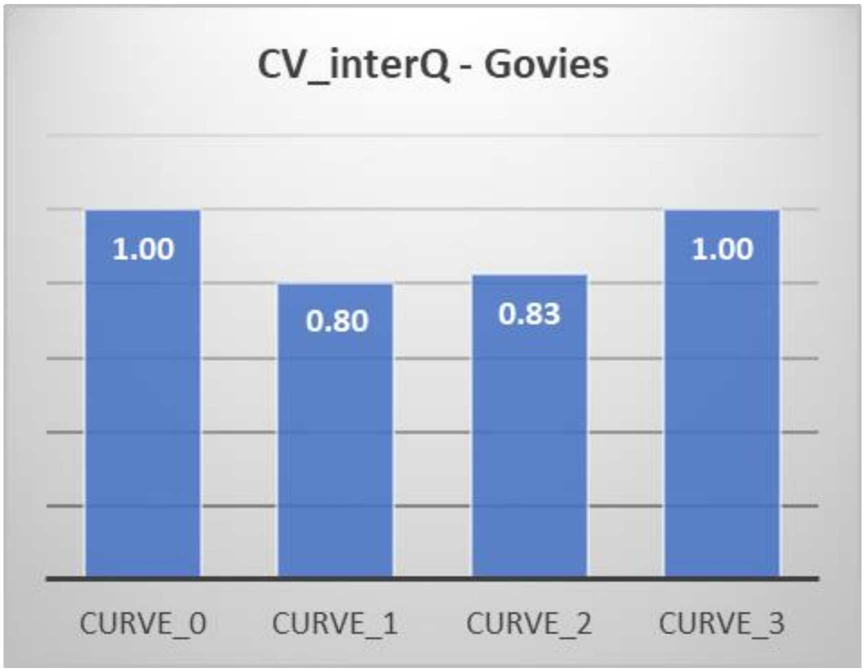

FIGURE 7-8 :CV_INTERQUANTILE FOR GOVIES (10.1.1)

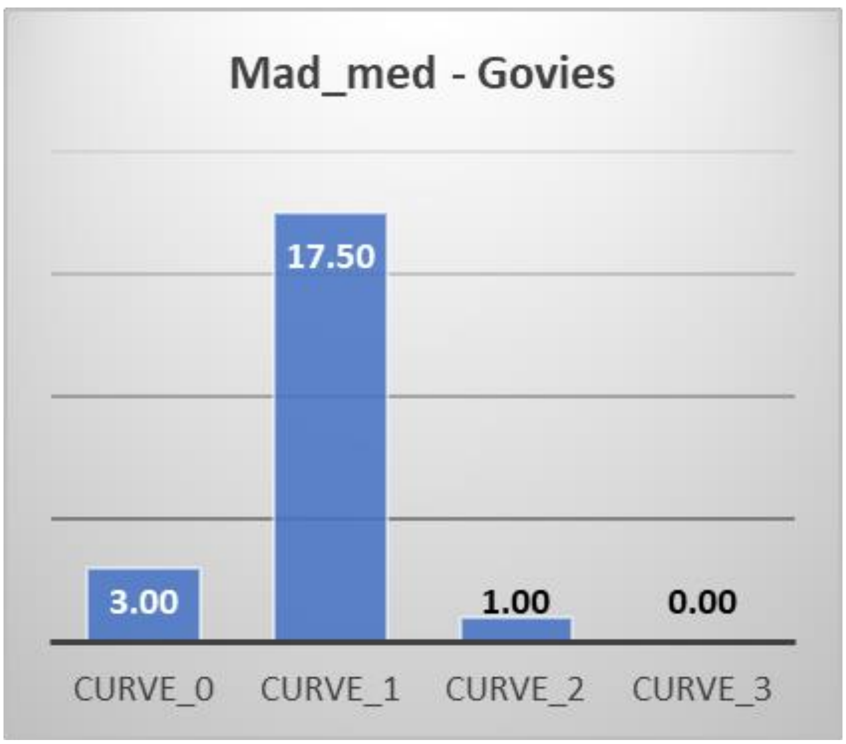

FIGURE 7-9 : MAD_MED FOR GOVIES (10.1.1)

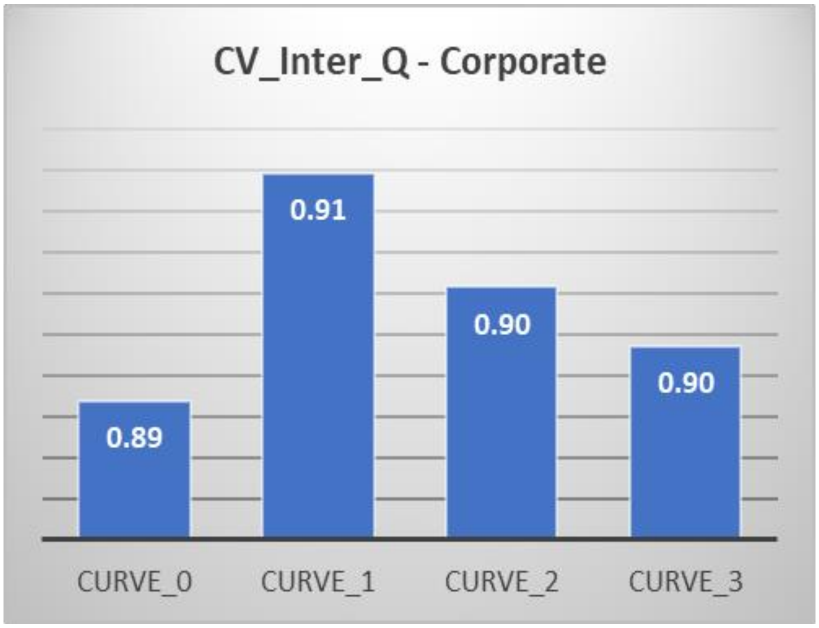

FIGURE 7-10 : CV_INTERQUANTILE FOR CORPORATE (10.1.2)

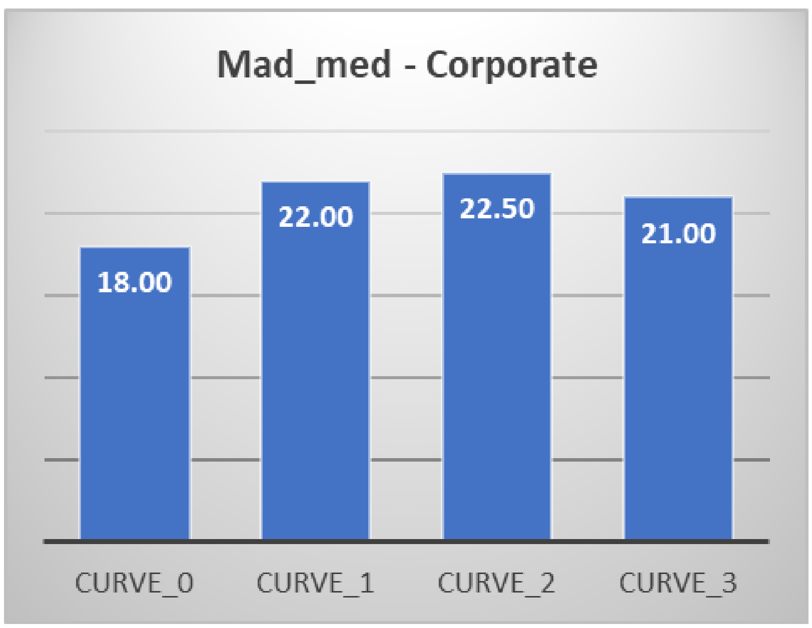

FIGURE 7-11 : MAD_MED FOR CORPORATE (10.1.2)

7.4.2 Discussion

7.4.2.1 Corporate Bonds

According to the two dispersion measures the calibration provided by the granularity 1 is the best one. However, the gap between all measures is not significant and it seems hard to give a conclusion about this part without considering a larger view of the problem and without aking into account rational reasons explained later.

7.4.2.2 Governmental Bonds

Mad_med measure highlights the granularity 1 as more dispersive than the other. Otherwise all other granularities have relatively close values for both dispersion measures. Consequently, the only clear conclusion that can be drawn is the exclusion of the granularity 1.

Part 8 Discussion

8.1 General observation

Crisis seems to have a positive impact on trading activity on bonds market (as shown in Part 4). Indeed, the flight to quality behaviour in period of crisis enhance the trading activity of high yield governmental bonds. These observations are not always true for corporate bonds which are, structurally, a less liquid market. Nonetheless the most impacting event are the regulations put in place after liquidity crisis in 2008 and 2012.
The two liquidity measures (frequency and traded volume) provide a good overview of the tendency of bonds market in the bank. The manner of trading has evolved: frequency goes up and average trade size decreased. Thus, it seems important that our scope reflects the current tendency. It is also observed that the traded volumes have increased in 2008 and 2012 for both governmental and corporate bonds.
The turnovers computed with different granularities put in evidence that bonds must be pooled depending on specific characteristics. However, I also show that some features are not that different from a dispersion point of view. Thereby, a choice is made with rational and experimental views. Definition of "homogeneous" groups of securities depends not only on quantitative criteria, but also on an expert basis.

8.2 Granularity choice

This part aims at describing the granularity and the model chosen to evaluate the capacity of the bank to liquidate its position under normal and stressed condition for both corporate and govies.
The decisions described below should meet several obligations imposed by the regulator and the bank:

- All choices can be explained clearly to the regulator
- All choices can be explained by rational arguments (not just mathematical analysis)
- The choices must be implementable in the database system.

It is essential that the above conditions are met in order to propose the model.
For implementation and monitoring concerns, it has been decided that the granularity must be the same for both liquidity scenarios.

8.2.1 Corporate

For corporate bonds the less dispersive granularity is the curve 0 for both measures. This granularity can be easily implemented and respond to rational reasons. Thereby, the granularity: "curve 0" has been chosen.

8.2.2 Govies

For Govies the choice is less evident than for corporate. All measures, except mad-Med for Curve 1, seem similar and no evident choices can be established. Consequently, this granularity

(granularity 1) has been removed from our scope. Thus, it has been decided, for rational reasons, to keep the same granularity than the corporate: curve 0.

8.3 Model Choice

This paper aims at proposing calibration and model to respond to the "research question" (see 1.4). Based on the result provide by benchmark and modelling results some decisions have been taken, depending on the liquidity scenario.

8.3.1 BAU Scenario

The recent market analysis provided in 4.1 shows that the bonds market for both corporate and govies is "relatively" stable. However, a periodicity is observed in both EU and US market. This observation is confirmed by internal data (see index (Pricewaterhouse Coopers, 2015) (Gady Jacoby, 2007) (Tarun Chordia, 2003) (BlackRock, 2016)10.5 and 10.6)
The frequency and the traded volume show the same result: a periodicity is observed but no trend since 2016.
Consequently, a calibration on a recent historic seems to be the best shot. The turnover provides a good day to day vision and is well adapted to model normal market conditions because it give an average behaviour.
The granularity chosen to apply the turnover model is described in 3.3.1
Model chosen:

- Turnover ratio with FIFO methodology
- The granularity: security type

8.3.2 CMB scenario

The historic analysis provides by 4.1 show that regulations have had an impact on bonds liquidity. However, crisis which correspond to the present definition of CMB are 2008 and 2012. During these periods the traded volume had increased (see 7.2) for corporate bonds and had increased in 2012 for governmental bond. The frequency had not been significantly affected by those crises and had remained in the same trend.
Consequently, the bank desired reflect the fact that bonds are more traded under stress. This meet a rational reason which is: under stressed condition the bank is able to raise its traded volume in the limit of the market depth in order to generate cash and improve the bank liquidity.
The bank has chosen to use a model which give a nominal amount that bank trading desks can sell/buy in order to reduce the bank exposure and generate cash. This model is called: traded volume projection.
One of the main issues of the model is that the trading activity has evolved since the crises; the model should catch the variation of volume during these crises instead of just taking the nominal amount sold during these stressed periods.

For rational reasons it has been decided that the granularity is the same between calibration in BAU and in CMB. Indeed, it seems reasonable to think that each security type reflects the same liquidity risk and could be pooled.

8.4 Conclusion

The model chosen are summarized in the table below:

- "FIFO Turnover" means the methodology describe in 5.5.1
- "traded volume projection" means the methodology described in 5.4

Scenario	Type of Bonds	Model	Granularity
BAU	Govies	FIFO turnover	Security Type
	Corporate	FIFO turnover	Security Type
CMB	Govies	traded volume projection	Security Type
	Corporate	traded volume projection	Security Type

TABLE 8-1: MODEL CHOICE SUM-UP

Part 9 Backtest

The model has to be back tested in order to be implemented in the liquidity management system. This part presents the methodology of backtest. Due to the difficulty to find a real stressed period it has been decided that only BAU liquidity scenario would be backtested.

9.1 Methodology

The idea is to compute various calibrations based on given time span (typically a few months) in order to get the turnover for this specific period. We repeat this process with a given step (typically one month) and recompute the calibrations. This back test will provide turnover per period that we could compare to our calibration to measure robustness and accuracy.

However, some problems due to this method have to be handled:

1. Sensibility of calibrations to the management of the remaining buys (buys which have not been cancelled by any sells during the period of calibration)

2. Difficulty to isolate and back test a specific period. For example, to back test January 2019 a buy realized the 10^{th}-Jan can be sold the 1^{st} of February and will be associated to the “remaining buys” even if it should be to the bucket “1 Month”.

The solutions proposed:

1. Sensibility to remaining buys: It has been decided to keep the same methods as used during previous calibration. The remaining buys are all sold at the end of the scope plus one day.

2. Period back test difficulty: To observe a specific period it has been decided to modulate the selection of buys and sells. For x-months period:

    - we select buys during x-months

    - we select sells during 2x-months

   Thus, the x-months period will be reliable because all unsold buys will be affiliate to a larger bucket than x-months.
   For example, the back test for the period [1^{st} February --> May 15^{th}] = 105 days: the calibration will be reliable until the 52 days.

In order to compare the different calibrations, we generate outflows based on Illiqo positions (we remove the security types which have not been traded during this period).
To summarize: the calibrations obtained from a full year back test (or more) we take the different quantiles (5,50,95) + the mean and observe if the calibration on 5-year historic fit these quantiles.

The following scheme resume the back-test process.

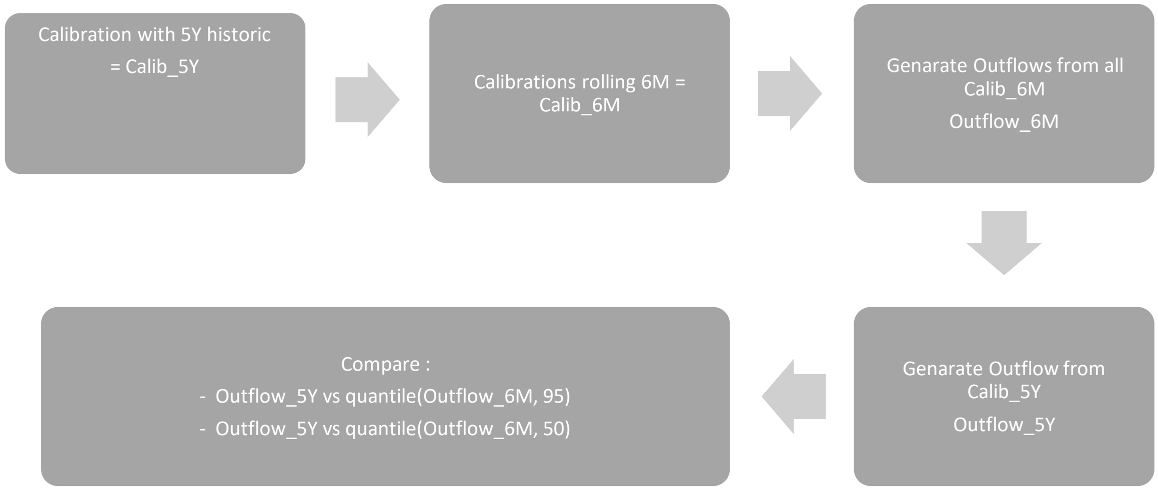

FIGURE 9-1 : BACKTEST PROCESS

Algorithm methodology: Calibration for Period with a step = StepX

- Set t0 (month Begin); step = 1M
- Take transactions with VD :
    - in [t0 , t0+ 2xPeriod] for sells
    - in [t0 , t0+ Period] for buys
- FIFO Calibrations: Taking remaining buys into account with time per default to sell = t0+2M +1D
- Evaluate the outflow of the month t0 with those calibrations with the formula describe in
- Set new t0 : t0 = t0+ StepX

9.2 Result

The calibrations compared are :

- the calibration in Liqor: “Liqor”
- the pending calibration validated in 2019: “Pending”:
- the calibration obtained with a historic from 2015-01-01 to 2019-12-31 to liquidate **long** position: “Calibration with recent historic long”
- the calibration obtained with a historic from 2015-01-01 to 2019-12-31 to liquidate **short** position: “Calibration with recent historic short”

We back test this model with 6M rolling back test from 2019 up to now. Note that the document refers to other back test on different rolling periods.

9.2.1 Compare to quantile 50

We compared the outflows generated by the calibration describe above to the quantile 50 of the outflows generated by the rolling calibration on 2019 and 2020.

The below table gives the difference in percent between calibrations (C0) and Quantile(50) of rolling calibration.
The colums (7,30, …) are a number of days and the values of the table are the gap between the runoff from the calibration in rows and the quantile 50 issue of the backtest. If the value is in green then the calibration is conservative otherwise (red color) the calibration is aggressive.

Corporate				
In percent	7	30	60	90
Liqor	16.8	13.4	9.7	6.6
Pending Calibration	-3.3	1.8	3.2	-0.9
Calibration with recent historic long	7.4	5.2	3.5	2.6
calibration with recent historic short	29.6	27.1	22.0	15.4

TABLE 9-1 : CORPORATE BACKTEST QUANTILE 50 RESULT

Govies				
In percent	7	30	60	90
Liqor	41.6	16.0	6.5	3.2
Pending Calibration	6.9	3.7	2.1	-0.2
Calibration with recent historic long	1.8	0.5	0.7	0.5
calibration with recent historic short	5.2	3.0	2.2	1.9

TABLE 9-2 : GOVIES BACKTEST QUANTILE 50 RESULT

All calibrations except the pending calibration are conservative to the quantile 50 backtest of 2019-2020. However, the BAU calibration aims at modelling the average market activity of bonds market so the gap between the backtest quantile 50 and the model should be minimized. Consequently, the Calibration on the recent historic for long positions ("Calibration with recent historic long") seems to be the best fit.

9.2.2 Compare to quantile 95

We compared the outflows generated by the calibration describe above to the quantile 95 of the outflows generated by the rolling calibration on 2019 and 2020.
The below table gives the difference in percent between calibrations (C0) and Quantile(95) of rolling calibration.
The colums (7,30, …) are a number of days and the values of the table are the gap between the runoff from the calibration in rows and the quantile 95 issue of the backtest. If the value is in green then the calibration is conservative otherwise (red color) the calibration is aggressive.

Corporate				
In percent	7	30	60	90
Liqor	12.3	9.7	5.9	1.0
Pending Calibration	-7.8	-1.8	-0.6	-6.5
Calibration with recent historic long	2.9	1.5	-0.3	-3.0
calibration with recent historic short	25.1	23.5	18.2	9.8

TABLE 9-3 : CORPORATE BACKTEST QUANTILE 95 RESULT

Govies				
In percent	7	30	60	90
Liqor	31.3	8.7	-2.0	-5.7
Pending Calibration	-3.4	-3.7	-6.3	-9.1
Calibration with recent historic long	-8.5	-6.8	-7.8	-8.5
calibration with recent historic short	-5.1	-4.3	-6.3	-7.0

TABLE 9-4 : GOVIES BACKTEST QUANTILE 95 RESULT

In a quantile 95 backtest most calibrations are overwhelmed. This observation makes sense if we consider that the extreme BAU on a specific period case could not be caught by a generalized model based on 5Y historic.
However, this point could be discussed, and the calibrations could be reviewed to remain conservative for a given backtest period and a quantile target (95-99).

9.3 Conclusion

The model chosen has been validated by the backtest carried out if we consider the hypothesis that the model is designed to manage no stress and be applied under normal conditions.
Consequently, the calibration proposed by the model can be implemented and recurrent backtest on Covid crisis have been carried out in order to assess the robustness of the model and to evaluate the impact of the crisis on the turnover on bonds market.
This specific and recurrent backtest is partially presented in appendix 10.2. The main conclusion about it is that no abnormal stress on bonds market have been observed and that the model implemented, and the future calibration remain conservative for the outflow generated from 2020-Feb up to 2020-July.

Part 10 Appendices

10.1 Result table granularity corporate and govies

10.1.1 Govies

GOVIES					
Type_dispersion	**Type_measure**	**curve_0**	**curve_1**	**curve_2**	**curve_3**
CoeffVariation	50%	1.60	1.17	2.06	2.99
	mean	1.69	1.42	2.19	3.26
	weighted	2.75	3.02	3.54	2.96
CoeffVariation Average		**2.01**	**1.87**	**2.60**	**3.07**
CV_interQ	50%	1.00	0.80	0.83	1.00
	mean	0.91	0.74	0.79	1.00
	weighted	0.49	0.48	0.60	1.00
CV_interQ Average		**0.80**	**0.68**	**0.74**	**1.00**
IQR	50%	15.00	52.63	4.00	2.00
	mean	82.02	59.63	42.75	2.33
	weighted	4.89	2.90	0.80	1.32
IQR Average		**33.97**	**38.39**	**15.85**	**1.88**
mad	50%	12.92	39.58	12.64	11.34
	mean	56.74	46.09	28.97	12.32
	weighted	4.62	4.08	3.31	4.37
mad Average		**24.76**	**29.92**	**14.97**	**9.34**
mad_med	50%	3.00	17.50	1.00	0.00
	mean	25.91	24.40	19.22	0.00
	weighted	1.47	0.78	0.09	0.00
mad_med Average		**10.13**	**14.23**	**6.77**	**0.00**
std	50%	22.24	55.45	26.24	28.72
	mean	77.93	68.93	40.21	25.95
	weighted	7.13	7.56	8.00	9.28
std Average		**35.76**	**43.98**	**24.82**	**21.32**

10.1.2 Corporate

Corporate							
Type_dispersion		**Curve_0**	**Curve_1**	**Curve_2**	**Curve_3**	**Curve_4**	**Curve_5**
CoeffVariation	50%	1.76	1.93	1.90	1.83	1.81	
	mean	1.76	1.90	1.90	1.83	1.84	
	weighted	1.81	1.82	1.82	1.83	1.82	

Corporate						
Type_dispersion	**Curve_0**	**Curve_1**	**Curve_2**	**Curve_3**	**Curve_4**	**Curve_5**
CoeffVariation Average		**1.78**	**1.88**	**1.87**	**1.83**	**1.82**
CV_interQ	50%	0.89	0.91	0.90	0.90	0.90
	mean	0.82	0.93	0.90	0.90	0.90
	weighted	0.90	0.90	0.90	0.90	0.90
CV_interQ Average		**0.87**	**0.91**	**0.90**	**0.90**	**0.90**
IQR	50%	60.75	77.00	72.50	70.00	72.00
	mean	69.08	75.67	72.50	70.00	71.67
	weighted	70.88	70.12	70.10	70.00	70.04
IQR Average		**66.90**	**74.26**	**71.70**	**70.00**	**71.23**
mad	50%	73.37	83.90	92.88	82.48	83.07
	mean	79.37	88.89	92.88	82.48	86.24
	weighted	83.14	84.27	83.79	82.48	83.21
mad Average		**78.62**	**85.69**	**89.85**	**82.48**	**84.17**
mad_med	50%	18.00	22.00	22.50	21.00	22.00
	mean	21.85	22.33	22.50	21.00	22.00
	weighted	21.63	21.52	21.17	21.00	21.34
mad_med Average		**20.49**	**21.95**	**22.06**	**21.00**	**21.78**
std	50%	118.72	144.24	154.93	133.77	133.54
	mean	134.78	148.97	154.93	133.77	140.31
	weighted	133.98	136.40	135.54	133.77	134.35
std Average		**129.16**	**143.20**	**148.46**	**133.77**	**136.07**

10.2 Covid bi-monthly backtest : Feb-2020 to Mid-July – 2020

10.2.1 Focus COVID 2019

During the COVID-19 crisis SCR has conducted various backtest on its models. The bonds market making activity has not be considered as stressed so the backtest will only concern the BAU scenario.

10.2.1.1 Outflow comparison

In order to determine whether the Covid-19 has conducted to an abnormal outflow in Feb/March/Apr/May/June 2020 it has been decided to compare the outflows of 2019 and 2020.

10.2.1.1.1 METHODOLOGY

The monthly positions (granularity = ISIN) is provided by Illiqo. And then we generate the realized outflow based on deals recorded by Eole and store in the database A/V_Bonds.
The outflows are set in percent to compare them.
Formula: Illiqo_long_position(isin,t) = Illiqo_long_position(isin,t0) – CumulSells(isin,t)

10.2.1.1.2 RESULT

The below charts display the monthly outflows. The 2020 months have been highlighted in order to compare them to the other months.

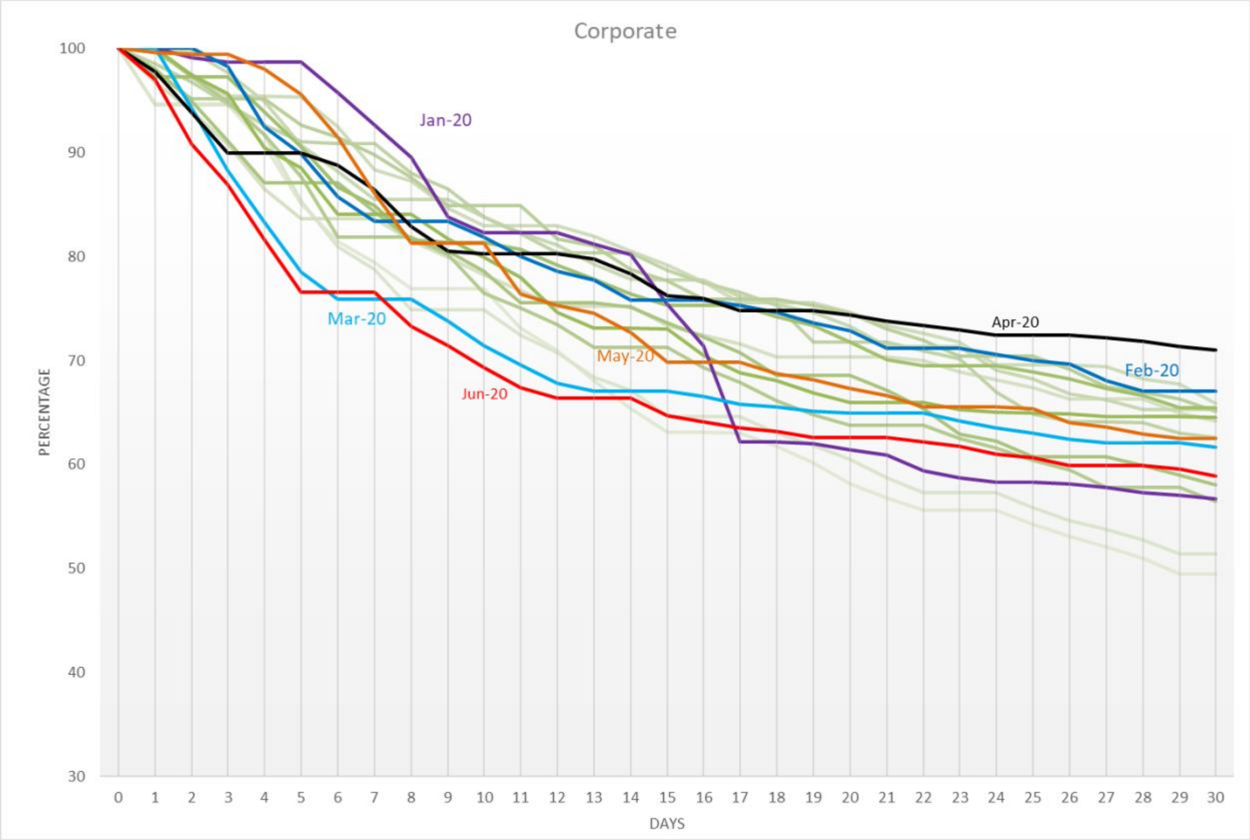

FIGURE 10-1 : OUTFLOW 2019-2020 PER PRODUCT FOR CORPORATE

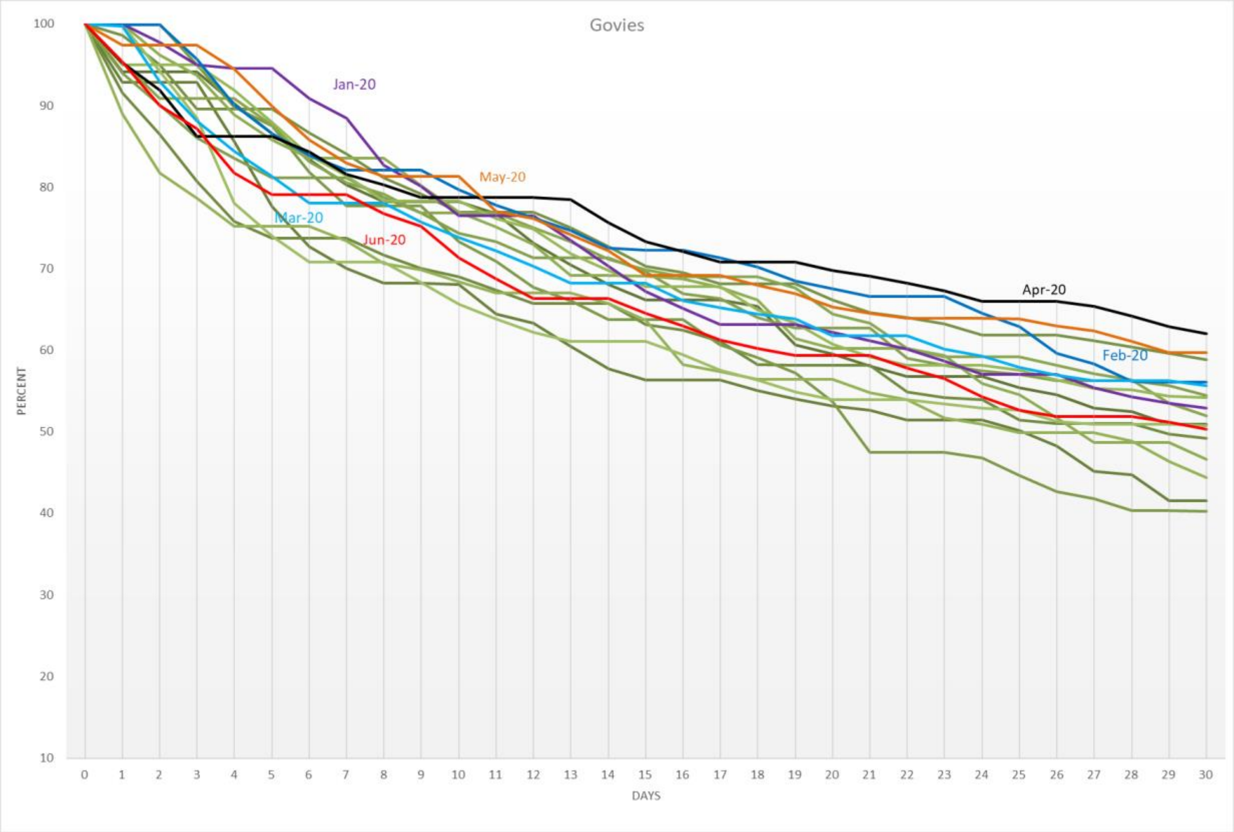

FIGURE 10-2 : OUTFLOW 2019-2020 PER PRODUCT FOR GOVIES

10.2.1.1.3 CONCLUSION

No abnormal trend has been observed in 2020 compared to 2019. The conclusion is that the COVID-2019 crisis did not affect directly the outflows.

Consequently, the backtest of this period will be conducted with the assumption of BAU activity. This assumption might be reviewed regarding the results obtained.

10.2.1.2 Backtest – February 2020

These charts display the outflows generated by different calibrations :

- Observed holding time : from 1st February to 15th of July
- Liqor Calibration in BAU
- Pending Calibration : validated by the committee but not yet implemented
- Long NewCalibration : calibration proposed in this document in BAU

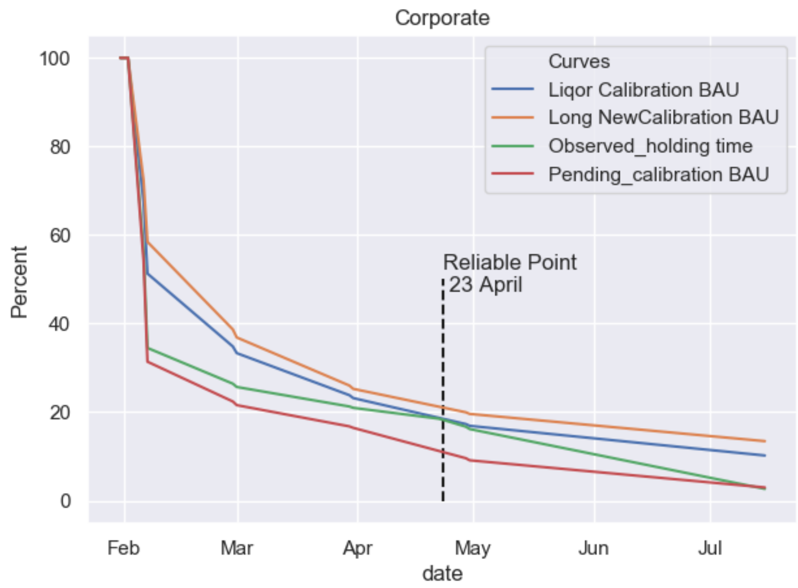

FIGURE 10-3 : MODEL SIMULATION FOR CORPORATE FROM FEB-2020

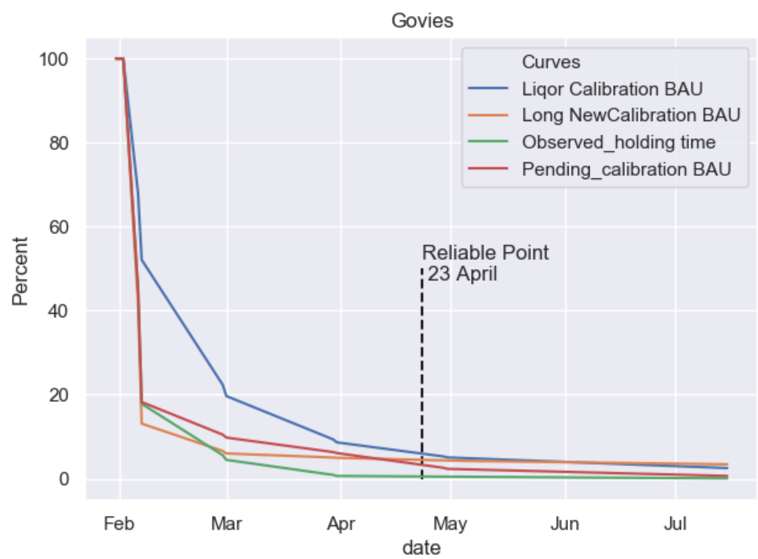

FIGURE 10-4 : MODEL SIMULATION FOR GOVIES FROM FEB-2020

10.2.2 Conclusion

The backtest confirm that the activity is assimilable to BAU and that the calibration of 2018 implemented in Liqor remain conservative for both corporate and governmental bonds.
The calibration proposed in this document remains as well conservative for both Corporate and Governmental Bonds.

10.3 Analysis: Secondary market activity vs Bonds age

This part study the correlation between the sells and buys and the age of the products. By getting the maturity and issue dates we can compute the “relative” age of the product at the trade date in percentage by the formula (given for a product i):

$$RelativeAge_i = \frac{TradeDate_i - IssueDate_i}{MaturityDate_i - IssueDate_i}$$

We also observe the weighted “RelativeAge” by using the nominal_amount converted in euros at the trade_date forex as weights.
The cumulative distribution functions for both buys and sells have also been plot. The 50-50 point represent the point corresponding to 50% lifetime product and and 50%of the cumulative function.

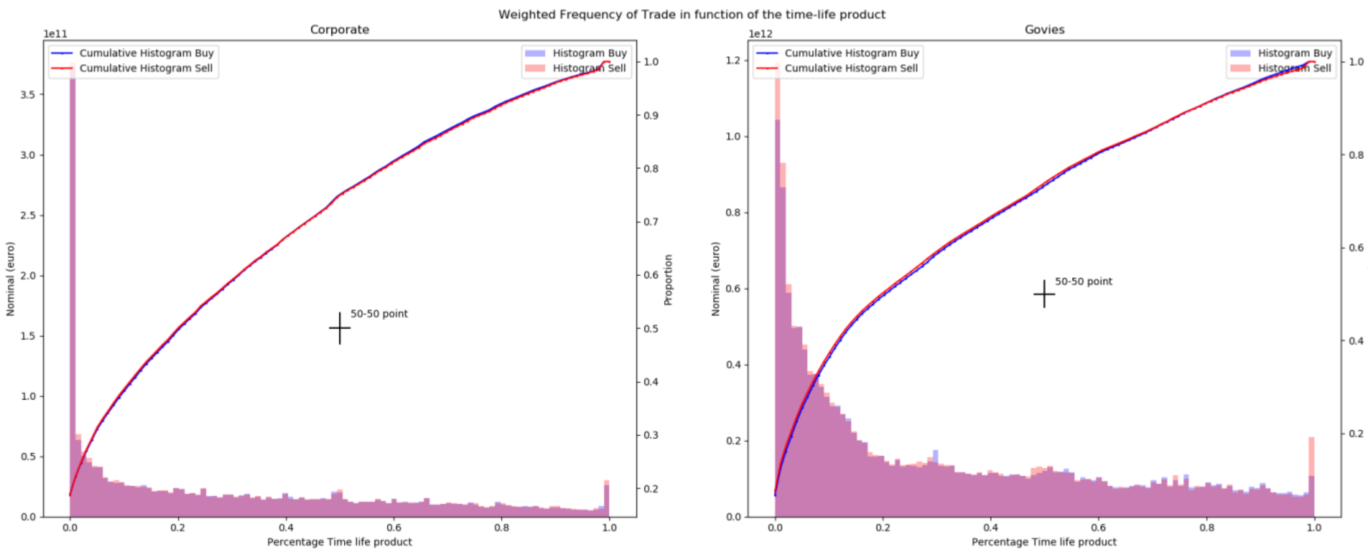

FIGURE 10-5 : WEIGHTED LIFE-TIME PRODUCT TRADING

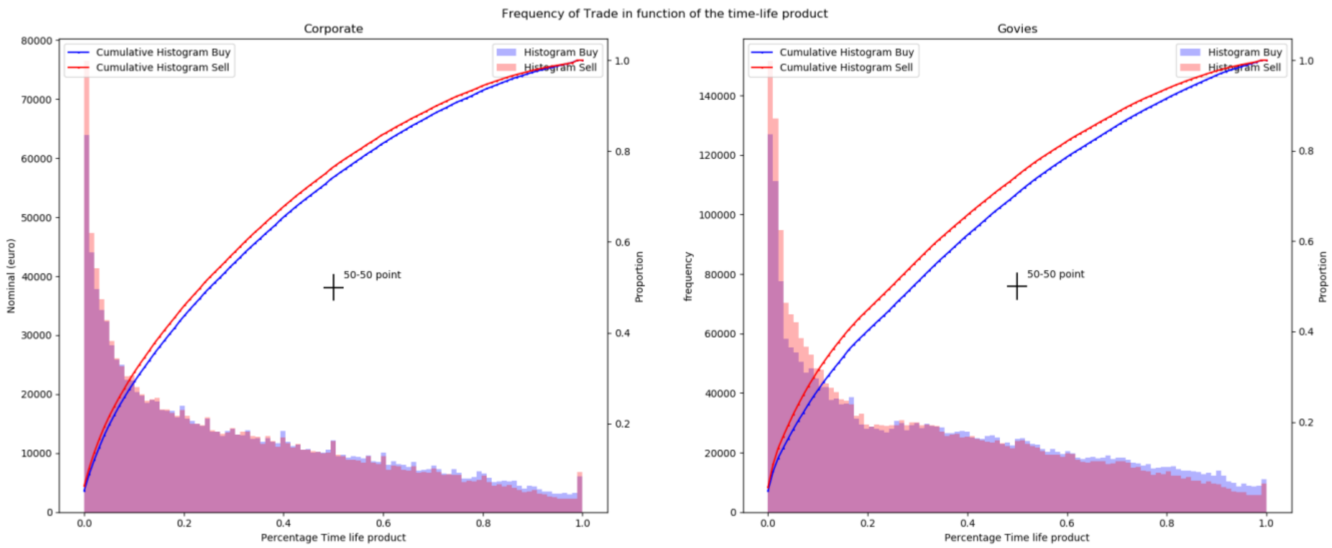

FIGURE 10-6 : LIFE-TIME PRODUCT TRADING

From the histogram we observe that both corporate and govies are traded during the beginning of their life-time.
From the cumulative distribution function which is above the 50-50% point we deduce that more than 50% of trades occur before the product half time life.

10.4 Sell/Buy difference

This part aims at observing the difference between sells and buys for frequency and traded volume

10.4.1 Frequency

The graph below shows the sell and buy frequency for both govies and corporate bonds:

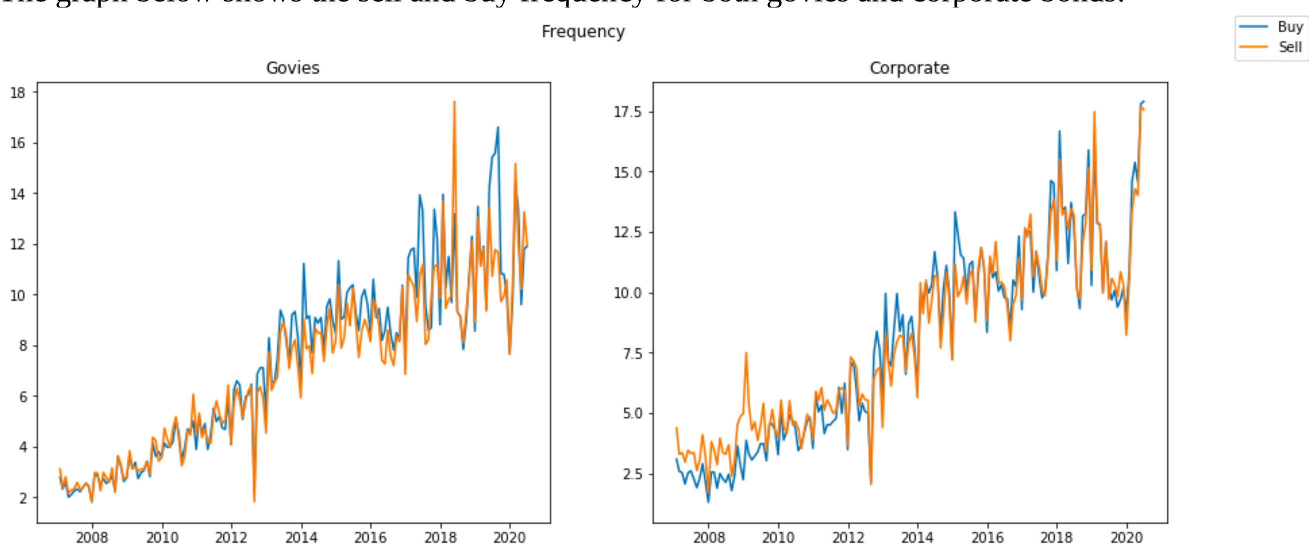

FIGURE 10-7 : FREQUENCY OF BUYS AND SELLS

The tale below shows the correlation:

			Frequency			
			Corporate		Govies	
			B	S	B	S
Frequency	Corporate	B	1.000000	0.918413	0.778726	0.780580
		S	0.918413	1.000000	0.772801	0.782043
	Govies	B	0.778726	0.772801	1.000000	0.891107
		S	0.780580	0.782043	0.891107	1.000000

TABLE 10-1 : FREQUENCY CORRELATION

<u>Conclusion</u>:
The two curves (sell and buy) are highly correlated. The assumption that the buy and sell behave in the same way seems relevant from mathematical point of view and rational point of view.

10.4.2 Traded Volume

The graph below shows the sell and buy frequency for both govies and corporate bonds:

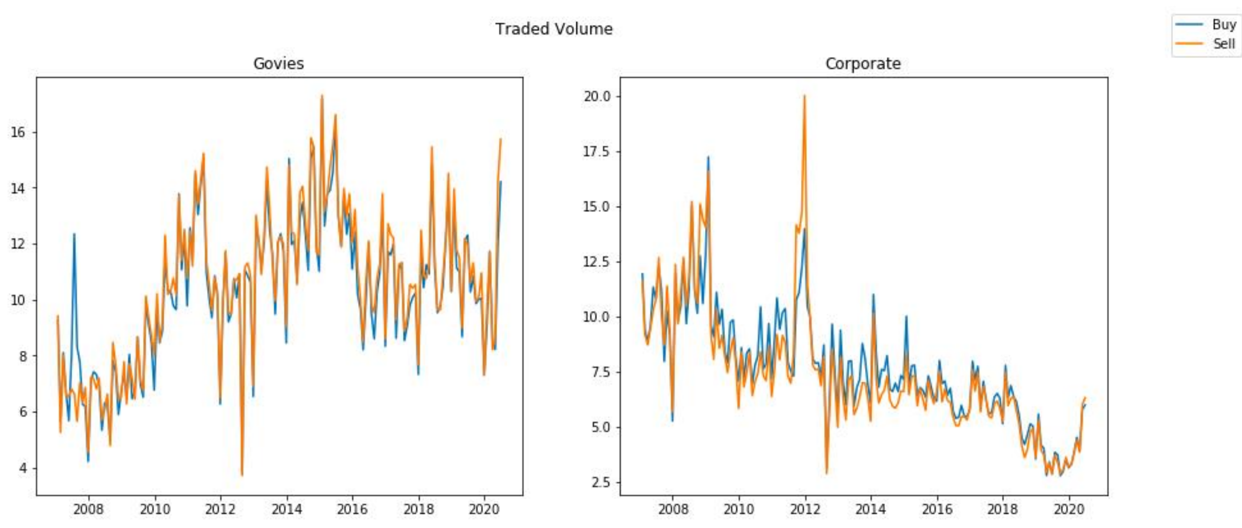

FIGURE 10-8 : TRADED VOLUME OF BUYS AND SELLS

The tale below shows the correlation:

			Traded Volume			
			Corporate		Govies	
			B	S	B	S
Traded Volume	Corporate	B	1.000000	0.897451	0.107937	0.093768
		S	0.897451	1.000000	0.040736	0.016788
	Govies	B	0.107937	0.040736	1.000000	0.896265
		S	0.093768	0.016788	0.896265	1.000000

TABLE 10-2 : TRADED VOLUME CORRELATION

Conclusion:
The two curves (sell and buy) are highly correlated. The assumption that the buy and sell behave in the same way seems relevant from mathematical point of view and rational point of view.

10.5 Frequency forecast

This part describes the processes to get the forecasting models of the frequency for Corporate and Govies. The process is similar for the two types of bonds but results are slightly different.

10.5.1 Corporate

The below graph displays the monthly tendency per years:

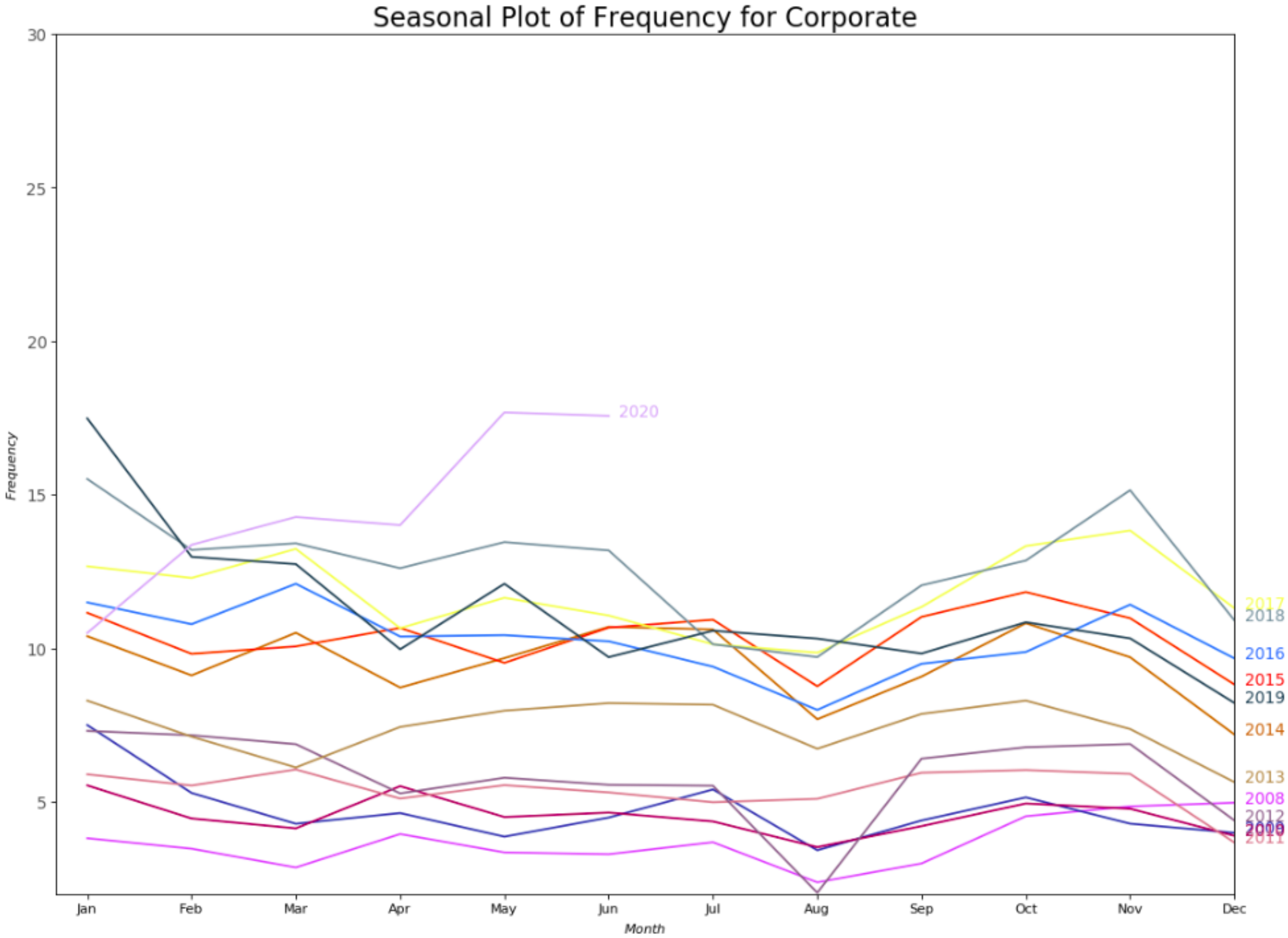

FIGURE 10-9 : FREQUENCY SEASONAL PLOT OF CORPORATE

The two graphs below show the trend and seasonality in BoxPlot format (median, quartile,, maximum and minimum) :

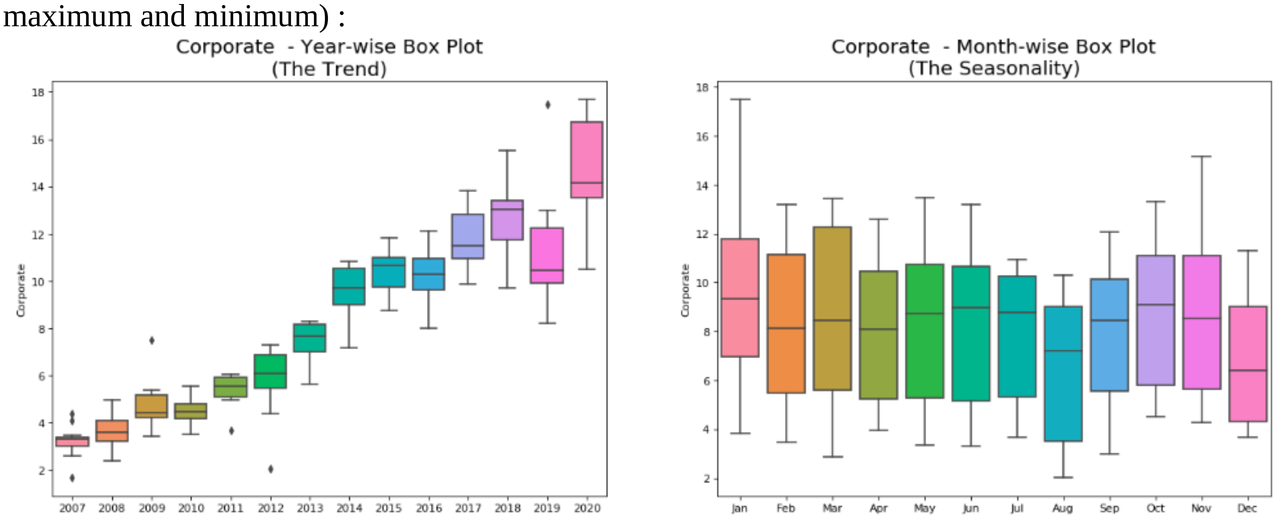

FIGURE 10-10 : FREQUENCY TREND AND SEASONALITY FOR CORPORATE

Then the monthly corporate frequency has been decomposed and the result is display below:

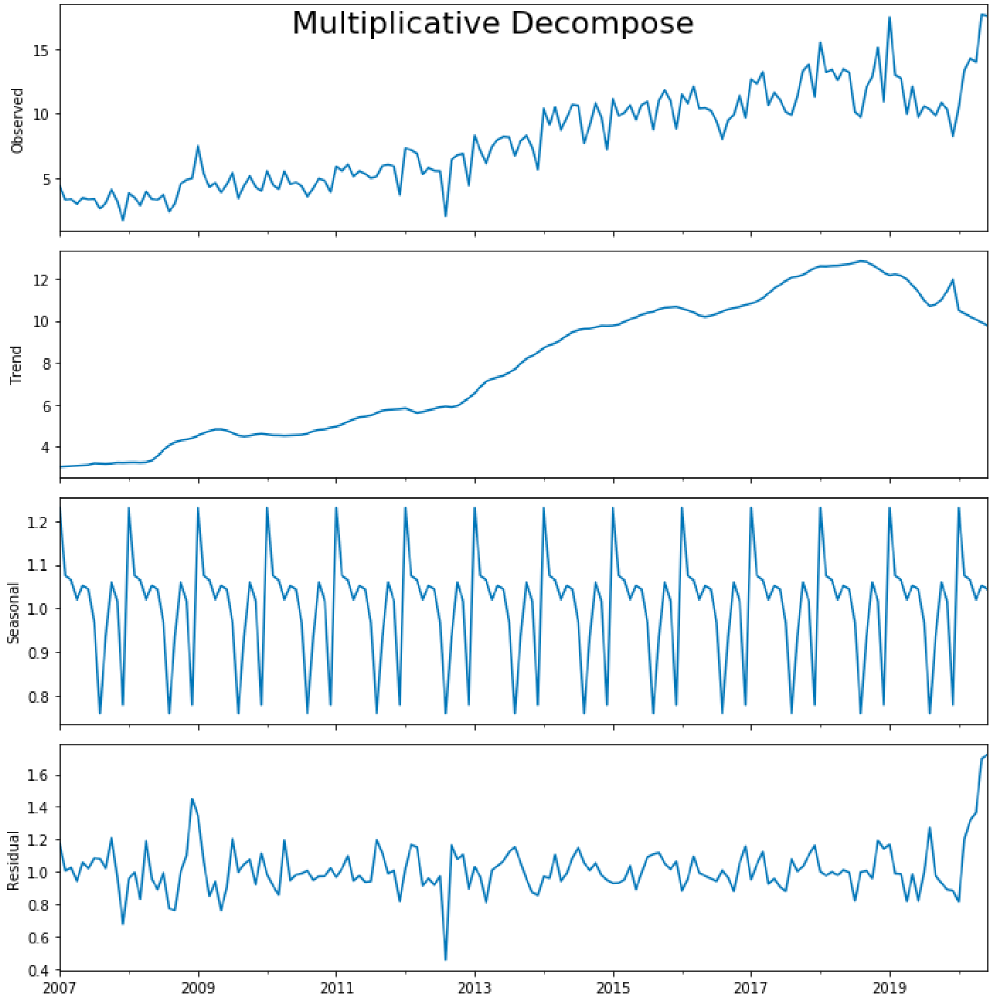

FIGURE 10-11 : FREQUENCY DECOMPOSITION FOR CORPORATE

Then we show detrended and deseasonalized to highlight these two phenomena:

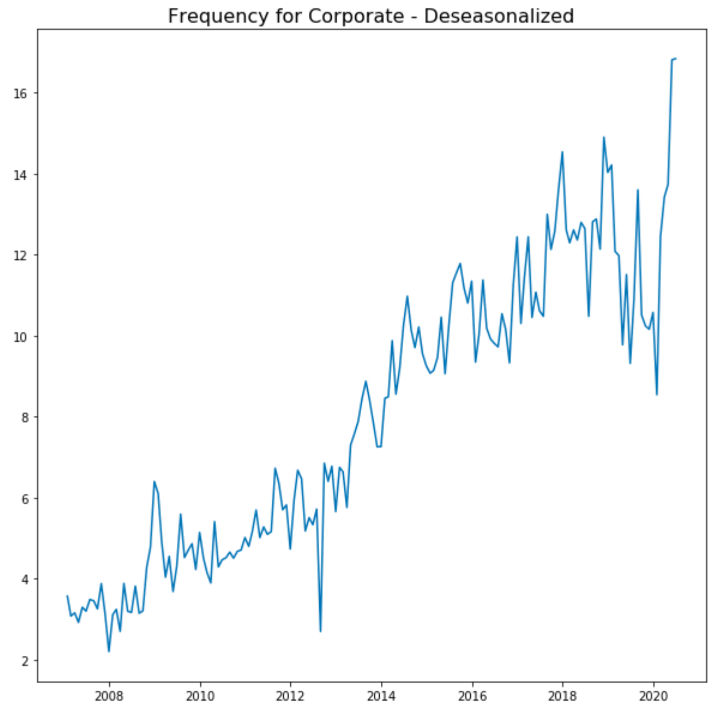

FIGURE 10-12 : FREQUENCY DESEASONALIZED FOR CORPORATE

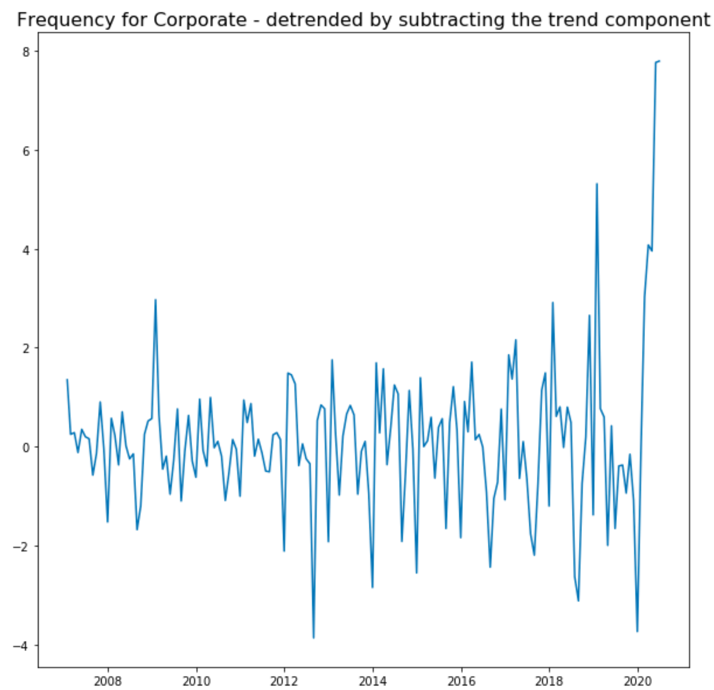

FIGURE 10-13 : FREQUENCY DETRENDED FOR CORPORATE

<u>All these analysis show:</u>

- **An increasing trend**
- **A 12-month seasonality**

To forecast the series, we first differentiate one time and check the stationarity with the Dickey-Fuller test:

```
Results of Dickey-Fuller Test:
Test Statistic                  -4.754104
p-value                          0.000067
#Lags Used                      11.000000
Number of Observations Used    149.000000
Critical Value (1%)             -3.475018
Critical Value (5%)             -2.881141
Critical Value (10%)            -2.577221
dtype: float64
```

TABLE 10-3 : FREQUENCY CORPORATE AD FULLER TEST

The p-value is below 1%. Thereby, the null hypothesis can be rejected and the series is supposed to be stationary.

To get the MA and AR parameters we observe the autocorrelation and partial autocorrelation, showed below:

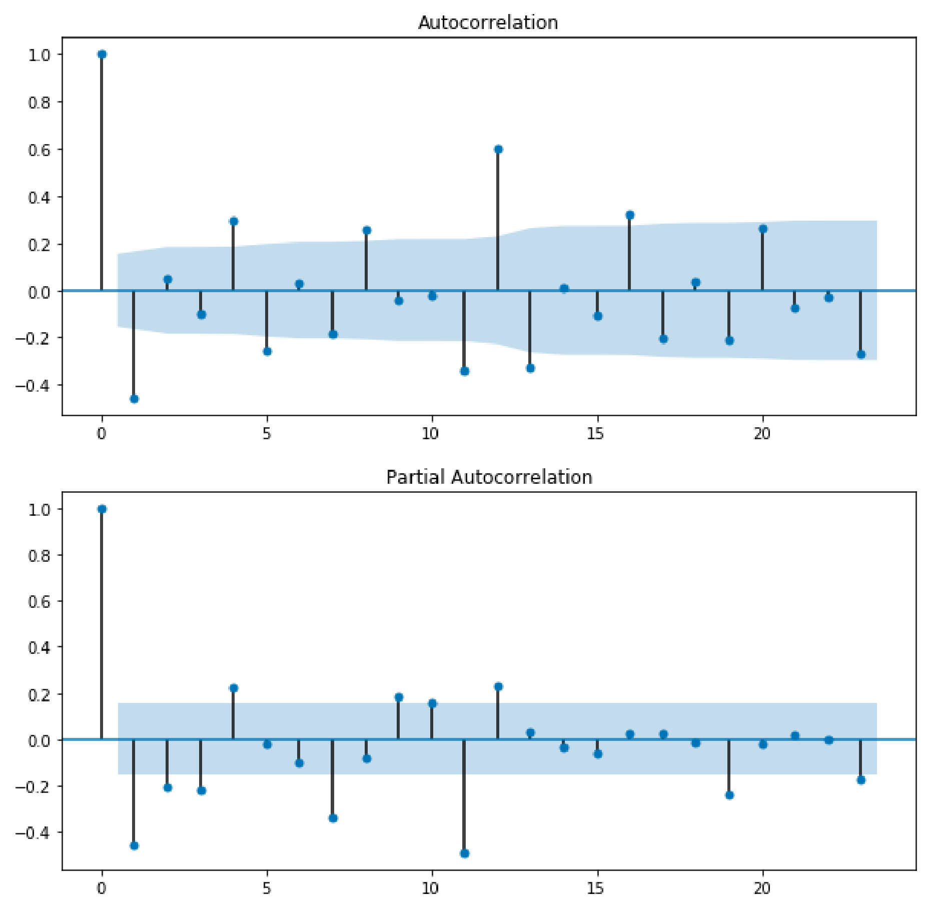

FIGURE 10-14 : FREQUENCY CORPORATE ACF AND PACF

The 12-months seasonality is clearly observed on both graphs and the first components of MA and AR seem significant.
However the implementation of AR(1) give a p-value of the parameter above 80% meaning that this parameter is irrelevant.
Below the table show the parameter of the SARIMA(0,1,1) with season 12 :

	coef	std err	z	P>|z|
ma.L1	-0.3415	0.057	-6.035	0.000
ar.S.L12	1.0105	0.028	36.045	0.000
ma.S.L12	-0.8019	0.082	-9.803	0.000
sigma2	1.2458	0.119	10.449	0.000

TABLE 10-4 : FREQUENCY CORPORATE SARIMA COEFFICIENTS

The one-step ahead forecast from 2019 show a good fit with low indicator errors. The graphs below show both the one step forecast and the approximation error :

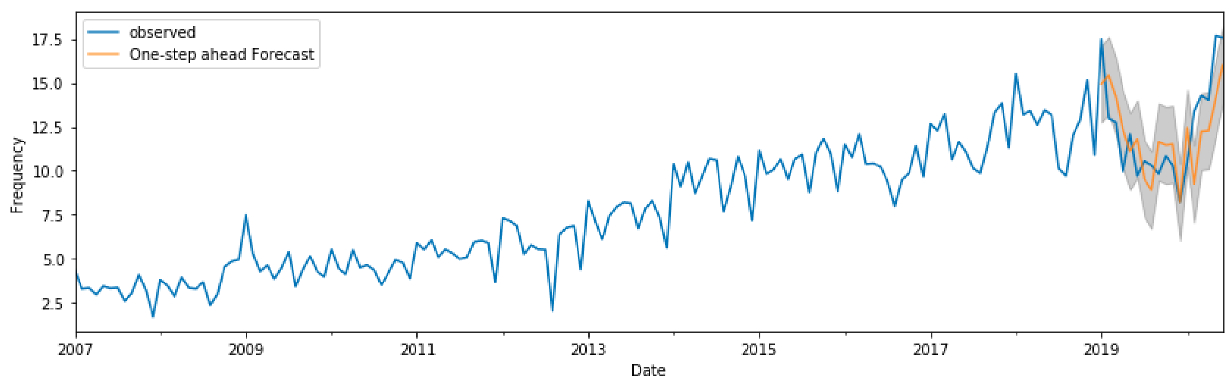

FIGURE 10-15 : FREQUENCY CORPORATE ONE STEP FORECAST

```
{'mape': 0.14587704156120285,
 'me': -0.27581078175978757,
 'mae': 1.828612572628286,
 'mpe': -0.0011496998674806985,
 'rmse': 2.063260785761993}
```

TABLE 10-5 : FREQUENCY CORPORATE ERROR

10.5.2 Govies

The below graph displays the monthly tendency per years:

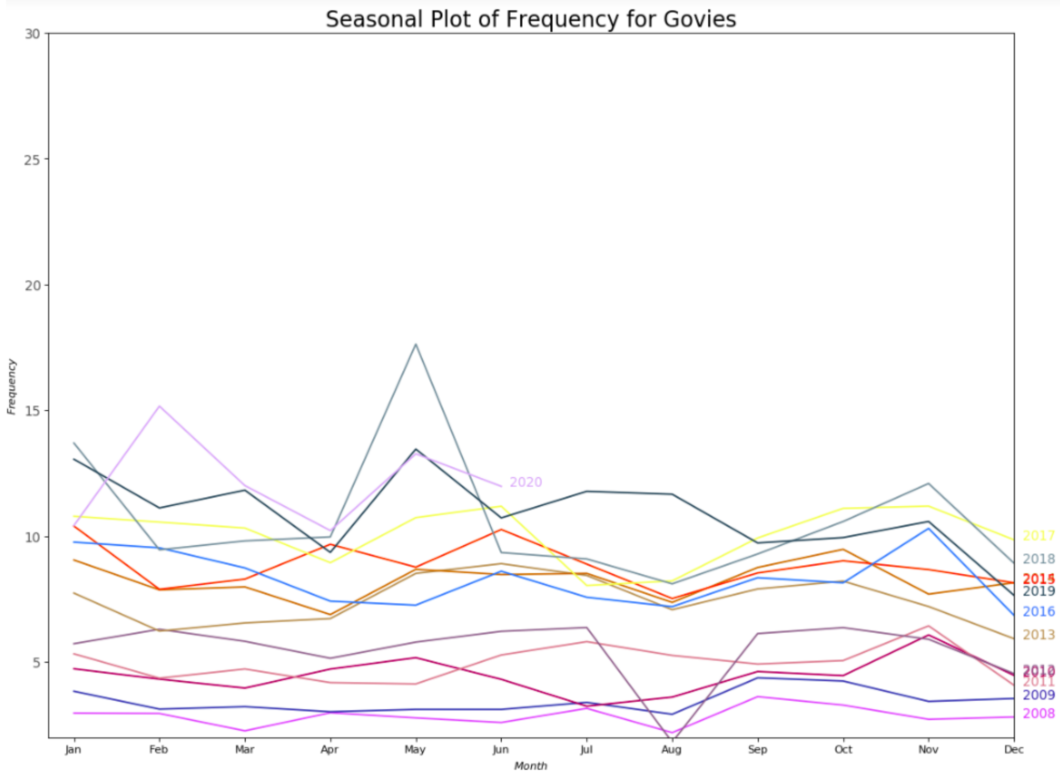

FIGURE 10-16 : FREQUENCY SEASONAL PLOT OF GOVIES

The two graphs below show the trend and seasonality in BoxPlot format (median, quartile,, maximum and minimum) :

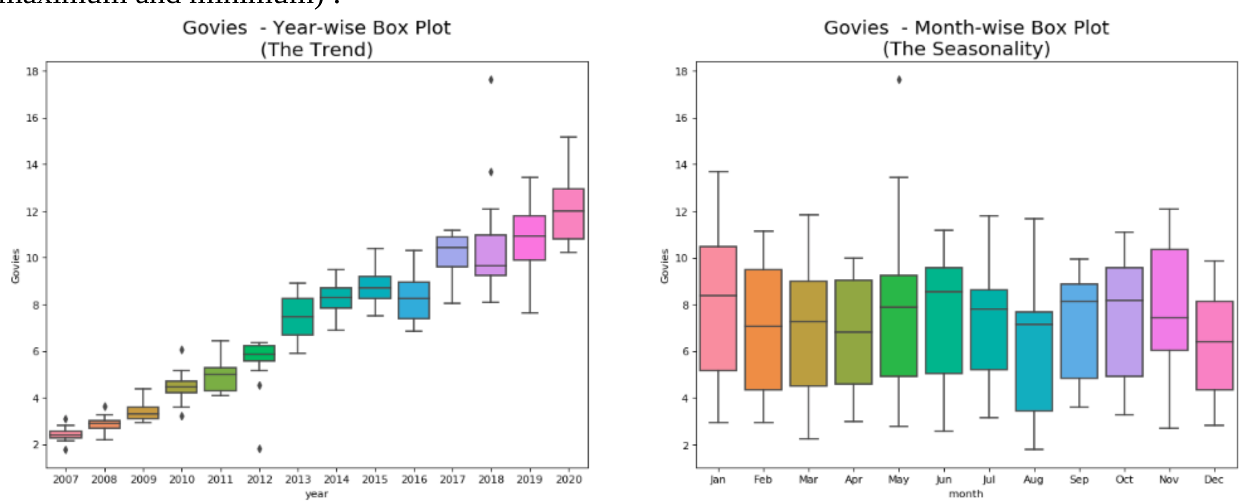

FIGURE 10-17 : FREQUENCY TREND AND SEASONALITY FOR CORPORATE

Then the monthly corporate frequency has been decomposed and the result is display below :

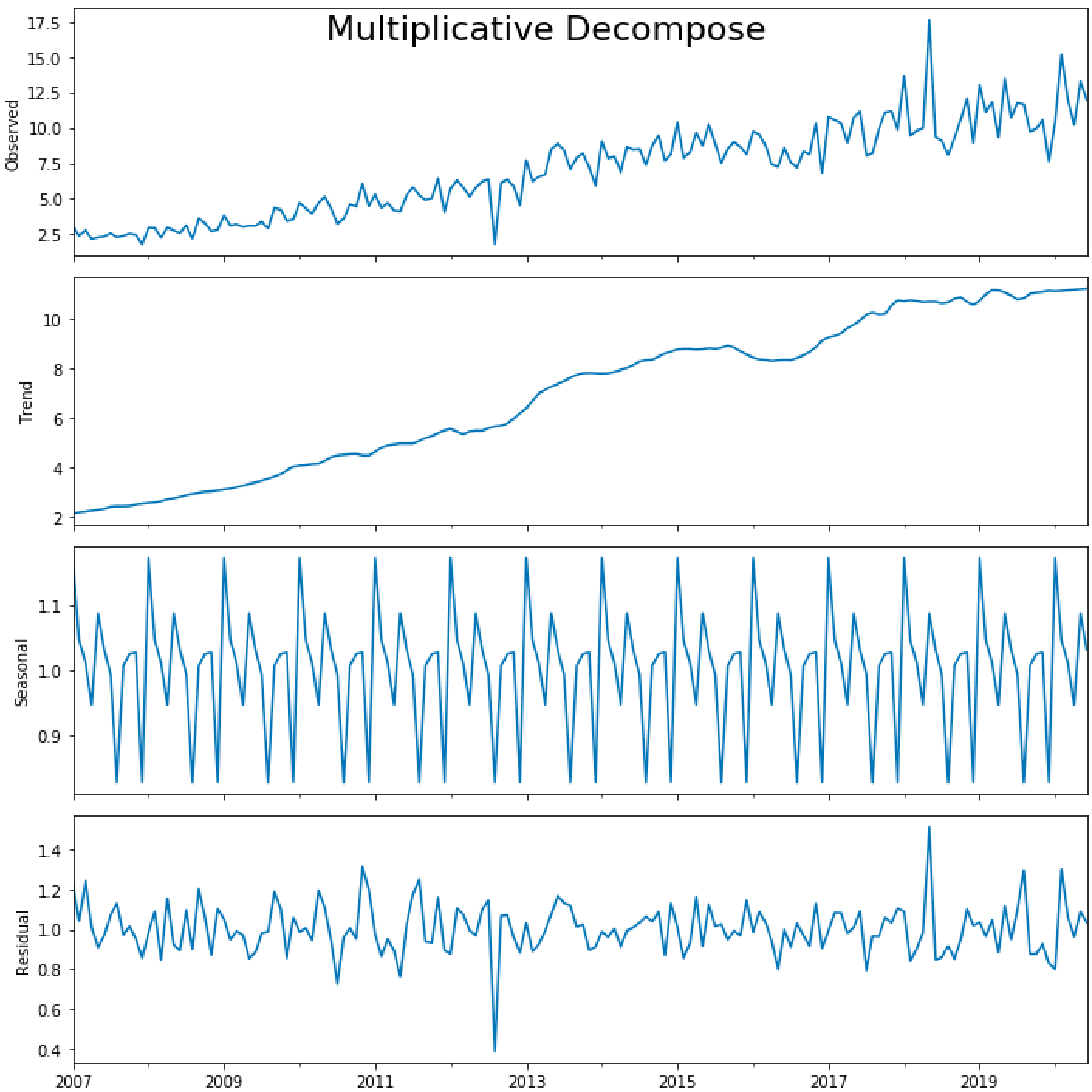

FIGURE 10-18 :FREQUENCY DECOMPOSITION FOR GOVIES

Then we show detrended and deseasonalized to highlight these two phenomena :

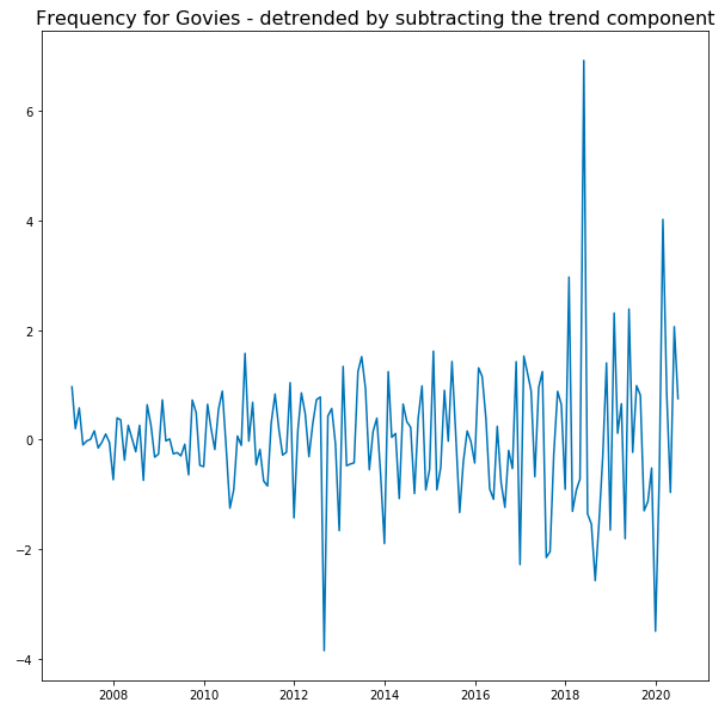

FIGURE 10-19 : FREQUENCY DETREDED FOR GOVIES

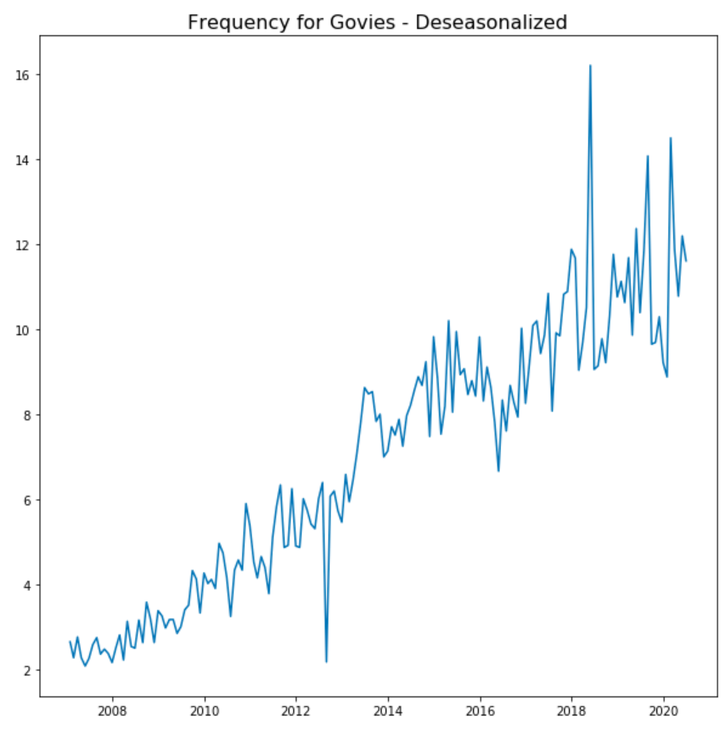

FIGURE 10-20 : FREQUENCY DESEASONALIZED FOR GOVIES

<u>All these analysis show:</u>

- **An increasing trend**
- **A 12-month seasonality**

To forecast the series, we first differentiate one time and check the stationarity with the Dickey-Fuller test:

The p-value is below 1%. Thereby, the null hypothesis can be rejected and the series is supposed to be stationary.

```
Results of Dickey-Fuller Test:
Test Statistic                -7.337650e+00
p-value                        1.085880e-10
#Lags Used                     1.000000e+01
Number of Observations Used    1.500000e+02
Critical Value (1%)           -3.474715e+00
Critical Value (5%)           -2.881009e+00
Critical Value (10%)          -2.577151e+00
dtype: float64
```

TABLE 10-6 : FREQUENCY GOVIES AD FULLER TEST

To get the MA and AR parameters we observe the autocorrelation and partial autocorrelation, showed below:

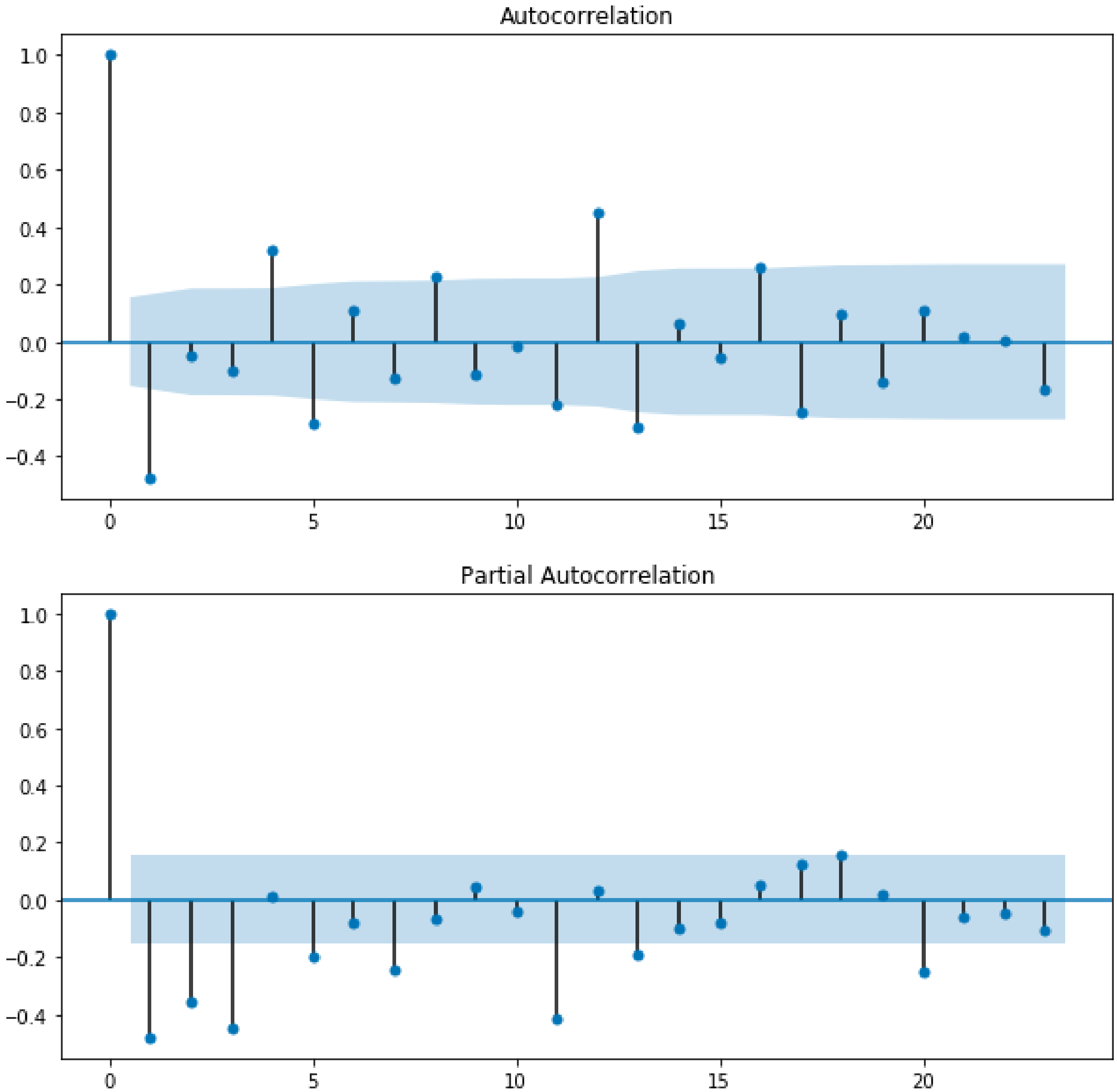

FIGURE 10-21 : FREQUENCY GOVIES ACF AND PACF

The 12-months seasonality is clearly observed on both graphs and the first components of MA and AR seem significant.

However the implementation of AR(1) give a p-value of the parameter above 80% meaning that this parameter is irrelevant.

Below the table show the parameter of the SARIMA(0,1,1) with season 12 :

	coef	std err	z	P>|z|
ma.L1	-0.8481	0.040	-21.137	0.000
ar.S.L12	1.0127	0.062	16.346	0.000
ma.S.L12	-0.7023	0.145	-4.829	0.000
sigma2	1.2927	0.079	16.415	0.000

TABLE 10-7 : FREQUENCY GOVIES SARIMA COEFFICIENTS

The one-step ahead forecast from 2019 show a good fit with low indicator errors. The graphs below show both the one step forecast and the approximation error:

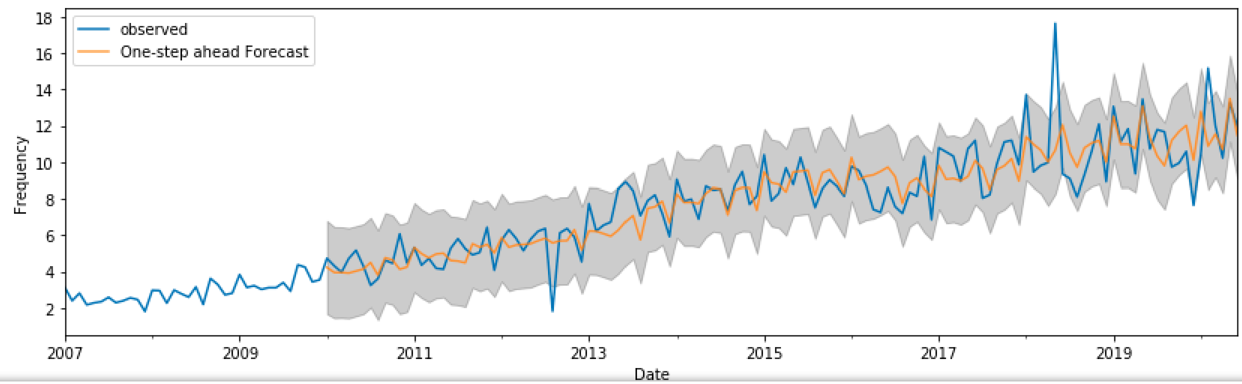

FIGURE 10-8 : FREQUENCY GOVIES ONE STEP FORECAST

```
{'mape': 0.11513274502760001,
 'me': 0.09322596496630142,
 'mae': 1.2534320010868774,
 'mpe': 0.026510094439098603,
 'rmse': 1.6141941221706453}
```

TABLE 10-9 : FREQUENCY GOVIES ERROR

10.6 Traded Volume forecast

This part aims to describe the model process for traded volume for both corporate and governmental bonds.

10.6.1 Corporate

The below graph displays the monthly tendency per years:

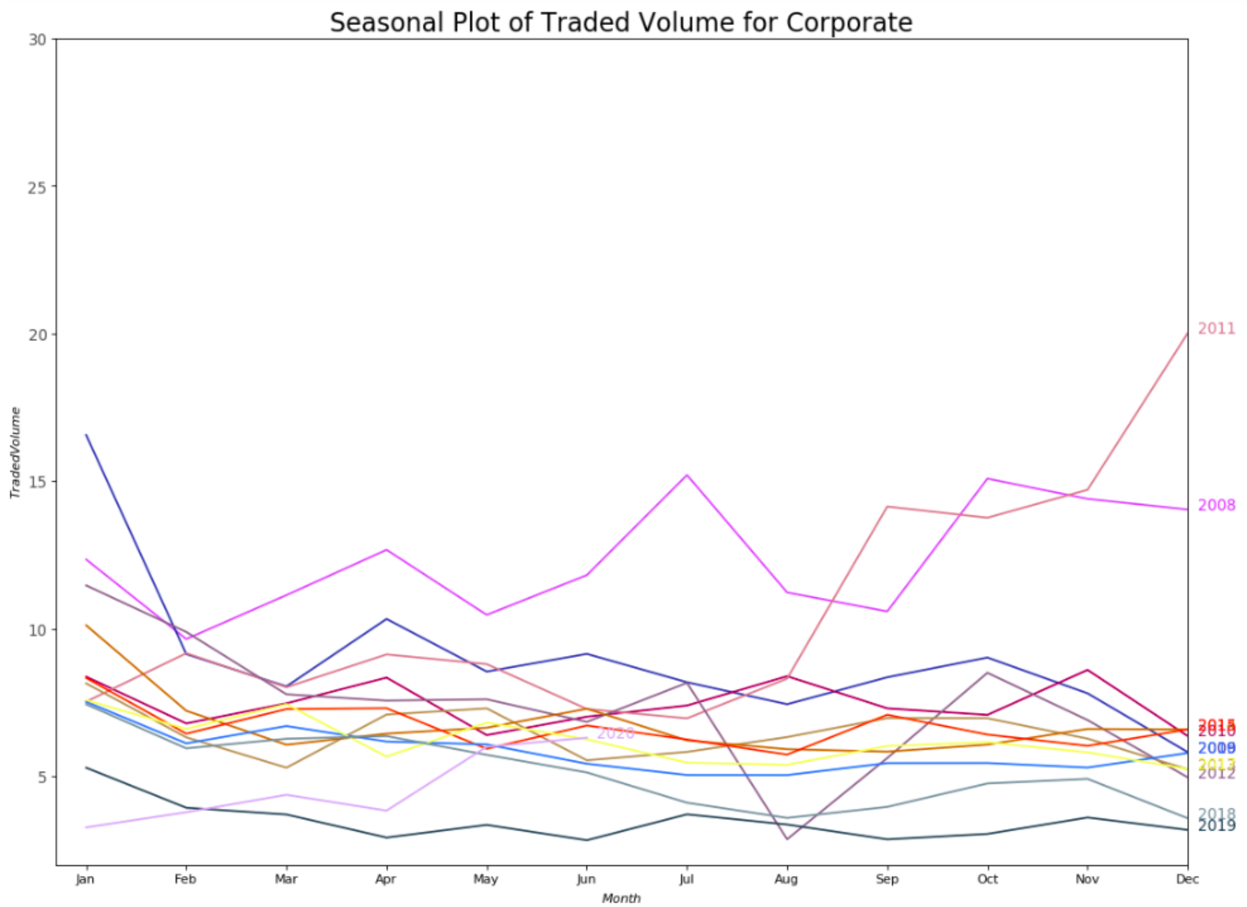

FIGURE 10-22 : TRADED VOLUME SEASONAL PLOT OF CORPORATE

The two graphs below show the trend and seasonality in BoxPlot format (median, quartile,, maximum and minimum) :

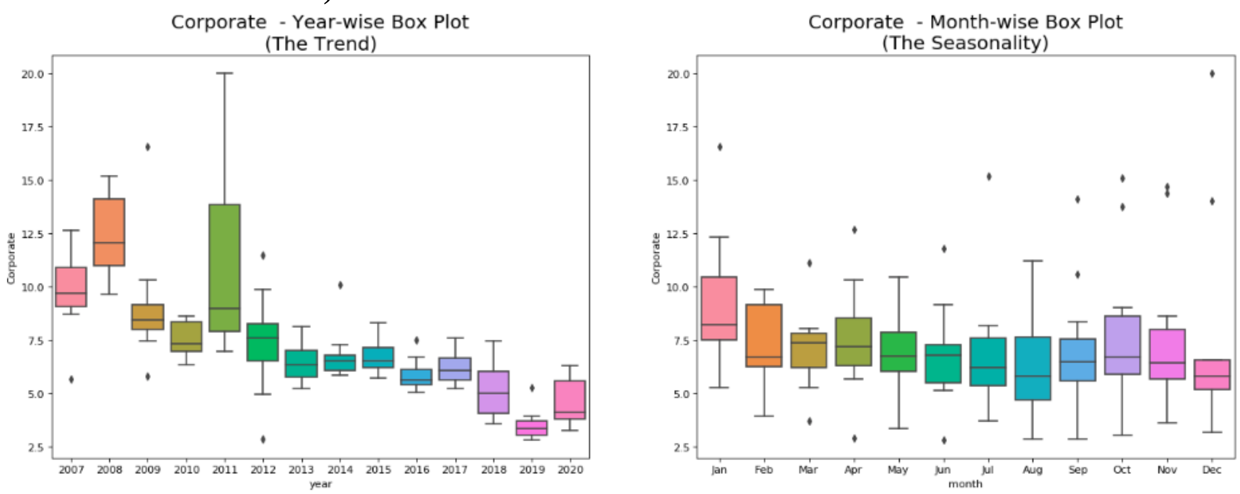

FIGURE 10-23 : TRADED VOLUME TREND AND SEASONALITY FOR CORPORATE

Then the monthly corporate frequency has been decomposed and the result is display below :

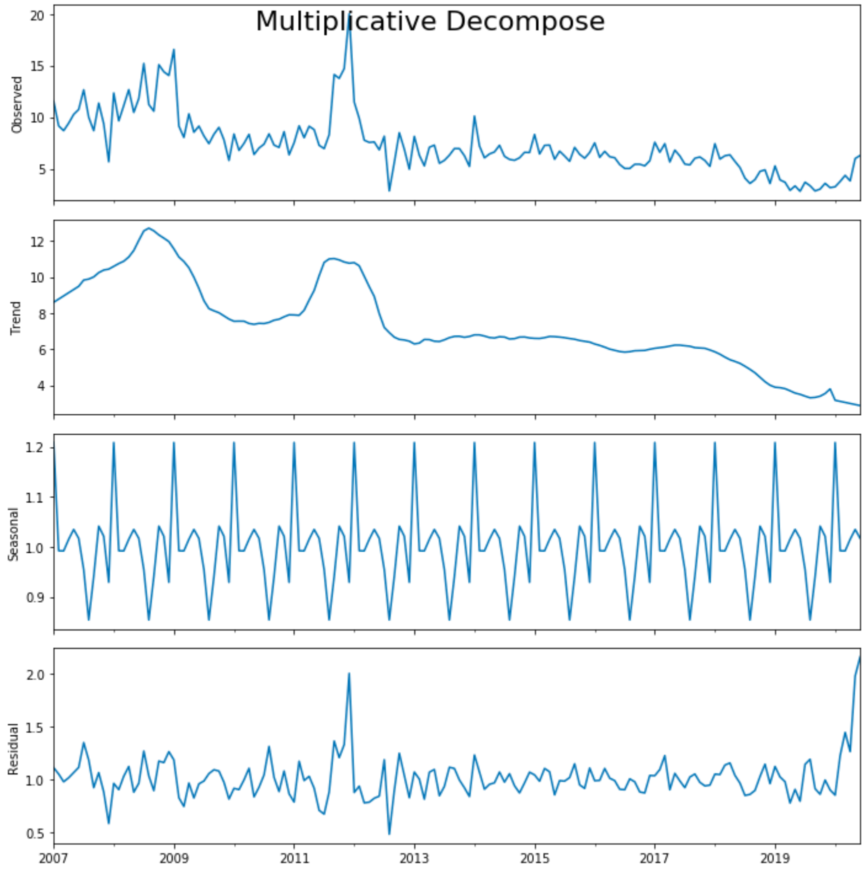

FIGURE 10-24 : TRADED VOLUME DECOMPOSITION FOR CORPORATE

Then we show detrended and deseasonalized to highlight these two phenomena :

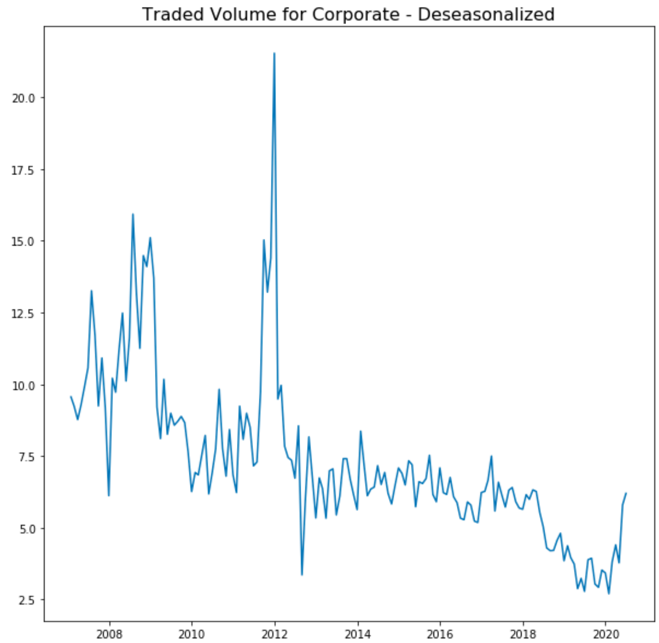

FIGURE 10-25 : TRADED VOLUME DESEASONALIZED FOR CORPORATE

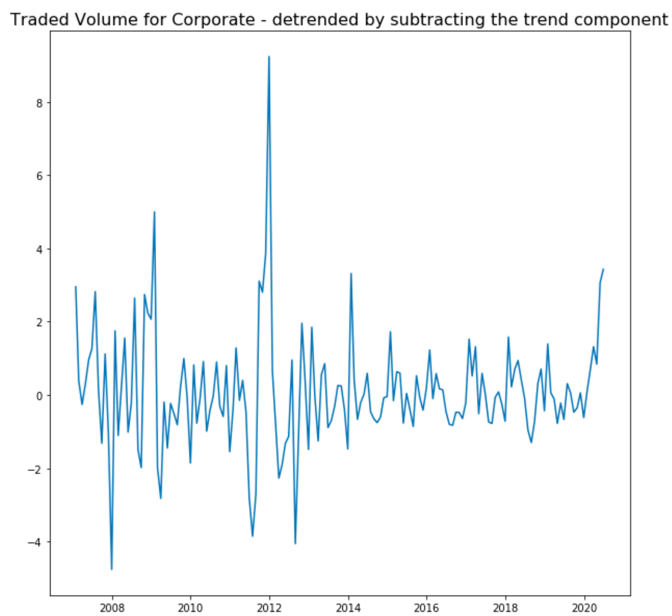

FIGURE 10-26 : TRADED VOLUME DETRENDED FOR CORPORATE

<u>**All these analysis show:**</u>

- **A decreasing trend**
- **No clear seasonality can be identified**

To forecast the series, we first differentiate one time and check the stationarity with the Dickey-Fuller test:

```
Results of Dickey-Fuller Test:
Test Statistic                 -7.504588e+00
p-value                         4.166963e-11
#Lags Used                      4.000000e+00
Number of Observations Used     1.560000e+02
Critical Value (1%)            -3.472979e+00
Critical Value (5%)            -2.880252e+00
Critical Value (10%)           -2.576747e+00
dtype: float64
```

TABLE 10-10 : TRADED VOLUME CORPORATE AD FULLER TEST

The p-value is below 1%. Thereby, the null hypothesis can be rejected and the series is supposed to be stationary.

To get the MA and AR parameters we observe the autocorrelation and partial autocorrelation, showed below:

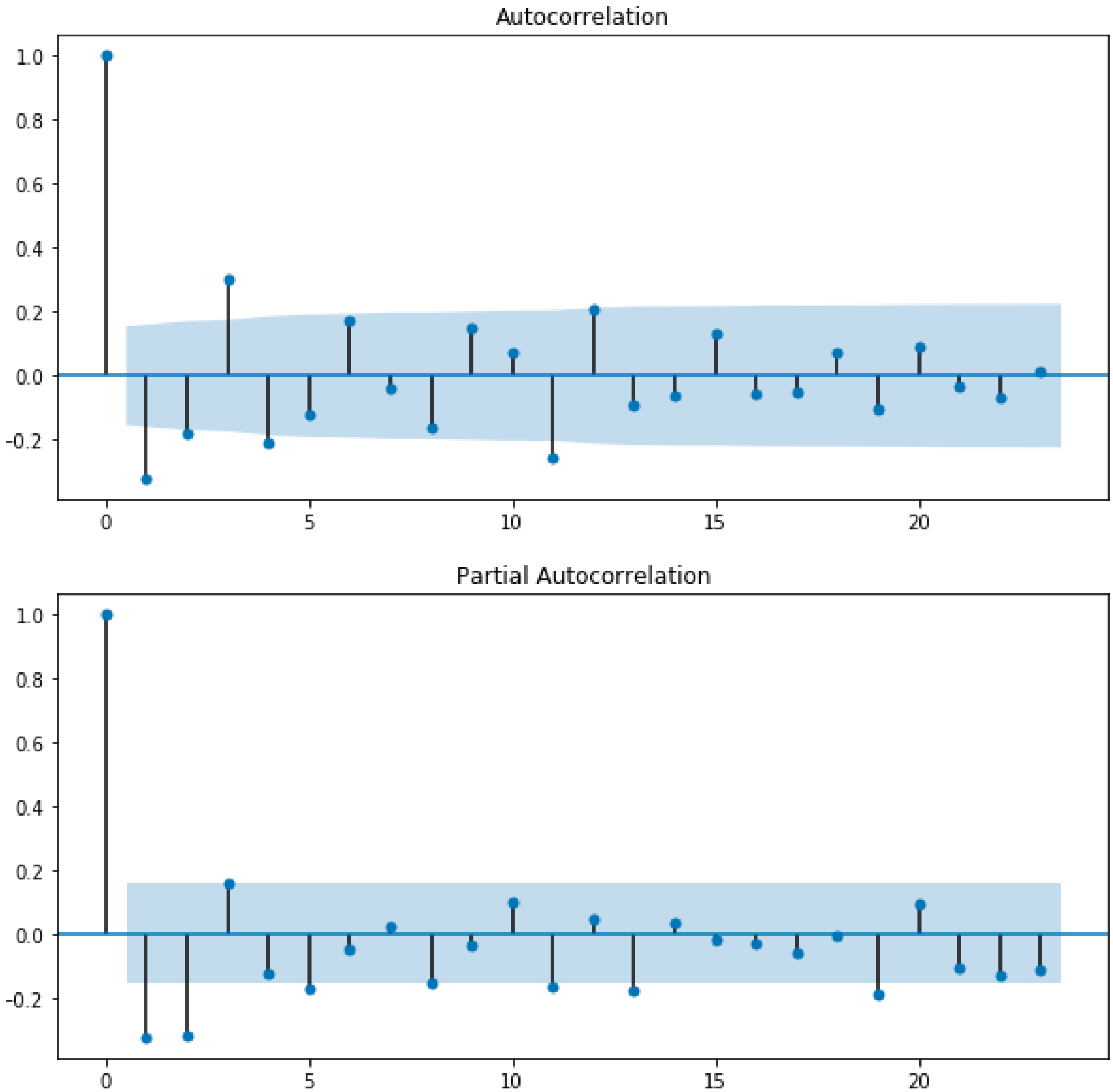

FIGURE 10-27 : TRADED VOLUME CORPORATE ACF AND PACF

The 12-months seasonality is clearly observed on both graphs and the first components of MA and AR seem significant.
Below the table show the parameter of the SARIMA(2,1,0) with season 3 :

	coef	std err	z	P>|z|
ar.L1	-0.3600	0.053	-6.819	0.000
ar.L2	-0.2305	0.050	-4.603	0.000
ma.S.L3	-0.9377	0.050	-18.890	0.000
sigma2	2.8442	0.192	14.848	0.000

TABLE 10-11 : TRADED VOLUME CORPORATE SARIMA COEFFICIENTS

The one-step ahead forecast from 2019 show a good fit with low indicator errors. The graphs below show both the one step forecast and the approximation error:

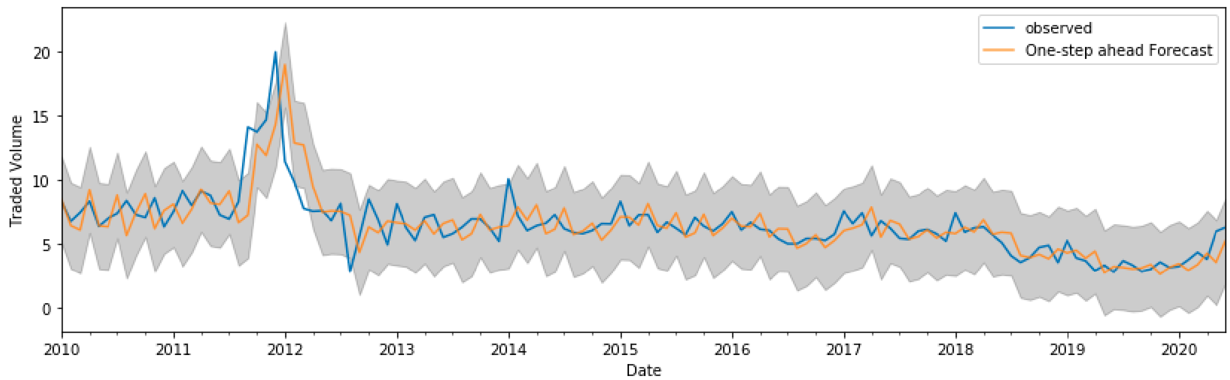

FIGURE 10-28 : TRADED VOLUME CORPORATE ONE STEP FORECAST

```
{'mape': 0.17476582890858192,
 'me': -0.25028299439701907,
 'mae': 0.7047535923768221,
 'mpe': -0.03178419586124623 5,
 'rmse': 0.8995479650175111}
```

TABLE 10-12 : TRADED VOLUME CORPORATE ERROR

10.6.2 Govies

The below graph displays the monthly tendency per years:

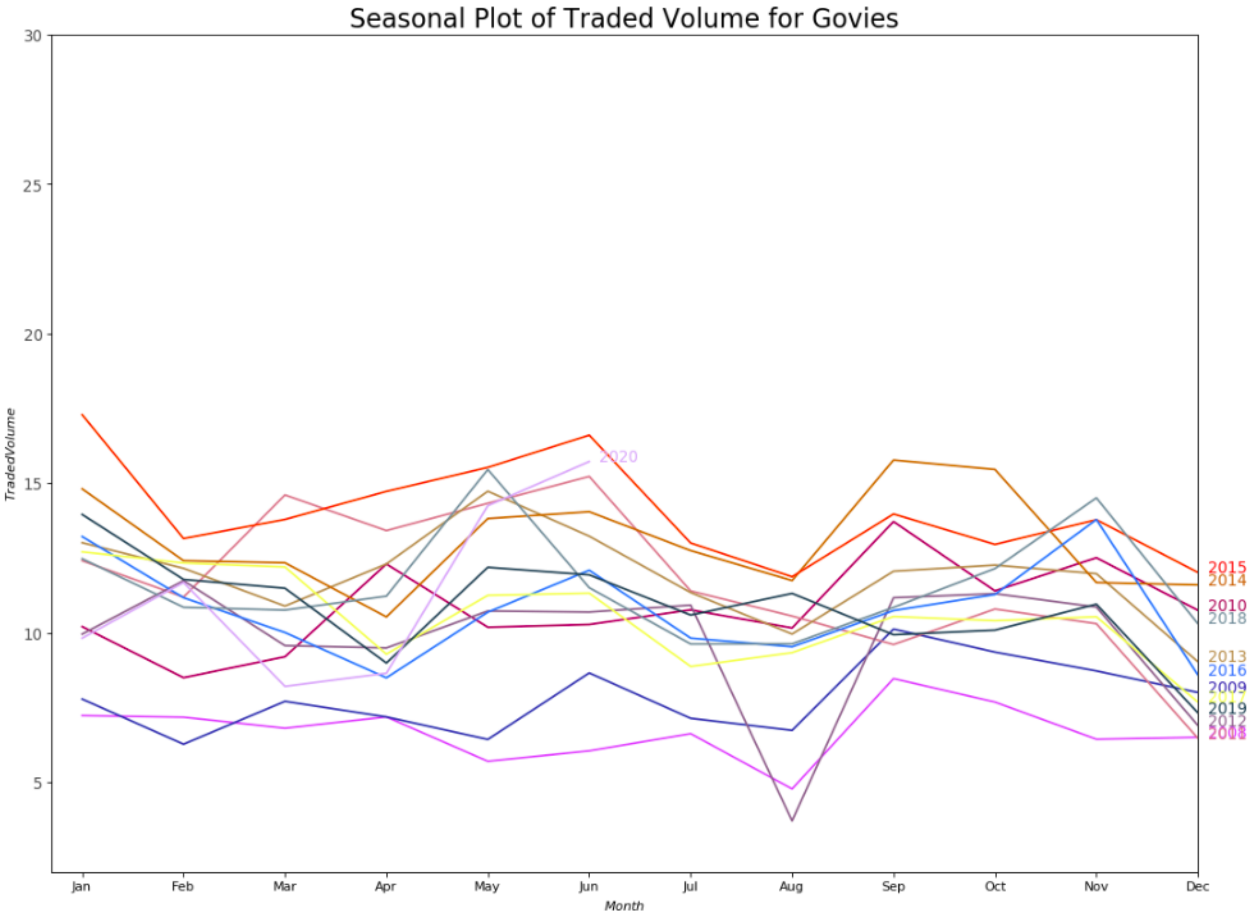

FIGURE 10-29 : TRADED VOLUME SEASONAL PLOT OF GOVIES

The two graphs below show the trend and seasonality in BoxPlot format (median, quartile,, maximum and minimum) :

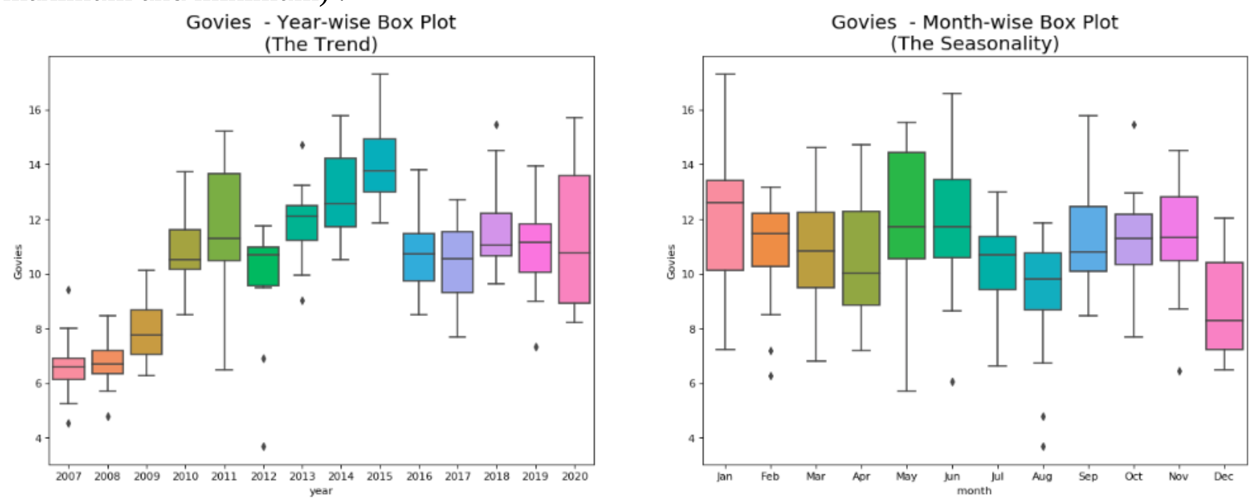

FIGURE 10-30 : TRADED VOLUME TREND AND SEASONALITY FOR GOVIES

Then the monthly corporate frequency has been decomposed and the result is display below:

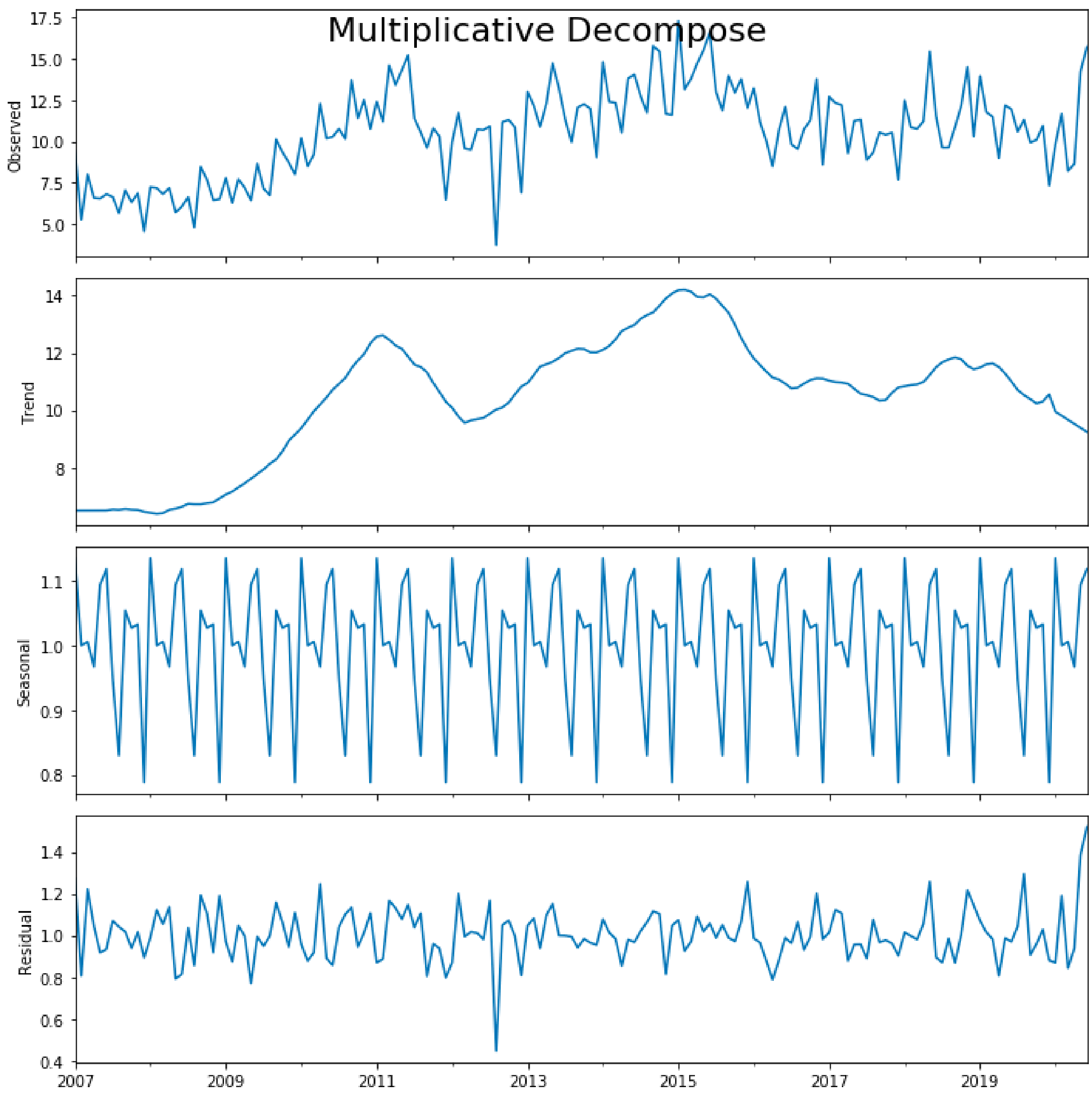

FIGURE 10-31 : TRADED VOLUME DECOMPOSITION FOR GOVIES

Then we show detrended and deseasonalized to highlight these two phenomena:

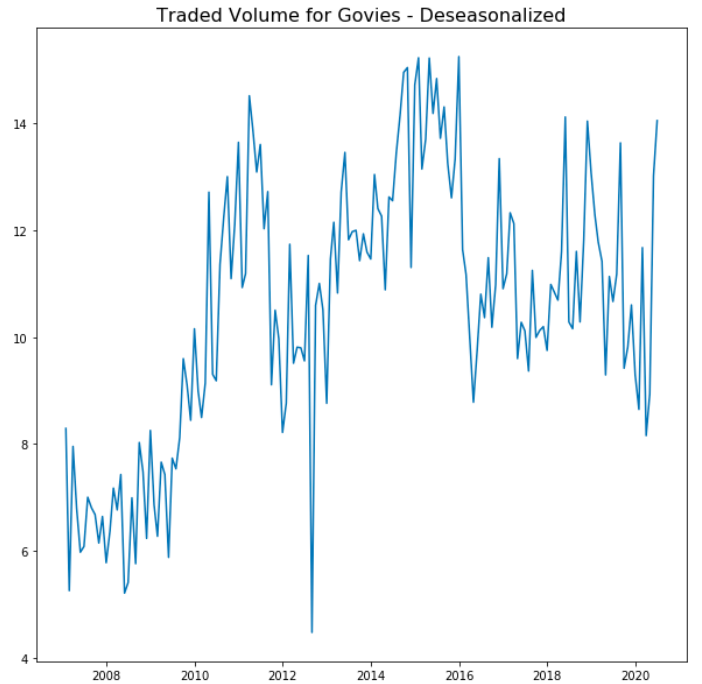

FIGURE 10-32 : TRADED VOLUME DESEASONALIZED FOR GOVIES

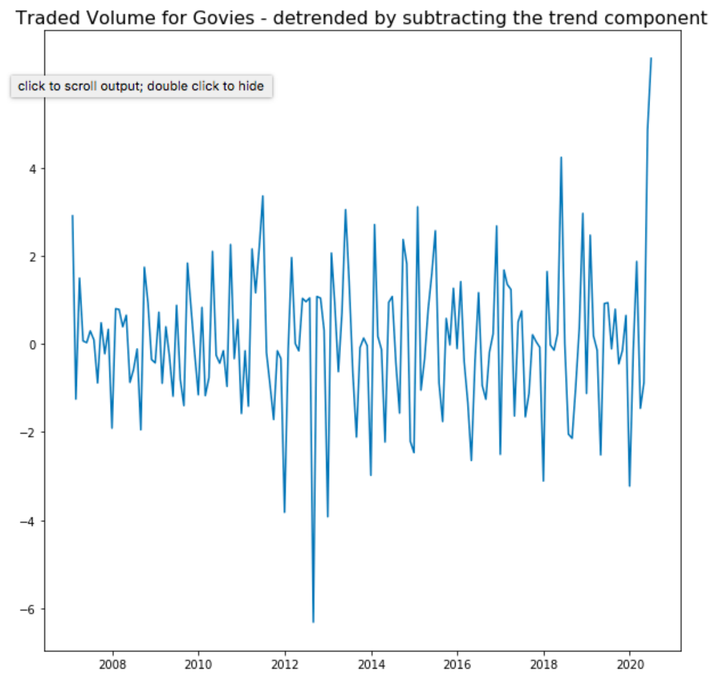

FIGURE 10-33 : TRADED VOLUME DETRENDED FOR GOVIES

<u>All these analysis show:</u>

- **No clear trend**
- **A 4 month seasonality**

To forecast the series, we first differentiate one time and check the stationarity with the Dickey-Fuller test:

```
Results of Dickey-Fuller Test:
Test Statistic                  -4.030154
p-value                          0.001261
#Lags Used                      11.000000
Number of Observations Used    149.000000
Critical Value (1%)             -3.475018
Critical Value (5%)             -2.881141
Critical Value (10%)            -2.577221
dtype: float64
```

TABLE 10-13 : TRADED VOLUME GOVIES AD FULLER TEST

The p-value is below 1%. Thereby, the null hypothesis can be rejected and the series is supposed to be stationary.

To get the MA and AR parameters we observe the autocorrelation and partial autocorrelation, showed below:

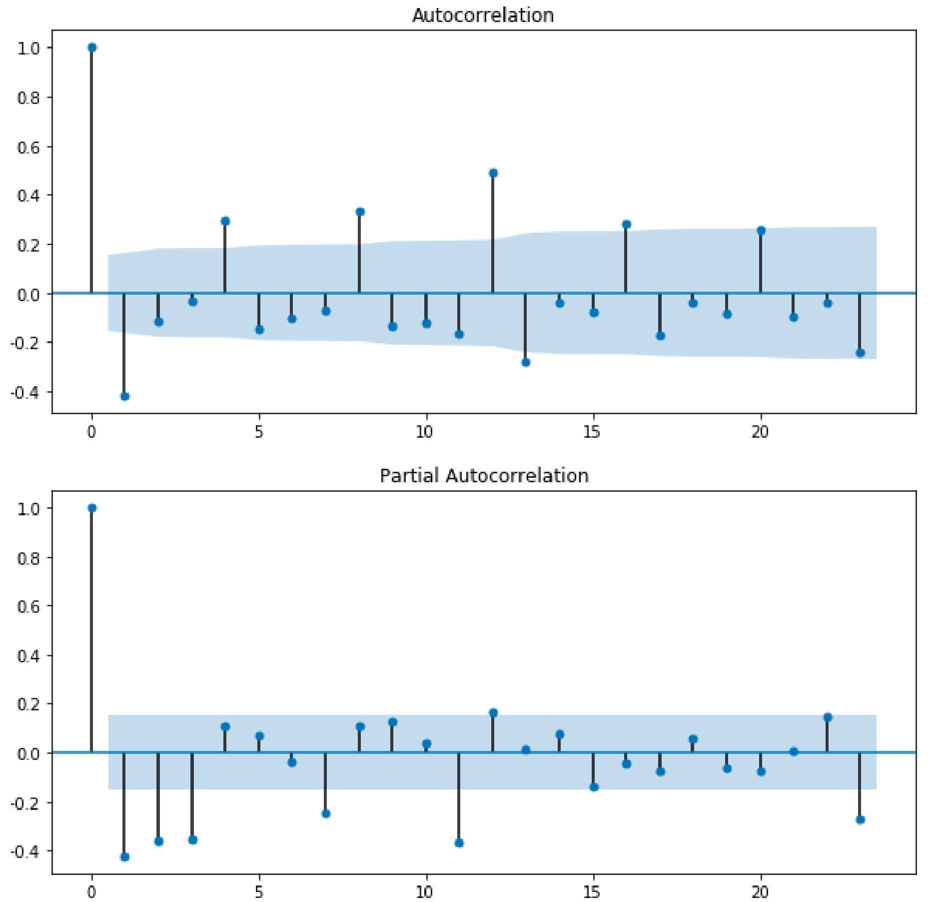

FIGURE 10-34 : TRADED VOLUME GOVIES ACF AND PACF

The 12-months seasonality is clearly observed on both graphs and the first components of MA and AR seem significant.
However the implementation of AR(1) give a p-value of the parameter above 80% meaning that this parameter is irrelevant.
Below the table show the parameter of the SARIMA(2,1,0) with season 12 :

	coef	std err	z	P>|z|
ar.L1	-0.5820	0.071	-8.141	0.000
ar.L2	-0.3597	0.073	-4.948	0.000
ma.S.L4	-1.0509	0.066	-15.903	0.000
sigma2	2.3171	0.316	7.324	0.000

TABLE 10-14 : TRADED VOLUME GOVIES SARIMA COEFFICIENTS

The one-step ahead forecast from 2019 show a good fit with low indicator errors. The graphs below show both the one step forecast and the approximation error:

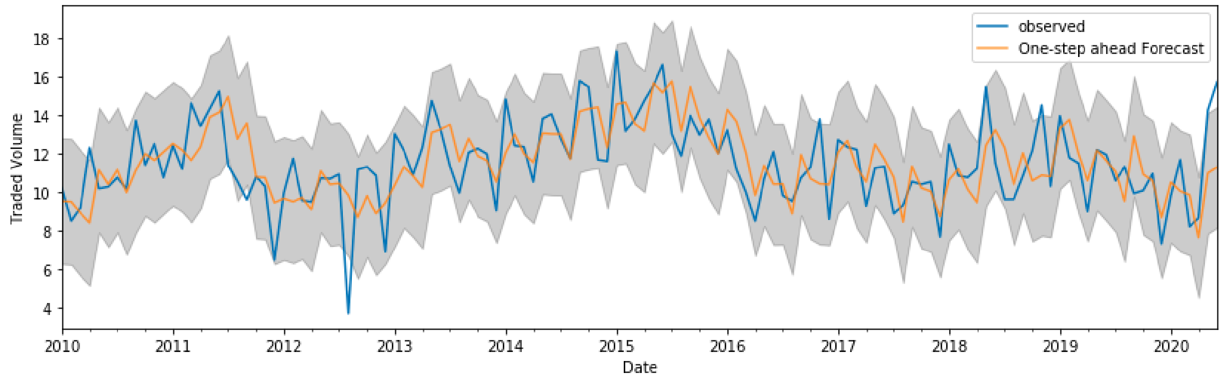

FIGURE 10-35 : TRADED VOLUME GOVIES ONE STEP FORECAST

```
{'mape': 0.12782097506408155,
 'me': -0.07875038248749927,
 'mae': 1.415140851647422,
 'mpe': 0.01332059039562545,
 'rmse': 1.813645050511476}
```

TABLE 10-15 : TRADED VOLUME GOVIES ERROR

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