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A connectedness analysis for euro area sovereign bonds

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Contents

Introduction

The last 20 years have been characterized by some economic and financial events that had a negative impact on the euro area and its sovereign bond market.

The financial crises that affected the euro area put in difficulty some countries and worsened the situation of others, also changing their capacity of "influence".

This is the key point of the thesis. The main argument is the one which studies systemic risk and connectedness/contagion inside the euro area, where connectedness is intended as the role that a country has in affecting the yields of another country.

An important feature of this analysis is the study of the four selected countries of the euro area, divided into core (Germany, France) and peripherical (Italy, Spain) through the degree of connectedness experienced by countries.

The empirical analysis will show which countries can be considered "strong" in terms of connectedness, i.e. the countries that are truly able to influence the euro area sovereign bond market.

Another important point is to demonstrate if the model used for the connectedness analysis is effectively useful to study how systemic risk moves inside the euro area during turbulent times.

In Chapter I will be described in detail the events that shocked the sovereign bond market and the euro area in the 2000-2022 period.

The analysis begins with the consequences of an increment in oil prices and inflation that slowed down economic growth inside the European and Monetary Union (EMU); then, it describes the main steps in the development of the 2007-2009 global financial crisis. Next, it examines the sovereign debt crisis that characterized the euro area in 2010-2011, which modified the relationships between core and peripherical countries and, finally, analyses the Covid-19 pandemic.

Chapter II is divided into two parts. The first one describes the literature on connectedness and different methodologies applied in practice.

The second part focuses on the detailed description of the model that will be used for the empirical analysis, that is the Diebold and Yilmaz (2014) model with generalized variance decomposition.

The third Chapter is fully dedicated to the empirical analysis of connectedness in yields of the euro area for the period 2000-2022.

Both a static and a dynamic analysis of the Diebold-Yilmaz model are carried out. The results show that, over the last 20 years, the degree of connectedness between Germany, France, Italy and Spain has changed many times and with different magnitudes.
The analysis also highlights the different reactions of short and long maturity yields in response to events that changed the connectedness measures.

CHAPTER I

Contagion and systemic risk in the euro area

1.1 What is systemic risk and definition of interconnectedness

Before talking about the evolution of the contagion events that characterised the last 20 years of the euro area, it is important to understand what systemic risk and interconnectedness mean.

1.1.1 Systemic risk

First of all, from a paper inside the Systemic Risk Centre there is the definition of systemic risk, that is: «Systemic risk can be endogenous, as a result from the collective behaviour of financial institutions or exogenous when the sources come from an external element of the financial system.» (Smaga, 2014); in this sense considering euro area as the object of the definition, this type of risk could grow from an internal shock due to a "bad" management of the financial institutions, thus inside one or more countries of the euro area, or from an external event that due to the famous "contagion" affected also the euro area, an example could be the global financial crisis of 2007-2009 that started in the United States and later spread around the world.

Looking at a document of the ECB about the Financial Stability Review (2009), there is a more deepened explanation regarding the definition of systemic risk. There is more than one perspective for describing it and one considers a "strong" systemic event, which implies a negative impact to important markets or intermediaries. What could activate the subsequent event may be, as cited before, of an exogenous nature so external from the financial system, or endogenous implying the opposite case. Concluding the definition of "strong" systemic event, to be considered like this, the event must include the near failure of intermediaries and the beginning of markets to be less functional.

There is another partition which consists of: "horizontal" perspective when the point of interest is inside the financial system; "vertical" perspective when there is a bilateral relationship between the financial system and the economy in general, thus both are taken into consideration. Obviously, the paper specifies that the magnitude of systemic risk is measured in terms of the effects that a determined event caused on the everyday activities, like consumption.

After this is possible to differentiate systemic risk in three forms, not mutually exclusive, that are:

1- Contagion risk: it refers to a characteristic problem that covers a more widespread area in a cross-sectional dimension;
2- Macro shocks risk: it is mainly the negative effects that an exogenous shock causes to a significant number of markets and intermediaries in a short period;
3- Risk of imbalances gradually risen in time: it refers to the gradual increase of imbalances inside the financial system as time passes, causing a possible future damage also to intermediaries and markets.

In conclusion, it was possible to describe systemic risk as an endogenous or exogenous event that could lead to different effects according to the magnitude of this event, a fundamental item to consider is to not confuse systemic risk with systematic risk. The latter is defined as: «Systematic risk refers to the risk inherent to the entire market or market segment. Systematic risk, also known as "undiversifiable risk," "volatility" or "market risk," affects the overall market, not just a particular stock or industry […] is both unpredictable and impossible to completely avoid. It cannot be mitigated through diversification, only through hedging or by using the correct asset allocation strategy.» (Investopedia, 2022), thus while systemic risk rises after an event happens, systematic risk is always present and considers the total market risk.

Bahaj (2020) talked about the effects that a request of aid from the Region of Catalonia to the Spain's Regional Liquidity Fund of 5 billion euros had. This leaded to an escalation of increased spreads inside the financial markets, in fact the yield of Spain raises but also the Italian 2-year and 10-year bond yields increased by around 5 basis points.

Looking at this was possible to analyse two features of the sovereign borrowing costs: the euro area's prices of sovereign bonds react impressively to specific events; there is a cross-border transmission between countries.

Important is to understand that a rise in sovereign spreads may reflect economic weaknesses.

1.1.2 How to define interconnectedness

As seen from the introduction, one of the aims of this paper is about discovering the magnitude and the strength of interconnectedness between some countries inside the euro area, in order to understand what could happen in moments of crisis and who is affected by.

Thus, before analysing this behaviour is important also to understand what connectedness means; to do so, in the past few years some authors came out with a personal definition about this phenomenon and how it is affected.

An important concept is to analyse the interconnectedness between the sovereign bond yields of the euro area, to describe them it is necessary to explain how this term is described and for any definition describe its characteristics.

According to Masson (1999) the macroeconomic connections of contagion are divided into different parts, these are:

- **monsoonal effects:** it comes from a global environment and passes over to the developed countries with a variable extent;
- **spillover effects:** it is mainly used for describing how a crisis in one country could have an effect on other emerging markets through the simple connections of economic activities or competitiveness;
- **shocks between multiple equilibria**: this is a remaining effect, in fact it succeeds when the previous two are not able to explain the concurrence of crises. Thus, there is the possibility that a role is given to self-fulfilling expectations, where the opinions about a determined country could change because of the crises in another one.

After saying that, Masson (1999) highlighted that the above macroeconomic fundamentals are not always able to describe alone what contagion effects could arise with a crisis, for example during the Tequila crisis these effects were insufficient in justifying the speculative attacks on other countries in Latin America.

For this reason, this confirms the importance of understanding and modelling how changes in sentiment happen and find out what are the motives behind this shift, because the effects are usually the herd behaviour of investors and the exposition to contagion.

In conclusion, the important part is to understand the magnitude with which diversities during the process of information and the reinforcement of expectations could modify the results in the macroeconomic factors; thus, the solution is located on the usage of a model with multiple equilibria, leading to changes in expectations on a self-fulfilling way.

Mentioning another paper, Forbes and Rigobon (2002), it is possible to give another perspective of what "contagion/interconnectedness" means.

In fact, the paper defines contagion as «[…] a significant increase in cross-market linkages after a shock to one country (or group of countries).» (Forbes and Rigobon, 2002), even if the definition is not always shared by any authors, in this case it reminds the one of Masson (1999) because also here it is talked about effects that the problems in

one country lead to others, probably through the connectedness of economy, culture's interests etc.

In fact, authors explained that a phenomenon could not be defined as contagion in the case where there are two markets with a high degree of co-movement in periods of economy stability, remaining highly correlated also in periods of shocks in one market; this because the phenomenon of **contagion** between these two markets exists only if the co-movements between them increase in a significant way only after the shock and not when it already exist.

However, when the movements between the two parties does not raise significantly and at the same time the level of correlation is still high, it means strong connectedness between the economies that are present in all states of the world, this behaviour is defined by Forbes and Rigobon as "**interdependence**".

This definition of interconnectedness leads two important benefits, these are:

1) The development of a straightforward structure for evaluating if that phenomenon is given by contagion or not. This happens with the monitoring of the links between two markets during a stable period and after the spread of a crisis or a shock.
2) The option to use another method of explanation about the different reasons for the transmission of a crisis.

In conclusion, for the author of these paper the measurement of interconnectedness is made through tests on contagion using cross-market correlation coefficients (that are conditional on market volatility) to demonstrate that these tests are not correct enough for heteroskedasticity and biased.

Another paper in which a different definition of contagion was made regards Kaminsky and Reinhart (2000), which analysed some aspects of contagion considering the facility of crisis to spread between countries.

Moving to the description of a crisis, according to the paper it is possible to arise simultaneously in a cross-border way when a common adverse shock happens, for example the rise of inflation. However, this represents a symmetric shock which is normally not shared in the definition of contagion.

Inside the paper, Calvo and Reinhart (1996) defined the term **fundamentals-based contagion** as the phenomenon that begins when the country in distress is connected to others with a trading or financial relationship, while they defined an authentic contagion the one where the symmetric shocks and the possible links of connections are both not

present or not still controlled, this is mostly reconnected with the herd behaviour by investors, a phenomenon cited also in the previous paper of Forbes and Rigobon (2002). Focusing on the fundamentals-based contagion term, it is important to analyse it to understand how contagion could arise through the links of trade and finance and filling the gap of how the disturbances are transmitted.

Considering the role of more than one creditor when a crisis spreads, in conclusion they came out with some assumptions:

1) Contagion happens mainly in a regional way rather than a global one, for example the inter-regional trade from goods and services has been stable in recent times, instead inter-regional trade in assets increased to stratospheric levels.
2) Contagion tends to have a non-linear vulnerability, in fact when one country starts to suffer a crisis it does not mean that there will be other crisis; at the same time, the discourse is different when more than one country begins to suffer a crisis, because the probability to be damaged with a domestic crisis is more concrete.
3) Is the regional contagion more efficient through finance or trade's links between countries? After some studies the conclusion is that if exists a group of countries that relates with the same creditor, the possibility to be aware of a crisis developed in the core of this group could be a more powerful predictor respect to have a country which has a bilateral or third-party trade clusters.

   In conclusion, the results obtained with forecasting the performances leads higher values regarding the financial sector links than the one for trade links.

In conclusion, for Kaminsky and Reinhart (2000), contagion's vulnerability is mainly non-linear. In fact, when the existence of crises inside a determined group is relevant, the most powerful choice of fundamentals-based contagion is through the financial sector links using common bank lenders

However, the links between countries that comes from trade and the exposure to the same creditor is useful for explaining the observed historical configuration of contagion; thus, the main used financial market channels should be better analysed and quantified if the policymakers from more than one part of the globe is interested in developing a "financial architecture" able to reduce the susceptibility of countries to crisis and to contagion.

1.2 Economic shocks in the euro area since 2000

1.2.1 The Internet Bubble

Some years later the creation of the European Union, with the Maastricht act was signed the steps necessary for the creation of an Economic and Monetary Union (EMU), basically with the aim of the introduction of a unique currency between Members.

Inside the ECB publication "Our money" is explained that the euro was introduced first on a virtual way, in fact the launch was on 1st January 1999 but only for accounting purposes (for example electronic payments), while on 1st January 2002 was introduced in form of cash, through the conversion with fixed rates of the banknotes and coins of the members' national currencies.

An act emitted by the European Commission "The euro area in the world economy – developments in the first three years –" (2002) about the first 3-year period of the EMU said that after an initial rising (+3%) there was a slowdown during 2001 due mainly to the rising in oil prices, variation inside the stock quotation and the shock after the terroristic attack of 11th of September 2001.

It was reported also in the BIS Annual Report (2001) that described this period as the result of some factors like the rise in inflation due to the energy crisis, the weakening of the euro currency and the worries about the increment of the rate of depreciation.

This decline was supposed to happen since the beginning of 2001 in a certain number of countries around the world, including the euro area, leading to a reduction of the interest rates from numerous central banks.

In the euro area, the level of inflation remained constant around 2% during the spring of 2000, the upper limit was determined by the Eurosystem for the maintenance of price stability. However, this level went up during that summer increasing again in autumn, due to the rise in oil prices and the weakening of the exchange rate.

ECB was in difficulty because found itself in a challenging position during the autumn 2000, where there was to prevent the rise in inflation due to the increment of oil prices and its effect on wage contracts and the risk of a second-round consequences.

At the beginning of 2000, ECB tried to pursue the tightening in monetary policy started in 1999; while inflation reached a level of 0.8% in January 1999 and as anticipated before, during 2000 started to increase till the peak in November 2000 of 2.9%. Obviously, this significant rise was mainly due to the sudden increase in oil prices and the depreciation of the euro equal to 16% cumulated in the period January 1999-December 2000.

An additional influence on monetary policy was the usual sensitivity of wages inside mostly continental European economies as an effect from the movements of inflation and labour market solidity.

In Europe there was the probability of a higher inflation in the future and a second-round adjustments in labour markets due to the raising trend of inflation and the unemployment rate inside the euro area that continued to decline from 9.5% (January 2000) to 8.6% (December). In this case, long bond yields remained constant around 5.5% for great part of the year and later begins to lower till 4.9% in the middle of March 2001.

Talking about the increment in oil prices in the second-half of the 2000 year, this leaded inflation to suddenly increase above the upper limits imposed by a lot of central banks. However, interest rates were not adapted after this event because the general thought was about a transitory shock.

Later, when more and more central banks saw the inflation reach the target, they started to suppose that if they would not react with interest rates adjustments in the first-round effects, they would consider tightening policy to a greater extent if the indicators pointed to the risk of a second-round effects.

Galeotti (2006) talked about oil prices during the period 1986-2006 and described also the steps that caused the increment in oil prices during the period 1998-2002. The increment in the oil prices in 1999-2000 killed the demand and leaded to an increment in the non-OPEC production, a growth controlled mainly by the Russian production, which was the country responsible for this increment in the production at the beginning of the new century.

In 2001 the lower of the US economy and the growth in the non-OPEC production would lead the prices to decrease; as a consequence, OPEC started a sequence of reductions in the production till 3.5 ml of b/g on the 1st of September 2001. Without the terroristic attack of the Twins Tower on the 11th of September, it would be sufficient to moderate or reverse the trend of prices, instead the prices collapsed.

Considering the delicate political mood OPEC delayed all the process till January 2002, when to the market were subtracted 1.5 ml b/g.

Even if a fragile global conjuncture and a greater supply on the market, political problems pushed the prices up till a value around 25 dollars in March 2002.

1.2.2 The Global Financial Crisis

According to the 79th Annual Report (2009) of the BIS organisation, there are mainly four stages in the development of the global financial crisis spread in the late 00's due to the subprime-mortgages and the failure of Lehman Brothers.

The **first stage** could relate to the period from June 2007 up to mid-March 2008, defined as "Prelude". In this period the effects of losses from subprime mortgages came stronger also due to the increasing use of leverage and financing from off-balance sheet, it was supposed to permit to low-risk assets the financing through short-term funds on a rolling basis.

Even if during those months a widespread banking failure has been avoided, the financial system found itself damaged; in fact, there was a large portion of credit exposure on the market by banks, while there was not the capacity to rehabilitate the capital positions.

Second stage is closer to the Lehman Brothers failure and went from mid-March to mid-September 2008. After the takeover of Bear Stearns by JP Morgan on the 16th of March, the financial market came another time under pressure. The principal effect of these 6-month period is the fact that investors started to understand that the growing recession in the United States had spread over the world, starting an economic downturn.

As a difference from the first stage, interbank market was not able to recover its capital positions, despite the recovery of Bear Stearns during a period of stability and of rising prices for financial assets.

A similar behaviour was observed both by the Libor-OIS spreads that stayed elevated for the major currencies (also including the US dollar) either in the foreign exchange swap markets, where the not-equal pressures in the major currencies and in the US dollar caused and increment of the costs in the dollar funds.

Third stage went from the 15th of September till the end of October 2008. This phase started with the request of Chapter 11 bankruptcy protection by Lehman Brothers Holdings Inc; however, the increasing confusion in the markets leaded more and more financial institutions to a realistically risk of default.

Talking about the even more realistic possibility of Lehman's bankruptcy, the effects were suffered also in the CDS market, in fact the not paid securities' debt came out with a dangerous situation. To prevent a part of the losses that a failure of Lehman Brothers could cause to CDS market participants, there were three events that tried to solve the situation, these are:

1- On the 14th of September 2008: special trading session, which involved the mainly CDS dealers with a credit position to Lehman Brothers. This permitted to these dealers to rebalance their books using a replacement of trades.
2- AIG is an important insurance company which at that time held around $440 billion of notional position in the CDS contracts and received in date 16th of September 2008 a support package by the government. This helped to avoid a disorderly AIG's failure and kept the CDS-related risks to be reintroduced into the BS of clients in that particular period.
3- The outstanding position of Lehman Brothers was smaller than expected, then they have been closed out in October with net settlement payments of about $5.2 billion.

Fourth stage went from late October till mid-March 2009 and interested the focus of the investors versus the global economic downturn. This uncertainty was referred to both the financial sector stability and the likelihood of a becoming more intense recession.

This likelihood was motivated by the values of the government bond yields, which was characterised by a downward trend in November and December 2008. These restrictions in the bond yields leaded US and the euro area to lower yields of about 1-2% by Mid-December. Talking about the euro area, the interest rate swap prices were expected to suffer another reduction in the policy rates within 12 months by the ECB, showing a low reaction of the organisation in the adjustments of the rates.

Fifth stage went from Mid-March 2009, and it was characterised by the first signs of stabilization. During this period volatility has declined and the values of the asset prices recovered from the downward trend; however, some signs of dysfunction were evident, demonstrating that the attempts of the governments and of the central banks together were not completely sufficient to recover the pre-crisis confidence in the financial system.

In terms of the financial sector, this crisis period was extremely stressful, for financial institution there was a long period of illiquidity with a large number of failing firms.

Concentrating on the medium term, a fundamental point for firms to go beyond this situation was the ability to respond to losses and the dynamics of macroeconomic conditions. Initially, the funds from capital investors were sufficient to cover the costs from write-downs on securities portfolios.

Going ahead in time was more and more necessary the help of the public sector, due to growing losses on the books of institution's loan.

Moving to a long-term perspective the events since the beginning of the crisis demonstrated that exists a strong interdependence between financial system components. In fact, there was a high underestimation by cautious authorities and market participants on the counterbalanced role of different agents for the securitisation links, for the strong relationship created between financial markets and institutions, and the interaction among funding liquidity and asset market.

1.2.3 The European sovereign debt crisis

After the global financial crisis of the previous years, Lane (2012) explained that what put in a difficult position the sovereign debt in the euro area was mainly due to Greece; in fact, right after the election of the new government in October 2009, it announced an updated budget deficit forecast of 12,7% of GDP.

Furthermore, after a new revision of the Greece's fiscal accounts of previous years was discovered that the deficits were larger than expected; violating euro's fiscal rules, Greece found themselves as the primary blame on fiscal irresponsibility by a peripherical nations. These events leaded the spreads on sovereign bonds to rise, for example the annual spread of 10-year sovereign bond yields between Germany and other euro area countries like Ireland, Greece, Spain, Portugal and Italy were close to zero before this crisis' period. Another important factor to consider is the common currency that these countries share, the euro, and this leaded to dissimilarities in expected yields due to detected credit risk and different levels of volatility.

After the rising of the 10-year yields, the first country to be left outside from the bond market was Greece in May 2010, with Ireland as the second one in November 2010 and Portugal as third in April 2011. In each of these bailouts the programmes of European Union and IMF (International Monetary Fund) jointly established that a three-year funding would be provided only if the country which would receive it, implements fiscal austerity packages and structural reforms for implementing growth (mainly for Portugal and Greece) extended also to the banking system (mainly for Ireland).

However, the funding's requests were enormous for IMF's lending capacity, thus European Union was the principal provider; in the meantime, was established a temporary European Financial Stability Facility (EFSF) able to issue bonds following the promises from the Member States of providing sufficient funding in case of another crisis. Consequently, the already existing European Stability Mechanism (ESM), mainly used

for balance-of-payments foreign currency support for non-euro Member States, was converted for providing funds also to euro Members.

During this crisis and prolong period of uncertainty, sovereign debt markets saw an incremented volatility in euro area. Even if the creation of EFSF and the mutation of the ESM were almost able to face the bailouts of Greece, Ireland and Portugal, they were not sufficient for helping also Spain and Italy, and the creation of another firewall fund was not possible.

However, the ECB's programme of sovereign bond purchase could be identified as a method for reducing the risk of "bad equilibrium"; in fact, in the period from May 2010 to October 2010 ECB bought around € 65 billion of bonds, and other purchases were made in later periods, but the liquidity created through the monetization of debt was immediately compensated by sterilized operations.

Neri (2013), inside a publication for the Bank of Italy, talked about the starting reasons of the sovereign crisis in Europe and that the starting point may be even during the global financial crisis of 2007-2009.

In fact, the subprime crisis caused a significant fragmentation between the countries in the European financial market, making difficult the communication of monetary policy issued by the ECB and permitting to avoid a uniform transmission of monetary impulses to the countries located in different euro-areas. In response, the Governing Council of the ECB tried to contain the situation adopting in the last months of 2008 some extraordinary measures for sustaining the private sector and maintaining the standard in the transmission of monetary policy inside the euro area.

At the beginning of 2010, some government securities markets of the euro area members, characterized by weak macroeconomic and fiscal fundamentals, were deeply strained. With the development of a weakening inside the euro area, the spreads in many countries started to reach levels never touched before and the sudden drop in liquidity that some government bond markets suffered worsen the situation.

As anticipated by Lane (2012) document, the first bailout was the one of Greece, which spread increased till unprecedented levels, this was due mainly by the fact that there was fear about the sustainability of its public finances; later was the turn of Ireland and Portugal during the period that goes from the autumn and winter of 2010-2011.

Moving to the peripherical countries Italy and Spain, their spreads around July 2011 increased significantly in confront with the German Bund, probably worsening after the volatile situation of Greece that deteriorated its situation on the bond market and required

a second bailout package for involvement of the private sector, granted after the announcement of the European Council.

The following extraordinary measures taken by the ECB in December 2011, aimed also to short-term refinancing operations and the reduction of the policy rates, managed to reduce tensions and mitigate the difficulties of banks in funding, thanks also to some fiscal adjustment measures actuated by some governments.

After some months of calmness, around March 2012 the financial market started to suffer again some difficulties, this is due to the increasingly worry of investors about the precarious political situation in Greece, the problems of the banking sector in Spain and the incapacity of governments inside the European Union to reform governance arrangements or simply the creation of effective tools for the crisis management inside the euro area.

Talking about spreads between Members, the one of the peripherical countries started to grow significantly till August 2012, when the Governing Council of the ECB announced extraordinary measures for helping the bond market interruption; the reasons were in part the worries about "redenomination risk", in other words, the reversibility of euro and the protection of the ECB monetary policy and the correct functioning of its transmission mechanism.

1.2.4 The Covid-19 pandemic

Another important economic shock during the recent years was determined by Covid-19, in fact the situation was defined as: «The Covid-19 pandemic is the most devastating shock to hit the global economy since the Second World War.» (BIS, 2020).

According to this paper for avoiding a fallout of the economy it is necessary to act differently than with a normal recession or a financial crisis; in fact, during the lockdown's period the goal of the governments was to permit to firms and household to overcome the closure period of their activities.

Some factors that complicated the implementation of the policies are:

- Uncertainty for policymakers, decisions had to be made trying to anticipate how long and how severe the pandemic would be in terms of people's lives. The risk was to arrange insufficient funds and to cause bankruptcies and layoffs, complicating the conditions of the financial markets and expanding the cost-cutting.

- Uncertainty about workers and firms in terms of survival mainly at the beginning of the pandemic: this situation suggested a general support in the first part of the stop, becoming more specific as time passes. A consequence was how to act and in which moment, in fact allowing bankruptcies immediately would have discouraged the growth of the "entrepreneurs of the future", while granting for too long the support to firms very close to failure would have slow down the structural adjustments of the government. Another issue to take into consideration was how many banks should be available in granting firms loans/loan guarantees, because the risk was to run into the phenomena of "moral hazard", with less financial prudence in the future.
- High debt levels: usually borrowing is used for covering some gaps in the income, but for some firms and households this could be too much to sustain. However, it was demonstrated that was more efficient cut promptly excess capacity and restructuring debts in order to recover faster than a gradual approach.

After explaining these factors, it is possible to explain what central banks decided to do with the pandemic. First step was to cut the policy interest rates when the pandemic became a concrete problem and, when the situation got worse, central banks tried to stabilise the financial market with a lot of emergency measures, in order to recover a part of confidence recently lost; some of these measures consisted in: imposing policy rates at the lower bound and introducing an open-ended APP to unblock the balance sheets of the market-makers.

Some of those measures have become part of the nowadays standard management of crisis, but central banks needed also to expand their playbook; for example, through lifelines to business in difficulty, buying their entire debt or supporting banks, especially with SMEs.

During this process, some central banks got worse on the credit rating scale, even below the investment grade (from AAA till BBB in the S&P scale).

The BIS Annual Economic Report (2021) explained what the expectations and forecasts about global economy were after a year of Covid-19.

Regarding the 2020 year in its second half, when containment measures were less severe, global economy recovered quickly, more than anticipated. This behaviour was due mainly to the less severe containment measures of Covid-19 that leaded to a higher private consumption demand in a short period.

A part of it, economists studied three principal scenarios of what it was possible to expect from that moment till the near future; obviously, the general situation was not the same as the past 1 year, but the level of uncertainty was still high due to doubts about vaccines' effectiveness and the possibility of new contagion waves.

In the construction of the scenarios there were three factors to consider: the impact and path of fiscal policy; path about consumption, which recovery was unexpectedly fast; potential magnitude of firm's credit losses.

The three scenarios that will be described now were used for understanding the problems that policymakers had, they are:

1- Central scenario: it was characterised by a soft recovery of the economy, due to a pandemic under control with a consumption that helped progression. Obviously, each country is not the same and some cross-country differences exist.

2- Second scenario: in this case inflation was not expected to be smooth but to increase over expectations. As a consequence, markets applied a stronger tight on monetary policy due to a larger impact of fiscal policy on demand and a bigger reversal about saving rates assumed in the previous scenario.

   Talking about the plausibility of this scenario, it is to consider that especially globalisation and technological advances have reduced the pricing power of labour and firms; besides, the impact of inflation in the last years on productive capacity was low and now, any increment of inflation (even if temporary) could cause an overreaction of the financial market participants against a future sustained inflation, but this did not happen. A key concept of this scenario is the resilience of non-bank financial intermediation, mainly about mismatches of leverage and liquidity.

3- Third scenario: in this case the expectations about pandemic were that the situation was difficult to take under control, leading to a stall in the recovery. The stall could be caused by new waves of Covid's stronger variants, also against vaccines, with new containment measures as a result. Regarding the economy, in this scenario the risk of insolvencies for a lot of firms became even more plausible. However, some studies about the probability of credit losses contained in the first scenario suggested that they would be manageable, in fact the debt in the most affected sectors accounted for a relatively tiny slice of the total.

   In this scenario, the losses suffered by firms may be larger, probably the same suffered during the Great Financial Crisis (GFC) and banks could start to feel the

strain. A sign could be the withdrawn of part of the provisions by some of them during 2020, suggesting that they could be caught by surprise.

A publication of CONSOB by Linciano et al. (2020) described what were the effects of Covid-19 inside the bond market. From March 2020 all the markets, bonds, public and private suffered a drop in prices and an even higher volatility of them. Specifically, the sovereign bond market encountered uncertainties about the development of the crisis also due to the preview of a rapid worsening of public financials' parameters, in fact a lot of countries tried out a substantial number of resources prone to cover the costs of Covid-19 healthcare emergency and the consequences of the pandemic to the real economy.

The publication said that inside the euro area, secondary markets of public bonds in major European countries registered a swift increment of the spread against the yield of 10-year home country bond and the German's benchmark.

After two announcements made by the ECB, one on 18th of March when was published the PEPP's (Pandemic Emergency Purchase Programme), an extraordinary programme of acquisitions of public and private bonds during the healthcare emergency, and one on 27th May with the announcement of a new fund for the reconstruction, helped secondary markets making their sovereign yields get lower to pre-pandemic levels.

Inside a publication of ECMI, European Capital Markets Institute, Papavassiliou (2021) described what happened inside the yields in the sovereign bond markets in the first period of Covid-19 through the sovereign yield curve. The analysis of the paper concentrated on the sovereign bond yields of all euro area countries, looking to the sovereign yields in two periods: the pre-Covid one (2nd January 2015 to 1st December 2019) and during Covid (2nd December 2019 to 15th April 2021).

During the analysis what came out was the presence of negative interest rates inside the euro area, due mainly by low inflation in recent past and to the demand pressures increased with the Asset Purchase Programme (APP) issued by the ECB in Mid-2014. However, the fact that negative rates are more sustainable on the longer-term is not shared by all, because it depends also on the capacity of market participants to tolerate these negative yields and growth prospects.

CHAPTER II

A model for measuring connectedness

2.1 Literature review

In the measurement of risk given by two parties to the system, in the years some models were developed and subsequently changed following more recent models. In this part of the paper, there will be the explanation of the major models that were used for the calculations, reaching at the end the decision of what model to choose and its explanation in details, this model is based on the forecast error variance decomposition and the explanation will consider the paper of Diebold and Yilmaz (2014).

Adrian and Brunnermeier (2011) developed a model called CoVaR for the measurement of systemic risk, applying it using the Value at Risk (VaR) of the financial system conditional to institutions under distress. According to Brunnermeier, Crocket, Perssaud, Goodhart and Shin (2009) a useful measure for the measurement of systemic risk should observe the risk that individually systemic institutions give to the system, in fact being large and linked between them they could lead to negative effects on others. For measuring risk in the calculations is used CoVaR, it represents the *i*'s institution CoVaR, thus the VaR of the entire financial sector conditional on institution *i* that is in distress; while ΔCoVaR is the difference between CoVaR conditional on institution's distress and CoVaR conditional on normal state of that institution, thus it is the marginal contribution of a determined institution to the overall systemic risk.

This method is different respect to others because permits to measure the contribute of *i*'s institution to the overall system, while others concentrate on the risk of individual institutions. An implementation of the model is given by the forward-ΔCoVaR, used for monitoring the evolution of systemic risk in a forward-looking manner.

In conclusion, this model developed by Adrian and Brunnermeier uses ΔCoVaR measure as a parsimonious one and useful for calculating systemic risk for individual financial institutions and the forward-ΔCoVaR one could be used also in macroprudential policy applications.

Engle and Kelly (2008) developed a model called Dynamic equicorrelation (DECO) and represents an extent of the CCC and DCC (Engle, 2002) models; the assumption in this case is that at every time period all the pairwise correlations are the same.

Basically, DECO's model avoids all the complications given by high dimension systems, in fact here the system considers all pairs of returns that have the same correlation in a determined day, but it changes as time passes.

However, as anticipated, the Dynamic Conditional Correlation was developed by Engle in 2002, this leads to a simplified version of multivariate specifications. In fact, in large systems there is a double difficulty, one about the estimation of dynamic correlation and the other about the analysis and presentation of these correlations.

Acharya et al. (2012) developed a model called Marginal expected shortfall or LRMES. It was created concentrating on the "Expected capital shortfall of the firm in a crisis" element inside the formula of the systemic risk of a firm. The expected capital shortfall contains all the characteristics that are important for measuring systemic risk and are size, leverage and interconnectedness; the just mentioned factors usually rise the capital shortfall of the firm when losses in the financial sector are huge.

Besides, this term provides the co-movements of the assets inside the financial firm together with the aggregate financial sector in a crisis.

The model starts with the computation of SRISK, that is the expected capital needed by a firm in case of a new financial crisis.

(1) $SRISK_{i,t} = E_{t\_1}\ (Capital\ Shortfall_i \mid Crisis)$

It is possible to estimate it through a bivariate time series model with equity returns on firm i and a broad market index, $R_{m,t}$. The last-mentioned element i is characterized by a volatility composed by asymmetric GARCH processes and the estimation of the correlation through DCC.

This model calculates the systemic risk evaluating first the possible losses of an equity holder in case of a crisis in the future, thus the system is simulated many times for six months into the future. To give a parameter, if the index drops below 40% in the six months period, this is considered as a crisis.

In this case, the expected loss of equity value of firm i is defined as the Long Run Marginal Expected Shortfall (LRMES); it represents the mean of the tiny returns of the equity of the firm in the scenario of a crisis.

The capital shortfall could be obtained considering that the book value of debt will not change during the window of six months defined before, while the values of equity decrease by LRMES.

The prudential capital ratio is defined by the term k and, if E represents the sum of the total equities inside the financial sector, while D is the book value of debt, a crisis is concrete if:

$$(2) \qquad E < \frac{k}{1-k} D$$

LRMES would be calculated on scenarios able to satisfy the previous formula (2), permitting to evaluate the probability of a crisis in equation (1), increasing the leverage externalities through the systemic risk, because the leverage in each firm will go up together with the leverage of the other firms.

Caporin et al. (2013) analysed the contagion during the sovereign debt crisis using Credit Default Swap (CDS) of the euro countries.

After considering the rolling evaluation of the linear correlation through changes inside the CDS spreads, the authors controlled the presence of non-linearities in the process using the exceedance correlation measures by Longin and Solnik (2001).

This model is computed mainly with two formulas, thus having the quantile level q, the exceedance correlations are calculated as follows:

$$(3) \qquad \rho^{-} = Corr\left[\Delta CDS_{i,t}, \Delta CDS_{j,t} \middle| F_i\left(\Delta CDS_{i,t}\right) < q,\ F_j\left(, \Delta CDS_{j,t}\right) < q\right]$$

$$(4) \qquad \rho^{+} = Corr[\Delta CDS_{i,t}, \Delta CDS_{j,t} | F_i\left(\Delta CDS_{i,t}\right) > 1\text{-}q,\ F_j\left(\Delta CDS_{j,t}\right) > 1\text{-}q]$$

In detail, $\Delta CDS_{i,t}$ corresponds to the changes of CDS from period t to $t\text{-}1$ and i,j are a combination of two countries; while F_i and F_j represents the cumulative density functions of the variations in CDS.

Thus, ρ^{-} calculates the connection between two CDS changes in the case where both are placed in their lower q quantile; on the other hand, ρ^{+} represents the joint occurrence of positive alterations above $1 - q$.

When reported graphically, the exceedance correlation ρ^{+} decreases as the value q decreases, considering the fact that positive and significant changes of CDS correspond to a reduced correlation between countries, inverse reaction when dealing with negative CDS movements.

However, the just cited model is affected by the movements in the marginal densities of the variables.

After describing the literature of some models used for connectedness analysis or papers that studied the connectedness in the euro area, it is necessary to define what model will be used for the empirical analysis of this thesis, it is the version of 2014 of the forecast

error variance decomposition method used by Diebold and Yilmaz and it will be described in the next Section.

2.2 The Diebold and Yilmaz model

The model that will be used for the empirical analysis is the one developed by Diebold and Yilmaz, which was presented in 3 different papers (2009,2012,2014). In this paper the description will be made referring mainly to the document of 2014, because is more complete and the latest.

In Diebold and Yilmaz (2014) the model is used in various perspectives, considering connectedness both from pairwise and system-wide point of view, with the utilizations of the variance decompositions from approximating models. The components are:

- Population connectedness: connectedness is considered as the assessment of shares of forecast error variation from various origins. This is linked to an econometric notion of variance decomposition, where the forecast error variance of the variable ***i*** is divided in parties that are allocated to the several variables inside the system. In technical terms, the symbol d_{ij}^{H} represents the *ij-th* H-step ahead variance decomposition component, basically it is the fraction of the H-step forecast error variance of ***i*** from the shocks of another variable ***j***. For the entire description of the model the connectedness measures are based on the cross-variance decomposition, thus d_{ij}^{H} with ***i,j=1,…,N*** considering ***i≠j***.
    - First of all, there is the need of describing the population connectedness table, which is important because permits to understand the connectedness measures and the magnitude of the relationship. In its structure the upper-left ***N x N*** block consists on the variance decompositions and can be called as the "variance decomposition matrix" and denoted by $D^H = [d_{ij}^{H}]$. The entries of D^H outside the diagonal are the parts of the N forecast error variance decomposition measuring pairwise-directional connectedness, it is defined as: $C_{i\leftarrow j}^{H} = d_{ij}^{H}$

      The connectedness table is defined as follows:

	x_1	x_2	…	x_N	*From others*
x_1	d_{11}^H	d_{11}^H	⋯	d_{1N}^H	$\sum_{j=1}^{N} d_{1j}^H, j \neq 1$
x_2	d_{21}^H	d_{22}^H	⋯	d_{2N}^H	$\sum_{j=1}^{N} d_{1j}^H, j \neq 1$
⋮	⋮	⋮	⋱	⋮	⋮
x_N	d_{N1}^H	d_{N2}^H	⋯	d_{NN}^H	$\sum_{j=1}^{N} d_{1j}^H, j \neq 1$
To others	$\sum_{i=1}^{N} d_{i1}^H \ i \neq 1$	$\sum_{i=1}^{N} d_{i2}^H \ i \neq 2$	⋯	$\sum_{i=1}^{N} d_{iN}^H \ i \neq N$	$\frac{1}{N}\sum_{i,j=1}^{N} d_{ij}^H, i \neq j$

Normally $C_{i\leftarrow j}^H \neq C_{j\leftarrow i}^H$, thus there are ***N²-N*** pairwise directional connectedness measures and the value that comes out from the connectedness from country ***i*** to country ***j*** is different from the value of the connectedness in inverse direction.

From the connectedness table is possible to divide between net pairwise connectedness, that is calculated as the difference from the connectedness that country ***i*** gives to country ***j*** and the one from country ***j*** to country ***i***, basically: $C_{ij}^H = C_{j\leftarrow i}^H - C_{i\leftarrow j}^H$, obviously this leads to a number of values equal to $\frac{N^2-N}{2}$.

Looking at the last row and the last column denominated as "From" and "to" of the above table, they are the off-diagonal sums and are defined as:

- ***Total directional connectedness from others to i***:
  $C_{i\leftarrow\blacksquare}^H = \sum_{\substack{j=1 \\ j\neq i}}^{N} d_{ij}^H$
- ***Total directional connectedness to others from j:***
  $C_{\blacksquare\leftarrow j}^H = \sum_{\substack{i=1 \\ i\neq j}}^{N} d_{ij}^H$

For each country considered in the analysis there will be two values, in fact there is the value "from others" or "received" and a value "to others" or "transmitted", for a total of ***2N*** directional connectedness measures; in this paper analysis are considered 4 countries, thus the total directional connectedness measures will be 8, 4 values and 4 values.

The ”FROM” column, or total directional connectedness from others, measures the share of shocks received from the other countries in the total variance of the forecast error for each stock; it is calculated as 100% minus the share of the total forecast error variance for each country.

However, the “TO” row, or total directional connectedness to others, has not the limit to reach at maximum 100% as the contribution to others’ error variances.

Obviously, also for this measure there is the net total directional connectedness, is defined as $C_i^H = C_{\blacksquare \leftarrow i}^H - C_{i \leftarrow \blacksquare}^H$, meaning that this value corresponds to what country $\boldsymbol{i}$ transmits to others minus what receives from others, thus for each country there is one value and the net total directional connectedness are equal to $\boldsymbol{N}$.

Finally, the sum of the “from” and “to” cells of the table not considering the diagonal ones, is the total connectedness (at the bottom right of the table) and is defined as: $C^H = \frac{1}{N} \sum_{\substack{i,j=1 \\ i \neq j}}^{N} d_{ij}^H$.

This connectedness table is used because permits to start the analysis with a disaggregated measure for aggregating them in different ways to a macroeconomic economy-wide total directional and connectedness measures.

- Correlated shocks: before has been presented an orthogonal reduced-form system, the variance decompositions are calculated considering the fact that orthogonality permits to the variance of a weighted sum to correspond to an appropriately weighted sum of variances, even if this reduced-form system are infrequently orthogonal. To solve this problem are necessary some assumptions, thus it is important to take into consideration the VAR identifications of Cholesky and Sims (1980) and the GVD (Generalized variance decomposition framework) by Koop et al. (1996) and Pesaran and Shin (1998).

  About assumptions, Cholesky-factor identifications ordering makes the total connectedness robust, thus the estimates of this value across orderings does not change a lot; the model is based on agnostic data-based spirit.

  On the other side, the GVD model relies on a largely data-based identification but differently from the Cholesky’s model, it is invariant to ordering.

With the Cholesky one, when the first variable in the ordering is affected at the same time only by its own innovations, the second one is affected by innovations of the first and the second variable, and the process will continue in this way.

GVD, instead, considers each element as the first in ordering, this in order to obtain correlated shocks and at the same time accounting for the correlation of them observed in the past, using normality as assumption.

After saying it, the H-step generalized variance decomposition matrix $D^{gH} = [d_{ij}^{gH}]$ is composed by: $d_{ij}^{gH} = \frac{\sigma_{jj}^{-1} \sum_{h=0}^{H-1} (e_i' \Theta_h \sum e_j)\hat{}2}{\sum_{h=0}^{H-1} (e_i' \Theta_h \sum \Theta_h' e_i)}$.

e_i represents a selection vector that has *jth* element unity and zeros in the other places; Θ_h is the coefficient of the matrix that multiplies the H-lagged shock vector in the infinite moving-average representation characterized by the non-orthogonalized VAR; σ_{jj} is the *ith* diagonal element of $\sum$, that represents the covariance matrix of the shock vector in the non-orthogonalized VAR. However, in the GVD model the shock are not inevitably orthogonal, neither sums of forecast error variance contributions are unity, thus the generalized connectedness indexes are $D^{\sim g} = [d_{ij}^{\sim g}]$ which is composed as $d_{ij}^{\sim g} = \frac{d_{ij}^{g}}{\sum_{j=1}^{N} d_{ij}^{g}}$.

In conclusion, $\sum_{j=1}^{N} d_{ij}^{\sim g} = 1$ and $\sum_{i,j=1}^{N} d_{ij}^{\sim g} = N$, thus using the new index $D^{\sim g}$ it is possible to directly calculate the generalized connectedness measures.

- Sample connectedness: the element *C* is dependent from a set of variables denominated *x* which needs to be calculated the connectedness, *H* that is the time horizon for the variance decomposition and the dynamics *A(L)* (unknown value, need to be approximated), all can be rewritten as *C(x, H, A(L))*. Considering the importance of approximation in the chosen model, the model can be written as *C(x, H, A(L), M(L;θ))*, the new element *M(L;θ)* represents a dynamic approximating model with *θ* as a finite-dimensional parameter.

  In addition, for the model it is requested a time varying connectedness, permitting to move from a static perspective (unconditional and considered so far), to a dynamic one.

  The time-varying element *A(L)* (and so time-varying connectedness) could develop slowly with changes in technologies, tastes, variation in the business cycle, or change brusquely following the crisis inside the financial market; considering the fact that *A(L)*'s changes are an empirical matter, and the result

will be different based on applications, surely cannot be defined as constant. Thus, allowing the connection table and the variation of the elements over time, the final model can be written as $C_t(x, H, A_t(L), M(\theta_t))$.

What was already written refers to the population, while in reality there are only finite samples of observed data, in order to approximate it, the right model to write is $\hat{C_t}(x, H, A_t(L), M(\hat{\theta_t}))$, with t=1, . . . , T.

- The reference universe *x*: *x* represents the elements composing the object of interest to be studied. The choice of *x* is important for the implications for the appropriate model, for example *x* may be conditionally heteroskedastic or strongly correlated; however, connectedness measures usually are not robust to the choice of *x*.

  There are more aspects about the reference universe *x*, and they are: "x object" that is the type of variable used; "x choice" refers precisely to the *x* variables used in the study; "x frequency" is the frequency of the variables, if are daily, monthly, or annual data.
- The predictive horizon *H*: the choice of connectedness horizon changes for some reasons, for example H=10 could be consistent with the 10-day value at risk (VaR) as established in the Basel accord. This element is important to select because it is linked with problems related to dynamic connectedness, instead of contemporaneous connectedness. In terms of pairwise connectedness, shocks to *j* could attach the forecast error variance of *i* with only a lag, so that $C_{i\leftarrow j}$ can result with a small value for small *H*, while larger for larger *H*. Obviously, as the time horizon becomes longer there is more probability for connectedness to come out.

  Thus, the modification of the *H*'s value permits to get a related sequence of conditional prediction error variance decompositions for which the conditioning information becomes less important. If it is considered the limit as H→ ∞, an unconditional variance decomposition is obtained.
- The approximating model M(θ_t): the selection of the approximating model starts with the definition of its class, it can go to various ways, for example a traditional data-driven VAR approach, a structural VARs or a fully articulated dynamic stochastic general equilibrium (DSGE) models. Besides, another point is the allowance of time-varying connectedness; obviously, connectedness is simply a transformation of model parameters,

thus time-varying connectedness means concession for time-varying parameters in the approximating model.

The possibility for time-varying parameters a particular scheme involves the utilization of a rolling estimation window. To mark this element in the daily life, it is suggested to use a uniform one-sided estimation window of width *w* in every period, using only the most recent of the *w* periods for the approximation and the calculation of the connectedness measures; the final model will be $C_t^{\wedge}(x, H, M_{t-w:t}(\theta^{\wedge}))$.

This new approach permits a widespread utilization and the consistency with a lot of time-varying parameter mechanisms. Rolling-window need the selection of *w*, similar to the selection of the bandwidth in the density estimation.

CHAPTER III

Empirical analysis on the euro area sovereign bonds

3.1 Data analysis

In this part of the paper, after a deep presentation of the data, will be applied the Diebold-Yilmaz model to the time series of four countries in the euro area to arrive at the core of the thesis and analyse the connectedness measures and how to deal with them. The countries are divided into peripherical and core ones in the euro area, while the analysis will use the monthly sovereign bonds' yields considering a period that goes from 31 January 2000 to 31 March 2022, for a total of 267 observations, with maturities of 2-5-10-year.

The use of Diebold-Yilmaz model is useful because permits to draw a matrix (static part of the model), as described in the previous Chapter, and understand why and in which magnitude determined countries are interconnected each other, analysing also the possible variations due to different yields' maturity, analysing also the dynamic part.

In this analysis will be presented only four out of the ten selected euro area countries, which two of them will be from the "core" zone of the euro area and two from the "peripherical" zone; the countries were Portugal, Netherlands, Belgium, Italy, France, Germany, Spain, Finland, Austria and Ireland. The peripherical countries here are Italy, Portugal, Spain and Ireland, while all the others are core.

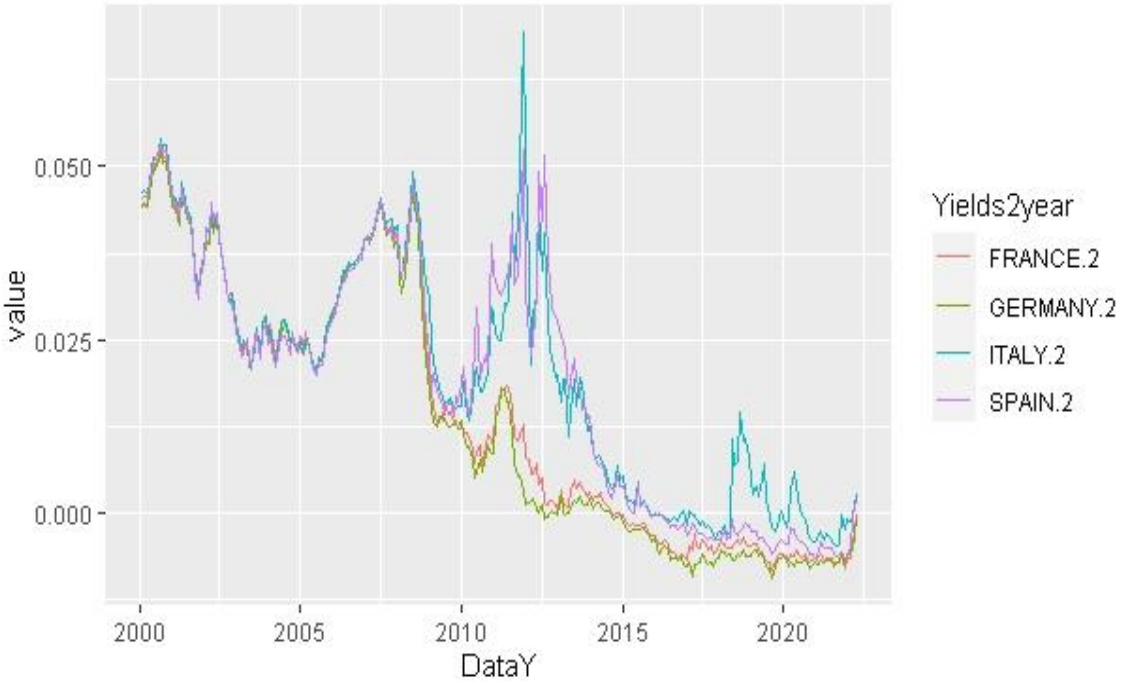
For selecting the countries, it was used the model of Diebold-Yilmaz inside the RStudio programme, matching different countries (divided in core and peripherical) and seeing the match which gave the highest total connectedness.

In conclusion, the four countries are: Germany, Italy, France and Spain; the explanation about the choice of these countries will be part of interest in the last point of this Chapter, because it will be simpler to understand seeing the level of connectedness given by the Diebold-Yilmaz model, the core of this analysis.

3.1.1 Description of economic shocks in the 2000-2022 period

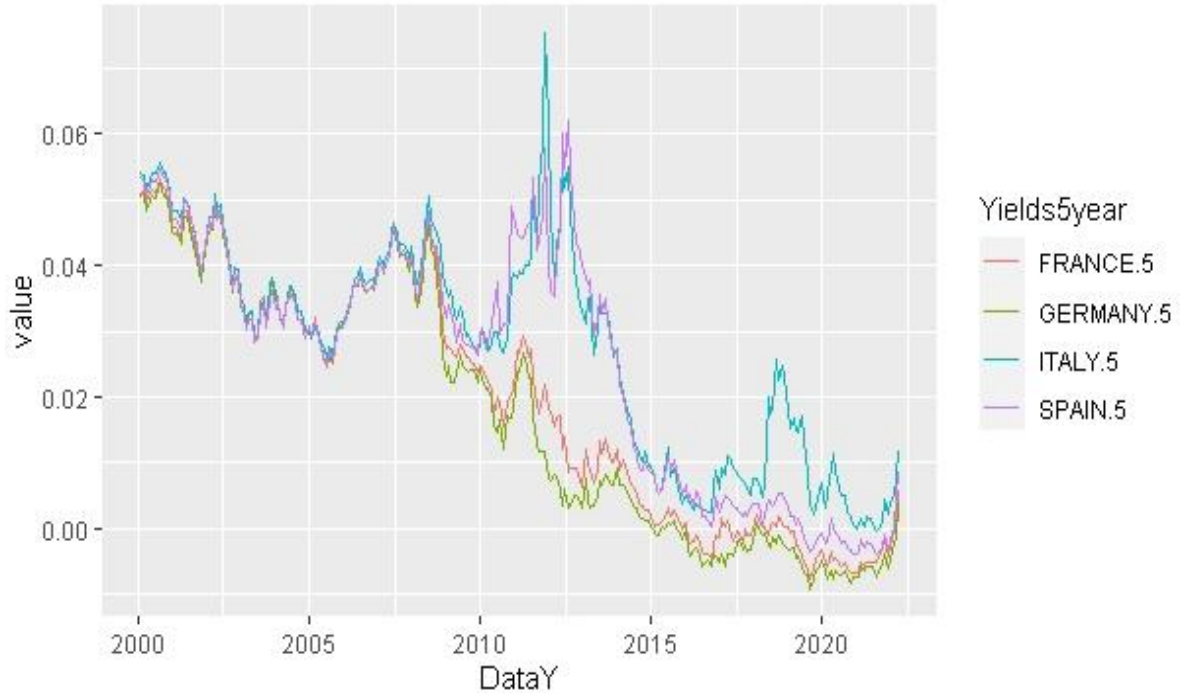
Below are printed the trends of the 2-5-10-year sovereign bond yields of the four selected countries during the sample period, to describe the effects that the economic shocks of the last 20 years leaded.

Graph 1: 2-year sovereign bond yields of the selected four countries (2000-2022)



Source: Bloomberg monthly data period 2000-2022

Graph 2: 5-year sovereign bond yields of the selected four countries (2000-2022)



Source: Bloomberg monthly data period 2000-2022

Graph 3: 10-year sovereign bond yields of the selected four countries (2000-2022)

Source: Bloomberg monthly data period 2000-2022

The sample period goes from January 2000 to March 2022 and, as presented in Chapter I, the main economic events that disturbed the euro area economy were the decline in the European Monetary Union in 2001, the global financial crisis 2007-2009, the sovereign debt crisis 2010-2012 and the Covid-19 pandemic (2020-).

Before showing exactly what happened in that years is better to briefly describe the whole trend looking to Graphs 1-3; it is evident that for all the maturities the yields of the four countries declined significantly from 2000 to 2022.

Clearly, longer term yields are higher than the shorter term one because surviving for more years is more probable to encounter some economic damages, but Graph 1 shows a more volatile trend in the first part of the sample period than Graph 3, where the declining trend is more or less constant till the end.

Starting now with the detailed description of the economic shock effects, the increment in oil prices, on inflation and the 11th of September 2001 terroristic attack on the Twin Tower did not deteriorate in a significant way the values of the sovereign bond yields.

Obviously, the worsening of the US economy together with the increasing uncertainty about inflation and the oil prices leaded to a reduction of the yields but in a volatile way, the following period till the global financial crisis continued with the same declining trend for the raising of the economy.

The period of the global financial crisis signed a strong impact in the euro area, because if at the beginning it was only considered as a US limited shock, rapidly affected the European economy, worsening the situation and increasing the yields in the bond market. During the fourth stage of the global financial crisis (from October 2008 till Mid-March-2009) described by the BIS Annual Report (2009), the recession fear given by a decreasing trend of the government bond yields mainly in the period between November-December 2008, leaded to apply a reduction in policy rates and an attempt in saving the situation with a reduction of about 1-2% of the bond yields by Mid-December in the US and the euro area.

In the corresponding period, Graphs 1-3 show different representation of this drop, with a more significant change in Graph 1 and an almost invisible one in Graph 3.

As anticipated in Chapter I, right after the crisis period, inside the euro area Greece started to suffer some financial turmoil, with the new political elections of 2009 and some fiscal problems, leading this country to be the first to request a bailout in 2010. On the Graphs the starting turmoil of Greece seemed not to highly influence the yields, in fact in all the maturities there is a first drop after the global financial crisis (the drop is obviously more significant on Graph 1 than on Graph 3).

What happened instead with the bailout of Greece changed suddenly the yields trend, that started to increase again. Neri (2013) wrote that the effects of Greece started to be suffered inside the euro area at March 2012, due also to a difficult banking situation in Spain and a slowdown of the whole euro area; in the same year the spreads of the peripherical countries started to grow till August 2012, in fact on the above Graphs is evident how the sovereign bond yields are extremely higher than the Germany and France one, that instead show declining yields.

In that period Italy reached as maximum value 0.07 while Germany had a value around 0.015-0.02 on Graph 3, the spread is a little narrower on Graph 2 with Italy that reached a value >0.065 and Germany equal to 0.01; concluding with Graph 1 where the yields' values are lower because is a short-term one, but for Italy corresponds to >0.055 and Germany had almost 0.

Moving to the final part of the sample period, the Covid-19 one, is evident how the yields are again a little more connected, in fact all the four countries tended to follow more or less the same behaviour during the last 2 years of the sample period.

In addition of this, Papavassiliou (2021) highlighted the fact that during that period France and Germany took negative yields in all three maturities. This behaviour could be the

consequence of a low inflation in the last years and to pressures on demands from the APP (Asset Purchase Programme) by ECB launched in Mid-2014.

The presence of these negative yields in the long-term could have mainly two consequences:

- Talking again about the APP, the banking institutions inside the euro area accumulated a high levels of reserve balances, because these assets were acquired on credit, providing to the reserve accounts to the banks inside the Eurosystem. Besides, negative interest rates leaded the banks of the euro area to hold reserves only for the minimum amount, sufficient for accommodating the reserve requirements. In conclusion, when there is the need of more money supply, interest rates will respond taking low levels.
- Banks usual are not incentivized to give negative interest rates to their customers, mainly for competitive reasons, because in this case they will find their interest margins affected on a negative way and also their profitability.

3.1.2 Stationarity analysis of sovereign bond yields and GARCH estimates

In this Section will be shown the stationarity of the euro area sovereign bond yields, the study will consider the data of the four countries in the 2-5-10-year maturity.

The Graphs are characterised by the representation of the trend of the yields during the entire period and the corresponding plots with the application of the GARCH process.

Following are the graphs just presented, but the one with the trend of the yields during the period has been modified.

The modification was necessary because looking at Graphs 1-3 on the previous Section is evident how the trend of the yields was non-stationary; in fact, from 2000 till 2008 circa the variation of the yields is contained between 0.06-0.04, while from 2010 till 2022 the yields start to show high volatility, for example Italy and Spain go to 0.04, with peaks till 0.08 or drops till 0.02.

In conclusion, stationarity signifies that there is some volatility during the period of observation that goes around (up and down) a constant value that is the mean; thus, looking at the Graphs is obvious that all the countries do not present a sign of stationarity and shall be transformed to a stationary one.

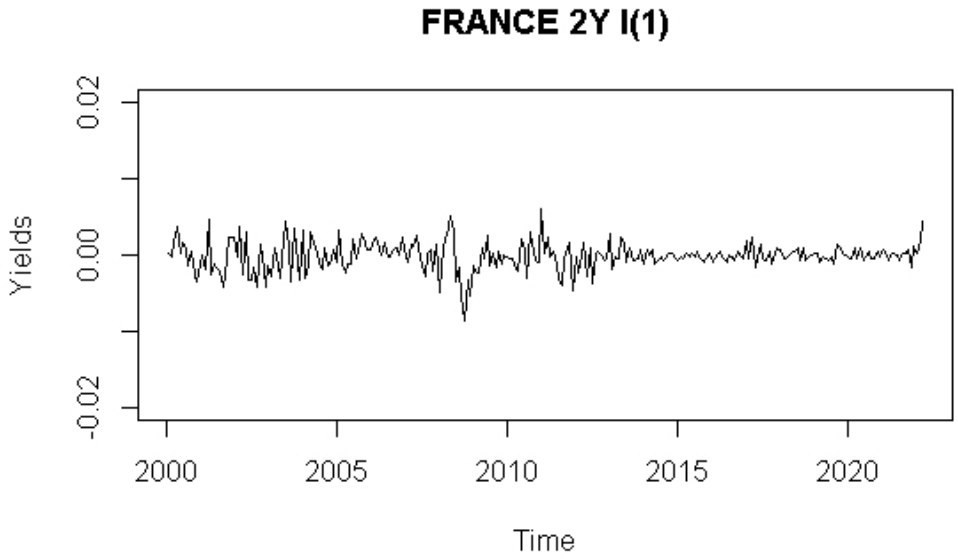
Thus, for transforming the yields in a stationary trend, it is necessary to apply a first differentiation, defined **I(d)** (integration of order **d**) with **d=1**, meaning that for stationarity was sufficient only a first differentiation.

The Graphs are:

Two-year maturity

Core countries

Graph 4: First difference of 2-year sovereign bond yields of France



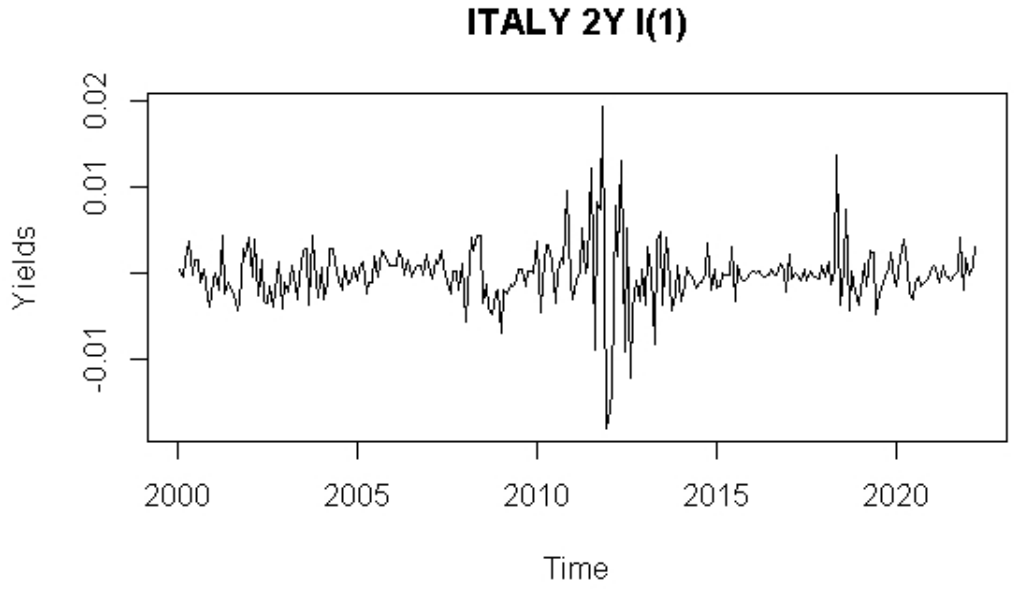
Source: Bloomberg monthly data period 2000-2022

Graph 5: First difference of 2-year sovereign bond yields of Germany

Source: Bloomberg monthly data period 2000-2022

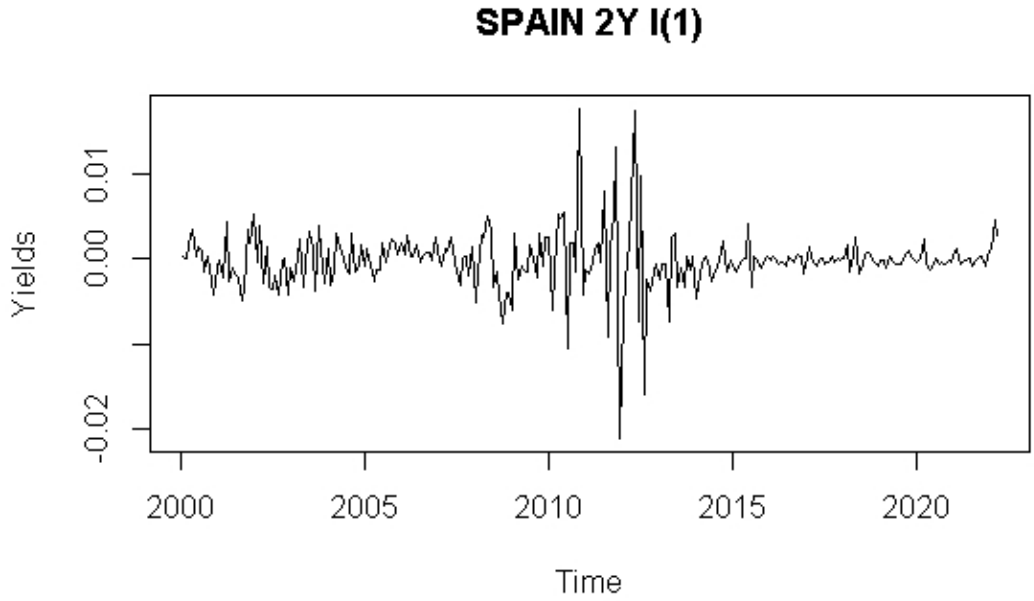
Peripherical countries

Graph 6: First difference of 2-year sovereign bond yields of Italy



Source: Bloomberg monthly data period 2000-2022

Graph 7: First difference of 2-year sovereign bond yields of Spain



Source: Bloomberg monthly data period 2000-2022

In the 2-year Graphs (4-7) of first differentiated (**I(d)**) sovereign bond yields, the first thing to point is that all the plots have the same range on the y-axis, in order to describe and compare them with the same magnitude.

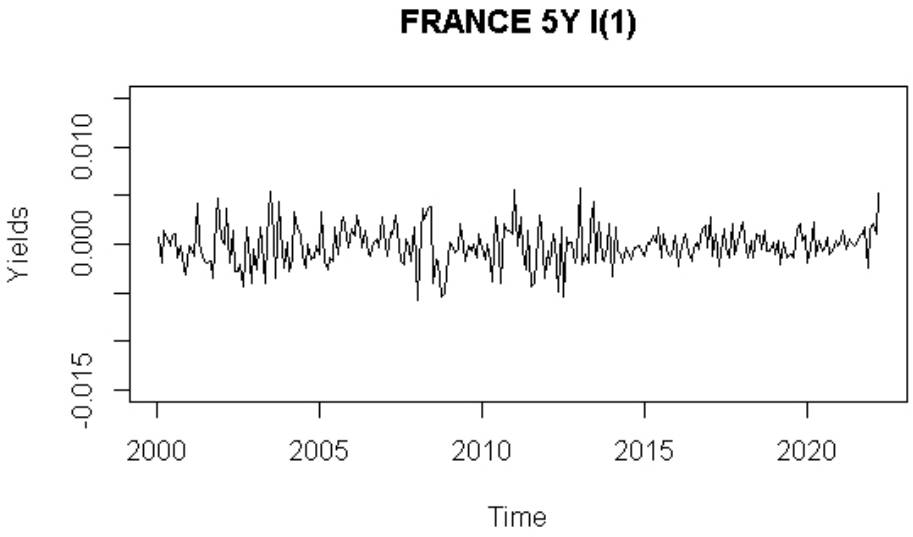
At a first look all the countries show a more constant trend than before, thus the first differentiation was necessary for the stationarity of the yields. Here, the difference between core and peripherical countries is evident, in fact Italy and Spain show a highly volatile behaviour, with a cluster between 2010-2013/14 years for Spain and of 2011-

2013 for Italy, that is the country with the more volatile yields. Moving to France and Germany, both have a mainly balanced trend of the first differentiated yields, with a low volatility apart for some movements from 2000 till 2012-2013.

Five-year maturity

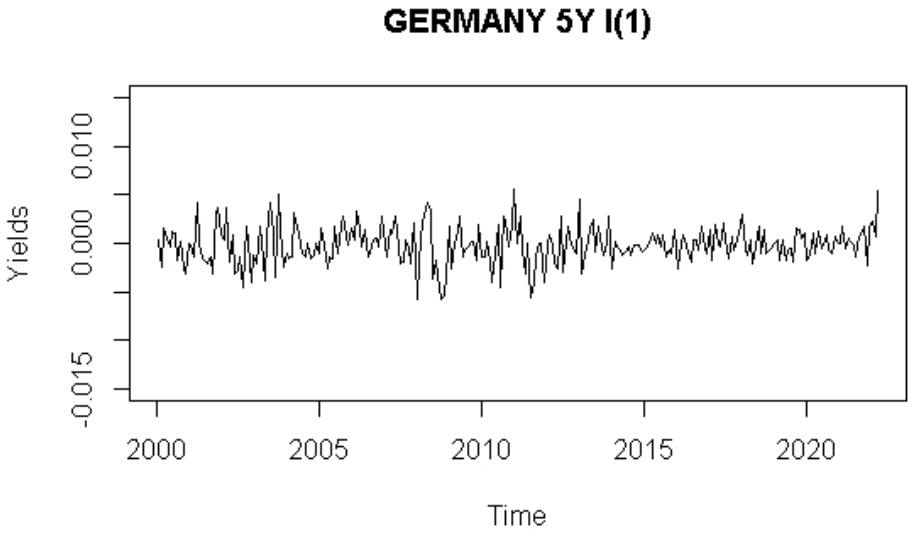
Core countries

Graph 8: First difference of 5-year sovereign bond yields of France



Source: Bloomberg monthly data period 2000-2022

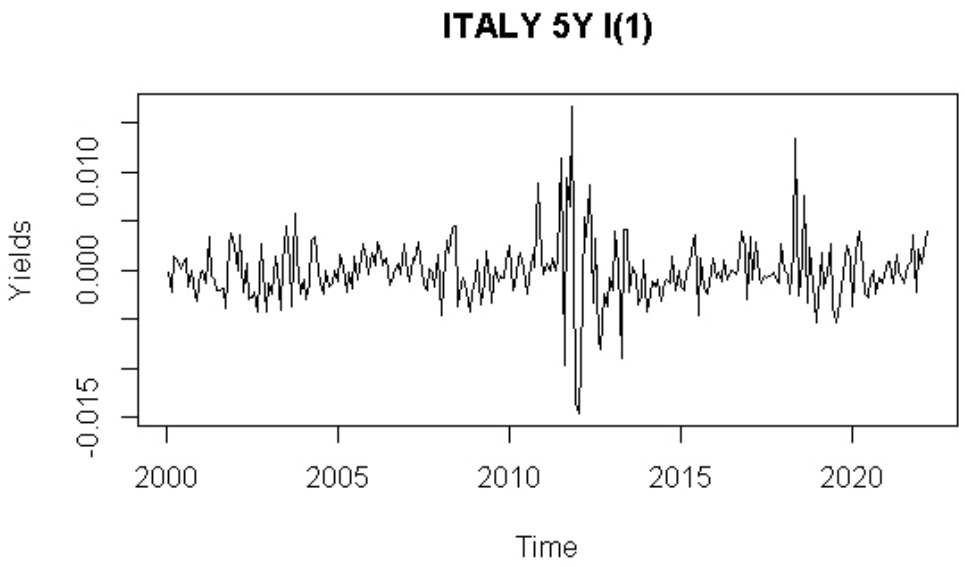
Graph 9: First difference of 5-year sovereign bond yields of Germany



Source: Bloomberg monthly data period 2000-2022

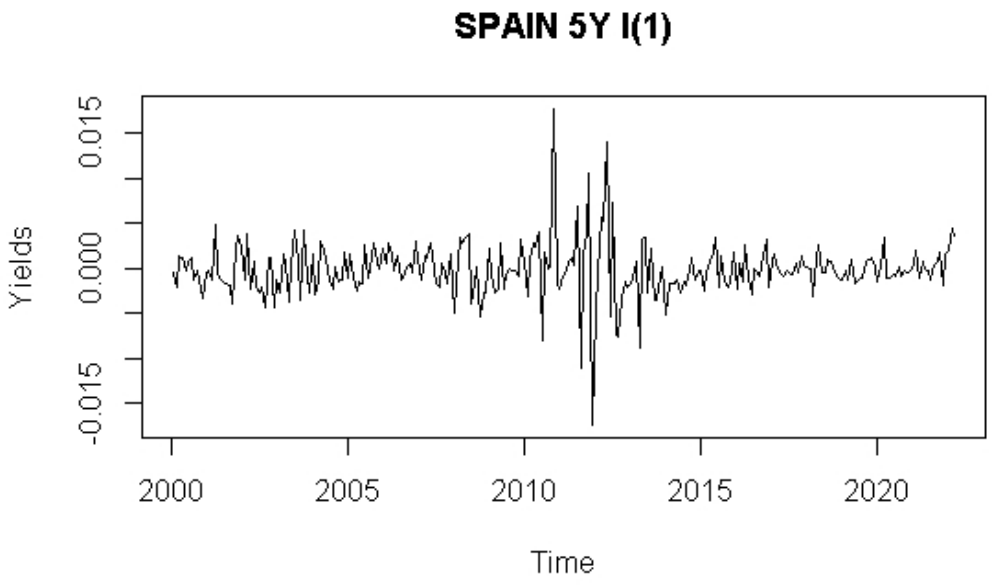
Peripherical countries

Graph 10: First difference of 5-year sovereign bond yields of Italy



Source: Bloomberg monthly data period 2000-2022

Graph 11: First difference of 5-year sovereign bond yields of Spain



Source: Bloomberg monthly data period 2000-2022

With Graphs 8-11 what is important to notice is that the range of the plots is slightly narrower. This is a normal consequence of the higher maturity, in fact as was possible to notice on Graphs 1-3 of the previous section, as the maturity increased the yields were higher for the larger risk that they had to cover but their behaviour was smoother than the shorter one; saying this, the shocks in the 5-year yields is a little less volatile than before.

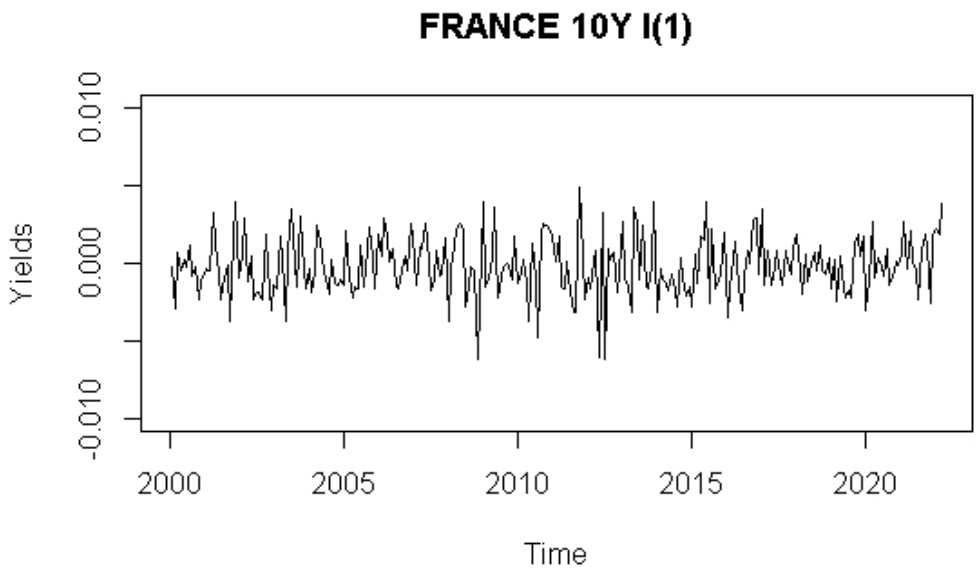
Moving to the country's analysis, also here is evident the difference between core and peripherical countries, even if France and Germany seem to have a more volatile trend, it is given by the fact that the range is narrower, because looking to their maximum and minimum values, they are mainly contained between -5/5, more or less the same as before; however, from Graphs 4-7 the trend of the yields is less volatile and more stable around the mean.

For Spain and Italy, the trend seems more volatile than in Graphs 4-7 but, in reality, is more or less the same, while for the clusters during the sovereign debt crisis is again evident but with a volatility slightly more contained.

Ten-year maturity

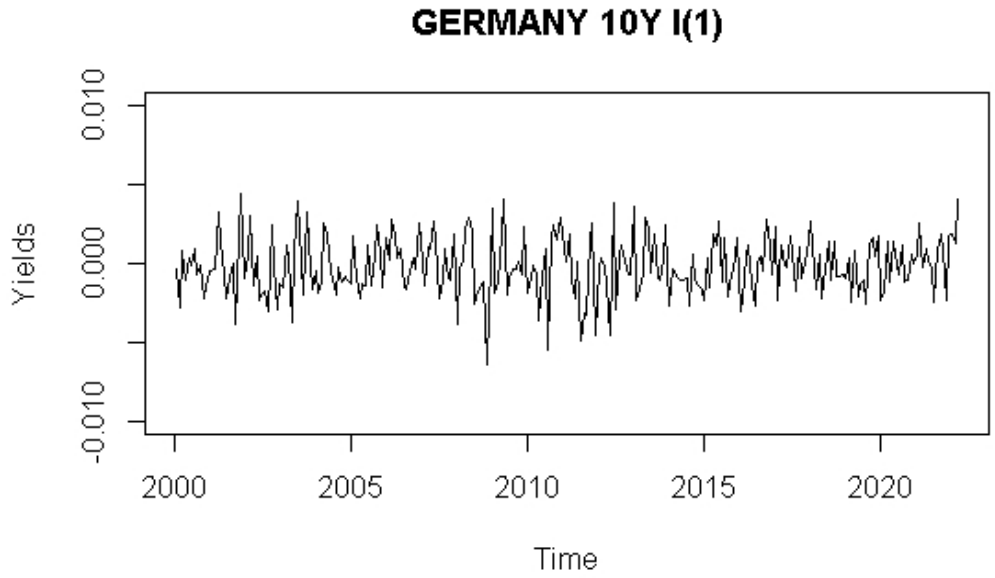
Core countries

Graph 12: First difference of 10-year sovereign bond yields of France



Source: Bloomberg monthly data period 2000-2022

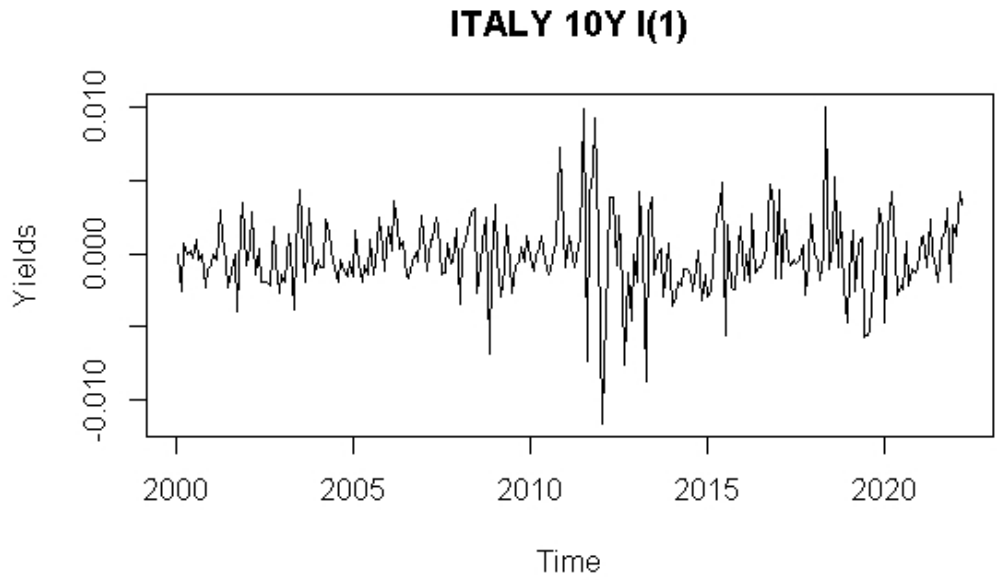
Graph 13: First difference of 10-year sovereign bond yields of Germany



Source: Bloomberg monthly data period 2000-2022

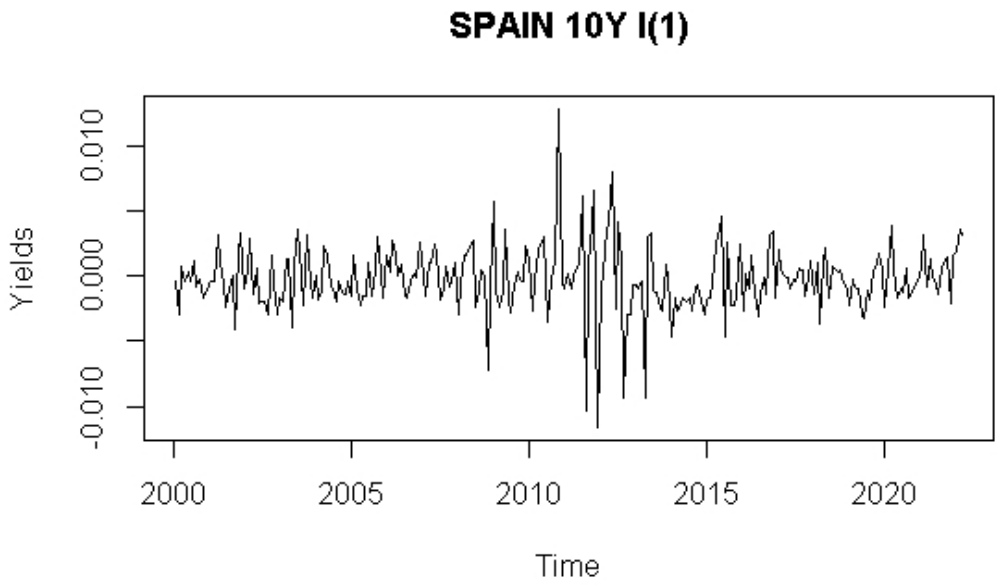
Peripherical countries

Graph 14: First difference of 10-year sovereign bond yields of Italy



Source: Bloomberg monthly data period 2000-2022

Graph 15: First difference of 10-year sovereign bond yields of Spain



Source: Bloomberg monthly data period 2000-2022

Before the description of Graphs 12-15, also in Graphs 4-7 the range was a little narrower than in Graphs 8-11 for the same reasons.

In fact, for France and Germany the trend seems highly volatile if compared with Graphs 4 and 5 but looking more carefully the volatility now is more constant during all the sample period with values circa -5/5, while in the other case it was evident how the volatility was higher till 2012/2013 and later was lower.

The peripherical countries Italy and Spain, Graphs 14 and 15, show a similar behaviour to the previous maturities, a mainly constant contained volatility around -5/5 with a significant cluster during the global financial crisis.

What changed from the other Graphs is, as for Germany and France, a more stable volatility also in the post sovereign debt crisis where the volatility was lower, and a cluster were the shocks are lower as the maturity increased.

In conclusion, from the analysis of the stationarity of the yields, what is important to point out is the non-stationarity of the yields, that was solved with the first differentiation. Their trend was characterized by a significant volatility, that was possible to notice also from Graph 1-3 in the previous section.

Another point that was known, is the fact that as maturity increased, the yields showed a smoother trend, with less significant shocks and a volatility even balanced during the sample period; in fact in Graphs 4-7 the volatility was not constant and were evident more than one peak above the mean, while in Graphs 12-15 the volatility is more evident,

because the ranges were narrower and it was possible to see a better vision of the sample, but the clusters and the total volatility during the period was balanced and contained in all the countries.

GARCH representation

After analysing the stationarity of the sovereign bond yields of France, Germany, Italy and Spain, it was evident some volatility clustering during the sovereign debt crisis period.

Ruppert (2011) described the main characteristics of the GARCH model (Generalized ARCH) and after its description will be shown the application of this process on the previous yields, for explaining the reasons of that clustering.

The ARCH (q) model is a conditional standard deviation process with significant oscillations due to a high volatility in short period of time; in order to solve this problem, it is possible to use the GARCH process that allows larger limits of behaviour, among which more persistent volatility. Following there are the main characteristics of the model:

(5) $a_t = \sigma_t \varepsilon_t$ (6) $\sigma_t = \sqrt{\omega + \sum_{i=1}^{P} \alpha_i a_{t-i}^2 + \sum_{i=1}^{q} \beta_i \sigma_{t-i}^2}$

The longer periods of high/low volatility are due to the fact that the past values of the $\sigma_t$process are reported back to the present value.

As for the ARIMA (p_A,d,q_A), also the GARCH (p_G,q_G) process, when applied to a time series, ends up with two types of residuals. One is the ordinary residual, denoted by $\hat{a_t}$, which is simply the difference between the time series and its conditional expectation; the other is the standardized residual, denoted by $\hat{\varepsilon_t}$, which is an ordinary residual divided by its conditional standard deviation, they are mainly used for model checking.

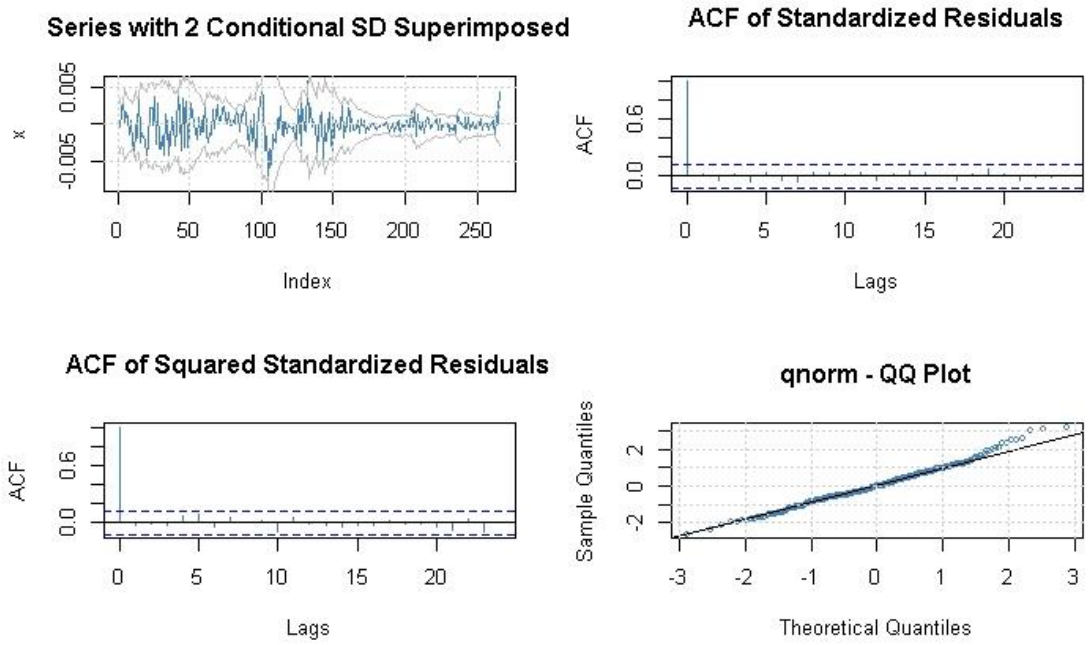
After presenting the model, it would be interesting to apply it to the yields of the previous paragraphs and see if the GARCH process is able to explain the volatility clustering.

The description of the GARCH application would take place with four graphs for each country in all three maturities with the following subjects: the GARCH representation of the yields for analysing the conditional volatility of the model; the ACF (autocorrelation function) of both the standardized and squared standardized residuals in order to see if some correlation still exist; the q-norm plot for showing if the model follows a Normal distribution or not.

Two-year maturity

Core countries

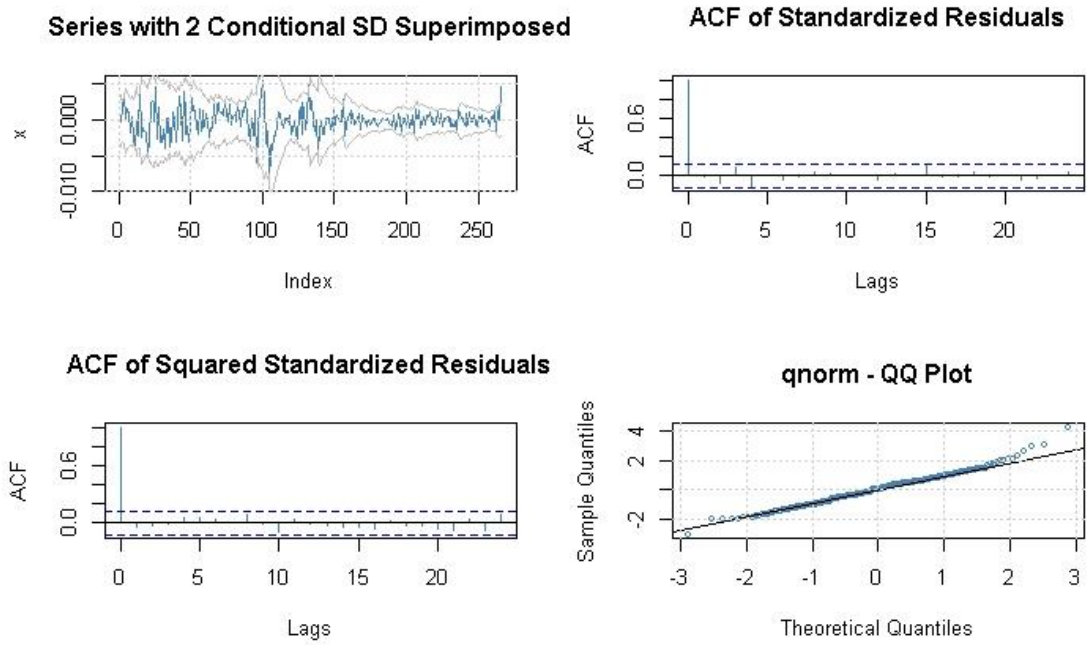
Graph 16: GARCH representation of the 2-year yields of France



Source: Bloomberg monthly data period 2000-2022

NB: Obs 0-50 equal to 01/2000-02/2004; obs 51-100 equal to 03/2004-04/2008; obs 101-150 equal to 05/2008-06/2012; obs 151-200 equal to 07/2012-08/2016; obs 201-266 equal to 09/2016-03/2022

Graph 17: GARCH representation of the 2-year yields of Germany

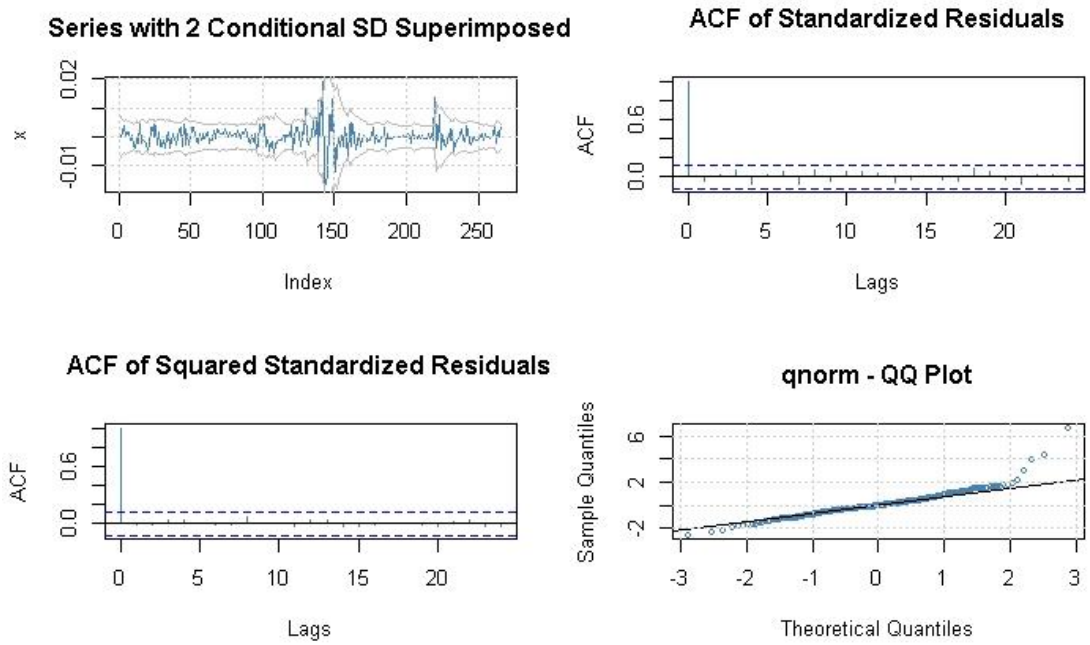


Source: Bloomberg monthly data period 2000-2022

NB: Obs 0-50 equal to 01/2000-02/2004; obs 51-100 equal to 03/2004-04/2008; obs 101-150 equal to 05/2008-06/2012; obs 151-200 equal to 07/2012-08/2016; obs 201-266 equal to 09/2016-03/2022

Peripherical countries

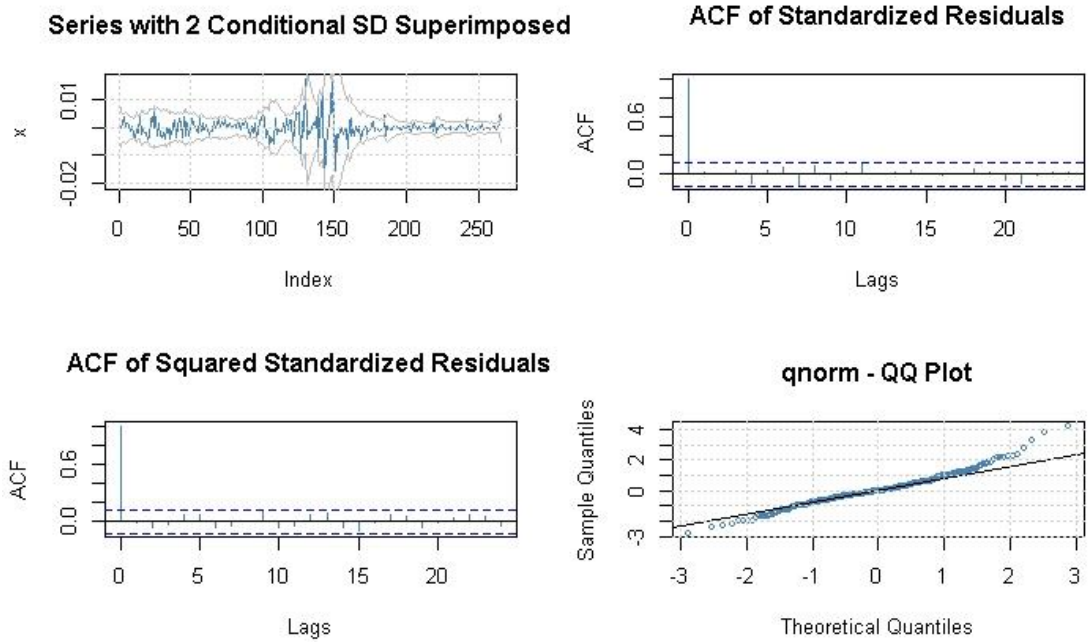
Graph 18: GARCH representation of the 2-year yields of Italy



Source: Bloomberg monthly data period 2000-2022

NB: Obs 0-50 equal to 01/2000-02/2004; obs 51-100 equal to 03/2004-04/2008; obs 101-150 equal to 05/2008-06/2012; obs 151-200 equal to 07/2012-08/2016; obs 201-266 equal to 09/2016-03/2022

Graph 19: GARCH representation of the 2-year yields of Spain



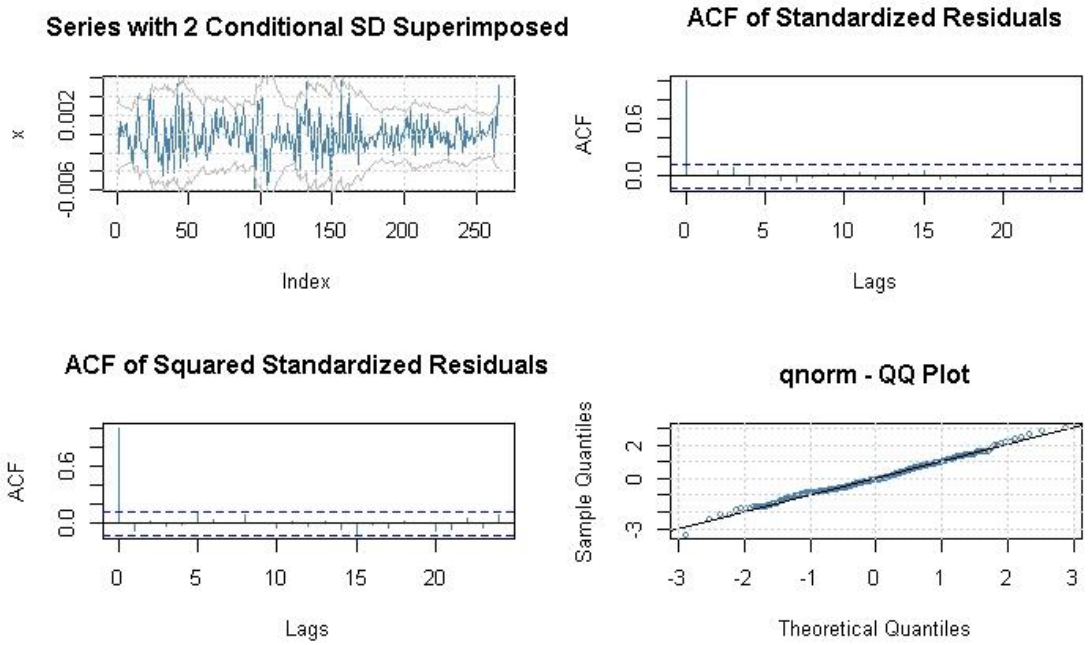
Source: Bloomberg monthly data period 2000-2022

NB: Obs 0-50 equal to 01/2000-02/2004; obs 51-100 equal to 03/2004-04/2008; obs 101-150 equal to 05/2008-06/2012; obs 151-200 equal to 07/2012-08/2016; obs 201-266 equal to 09/2016-03/2022

Five-year maturity

Core countries

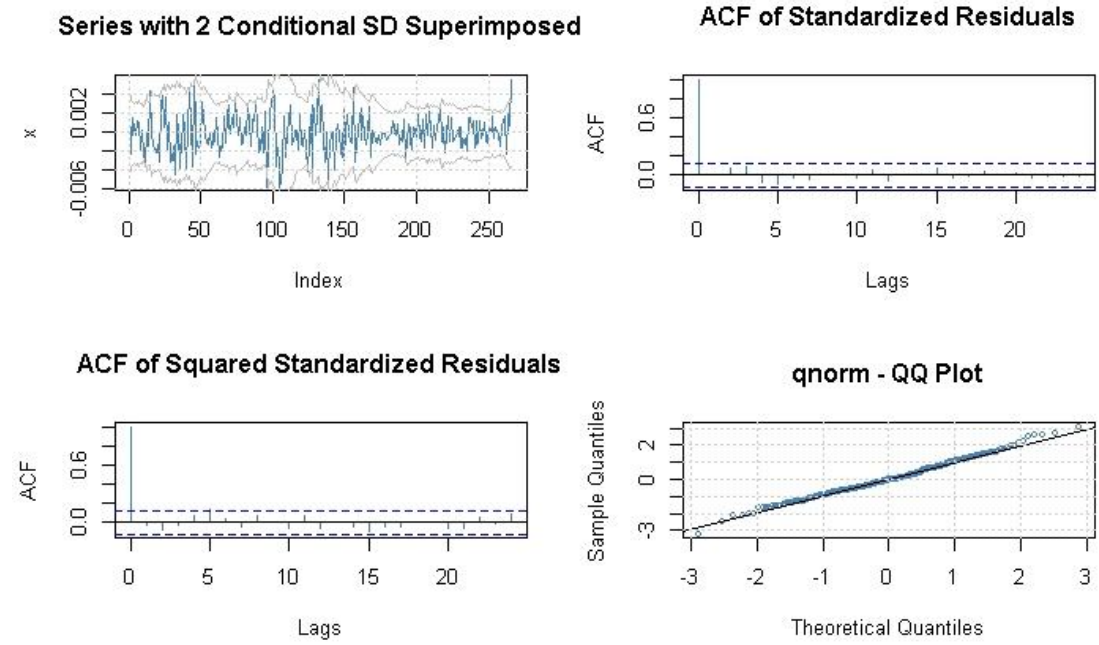
Graph 20: GARCH representation of the 5-year yields of France



Source: Bloomberg monthly data period 2000-2022

NB: Obs 0-50 equal to 01/2000-02/2004; obs 51-100 equal to 03/2004-04/2008; obs 101-150 equal to 05/2008-06/2012; obs 151-200 equal to 07/2012-08/2016; obs 201-266 equal to 09/2016-03/2022

Graph 21: GARCH representation of the 5-year yields of Germany



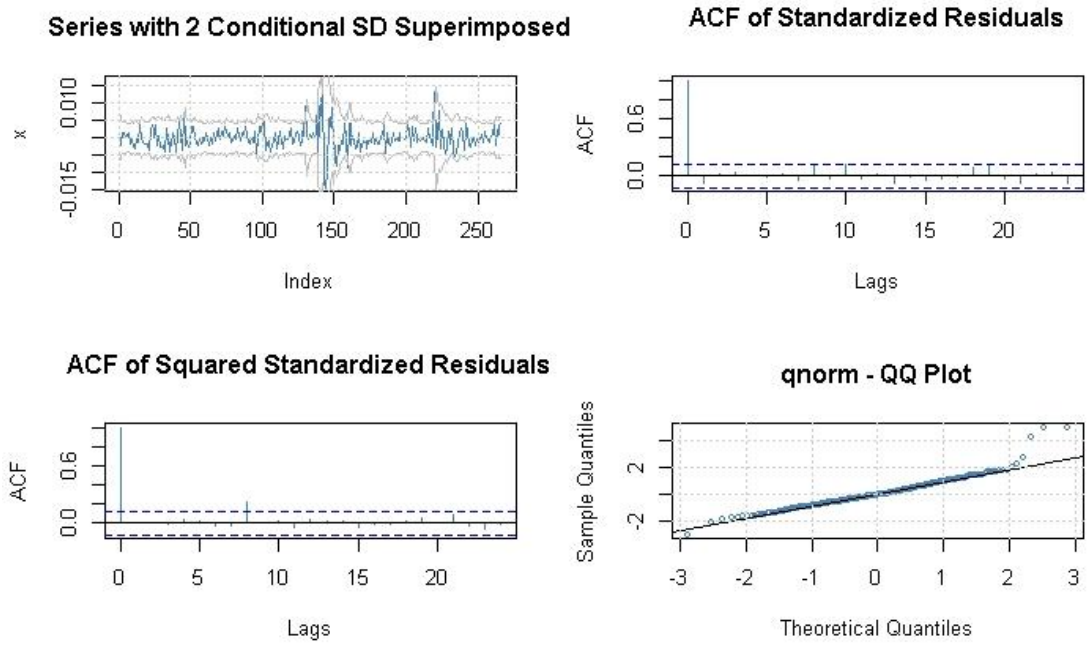
Source: Bloomberg monthly data period 2000-2022

NB: Obs 0-50 equal to 01/2000-02/2004; obs 51-100 equal to 03/2004-04/2008; obs 101-150 equal to 05/2008-06/2012; obs 151-200 equal to 07/2012-08/2016; obs 201-266 equal to 09/2016-03/2022

Peripherical countries

ITALY

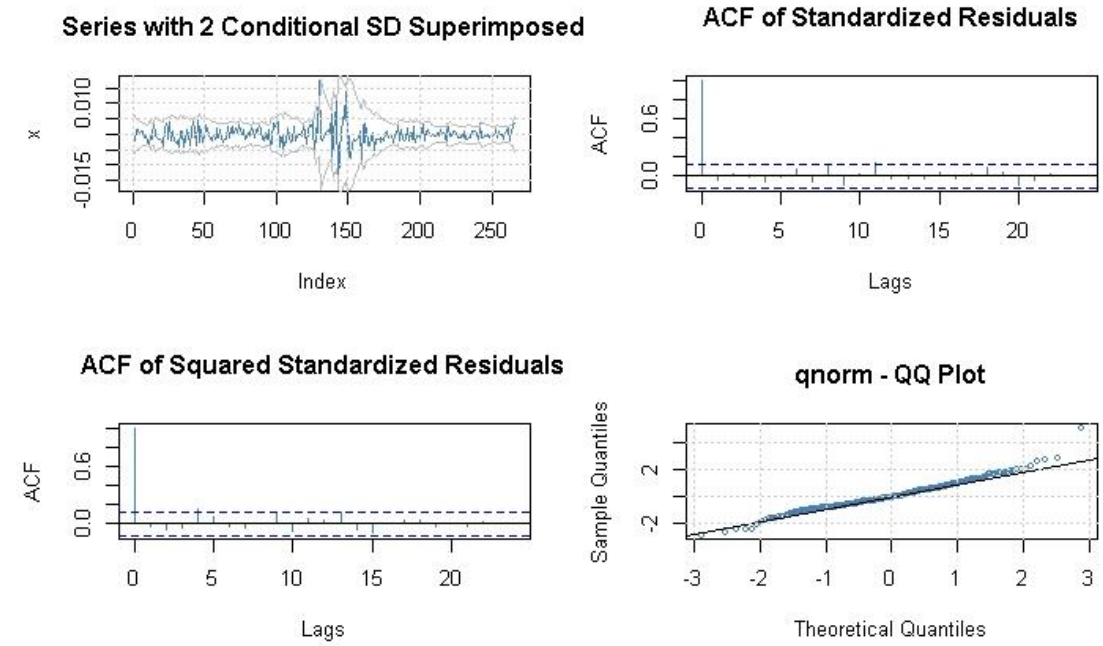
Graph 22: GARCH representation of the 5-year yields of Italy



Source: Bloomberg monthly data period 2000-2022

NB: Obs 0-50 equal to 01/2000-02/2004; obs 51-100 equal to 03/2004-04/2008; obs 101-150 equal to 05/2008-06/2012; obs 151-200 equal to 07/2012-08/2016; obs 201-266 equal to 09/2016-03/2022

Graph 23: GARCH representation of the 5-year yields of Spain



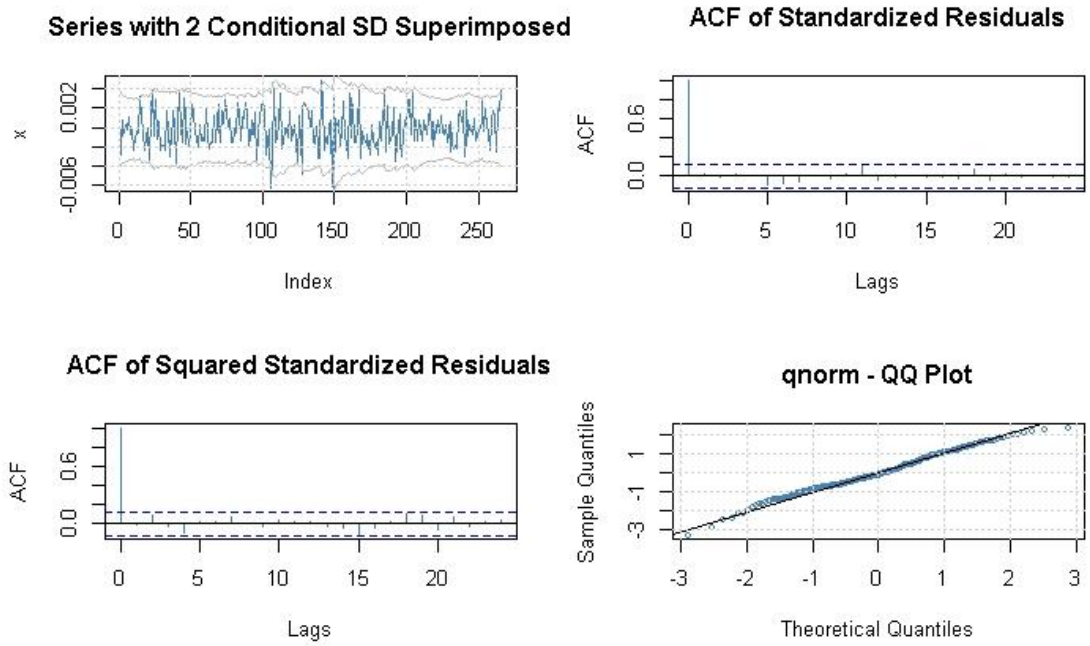
Source: Bloomberg monthly data period 2000-2022

NB: Obs 0-50 equal to 01/2000-02/2004; obs 51-100 equal to 03/2004-04/2008; obs 101-150 equal to 05/2008-06/2012; obs 151-200 equal to 07/2012-08/2016; obs 201-266 equal to 09/2016-03/2022

Ten-year maturity

Core countries

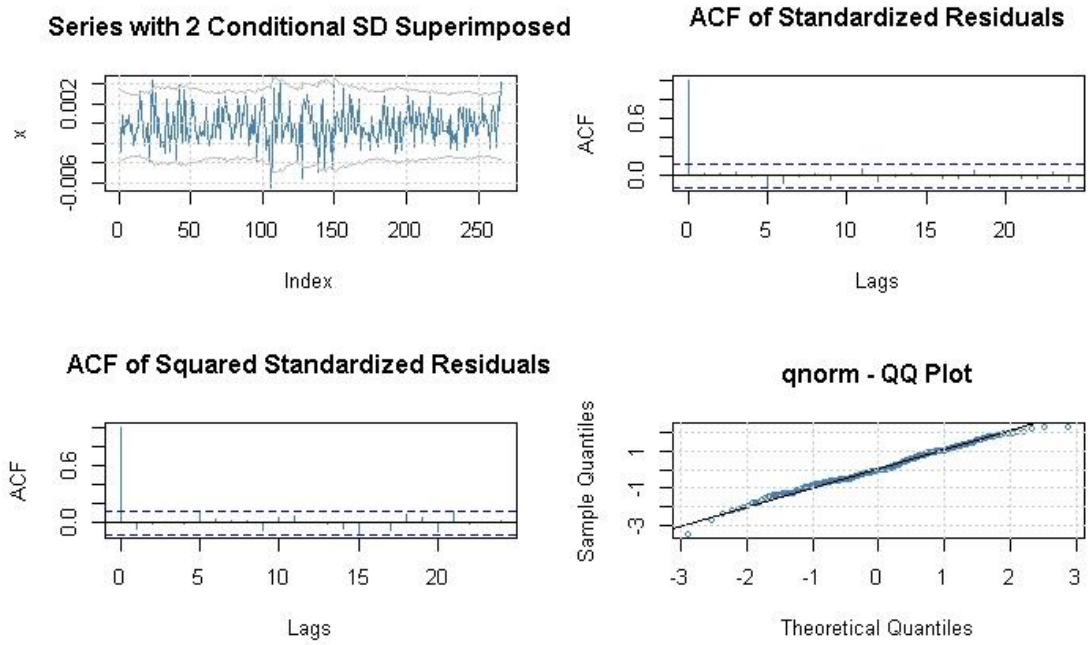
Graph 24: GARCH representation of the10-year yields of France



Source: Bloomberg monthly data period 2000-2022

NB: Obs 0-50 equal to 01/2000-02/2004; obs 51-100 equal to 03/2004-04/2008; obs 101-150 equal to 05/2008-06/2012; obs 151-200 equal to 07/2012-08/2016; obs 201-266 equal to 09/2016-03/2022

Graph 25: GARCH representation of the 10-year yields of Germany



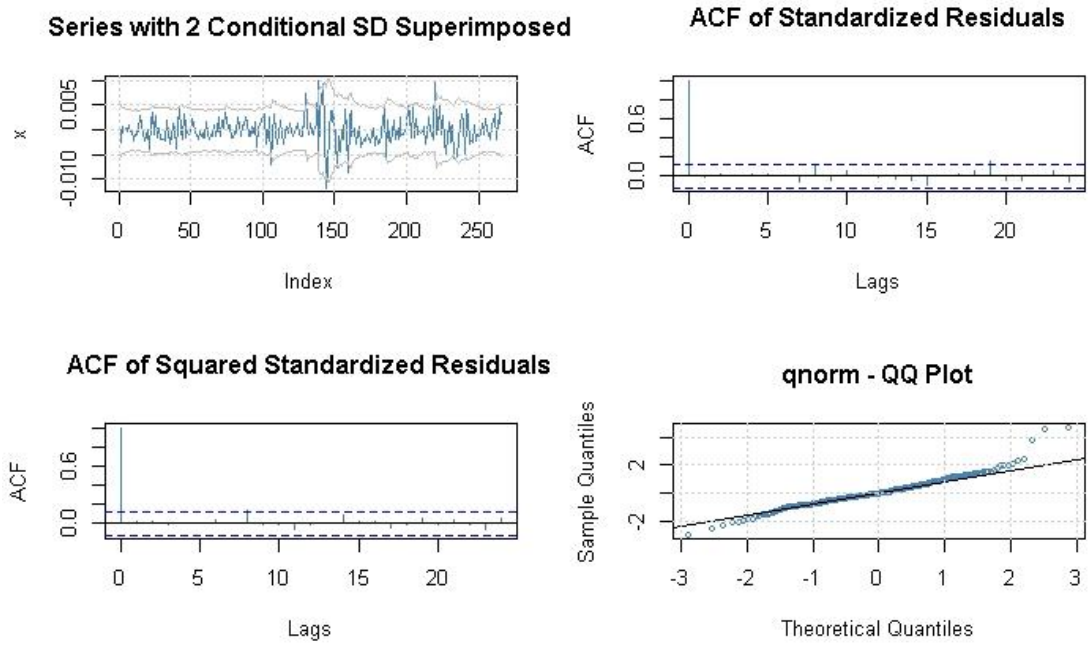
Source: Bloomberg monthly data period 2000-2022

NB: Obs 0-50 equal to 01/2000-02/2004; obs 51-100 equal to 03/2004-04/2008; obs 101-150 equal to 05/2008-06/2012; obs 151-200 equal to 07/2012-08/2016; obs 201-266 equal to 09/2016-03/2022

Peripherical countries

ITALY

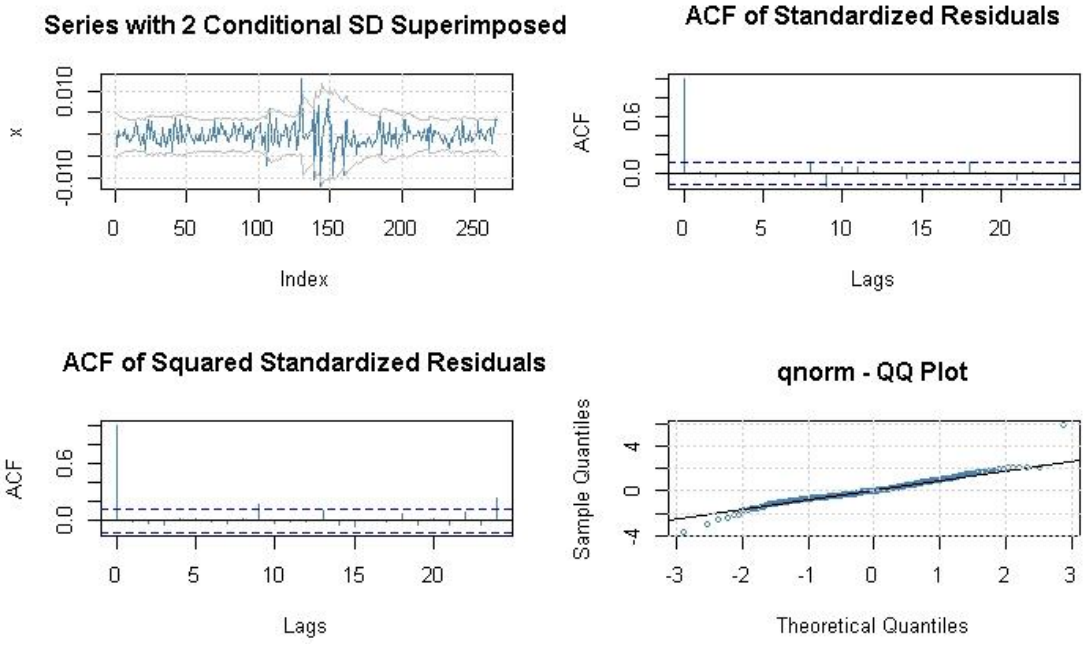
Graph 26: GARCH representation of the 10-year yields of Italy



Source: Bloomberg monthly data period 2000-2022

NB: Obs 0-50 equal to 01/2000-02/2004; obs 51-100 equal to 03/2004-04/2008; obs 101-150 equal to 05/2008-06/2012; obs 151-200 equal to 07/2012-08/2016; obs 201-266 equal to 09/2016-03/2022

Graph 27: GARCH representation of the 10-year yields of Spain



Source: Bloomberg monthly data period 2000-2022

NB: Obs 0-50 equal to 01/2000-02/2004; obs 51-100 equal to 03/2004-04/2008; obs 101-150 equal to 05/2008-06/2012; obs 151-200 equal to 07/2012-08/2016; obs 201-266 equal to 09/2016-03/2022

In the brief description of Graphs 16-27 it will be sufficient to point some features. After the application of an ARMA(1,2)+GARCH(1,1) model to the data, in all the Graphs is evident how the ACF of both the standardized and squared standardized residuals plots do not show any correlation after the first lag a part for Graphs 22 and 27.

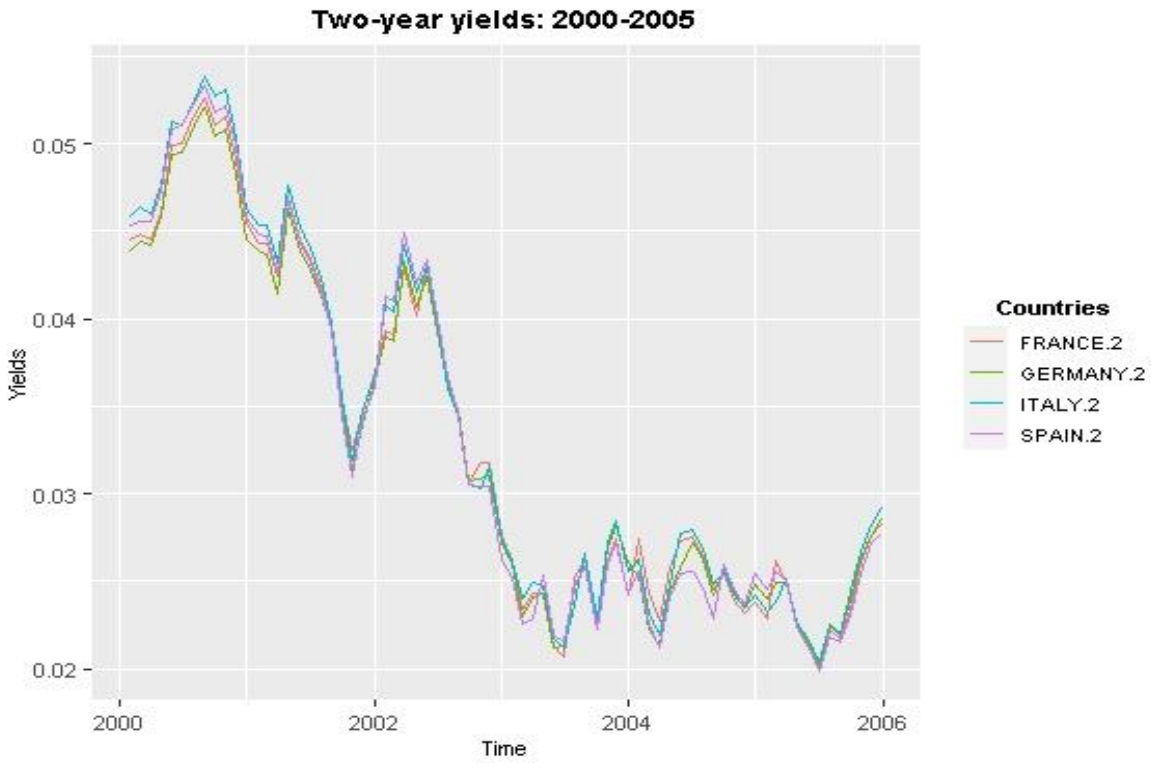
Moving to the q-norm plots, a part for Graphs 18-19-22-26 that did not follow the Normal distribution in the last observations, in all the other this behaviour does not happen; however, it is possible to conclude that in all the cases the Normal distribution seem appropriated and the GARCH distribution is effectively dealing with non-constant volatility variations for all the yields taken into consideration.

3.1.3 Specific analysis for subperiods

The important years to highlight are 2001, 2007-2009, 2010-2012, 2020-2021; thus, the data go from 2000 till March 2022 and it is possible to divide the period as: 2000-2005, 2006-2009, 2010-2016, 2017-2022

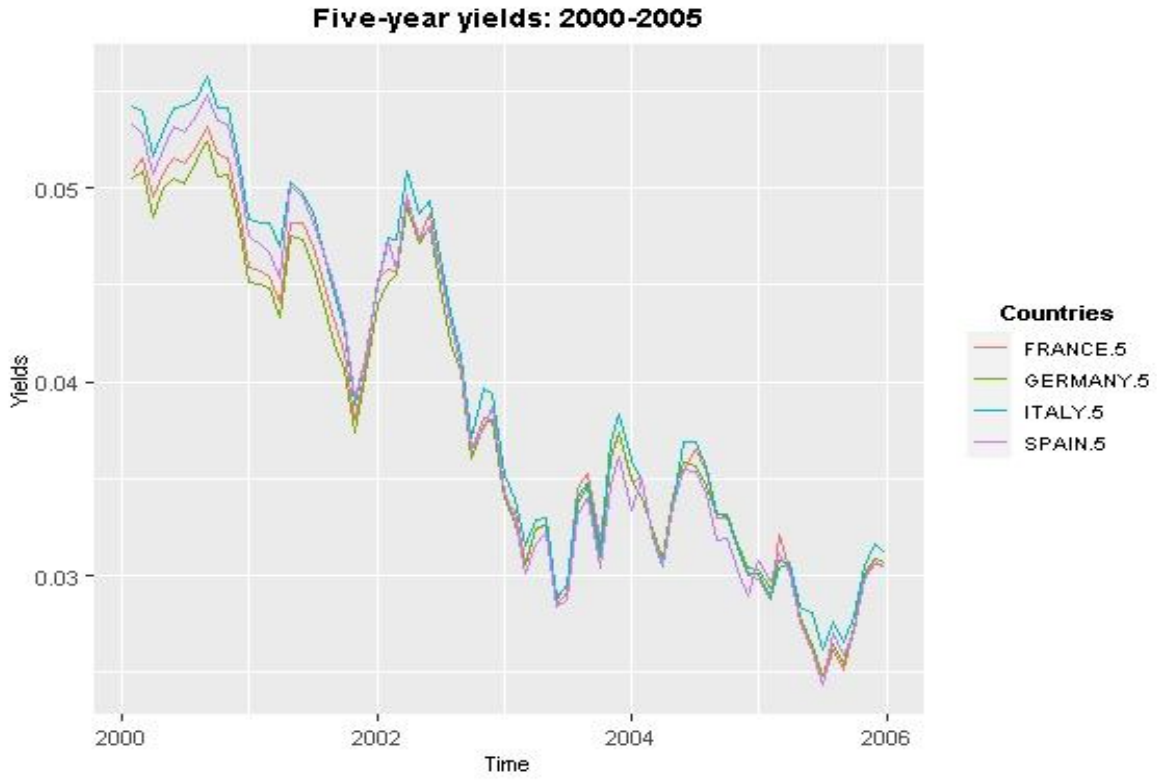
Two-five-ten-year yields evolution in 2000-2005

Graph 28: 2-year yields of the four selected countries in the subperiod 2000-2005



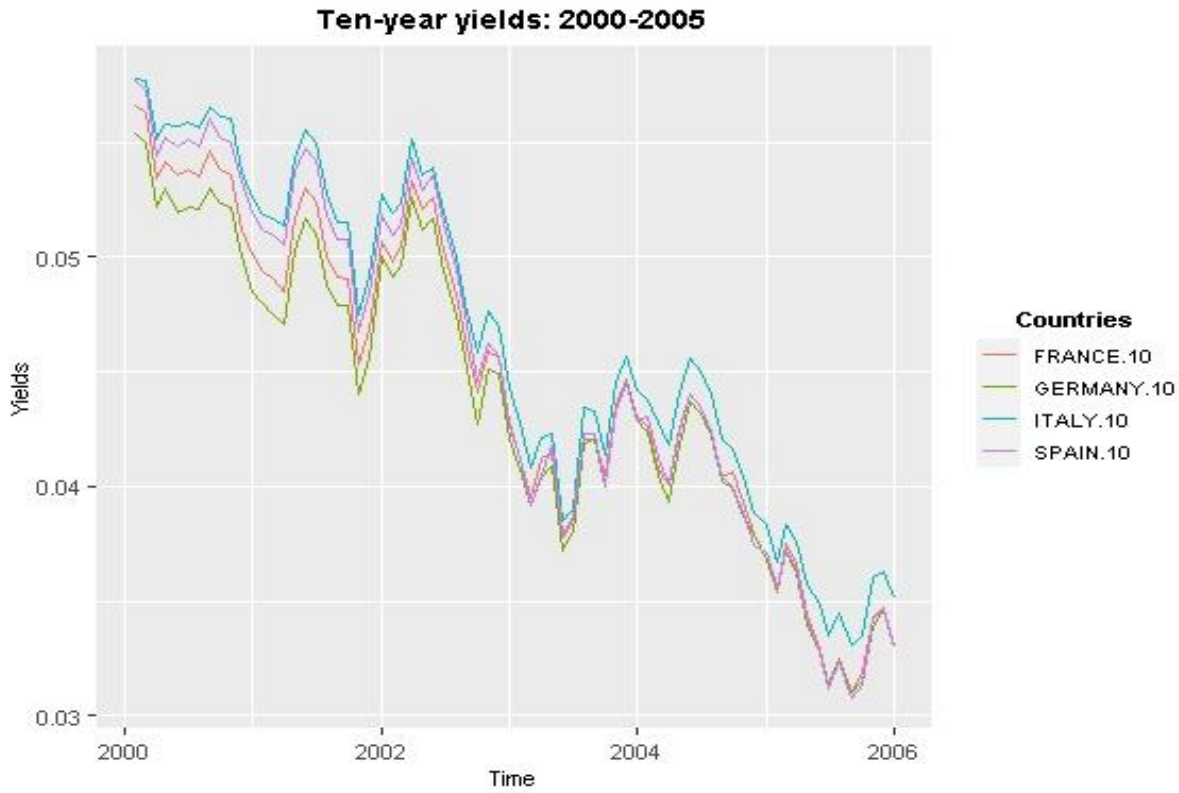
Source: Bloomberg monthly data period 2000-2022

Graph 29: 5-year yields of the four selected countries in the subperiod 2000-2005



Source: Bloomberg monthly data period 2000-2022

Graph 30: 10-year yields of the four selected countries in the subperiod 2000-2005



Source: Bloomberg monthly data period 2000-2022

In this first subperiod, the main event that touched the euro area is the increment in oil prices and inflation, the terroristic attack of the Twin Tower and the slowdown of the EMU growth all concentrated around 2001.

With a total overview, the first characteristic that comes out is how as the maturity gets longer the yields are less "interconnected". Looking at Graphs 28-30, the four countries have yields very close each other, obviously Germany had the lowest value and Italy almost always the highest, with a spread of about 30 basis points during the first year and then with little changes between the country's yields.

In Graph 29, in a different way from Graph 28, during the 2000-2005 subperiod the shocks are reduced in terms of magnitude, and the yields of the four countries at the beginning are less close each other. In fact, between Italy and Germany is close to 50 basis points, while later as before the yields of the four countries became closer a part for some little and short movements in the single countries.

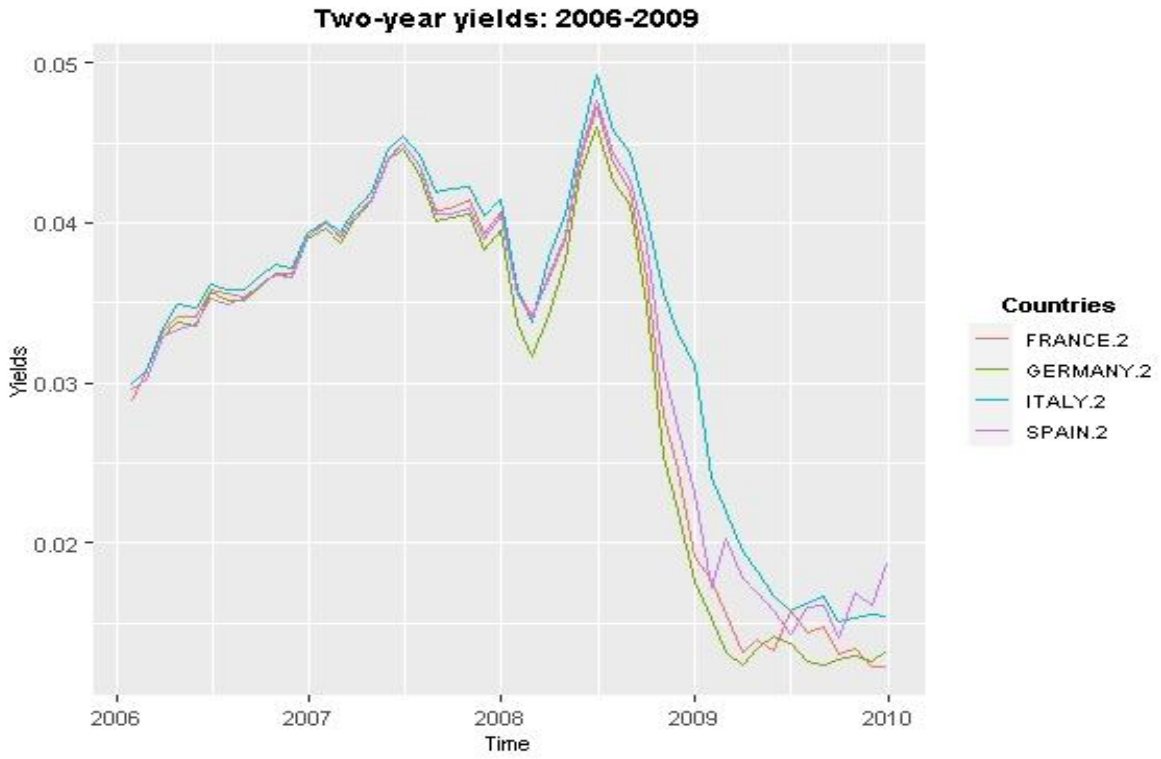
All three maturities show the same trend, starting with yields around 0.045-0.055, which then declined till 0.03-0.035 reached at the end of 2005, obviously longer maturity yields tend to have higher values than the shorter one for compensating higher risk.

The first significant drop of the values is evident at the end of 2001, just up against 2002, probably due to the problems described at the beginning of the paragraph, with the addition of the uncertainty in the US economy for the terroristic attack, attaching also the euro area bond market.

After an almost immediate recover of the yields during the first half of 2002, later they started to decrease constantly, more or less in the same way for all three maturities. Comparing the Graphs 28 and 30, the difference about the yields reaction to the shocks is clear, in fact in Graph 30 Italy constantly had the highest yields almost during all the period 2000-2006, while the other countries from 2002 followed mainly the same trend and yields' values.

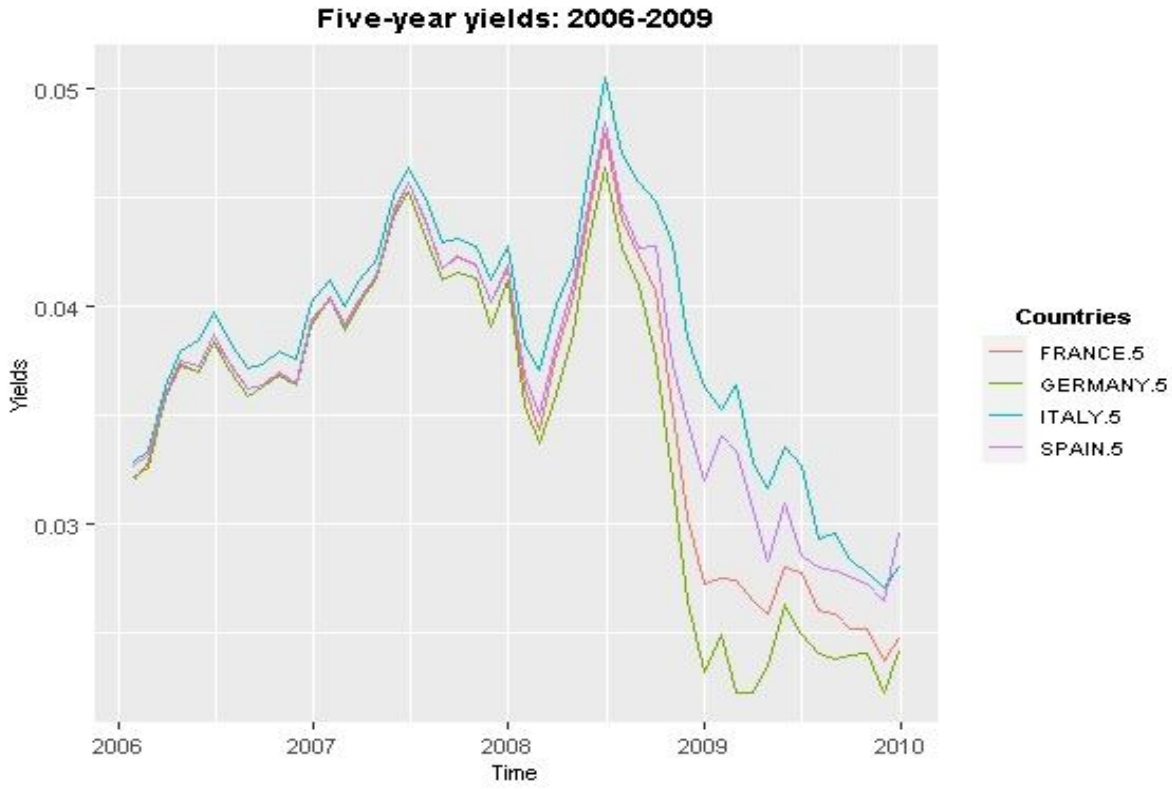
Two-five-ten-year yields evolution in 2006-2009

Graph 31: 2-year yields of the four selected countries in the subperiod 2006-2009



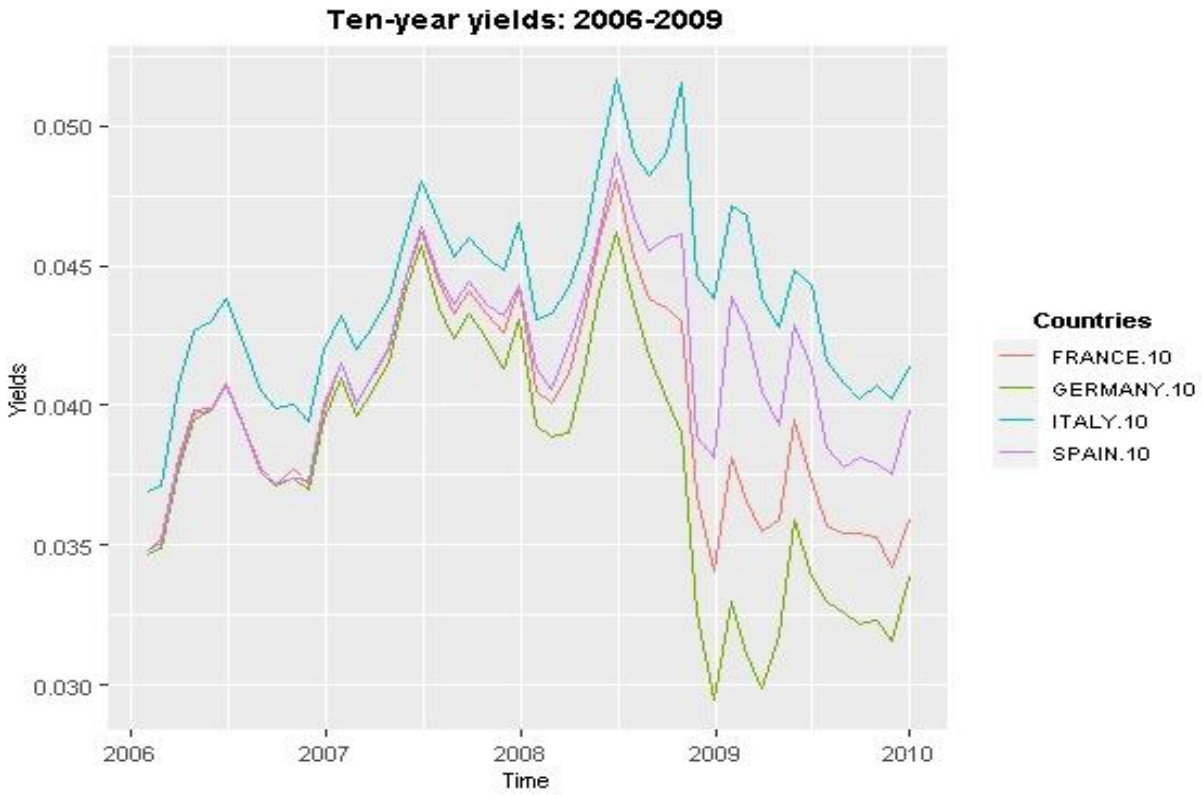
Source: Bloomberg monthly data period 2000-2022

Graph 32: 5-year yields of the four selected countries in the subperiod 2006-2009



Source: Bloomberg monthly data period 2000-2022

Graph 33: 10-year yields of the four selected countries in the subperiod 2006-2009



Source: Bloomberg monthly data period 2000-2022

This subperiod goes from the beginning of 2006 to the end of 2009, comprehending the shock due to the global financial crisis of 2007-09 and the failure of Lehman Brothers.

Talking about the trend of the yields in this period, their values started growing from the beginning of 2006 till the end of 2007, reaching a level of circa 0.045 in all three maturities but later, as described in Chapter I, during the first half of 2008, the growing recession in US due to the subprime crisis started to spread to all over the world.

This phenomenon is evident on Graphs 31-33 because the yields started to increase again reaching the peak at Mid-2008, close to the Lehman Brothers' failure happened in September 2008.

After this shock something changed between the countries, in fact from that moment the yields started to be less close and with a more volatile behaviour.

In detail, the different three maturities gave a very different situation if the Graphs 31 and 33 are compared, probably because the serious economic situation leaded a heavy risk to cover for the 10-year yields, suffering the more evident change.

During 2009 the yields started to decrease significantly, but in Graph 31 the trends confirmed almost always Italy as the worst country and Germany as the better; in Graph 32 the drop is significant for Germany and France which decreased their yields of almost

0.02, while Italy and Spain saw a slower decline, signing the beginning of the discrepancy between core and peripherical countries.

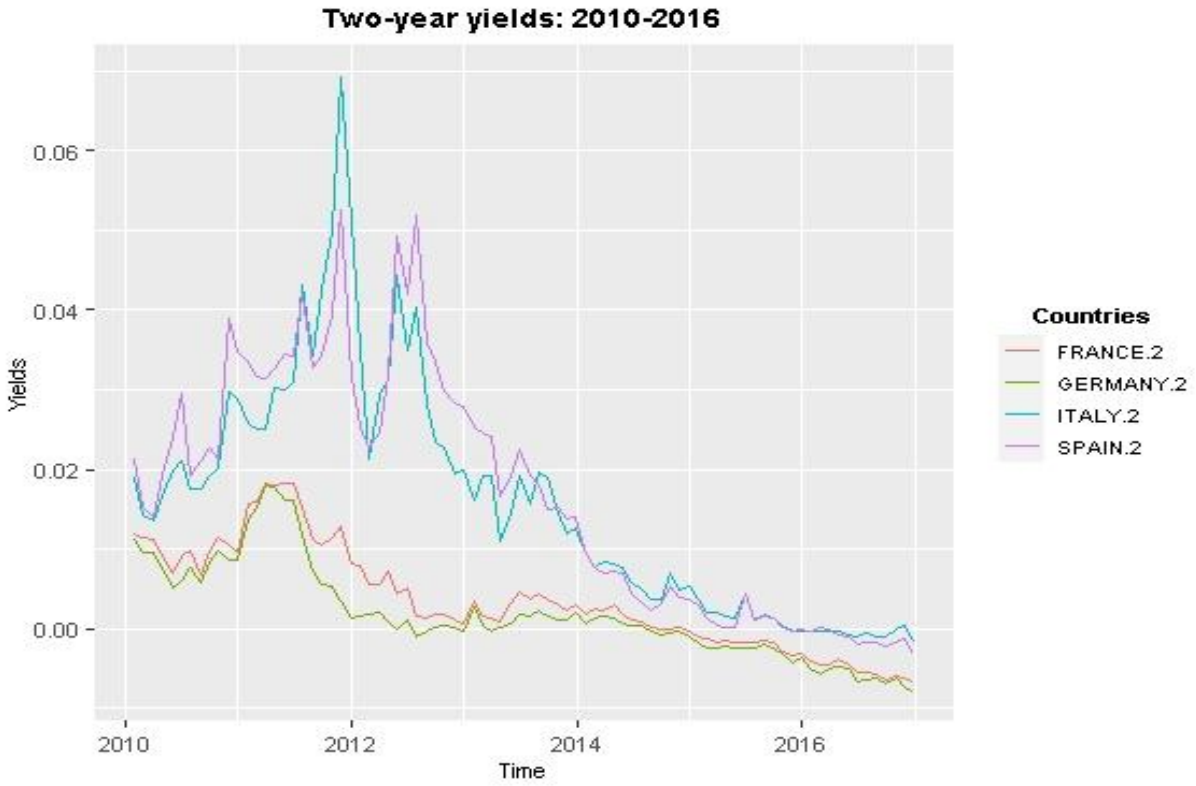
As anticipated, in Graph 33 the situation is different, in fact the total graph shows a smoother version of the other two without highlighting too much the drop/peaks. Here during 2009 is evident only a brief drop at the end of the year with only Germany that reduced its yields of a significant value. In Graph 33 the difference is the fact that the drop is less significant, but more important is the increasing spread between countries.

In the other two graphs the end of 2009 was with the four countries that developed a maximum spread of almost 50 basis points between Germany and Italy (the highest), now the spread between these two countries is of almost 100 basis points, and between each country there is a significant difference on the values of the yields.

The just mentioned behaviour could mean that the global financial crisis and the Lehman Brothers' failure leaded for the 10-year yields a significant risk to cover respect to shorter yields, ending up with this plot.

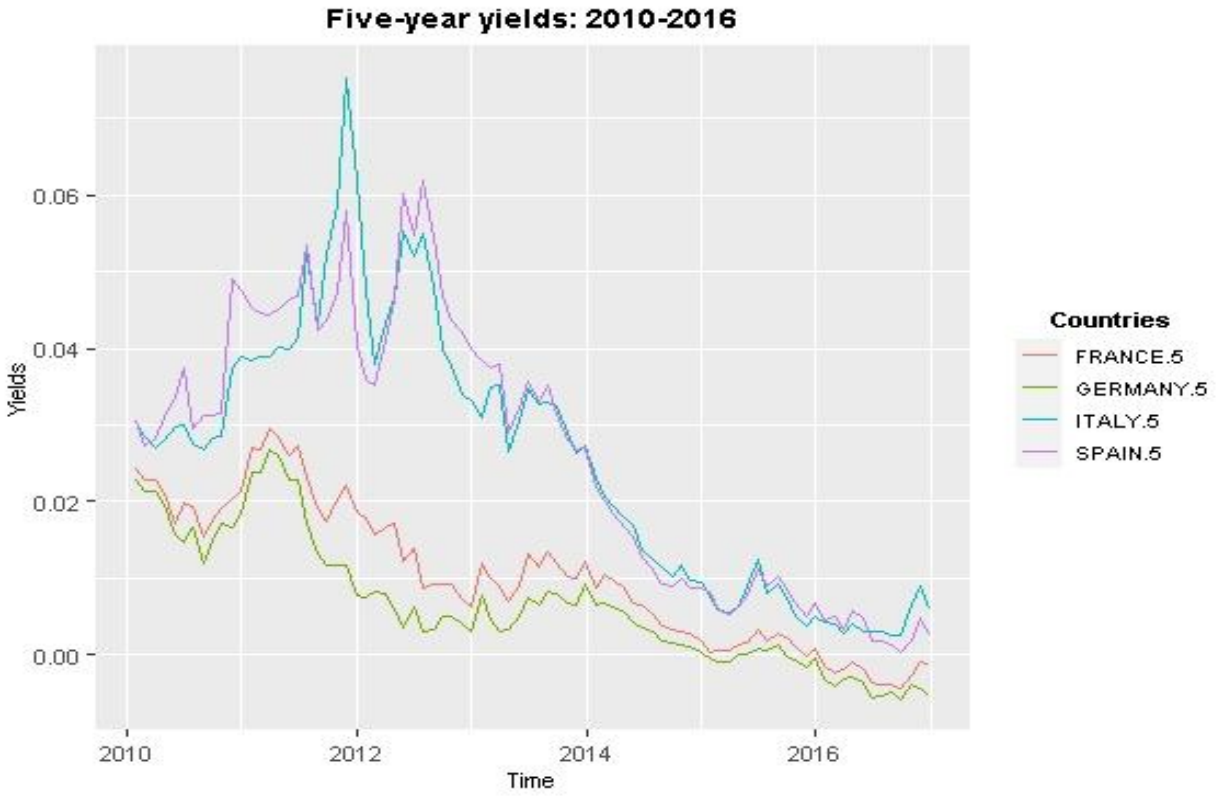
Two-five-ten-year yields evolution in 2010-2016

Graph 34: 2-year yields of the four selected countries in the subperiod 2010-2016



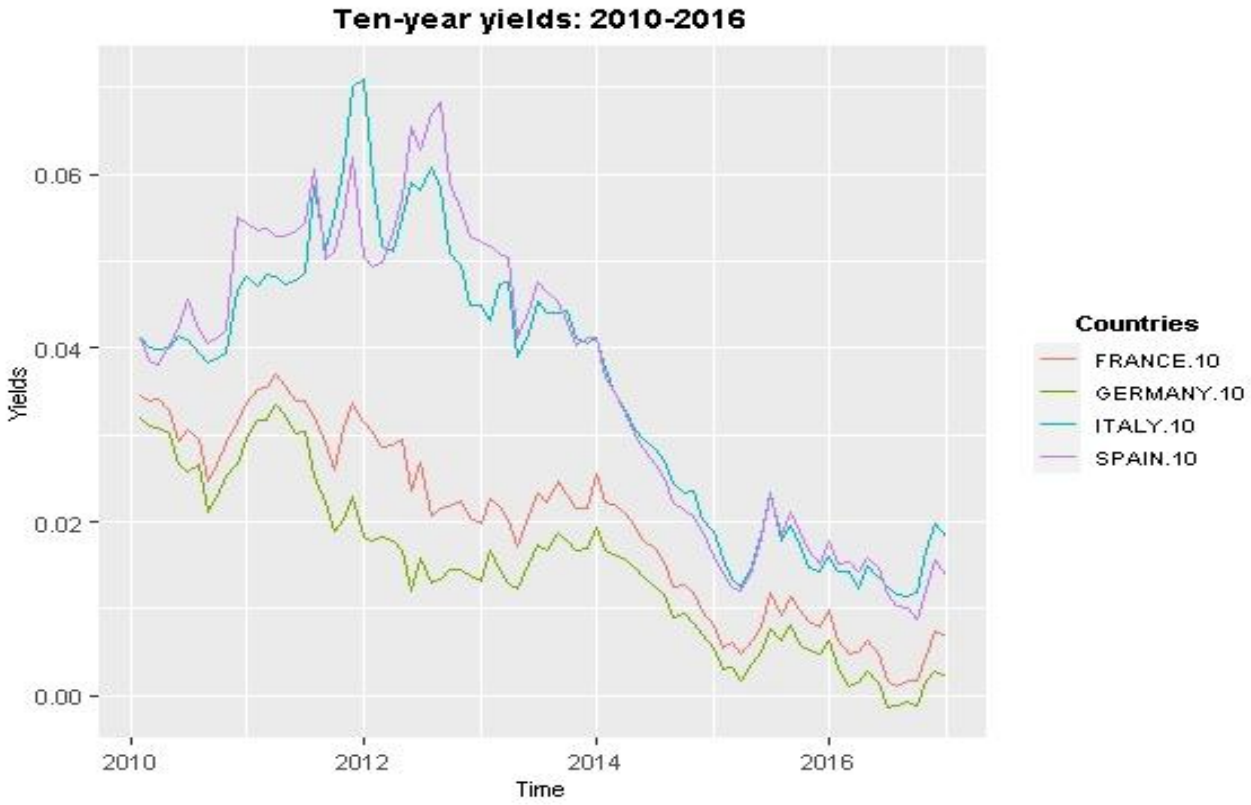
Source: Bloomberg monthly data period 2000-2022

Graph 35: 5-year yields of the four selected countries in the subperiod 2010-2016



Source: Bloomberg monthly data period 2000-2022

Graph 36: 10-year yields of the four selected countries in the subperiod 2010-2016



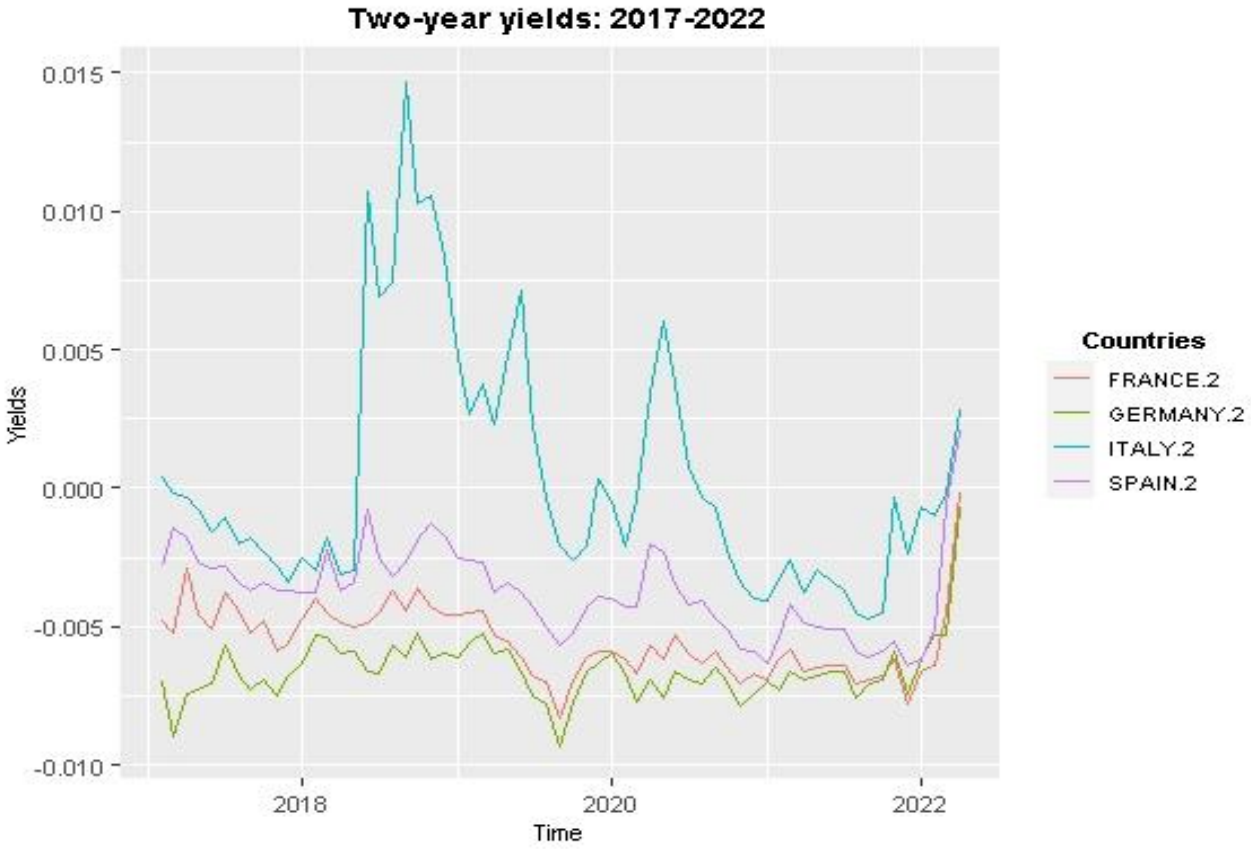
Source: Bloomberg monthly data period 2000-2022

In this subperiod that goes from beginning 2010 till the end of 2016, the main economic shock that the euro area suffered is the one of the sovereign debt crisis, considering also that Europe was coming out from the recession of the global financial crisis.
As said before, from the end of 2009 there was the beginning of the gap that exists between the core and peripherical countries inside the euro area, with Italy and Spain that took the highest yields and France and Germany with the lowest.
In detail, the sovereign debt crisis started in 2011 with the increment of the yields after the bailouts of Greece, Portugal and Ireland that leaded the euro area in a difficult period for lifting up again that three countries.
In this case all the three maturities in Graphs 34-36 gave similar reactions to the shocks, obviously with different yield's values; in general the 2010 year was characterized by a slight increasing trend in case of Spain and Italy, with Spain that encounters a difficult banking position and so this worsened its yields, while in case of Germany and France there was a declining trend till the last months of 2010 and then also these two countries started to increment the values of the yields.
The situation that the bailouts and the difficulty of IMF to rescue Greece, Ireland and Portugal leaded to a worsening inside the bond market, in fact on the Graphs is evident how during 2011 the yields started to grow significantly.
For the peripherical countries, there are two moments where their yields accumulated a significant spread with the German Bund, and they are:
- in 2011, caused by the difficult situation of Greece and the consequent uncertainty, in Graphs 34-36 is possible to notice the increment of the yields that accelerated as time passes reaching for Italy a level about 0.07 in all three maturities, accumulating a spread of circa 700 basis points in Graph 34, about 550-600 in Graph 35 and about 500 in Graph 36. Spain accumulated a slight lower spread with Germany, almost 100 basis points lower than Italy. In December the ECB actuated extraordinary measures for containing the situation and it worked, in fact at the beginning of 2012 there was a drop on the yields of Italy and Spain.
-After the initial drop of the first months in 2012, the uncertain political situation of Greece and the difficult banking situation of Spain leaded again the euro area in a difficult period, in fact the yields of Italy and Spain rose again, even if the peak was not high as before. The unique difference is that in this second peak Spain reached higher values than Italy.

Later, the situation started to be more contained, in fact the yields in the core countries continued to decrease as they were doing from the beginning of 2011, reaching at the end of 2016 values around -0.01 in Graph 34 and 0-0.005 in Graph 36. For the yields in the peripherical countries the situation was similar to the core countries, but this reduction was more efficient, starting with values around 0.05-0.07 for Spain and 0.04-0.06 for Italy, ending in 2016 with values of almost 0 in Graph 34 and about 0.015-0.02 in Graph 36.

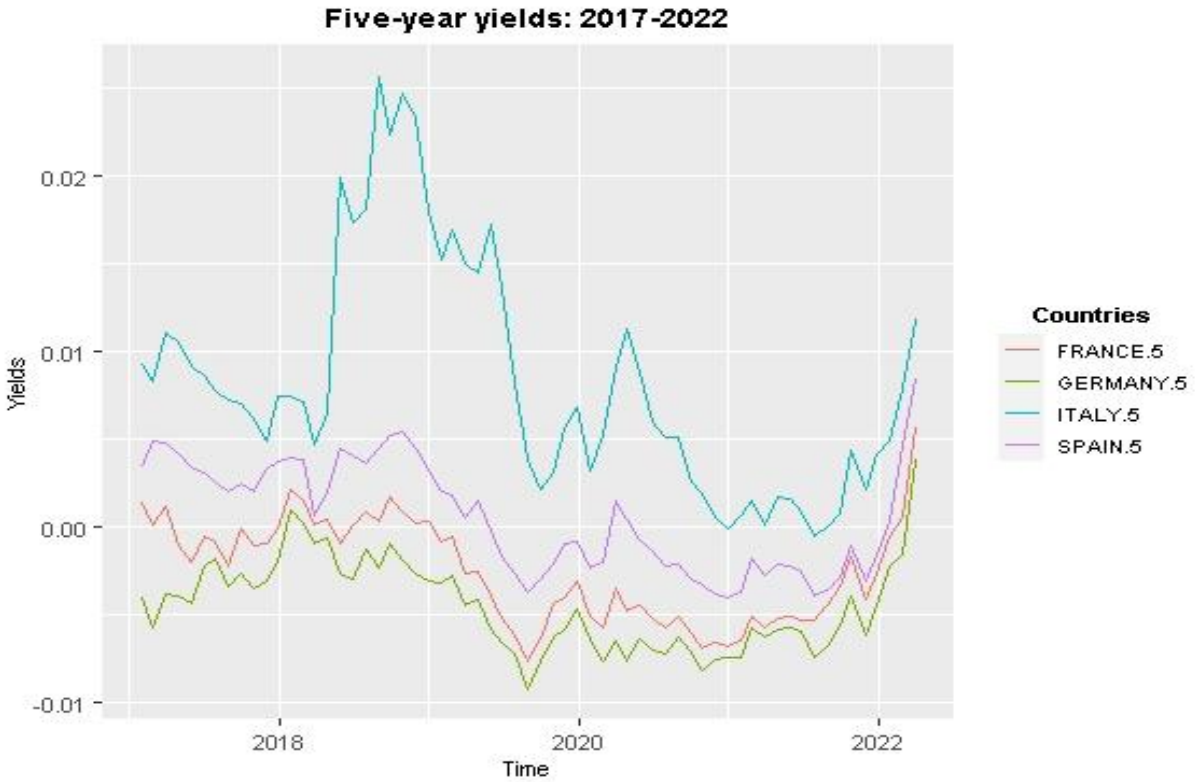
Two-five-ten-year yields evolution in 2017-2022

Graph 37: 2-year yields of the four selected countries in the subperiod 2017-2022



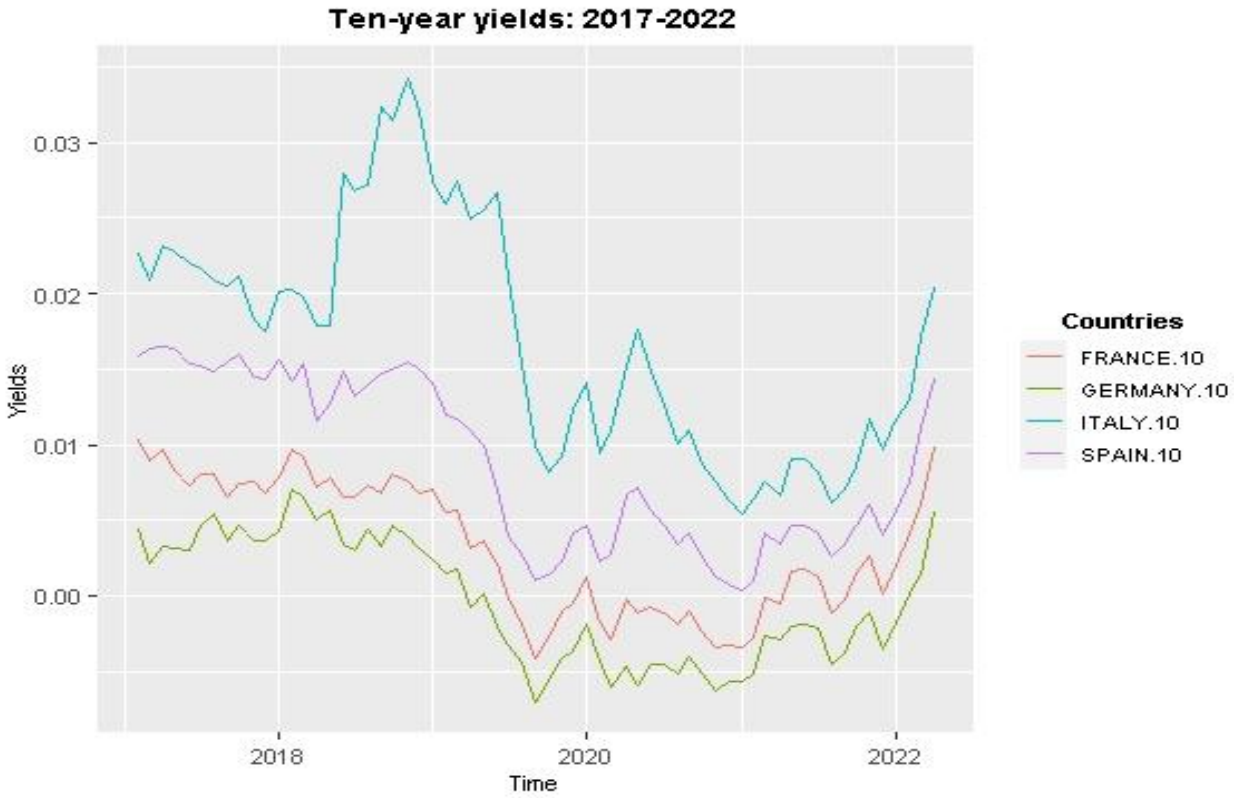
Source: Bloomberg monthly data period 2000-2022

Graph 38: 5-year yields of the four selected countries in the subperiod 2017-2022



Source: Bloomberg monthly data period 2000-2022

Graph 39: 10-year yields of the four selected countries in the subperiod 2017-2022



Source: Bloomberg monthly data period 2000-2022

In this last subperiod (2017-2022) is evident how the connected picture of the yields that was plotted on the first interval is almost gone, in fact the range between them is different in the three maturities also indicating the reactions to shocks no more equal between the euro area countries.

In this part of the sample period, what caused an economic shock was the development of the Covid-19 pandemic that reached all the world and in Europe, in almost the same period, were taken similar containment measures causing some economic, social and healthcare consequences.

In the ECMI document by Papavassiliou (2021), cited also in Chapter I, there was the description of the behaviour in the euro area yields during the Covid-19 pandemic through the yield curve, and this could help in the analysis of the above Graphs.

What is evident is that even if the Covid-19 situation created some difficulties of various nature inside the euro area, in Graphs 37-39 the yields had lower values during the pandemic period (from 2020) than in the pre-pandemic one, it is possible to see it better on Graph 39.

In fact, looking at the above Graphs till the end of 2019 Spain, France and Germany had yields around -0.0075/-0.0025 in Graph 37, -0.005/0.005 on Graph 38 and 0.005/0.015 on Graph 39.

Italy followed the other three countries' trend till half 2018, later showed a sudden jump of the yields that lasted for many months and till the last period of 2019, where yields reduced again even if with significant difference from the other countries.

Another point highlighted by Papavassiliou (2021) was the narrower range between short and long-maturity yields in the countries from the pre-pandemic to the pandemic period.

In Graphs 37-39 the situation is evident mainly for Italy, which showed a constant peak with a significant difference from the other countries, while during the Covid-19 period Italy started again to behave similarly to the others, even if its yields where always the highest.

For making a concrete example, it may be interesting to see the yields of Spain and France at the beginning of 2018 and 2021 in Graphs 37 and 39 and evaluate if effectively the gap between them is narrower or not.

France in January 2018 had a 2-year yield equal to -0.004, while in 2021 the corresponding 10-year yield was of 0.0097, concluding with a gap of 0.0137 (1.37%); moving to the yields in January 2021, the 2-year one was of -0.0062 and the 10-year one was of -0.0028, with a gap of -0.0034 (-0.34%), the narrower gap is significant.

Considering now the case of Spain, the values in January 2018 were equal to -0.0038 in the 2-year yields and of 0.0142 in the 10-year one, with a gap of 0.018 (1.8%); instead, the yields in January 2021 were of -0.0054 in Graph 37 and of 0.0010 in Graph 39, the final gap is of 0.0064 (0.64%).

In the previous two examples there is the proof about the real reduction of the gap between shorter and longer maturity yields both in peripherical and core countries; according to Papavassiliou (2021), this phenomenon is probably due to a flattening of the yield curve and one reason could be the increment of the short-term yields by the ECB for making a change in the actual monetary policy.

Finally, concentrating on the narrower gap between 2- to 10-year yields, the increasing curve that anticipated the Covid-19 event, was the expectation for the euro area to increase in the future, in fact market participants will expect an increment on the interest rates by the ECB.

However, the spread since 2021 became more stable and the yields tended to increase again, this suggested a reduction on the possibilities of a recession due to the pandemic, quite the opposite this positive trend of the spread could suggest positive signals about an economic growth.

3.2 Connectedness analysis

3.2.1 Countries of the euro area selected for the analysis

Before starting with the analytical part, it is important to understand how it was possible to select the four countries from the original ten, that are: Portugal (POR), Netherlands (NETH), Belgium (BEL), Italy (ITA), France (FRA), Germany (GER), Spain (SPA), Finland (FIN), Austria (AUS) and Ireland (IRE).

Obviously, to discover the combination which had the highest connectedness was necessary to analyse the matrices of Diebold and Yilmaz (2014) on the full-sample of countries in the different maturities. The chosen predictive horizon is H=1 and the matrices represent the yields of 2/5/10-year maturity, the results are:

Table 1: Connectedness table for 2-year yields maturity of the ten countries period 2000-2022

2 years	POR	NETH	BEL	ITA	FRA	GER	SPA	FIN	AUS	IRE	FROM
POR	42.81	2.52	4.32	13.00	3.65	1.96	12.14	2.47	2.80	14.33	**57.19**
NETH	0.92	18.31	10.31	2.02	15.87	17.57	3.02	15.74	15.34	0.89	**81.68**
BEL	1.52	11.86	18.79	6.37	13.64	12.42	6.25	11.27	14.99	2.89	**81.21**
ITA	8.61	4.34	10.52	27.38	6.58	3.87	19.53	4.28	6.28	8.61	**72.62**
FRA	1.14	15.31	11.96	3.19	17.86	16.51	3.90	14.47	14.77	0.90	**82.15**
GER	0.57	16.68	10.63	1.85	16.39	19.27	2.83	16.02	15.08	0.68	**80.73**
SPA	8.07	5.40	8.49	17.40	6.89	4.81	27.97	4.98	6.71	9.28	**72.03**
FIN	0.88	15.98	10.16	2.18	15.49	17.28	3.00	19.61	14.54	0.87	**80.38**
AUS	0.83	14.81	13.91	3.39	14.96	15.24	4.19	13.37	18.17	1.11	**81.81**
IRE	9.61	3.17	7.13	9.92	3.23	2.68	13.10	2.90	4.45	43.79	**56.19**
TO	**32.15**	**90.07**	**87.43**	**59.32**	**96.70**	**92.34**	**67.96**	**85.5**	**94.96**	**39.56**	**74.60**
NET	**-25.04**	**8.39**	**6.22**	**-13.3**	**14.55**	**11.61**	**-4.07**	**5.12**	**13.15**	**-16.63**	

Source: Own production with Bloomberg data (2000-2022)

Table 2: Connectedness table for 5-year yields maturity of the ten countries period 2000-2022

5 years	POR	NETH	BEL	ITA	FRA	GER	SPA	FIN	AUS	IRE	FROM
POR	45.42	1.64	5.18	8.66	4.52	2.12	13.20	2.45	2.78	14.02	**54.57**
NETH	0.53	17.06	12.37	3.00	15.23	15.83	3.66	14.98	15.00	2.33	**82.93**
BEL	1.10	12.54	17.27	6.23	13.59	11.91	7.09	12.36	13.36	4.54	**82.72**
ITA	4.03	5.84	12.26	27.49	6.92	4.18	19.01	5.46	5.88	8.94	**72.52**
FRA	1.10	14.56	13.32	3.62	16.44	15.09	4.39	14.18	14.63	2.67	**83.56**
GER	0.60	15.70	12.02	2.22	15.73	18.27	3.19	15.41	15.04	1.83	**81.74**
SPA	6.30	5.78	10.63	15.69	6.85	4.74	24.73	5.12	6.04	14.13	**75.28**
FIN	0.61	15.27	12.55	2.89	15.11	15.80	3.40	17.53	14.80	2.04	**82.47**
AUS	0.70	14.49	13.88	3.64	14.94	14.51	4.25	14.20	16.75	2.63	**83.24**
IRE	6.64	4.96	9.43	9.35	6.18	3.93	18.00	3.94	5.64	31.93	**68.07**
TO	**21.61**	**90.78**	**101.64**	**55.3**	**99.07**	**88.11**	**76.19**	**88.10**	**93.17**	**53.13**	**76.71**
NET	**-32.96**	**7.85**	**18.92**	**-17.22**	**15.51**	**6.37**	**0.91**	**5.63**	**9.93**	**-14.94**	

Source: Own production with Bloomberg data (2000-2022)

Table 3: Connectedness table for 10-year yields maturity of the ten countries period 2000-2022

10 years	POR	NETH	BEL	ITA	FRA	GER	SPA	FIN	AUS	IRE	FROM
POR	39.11	3.03	8.36	7.65	5.05	3.41	12.30	3.89	4.97	12.24	**60.90**
NETH	1.00	15.54	12.16	3.53	14.16	14.70	5.44	14.52	14.73	4.23	**84.47**
BEL	2.43	12.01	15.06	6.04	12.76	11.50	8.18	12.18	13.00	6.83	**84.93**
ITA	4.17	6.34	11.55	24.83	8.46	5.35	16.77	6.01	7.40	9.13	**75.18**
FRA	1.63	13.79	12.87	4.69	14.83	13.75	6.24	13.62	14.01	4.56	**85.16**
GER	1.15	15.06	11.80	3.10	14.41	16.32	4.94	14.77	14.63	3.81	**83.67**
SPA	5.94	7.53	10.98	12.38	8.79	6.66	20.05	7.21	8.96	11.51	**79.96**
FIN	1.25	14.62	12.46	3.49	14.01	14.57	5.38	15.39	14.66	4.15	**84.59**
AUS	1.62	14.03	12.87	4.09	13.61	13.51	6.27	13.82	15.27	4.91	**84.73**
IRE	5.95	7.04	10.95	7.75	7.57	6.13	13.45	6.73	8.50	25.92	**74.07**
TO	**25.14**	**93.45**	**104**	**52.72**	**98.82**	**89.58**	**78.97**	**92.75**	**100.86**	**61.37**	**79.77**
NET	**-35.76**	**8.98**	**19.07**	**-22.46**	**13.66**	**5.91**	**-0.99**	**8.16**	**16.13**	**-12.7**	

Source: Own production with Bloomberg data (2000-2022)

As shown above in the three matrices of the Diebold and Yilmaz (2014) model, it is possible to analyse the level of connectedness between the countries and explain how the four selected countries where chosen.

At the beginning of the Chapter was anticipated that Germany, France, Italy and Spain were divided as two countries of the core euro area and two countries of the peripherical euro area.

A first reason about the selection of these four countries is purely strategical, because Italy and Spain represent the strongest countries of the four in the peripherical area, Ireland and Portugal in fact were subject to bailouts during the sovereign debt crisis in 2011 (as anticipated in Chapter I); while Germany represents the surest country in the euro area, with the lowest yields on sovereign bonds and France is another strong economy of the core area.

Obviously, purely looking at the matrices from Diebold and Yilmaz (2014) model, there have been other combinations that would end up with a higher total connectedness measure. Considering the other countries, with a "marginal" economic role into the euro area, it is evident that Belgium has a high influence on other countries, for example the values of 101.64 and 104 in the "TO" columns of the 5/10-year matrices. Strong is also the impact that had to Italy (10.52; 12.26; 11.55) and Spain (8.49; 10.63; 10.98), larger than the values of Germany and France to these two countries.

Another country relatively stronger than the selected Germany versus the peripherical countries is Austria, in fact in all three maturities had a positive and large connectedness

value (13.15;9.93; 16.13), while to Italy (6.28; 5.88; 7.40) and Spain (6.71; 6.04; 8.96) the values where greater than the ones of Germany, but not than the values of France.

In conclusion, substituting Germany with Austria or substituting both the core countries with Belgium and Austria would have given better evidence of which countries were truly connected, but it would have had a lower impact in terms of an empirical analysis, because these two countries are not crucial and their decisions do not condition significantly the euro area as a whole.

Concentrating on the behaviour that the selected four countries have inside the connectedness Tables 1-3, it is clear that France had always the sum of the "TO" column higher than the Germany one, in fact this country is the reference point in the euro area but at the same time seems not to be capable to influence the others as other countries do like France and Austria.

3.2.2 Static analysis of connectedness

In this part of the static analysis will be considered the full-sample of Italy, France, Germany and Spain, with monthly data that goes from January 2000 to March 2022; in order to analyse the relationship between them will be used the connectedness table from the Diebold and Yilmaz (2014) model in the three different maturities, as follows:

Tables 4.a (left) and 4.b (right): Connectedness table for 2-year yields (left) and 5-year yields (right) of four selected countries

2 years	ITA	FRA	GER	SPA	FROM
ITA	49.64	9.87	4.21	36.28	**50.36**
FRA	7.02	44.12	40.31	8.55	**55.88**
GER	2.98	41.73	50.26	5.04	**49.74**
SPA	33.07	10.59	5.78	50.56	**49.44**
TO	**43.07**	**62.19**	**50.30**	**49.87**	**51.36**
NET	**-7.29**	**6.31**	**0.56**	**0.43**	

5 years	ITA	FRA	GER	SPA	FROM
ITA	49.61	11.29	5.56	33.54	**50.39**
FRA	8.71	42.47	38.12	10.69	**57.52**
GER	4.39	40.33	48.52	6.76	**51.48**
SPA	30.41	12.98	7.49	49.11	**50.88**
TO	**43.51**	**64.60**	**51.17**	**50.99**	**52.57**
NET	**-6.88**	**7.08**	**-0.31**	**0.11**	

Source: Own production with Bloomberg data (2000-2022)

Table 4.c: Connectedness table for 10-year yields of four selected countries

10 years	ITA	FRA	GER	SPA	FROM
ITA	46.27	15.81	8.98	28.94	**53.73**
FRA	11.98	38.54	34.62	14.85	**61.45**
GER	7.13	37.46	43.46	11.95	**56.54**
SPA	25.31	17.81	12.92	43.96	**56.04**
TO	**44.42**	**71.08**	**56.52**	**55.74**	**56.94**
NET	**-9.31**	**9.63**	**-0.02**	**-0.30**	

Source: Own production with Bloomberg data (2000-2022)

After showing how the connectedness tables are drawn (Tables 4.a-c), it is possible to start the analysis of the data looking at the pairwise directional values, the total connectedness, the net total directional connectedness and the "TO" and "FROM" measures.

At a first look is evident how the total connectedness ($C^H = \frac{1}{N}\sum_{\substack{i,j=1 \\ i\neq j}}^{N} d_{ij}^H$) in the three tables increased as the maturities of the yields got longer, in fact with the measure in Table 4.a is equal to 51.36, in Table 4.b increased a little more till 52.57, while in Table 4.c the value increased in a bigger way resulting 56.94; this value simply confirms how the connectedness between the selected four countries became stronger as the maturity of the yields increased, with a higher magnitude from 5 to 10 years (+4.37) than from 2 to 5 (+1.21).

Concentrating on the off-diagonal values of Table 4.a, at a first look the separation between core countries and peripherical countries of the euro area is clear, in fact these two groups have a high pairwise directional connectedness: Italy and Spain ($C^{\wedge 1}_{SPA\leftarrow ITA}$=33.07; $C^{\wedge 1}_{ITA\leftarrow SPA}$ =36.28), the same happened also between Germany and France ($C^{\wedge 1}_{FRA\leftarrow GER}$ =40.31; $C^{\wedge 1}_{GER\leftarrow FRA}$ = 41.73), while the measures obtained crossing one core and one peripherical countries were weak.

The pairwise directional connectedness measures from France to Germany represent the highest value of the off-diagonal elements, while the one from Germany to France is the second-highest; the lowest elements of the table are $C^{\wedge 1}_{GER\leftarrow ITA}$ =2.98 and $C^{\wedge 1}_{GER\leftarrow SPA}$ =5.04.

Looking now to the total directional connectedness from others ("FROM" column), the highest value is the one of France (55.88), meaning that it has a connectedness stronger from the other countries than the one given by its own-effects (the diagonal element, equal

to 44.12), in other words it is affected more by the other than itself. A similar behaviour is present also in Italy, with an own-effect equal to 49.64 and a row sum of 50.36.

For Germany and Spain instead the behaviour is opposite, in fact in both cases the own-effects are higher than the total directional connectedness from others, Germany (50.26; 49.74), Spain (50.56; 49.44).

Although, for Germany, Spain and Italy the values are very close to 50%-50%, imposing not a significant difference from the other's influence and the own one.

Moving to the sum per column of the pairwise directional connectedness measures, the "TO" row, also in this case France stands out for the highest value of the four countries, with an element in the row equal to 62.19, pointing out that this country is able to have a stronger connectedness to and from other countries than the one by its own.

Following there is Germany that showed a 50.30 (slightly higher than the 50.26 produced by itself) and at the end there are Italy (43.07) and Spain (49.87) that showed a weaker connectedness to others respect to the one from others and of own-effect.

Concluding the analysis of Table 4.a, it is interesting to see the net total directional connectedness ($C_i^H = C_{\blacksquare \leftarrow i}^H - C_{i \leftarrow \blacksquare}^H$), that is simply the difference between the connectedness of one country to others ("TO") minus the connectedness of that country from others ("FROM").

Obviously, a large value comes from France with 6.31, which means that is larger the connectedness that it sends to other countries than the one that receives. Italy is the only country with a negative value, equal to -7.29, confirming that the impact that it has to the other countries is really weak; in conclusion, both Spain and Germany obtained a value nearly to 0 (0.56_{GER}, 0.43_{SPA}), thus their impact is almost fictional.

Moving to Table 4.b, is clear that in addition to the increment in total connectedness equal to 52.57, it also happened to all the elements of the Table.

However, in this case the pairwise directional connectedness measures between Germany-France and Italy-Spain have decreased, while the other elements increased.

In fact, taking in consideration the weak connectedness in the element $C_{GER \leftarrow ITA}^{\wedge 1} = 2.98$ of Table 4.a, now it is equal to 4.39, while the element $C_{FRA \leftarrow GER}^{\wedge 1} = 40.31$ now is 38.12; the same happened to the elements from and to Italy-Spain and the ones of Italy-France-Spain. Even though, the previous stronger relationships between the core and the peripherical countries remained the same.

Looking now to the diagonal elements, apart from Italy that decreased of a tiny amount (from 49.64 to 49.61), the other three countries changed a little more their measures,

France from 44.12 to 42.47, Germany from 50.26 to 48.52 and Spain from 50.56 to 49.11, meaning that their measures are less dependent on own-effects and more from the other countries.

The measures of connectedness in the "FROM" column shows all the four values increased than before with different magnitudes and all above 50, confirming the changes on the elements of the diagonal. The highest value is again the one of France (57.52), while the country that showed the highest increment in this column is the one of Germany, that passed from 49.74 to 51.48.

On the other side, also the row cells of the "TO" connectedness measures demonstrated an increment in all the countries; in this case the country with the highest value and the larger change from the previous table is France (64.60), this element showed that going to a higher maturity of the yields the own-effect of France decreased, increasing the connectedness from the others.

Germany, Italy and Spain all increased in the "TO" elements, but with a magnitude lower respect to the "FROM" columns, thus in other words their connectedness is less robust than before.

For confirming what already said, the last row ("NET"), shows a larger value for France (7.08) and a light improvement of Italy (from -7.29 to -6.88), while for Germany (-0.31) and Spain (0.11) the results are worse than before.

Concluding with Table 4.c also here is possible to notice that the total connectedness has increased again, now it is equal to 56.94, together with almost all the off-diagonal elements.

The pairwise directional connectedness measures now have again modified the strength in the couples France-Germany and Italy-Spain, in fact the values are reduced in this combination and increased in the core-peripherical one making the connectedness table more unbiased.

The highest value is $C^{\wedge 1}_{GER \leftarrow FRA} = 37.46$, which is lower than the corresponding one in the Table 4.b, and the second-highest is the one with the opposite direction between these two $C^{\wedge 1}_{FRA \leftarrow GER} = 34.62$.

Looking to the other values is evident that the connectedness measures outside the couples France↔Germany and Italy↔Spain are becoming even more stronger, for example the highest here is $C^{\wedge 1}_{SPA \leftarrow FRA} = 17.81$, while the second-highest is $C^{\wedge 1}_{ITA \leftarrow FRA} = 15.98$. These values confirmed that France is the strongest country of the four in terms of connectedness to

the others, and also that Germany is improving its elements but not with the same performances.

Considering the "FROM" column, now all the four countries have this element clearly above 50, the one with the larger value is France (61.45) followed by Germany (56.54); all the countries has increased a lot this measure respect to the other Tables: Germany (+5.06), France (+3.93), Spain (+5.16) and Italy (+3.34).

The row of "TO" sees all the elements with larger values than the previous one, with again France at the first place (71.08) and Germany (56.52) at the second, Italy is the only one that increased of a tiny amount (+0.91), and this will have consequences on the net total directional connectedness.

In fact, in the net total directional connectedness the measure of Italy is getting worse, reaching a value of -9.31, the worsen reached till the beginning; for the other countries France strengthen the connectedness measures with a 9.63, while Germany and Spain obtained similar values (-0.02; -0.3).

To sum up what already said, following there are some points of the most important features of the previous Tables 4.a-c, like:

- The total connectedness increased with a higher magnitude as the maturity got longer; +1.21 with a range of 3 years and +4.37 with 5 years range. In conclusion, the value in the last range was almost four times the previous one while time only doubled and it is possible to confirm that as maturity increases the connectedness tends to become stronger.
- Germany represents the country with the better economic situation and is the reference point in the euro area but, looking at the connectedness Tables of Diebold-Yilmaz model, it does not mean that it shall end up with the best performances in terms of connectedness measures. In fact, in all three Tables the elements of the net total directional connectedness were close to 0 or even negative, this means that even though Germany has a strong economic position its connectedness to other is almost equal to the one that receives, not a robust connectedness.
- As anticipated in the description of the Tables, as the yields' maturities got longer, the pairwise directional connectedness measures reduced between the countries with a strong connection, increasing with the other, obviously without changing a lot. This would mean that as the yields get longer, the connectedness tends to

move in different directions, does not remain stable to the starting point and becomes smoother.

- Another evident change is the one about the own-effects of each country. This measure represents how much each country is affected by its own total variance forecast error.

  Describing all the three Tables, this measure decreased for each country as the maturity of the yields became longer; Germany was the country with the highest change in this element (2-year = 50.26, 10-year = 43.96), leading the country to a smaller connectedness with itself and a higher vulnerability from the others.

3.2.3 Static analysis for subperiods

To show more aspects of this model and how it works analysing the history of the euro area yields, it could be interesting to analyse the subperiods of Section 3.1.3 where the yields were close each other and where they were not, like in the 1° (2000-2005) and 3° (2010-2016) subperiods.

This method permits to explain how the connectedness measures varies taking a specified subperiod from the whole sample, in fact the 1° subperiod replicates the first period after the introduction of euro and the one with the closest relationship between the bond yields of the countries, while the 3° subperiod represents the opposite case, with the sovereign debt crisis and a spread of almost 500 basis point between Germany and Italy for example. As in the previous paragraph, the analysis will be composed by a matrix which shows the level of connectedness between the countries, one will analyse the subperiod 2000-2005 and the other the interval 2010-2016, in the three different maturities.

2-year yield maturity

Tables 5.a (left) and 5.b (right): Connectedness table of 2-year yields of subperiod 2000-2005 (left) and subperiod 2010-2016 (right) of the four selected countries

2000-2005	ITA	FRA	GER	SPA	FROM
ITA	26.47	23.77	24.74	25.01	**73.52**
FRA	25.19	25.44	24.58	24.79	**74.56**
GER	25.65	23.59	25.59	25.18	**74.42**
SPA	25.43	23.28	24.61	26.68	**73.32**
TO	**76.27**	**70.64**	**73.93**	**74.98**	**73.95**
NET	**2.75**	**-3.92**	**-0.49**	**1.66**	

2010-2016	ITA	FRA	GER	SPA	FROM
ITA	53.01	5.42	1.62	39.95	**46.99**
FRA	1.80	54.24	42.45	1.52	**45.77**
GER	3.14	38.29	57.75	0.82	**42.25**
SPA	36.90	4.37	0.71	58.02	**41.98**
TO	**41.84**	**48.08**	**44.78**	**42.29**	**44.25**
NET	**-5.15**	**2.31**	**2.53**	**0.31**	

Source: Own production with Bloomberg data (2000-2022)

At a first look what comes out is that during the period 2000-2005 (Table 5.a) the total connectedness (73.95) is sensibly higher than the one of the 2010-2016 period in Table 5.b (44.25), as shown by the yields' trend on the graphs in Section 3.1.3.

About the Table 5.a, the one regarding the euro introduction and the early years after this event, the off-diagonal elements are even balanced with values between 23-26; this behaviour also comprehends the values on the diagonal.

It implies that there are not stronger relationship between countries, for example among core or peripherical one and at the same time, each country depends more or less with the same magnitude from the other countries and from itself.

In detail, on the main diagonal the countries with the highest values are Spain ($C^{\wedge 1}_{SPA}$=26.68) followed by Italy ($C^{\wedge 1}_{ITA}$=26.47), almost a half of the corresponding values on the Table 4.a (50.56 and 49.64).

Looking at the pairwise directional connectedness measures, the highest is $C^{\wedge 1}_{GER \leftarrow ITA}$ =25.65 with the second-highest $C^{\wedge 1}_{SPA \leftarrow ITA}$ =25.43, demonstrating that in this case Italy's influence to other countries was stronger in the early years of the sample, also towards Germany that in the full-sample connectedness table (Tables 4.a) was the one with the weaker connectedness with Italy.

Considering the row-sum column "FROM", the values are stable around 73-74 without a peak from a determined country, the highest measure is the one of France (74.56) meaning that almost the 75% of connectedness derives from Italy, Spain, and Germany while only the left over 25% comes from itself; the lowest measure in this part is of Spain (73.32).

Moving to the column-sum row "TO", the highest measure derives from Italy (76.27) with the lowest from France (70.64), inverting the roles that these two countries had inside the full-sample table, France almost always with the better values and Italy with the worsen.

In conclusion, looking at the net total directional connectedness, as a confirm of the previous measures, the largest value is the one of Italy (2.75), while the smallest is the one of France (-3.92).

The Table 5.b appears immediately different and closer to the situation of the Table 4.a, in fact: the total connectedness is lower than the previous one (44.25) and again the stronger relationship between core and peripherical countries is evident.

Obviously, this means that the sovereign debt crisis which involved mainly Spain and Italy in a negative way had also damaged their role inside the euro area in terms of connectedness.

Talking about the diagonal elements of the Table is evident how now are all almost doubled respect to before, and the highest value is of Spain (58.02), which means that this country is influenced mainly by itself than by the other three countries.

Moving to the off-diagonal, the pairwise directional connectedness measures, the highest value is $C^{\wedge 1}_{FRA \leftarrow GER} = 42.45$ and the second-highest is $C^{\wedge 1}_{ITA \leftarrow SPA} = 39.95$; considering the large role that Italy had in the period 2000-2005 towards the other countries now the connectedness to Germany is only of $C^{\wedge 1}_{GER \leftarrow ITA} = 3.14$.

The "FROM" column shows as the highest value the one of Italy (46.99), while the others are around 41-45, meaning that they receive less connectedness from the other countries than from themselves, as it is evident looking to the diagonal measures (>53).

However, the "TO" column has as highest value the one of France (48.08) and the lowest is the one of Italy (41.84), showing how in few years the ability of Italy to be competitive in terms of giving connectedness is reversed.

Finally, the net total directional connectedness shows Italy with the worsen situation (-5.15) and Germany with the better (2.53), slightly higher than the France one (2.31).

5-year yield maturity

Tables 6.a (left) and 6.b (right): Connectedness table of 5-year yields of subperiod 2000-2005 (left) and subperiod 2010-2016 (right) of the four selected countries

2000-2005	ITA	FRA	GER	SPA	FROM
ITA	26.16	24.36	25.04	24.44	**73.84**
FRA	24.75	25.45	25.38	24.42	**74.55**
GER	24.98	24.93	25.83	24.26	**74.17**
SPA	24.90	24.34	24.67	26.08	**73.91**
TO	**74.63**	**73.63**	**75.09**	**73.12**	**74.12**
NET	**0.79**	**-0.92**	**0.92**	**-0.79**	

2010-2016	ITA	FRA	GER	SPA	FROM
ITA	54.21	6.26	0.20	39.33	**45.79**
FRA	4.61	50.17	41.03	4.19	**49.83**
GER	0.00	42.08	57.64	0.29	**42.37**
SPA	35.63	6.75	0.50	57.12	**42.88**
TO	**40.24**	**55.09**	**41.73**	**43.81**	**45.22**
NET	**-5.55**	**5.26**	**-0.64**	**0.93**	

Source: Own production with Bloomberg data (2000-2022)

In this case the maturity of the yields gets longer from 2 to 5-year and, as happened with the full-sample, the total connectedness increased as the maturity increased too ($73.95_{2000\text{-}2005} \rightarrow 74.12_{2010\text{-}2016}$, $44.54_{2000\text{-}2005} \rightarrow 48.54_{2010\text{-}2016}$).

In general, the situation in both the connectedness Tables 6.a-b is similar to the previous one in terms of balanced relationship between the countries in the 2000-2005 subperiod (Table 5.a), and the stronger core-peripherical relationship in the 2010-2016 one (Table 5.b), but something gets better or worsen.

Concentrating on Table 6.a and looking at the off-diagonal elements, the highest value is $C^{\wedge 1}_{FRA \leftarrow GER} = 25.38$ and the second-highest is $C^{\wedge 1}_{ITA \leftarrow GER} = 25.04$, meaning that moving from the 2-year to the 5-year maturity the measures of connectedness changed, for example Italy now is not the country which influences mostly the others.

Analysing the measures on the "FROM" column, the highest value is of France (74.55) and the others have similar values between 73-74.

In the "TO" row the highest value is the one of Germany (75.09), while in the previous table was Italy confirming again the reduction in the Italy's competitiveness.

The net total directional connectedness ends with the peripherical and the core euro area countries that compensate the other, Italy (0.79) with Spain (-0.79) and Germany (0.92) with France (-0.92).

Considering now the Table 6.b, the measures inside the Tables changed a little moving to the 5-year maturity, in fact some relationships got better and other worsened.

Considering the off-diagonal elements, it is evident how the $C^{\wedge 1}_{GER \leftarrow ITA}$ measure decreased passing from a 3.14 to a 0.00, meaning that in this Table the level of connectedness that

Germany receives from Italy is null; a similar situation happened to $C^{\wedge 1}_{SPA \leftarrow GER}$ passing from 0.71 to 0.51, highlighting the poor role that the peripherical countries had.

However, in the pairwise directional connectedness measures, the highest value is $C^{\wedge 1}_{GER \leftarrow FRA}$= 42.08 and the second-highest is $C^{\wedge 1}_{FRA \leftarrow GER}$ =41.03, confirming the stronger relationship between central countries developed in the sovereign debt crisis.

Looking at the "FROM" column, the highest value is the one of France (49.83), while the lowest are Germany (42.37) close to Spain (42.88) which are all increased, apart from Italy that moved to a higher yield maturity.

Also, in the "TO" row the highest value is the one of France (55.08), the only country to significantly increase its capacity to influence the other countries from the previous Table, becoming more and more close to the country with the best performance as in the full-sample one.

Concluding with the net total directional connectedness, France had the highest measure (5.26), while the others got worsen, mainly the one of Germany that in the 2-year maturity was 2.53 and, in this case, decreased till -0.64.

10-year yield maturity

Tables 7.a (left) and 7.b (right): Connectedness table of 10-year yields of subperiod 2000-2005 (left) and subperiod 2010-2016 (right) of the four selected countries

2000-2005	ITA	FRA	GER	SPA	FROM
ITA	25.61	25.16	24.28	24.95	**74.39**
FRA	24.86	25.69	24.65	24.80	**74.31**
GER	24.76	25.45	25.10	24.69	**74.90**
SPA	25.00	25.22	24.32	25.47	**74.54**
TO	**74.62**	**75.83**	**73.25**	**74.44**	**74.53**
NET	**0.23**	**1.52**	**-1.65**	**-0.10**	

2010-2016	ITA	FRA	GER	SPA	FROM
ITA	51.99	12.77	2.89	32.36	**48.01**
FRA	10.25	42.62	35.60	11.53	**57.38**
GER	1.86	39.40	51.81	6.92	**48.19**
SPA	26.61	15.00	7.73	50.66	**49.34**
TO	**38.72**	**67.17**	**46.22**	**50.81**	**50.73**
NET	**-9.29**	**9.79**	**-1.97**	**1.47**	

Source. Own production with the Bloomberg data (2000-2022)

As seen in other connectedness Tables, increasing the yield maturity the total connectedness is higher than before, 74.53 for 2000-2005 period and 50.73 for the 2010-2016 period.

Concentrating on Table 7.a, the situation is more or less similar to the one of the previous Tables with balanced measures and no significant difference between countries and diagonal and off-diagonal elements.

The pairwise directional connectedness measures show as highest value $C^{\wedge 1}_{GER \leftarrow FRA}$= 25.45, and as second-highest $C^{\wedge 1}_{GER \leftarrow FRA}$=25.22, confirming the capacity of France to give connectedness to the other countries, role that in Table 5.a was of Italy.

Looking at the "FROM" column, all values are close each other and around 74, apart from France all the other countries saw an increment on this measure, with the highest of Germany (74.90); obviously this increment is not positive for these countries because it means that they tend to be more dependent from the other countries than by themselves as the yield maturity gets longer.

The "TO" row shows as highest value the one of France (75.83), that increased respect to before together with Spain, while the value of Germany decreased from 75.09 to 73.25, reducing its connectedness competitiveness.

In the Net total directional connectedness France obtained again the highest value (1.52) even if it is not so far from the one of Italy (0.23), while the lowest value is the one of Germany (-1.65), confirming the decreasing power seen in the Tables.

Moving now to the Table 7.b, as anticipated in Chapter I, at the beginning of the sovereign debt crisis there was a raising trend of the 10-year sovereign bond yields in all euro area, thus it is interesting to see how and if it significantly changed this Table from the others.

Looking at the diagonal elements, all the measures changed in positive or negative from Table 6.b, the only country that weakened its situation is France with a value of 42.62, meaning that is more exposed to the other countries' influence.

In the pairwise directional connectedness measures, the highest one is $C^{\wedge 1}_{GER \leftarrow FRA}$ =39.40, and the second-highest is $C^{\wedge 1}_{FRA \leftarrow GER}$ =35.60, the same directional measures of the previous Table.

Moving to the "FROM" column all the values have increased implying more dependence from the other countries than themselves, the higher measure is of France (57.38), while the lowest is the one of Italy (48.01).

The "TO" column shows a strong variation by all countries, like France from 55.09 to 67.17 (is also the highest value) and Spain from 43.81 to 50.81.

After analysing the "FROM" and "TO" measures, the net total directional connectedness values are of 9.79 for France, confirmed again as the more powerful country of the four and Italy as the weakest with -9.29.

As anticipated at the beginning, it is possible to confirm that the raise in the 10-year yields in 2010 exposed the countries to a strong reaction respect to the other maturities.

To sum up the previous Tables 5.a-b till 7.a-b, it is important to highlight the main features that came out in the analysis of the subperiods, these are:

- The fact that the total connectedness increases as the maturity of the yields gets longer is evident also in the cases with subperiods, in fact in both the subperiods the measure increased from the 2-year to the 10-year maturity.
- The Diebold-Yilmaz model showed that dividing the sample in subperiods the level of connectedness is not always the same but depends on the specific years of that subperiod and the measure on the full-sample is a "mean" of the connectedness that goes from 2000 to 2022. In the subperiods of 2000-2005 and 2010-2016 was evident how the level of connectedness was high in the first case, representing the close trend of the yields in the Graphs of Section 3.1.3 and the low connectedness of the second subperiod, the one of the sovereign debt crisis.
- Looking at the Tables 5.a-b and Tables 7.a-b the situation of Italy took different directions. In Table 5.a of the 2000-2005 subperiod, Italy was for the first time the country with the better Net total directional connectedness measures (2.75), while France had the worst position of the four (-3.92), the opposite of what happened in the full-sample Graph. However, as the maturity increased, the situation changed and in the Table 7.a France ended with the best values, recalling the situation of the full-sample, while Italy reduced its performances till 0.23; this for demonstrating how increasing the maturity of the bond yields the connectedness measures of the countries are able to change significantly.

In the subperiod 2010-2016 Italy started with a negative value in Table 5.b (-5.15), continuing to be the worst country in terms of Net total directional connectedness and reaching a value of -9.29 in Table 7.b.

- It is interesting the fact that in the subperiod 2000-2005, the one with the highest total connectedness measure, all the countries have balanced measures, which ranged between 23-26 in Tables 5.a and 6.a and reduced to 24-25 in Table 7.a. This phenomenon should mean that when there is a high connectedness between the countries inside a determined area, they tend to be connected each other and by its own-effects for the same value, without stronger relationship.

3.2.4 Dynamic analysis

In this part of the paper will be described the dynamic analysis of the Diebold and Yilmaz model (2014), the predictive horizon H is always 1, while the range of the rolling window is equal to 12 that, dealing with monthly data, corresponds to 12 months/1 year ahead. On

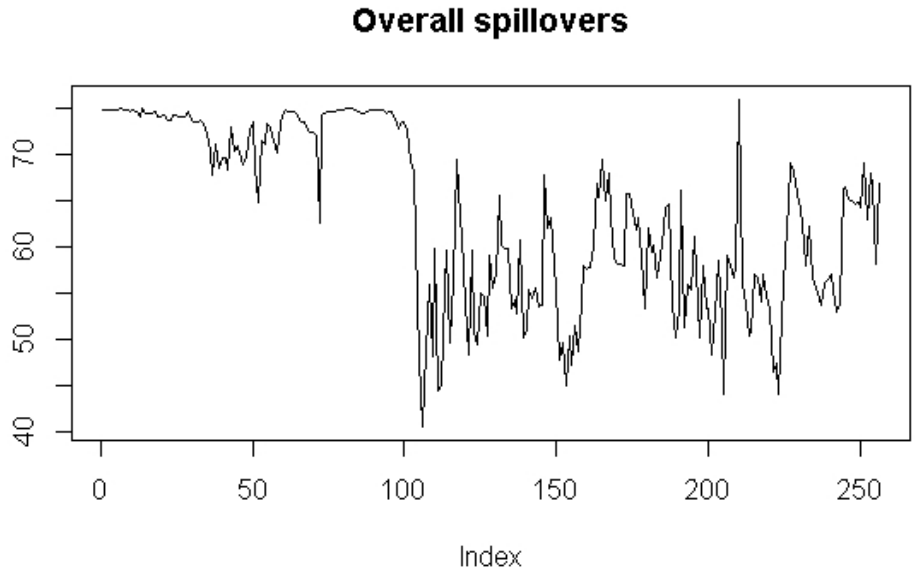
the x-axis are printed the number of observations, thus dealing with monthly data the time is distributed in this way: 0 is on January 2000, 50 is on February 2004, 100 is on April 2008, 150 is on June 2012, 200 is on August 2016, 250 is on October 2020 and the last 17 observations go from November 2020 till March 2022.

The analysis will consider the graphs about total connectedness (the highlighted cell of the connectedness Tables), the pairwise directional connectedness between countries in details and the net total directional connectedness measures.

About the total connectedness is important to show how the strength between all the countries has evolved during the period considered, giving the possibility of explaining the possible variations of the measures; the pairwise directional connectedness in this case permits to see for each combination of the chosen four countries how strong their relationships were during the period and how changed; finally, the "net" measure is the one that shows how much that country impacted on the others or received from the others.

2-year maturity

Graph 40: Overall/Total connectedness of the four selected countries' 2-year yields in period 2000-2022



Source: Own production with Bloomberg data (2000-2022)

NB: Obs 0-50 equal to 01/2000-02/2004; obs 51-100 equal to 03/2004-04/2008; obs 101-150 equal to 05/2008-06/2012; obs 151-200 equal to 07/2012-08/2016; obs 201-266 equal to 09/2016-03/2022

Starting from Graph 40, it is evident how the measure's trend had two cycles during the sample period.

In fact, the first one started at the beginning (2000) till the first period of the global financial crisis (2007-2008) and the total connectedness remained sufficiently constant to 75, meaning that inside the four countries and probably inside the entire euro area there

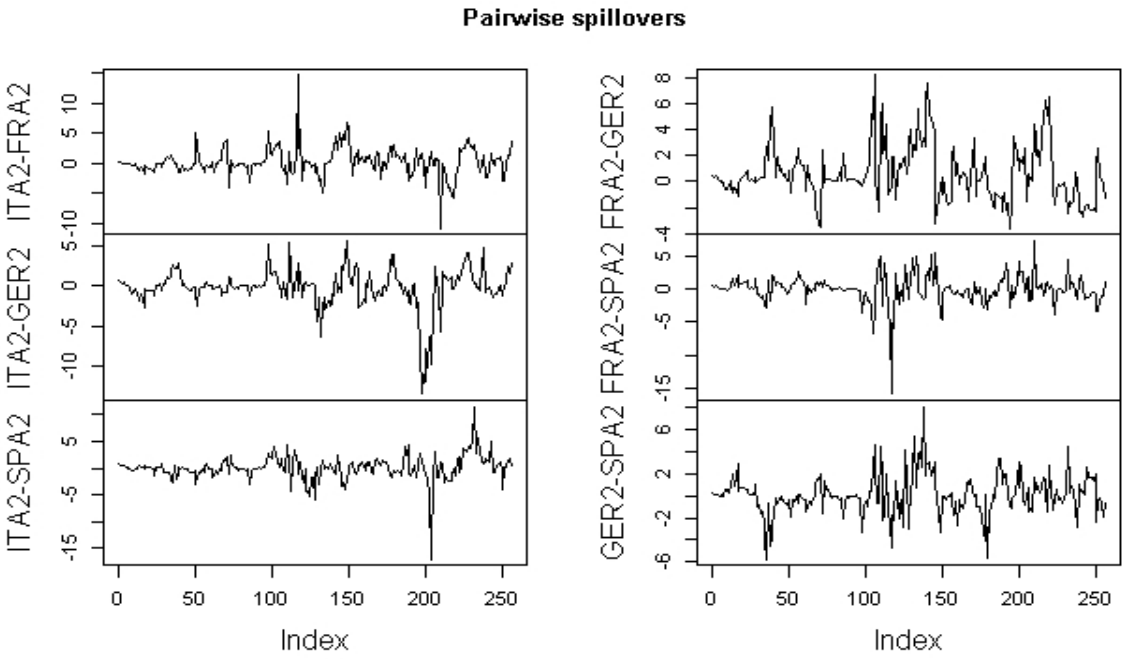
was a strong connectedness between them. After that period till 2022 the trend became highly volatile, reaching even a total connectedness of 40 and characterized the second cycle. Behind this behaviour it is obvious that the economic events that touched the euro area, first with the global financial crisis and later with the sovereign debt crisis, created a period of instability inside these four countries.

As anticipated in precedent Sections, with the sovereign debt crisis Greece accumulated a large spread that damaged also the Irish and Portuguese government bond markets, leading Spain and Italy to an increasing spread with the German Bund at middle-2011; thus, this event summed up with later shocks, leaded the connectedness inside the euro area to weaken in time.

After the sudden drop of the sovereign yields around 2008, there was a complicated recovery till a peak reached around 2014 close to 70, probably due to the better economic situation.

Later, again the connectedness felt back slowly for about 2 years reaching the 45% level of connectedness around Mid-2016, followed by a sudden and significant increment of the total connectedness that for a brief period touched the 75% total connectedness as the one of the first years. Finally, the measure went up and down many times for concluding in 2022 with a measure around 55-60%.

Graph 41: Pairwise directional connectedness of the four selected countries' 2-year yields in period 2000-2022



Source: Own production with Bloomberg data (2000-2022)

NB: Obs 0-50 equal to 01/2000-02/2004; obs 51-100 equal to 03/2004-04/2008; obs 101-150 equal to 05/2008-06/2012; obs 151-200 equal to 07/2012-08/2016; obs 201-266 equal to 09/2016-03/2022

In the Graph 41 are drawn the levels of pairwise directional connectedness between the four countries during all the period considered in the sample.

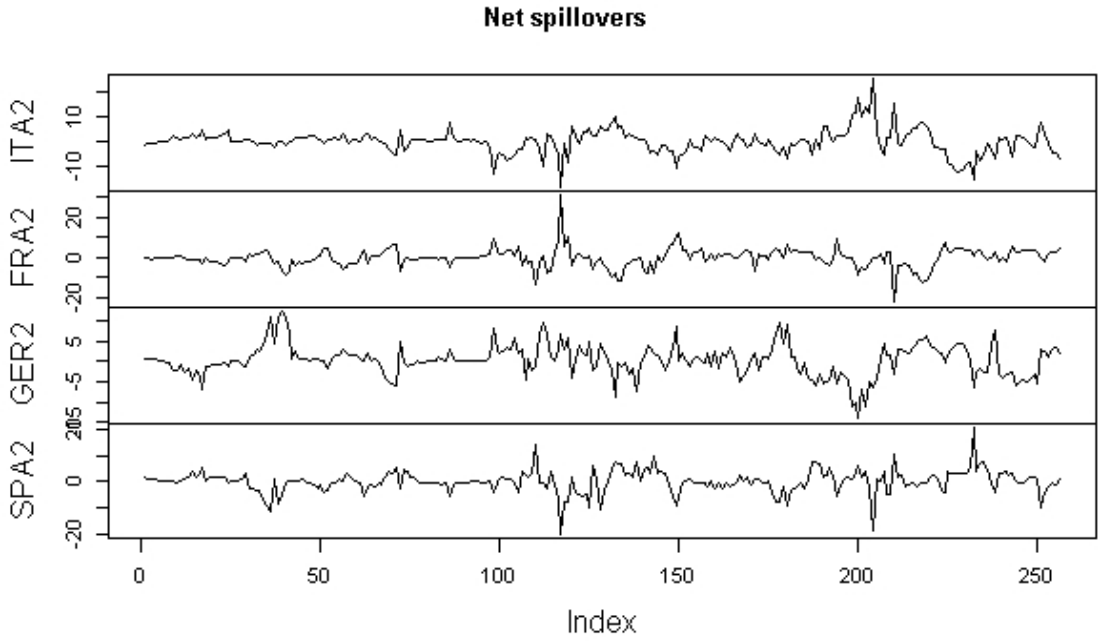
At a first look is possible to notice that some graphs have different upper and lower limits, meaning that the range and the magnitude of this measure seems similar but the magnitude of the changes is different.

In fact, the ITA-FRA graph has (-10)-15 as limits and ITA-SPA has (-15)-10, which have the same range but, in the first case with France, there are variations that go from a maximum of 15 to a minimum of -10, while in the latter the variations go from 10 till -15; in conclusion, the relationship of Italy with France is stronger respect to the one with Spain because reached higher maximum and lower minimum.

Looking at the graphs, the three with Italy have a similar behaviour till around April 2008, with the Germany and France the measure was around 0 apart some variations of -/+5, while with Spain the variations were more contained.

After April 2008 and so the developing of the global financial crisis for Italy, mainly with France and Germany, the volatility inside the graph started to increase, but the variations were almost always positive imposing a stronger relationship between those countries. However, with all three countries Italy suffered a strong reduction of the connectedness till -10/-15 around Mid-2016, certifying the weakness of Italy towards the core and peripherical countries, the reduction was stronger with Germany.

Graph 42: Net total directional connectedness of the four selected countries' 2-year yields in period 2000-2022



Source: Own production with Bloomberg data (2000-2022)

NB: Obs 0-50 equal to 01/2000-02/2004; obs 51-100 equal to 03/2004-04/2008; obs 101-150 equal to 05/2008-06/2012; obs 151-200 equal to 07/2012-08/2016; obs 201-266 equal to 09/2016-03/2022

Graph 42 shows the net total directional connectedness, precisely the difference between the "TO" and "FROM" measures, more is positive and high the net result better is for that country because means that is more the connectedness that gives to the other than the received one.

Also, here the graphs have different upper and lower limits, in facts Germany and Italy show the narrowest range with (-15)-10 and (-10)-15; for Spain and France the ranges are (-20)-20 and (-20)-25.

The country which suffered the most frequent variations is Spain because, as France, the range is larger than Italy and Germany, thus a variation in Spain that seems similar to the one of the previous countries in reality is much wider.

In fact, considering the first period that goes from 2000 till 2008-2009, the "Net" measure suffered some significant variations, like end-2002/2003 where the measure reached -10, while the other countries registered a high a positive value (Germany) or remained stable (Italy and France).

The effects of the financial crisis did not gave an immediate effect on this measure, in fact it started to show a higher volatility only during the end of 2008 and all 2009; Italy started before the other countries to respond in a negative way to the economic shock registering a negative Net value (-10/-15) during all the specified period, while Germany and, after an initial drop, France saw an increasing Net value with the first reaching almost 10 and the latter with a peak of 20.

It demonstrates that in periods of crisis not all the countries respond at the same time, Spain and Italy saw a weakening of their capacity to influence the others while France and Germany saw the opposite, probably due to their better economic situation and credibility inside the euro area.

Moving ahead, it is possible to notice that this period of instability lasted also during the debt sovereign crisis, stabilizing again after Mid-2012.

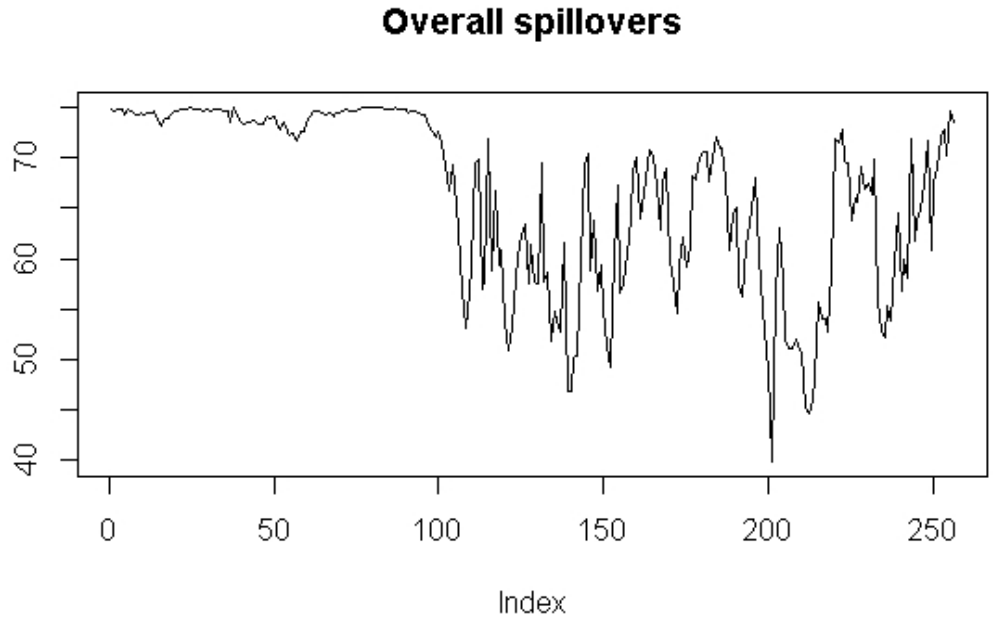
In this period of almost three years, Germany and France saw a reduction on the "Net" measure, while Italy and Spain saw a positive recover with measures of 5/10.

After that, the situation saw a higher volatility than the first period but more or less stable, while another shock is possible to notice around 2016-2017 where Italy saw a significant increment of this measure with a peak of almost 15 and then a stabilization again close to 0, while the other countries saw a drop with peaks of -15/-20 and then a recover till a value of 0-5.

After this variation the situation remains more or less stable with some changes versus positive or negative values but nothing too significant, indicating that the Covid-19 pandemic did not deteriorate a lot the connectedness capacity of the countries.

5-year maturity

Graph 43: Overall/Total connectedness of the four selected countries' 5-year yields in period 2000-2022



Source: Own production with Bloomberg data (2000-2022)

NB: Obs 0-50 equal to 01/2000-02/2004; obs 51-100 equal to 03/2004-04/2008; obs 101-150 equal to 05/2008-06/2012; obs 151-200 equal to 07/2012-08/2016; obs 201-266 equal to 09/2016-03/2022

Looking now to the 5-year yields maturity is evident how in the first period highlighted in Graph 42 (2000-2008), the line of the total connectedness in Graph 43 is more stable around the 72-75 than before, where in some period reached even a level of 60, confirming that if the maturity is longer will be less probable to see the shocks strong as in the shorter term one.

Also, after the first period the level of total connectedness is smoother than before, during the global financial crisis the volatility obviously increased but with an unstable trend, the lowest measure reached was of almost 50, while previously was of almost 40.

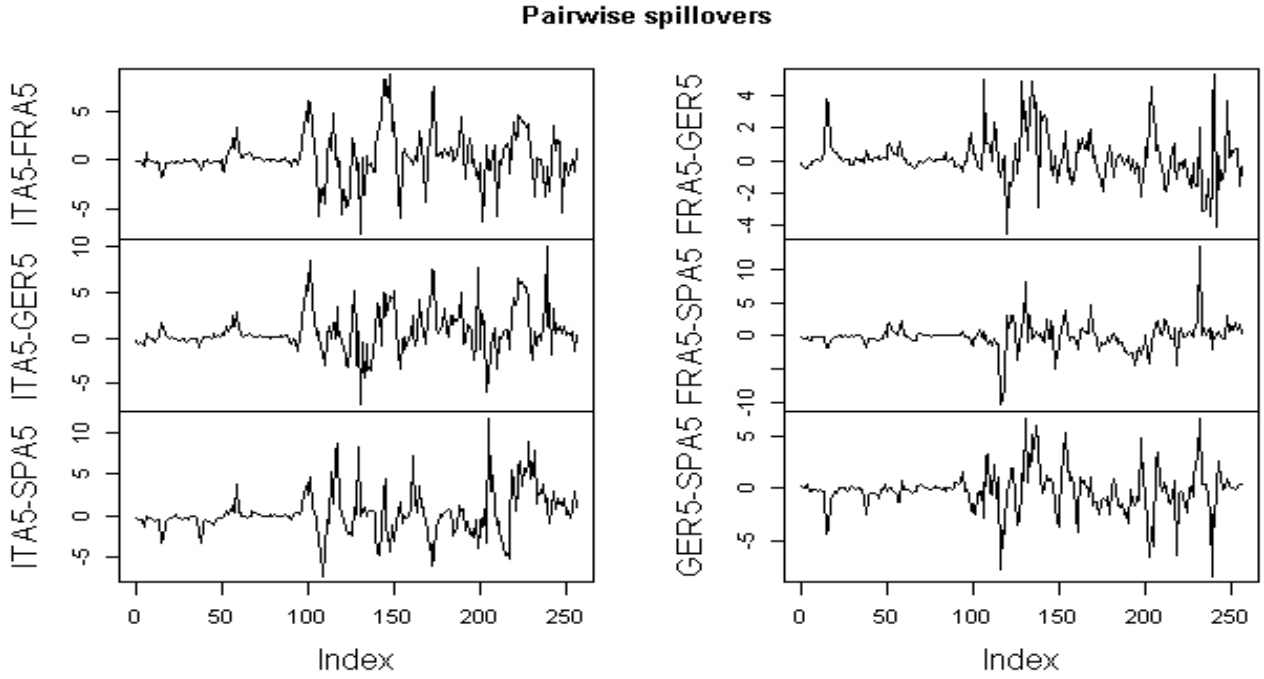
Thus, with the sudden drop caused by the global financial crisis, the impact on connectedness is reduced by 10 points only getting a longer maturity of three years.

Later, with the sovereign debt crisis the instable trend of the measure does not change a lot from before, apart from the fact that the connectedness reached a lower peak equal to 46-48.

In the subsequent period, the total connectedness started slowly to recover some points even if the highs and lows were very frequent, passing from 65-70 to 45-50 in narrow periods.

In the period that goes from End-2015 till 2022 it is possible to notice a growing trend of the measure passing from 50 till the original level of 75, demonstrating again that the economic shock due to Covid-19 did not attach the connectedness capacity between the countries.

Graph 44: Pairwise directional connectedness of the four selected countries' 5-year yields in period 2000-2022



Source: Own production with Bloomberg data (2000-2022)

NB: Obs 0-50 equal to 01/2000-02/2004; obs 51-100 equal to 03/2004-04/2008; obs 101-150 equal to 05/2008-06/2012; obs 151-200 equal to 07/2012-08/2016; obs 201-266 equal to 09/2016-03/2022

Moving to Graph 44, also here the upper and lower limits are different in some graphs, but what is important to notice is that the range in some graphs is reduced while in other is the same, but not bigger; for example, ITA-FRA was of (-10)-15 and now is of (-7/8)-7/8. The reason why the level of pairwise directional connectedness now is more contained is the fact that the maturity of the yields is longer than before and, as seen with Graph 43, the reaction in the level of connectedness after some economic shocks is smoother, thus also the measures in the pairwise directional connectedness will be less strong and more contained than before.

However, looking at all the six graphs, the situation seems to be more instable than in Graph 41, with higher and more frequent shocks, but this is mainly due to the reduction

of the limits and what seems to have a stronger reaction, in reality is the same as before only seen with a wider framework.

After that, it is possible to analyse the fact that all the graphs changed something from Graph 41, but in some cases the difference is more evident like in the FRA-SPA graph. In fact, during the period that went from 2000 till the global financial crisis the trend is more stable around 0 than Graph 41 where the variations were frequent and there was no long stability.

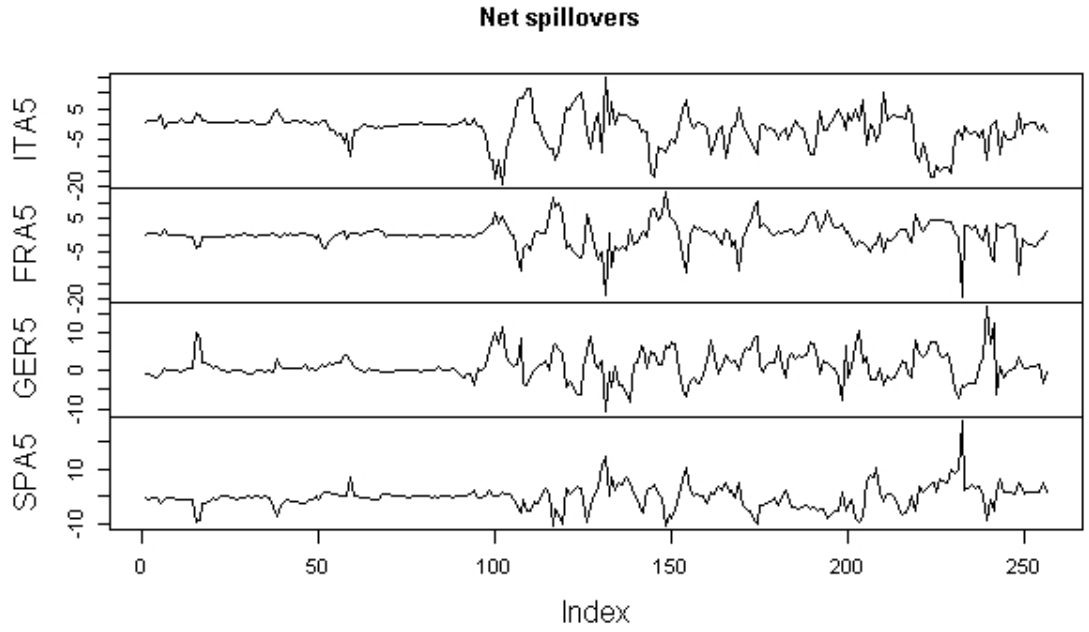
Another point is that is present a positive peak around Mid-2018 equal to >10, while in Graph 41 there was only a negative peak around 2009 equal to -10.

Other differences could be noticed in the graphs that Italy has with Germany and Spain. In the first case the upper limit has been increased to +10 and reduced to -5 meaning that the connectedness between them reached levels higher than the previous one; then, looking at the above graph the behaviour of the measure around April 2008 is volatile but there is not a unique peak, while in Graph 41 the situation was different.

Around Mid-2016 there was a huge negative peak equal to >-10 and the other values are not higher than +5, thus with a larger maturity the connectedness of Italy with Germany became stronger.

About the graph of Italy and Spain the situation is similar with the previous one, but dealing with two peripherical countries that also in the static analysis demonstrated a strong connectedness, is evident how the graph showed the same range of ITA-GER. Besides, in Graph 41 there was a deeper negative peak between ITA-SPA equal to -15 that is not present in the above one; thus, also here the longer maturity permitted to Italy the improvement of its situation.

Graph 45: Net total directional connectedness of the four selected countries' 5-year yields in period 2000-2022



Source: Own production with Bloomberg data (2000-2022)

NB: Obs 0-50 equal to 01/2000-02/2004; obs 51-100 equal to 03/2004-04/2008; obs 101-150 equal to 05/2008-06/2012; obs 151-200 equal to 07/2012-08/2016; obs 201-266 equal to 09/2016-03/2022

In Graph 45 is again evident how the limits between countries are different and that Spain, France and Germany saw a reduction on their range.

One reason may be the fact that a smoother situation of the yields leaded to lower reaction in both positive and negative directions after some economic events.

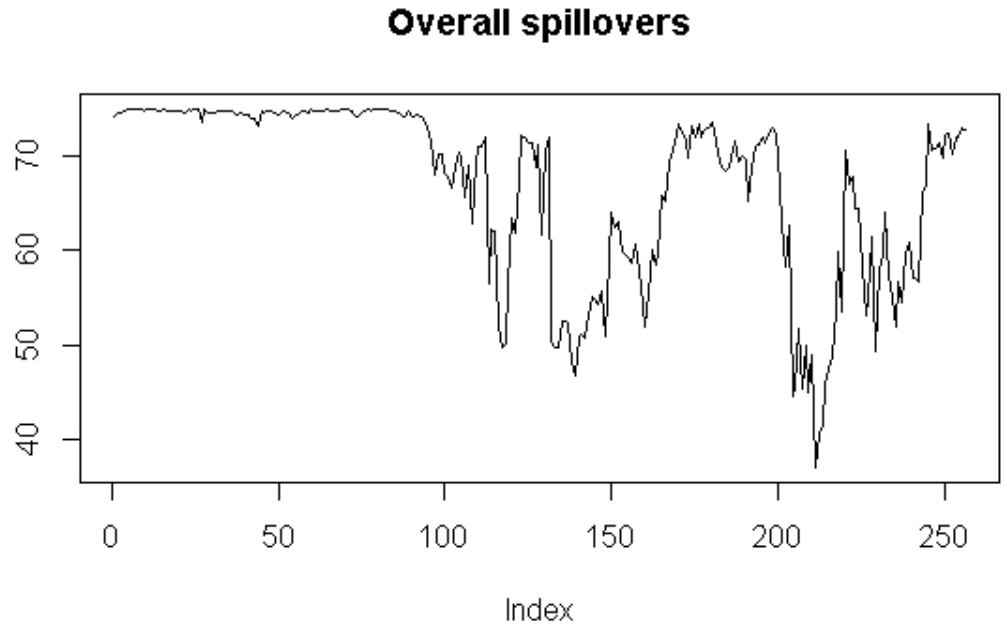
As seen in Graphs 43-44, a smoother situation increased the total connectedness and the pairwise one between the countries; due to this the "FROM" and "TO" measures tended to increase, probably with a light different magnitude, leading to lower and more stable peaks and so to a more stable net total directional connectedness measure.

Looking to the single countries Italy was the only country that increased its range, meaning that even if the yields were smoother the situation of Italy is still highly volatile and weaker than the other three countries.

With an overall view of the situation, the trend was mainly stable till the beginning of the financial crisis and later started to be more volatile and unstable; however, looking at the graph of France is impressive to see how the country which ended up with the best performances in almost all the connectedness tables of the static analysis, here has the same ranges of Italy, the country with the worst performances. This means that even if a country is on average the first in giving connectedness to others it does not exclude that it can suffer bad moments and deep drops.

10-year maturity

Graph 46: Overall/Total connectedness of the four selected countries' 10-year yields in period 2000-2022



Source: Own production with Bloomberg data (2000-2022)

NB: Obs 0-50 equal to 01/2000-02/2004; obs 51-100 equal to 03/2004-04/2008; obs 101-150 equal to 05/2008-06/2012; obs 151-200 equal to 07/2012-08/2016; obs 201-266 equal to 09/2016-03/2022

The maturity of the yields now is doubled than before and the first part of the total connectedness, that goes from 2000 till the beginning of the global financial crisis, is constant to 74-75 apart for some brief period, but the little negative peaks that were visible in Graph 43, now are almost in line with the other observations.

Moving to later periods, the period that goes from Mid-2008 to 2013 is shown on Graph 43 as a volatile but constant reduction of the total connectedness around a measure of 47-55, but in this case the drop is less volatile and more persistent.

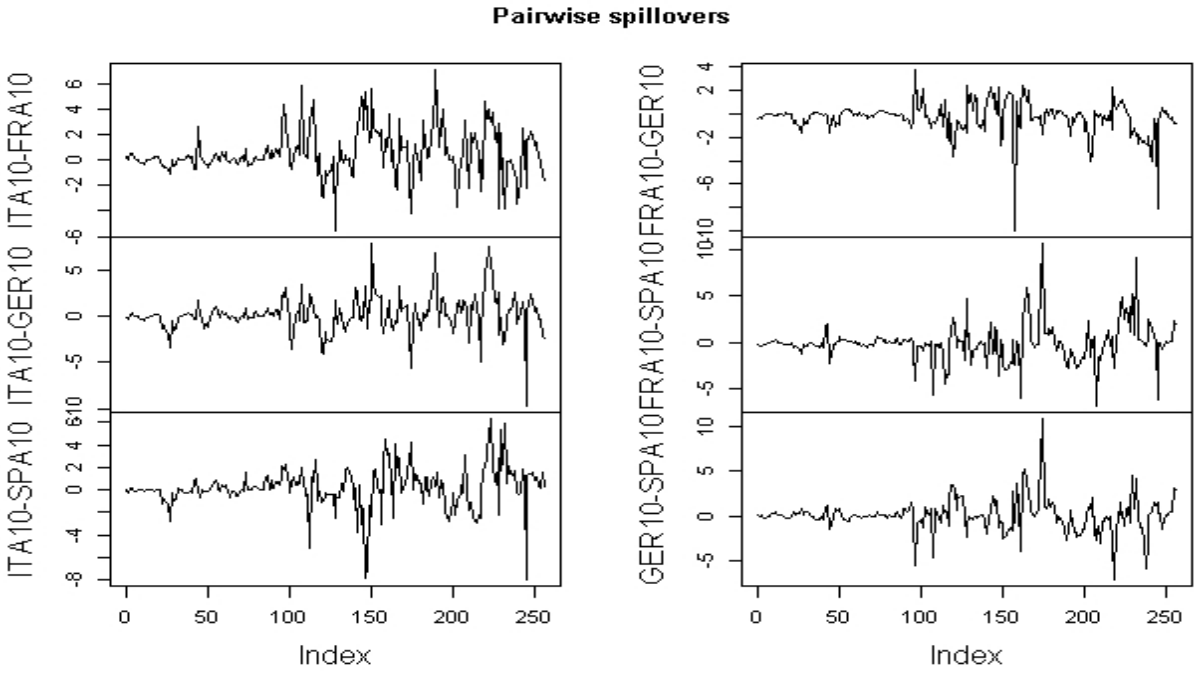
In fact, there is a first negative peak around the beginning of 2010 equal to 50, recovered almost immediately, and a second one later circa at the end of 2011 equal to 47/50 that lasts for a longer period with some variations till 2013.

Also, in this case the sovereign debt crisis had a stronger impact on the yields than the global financial crisis one, in fact during the period 2007-2009 the total connectedness value suffered only a deep drop but in the rest of the period stayed mainly stable around 65-70, while with the sovereign debt crisis the drop was persistent 50-60, a significant reduction.

The lowest peak was reached around the end of 2016 with a value of <40, the lowest of the three maturities even if with longer-term yields the effects seemed to be less strong than in the shorter one.

Later, till the end of the sample period it is possible to see an increasing trend of connectedness with periods characterized by higher volatility, concluding with a value of 70/72; also, in this case the impact of Covid-19 in the euro area seems not to damage the connectedness between countries, even the opposite.

Graph 47: Pairwise directional connectedness of the four selected countries' 10-year yields in period 2000-2022



Source: Own production with Bloomberg data (2000-2022)

NB: Obs 0-50 equal to 01/2000-02/2004; obs 51-100 equal to 03/2004-04/2008; obs 101-150 equal to 05/2008-06/2012; obs 151-200 equal to 07/2012-08/2016; obs 201-266 equal to 09/2016-03/2022

The last set of graphs about the pairwise directional connectedness measures in Graph 47 show different ranges in some graphs from the previous one, but the changes are not too significant.

What it is important is that the structure is more similar to Graph 44 than Graph 41, in fact the limits are slightly narrower and the first period (from 2000-2008) is more stable and constant around 0 for all the combinations.

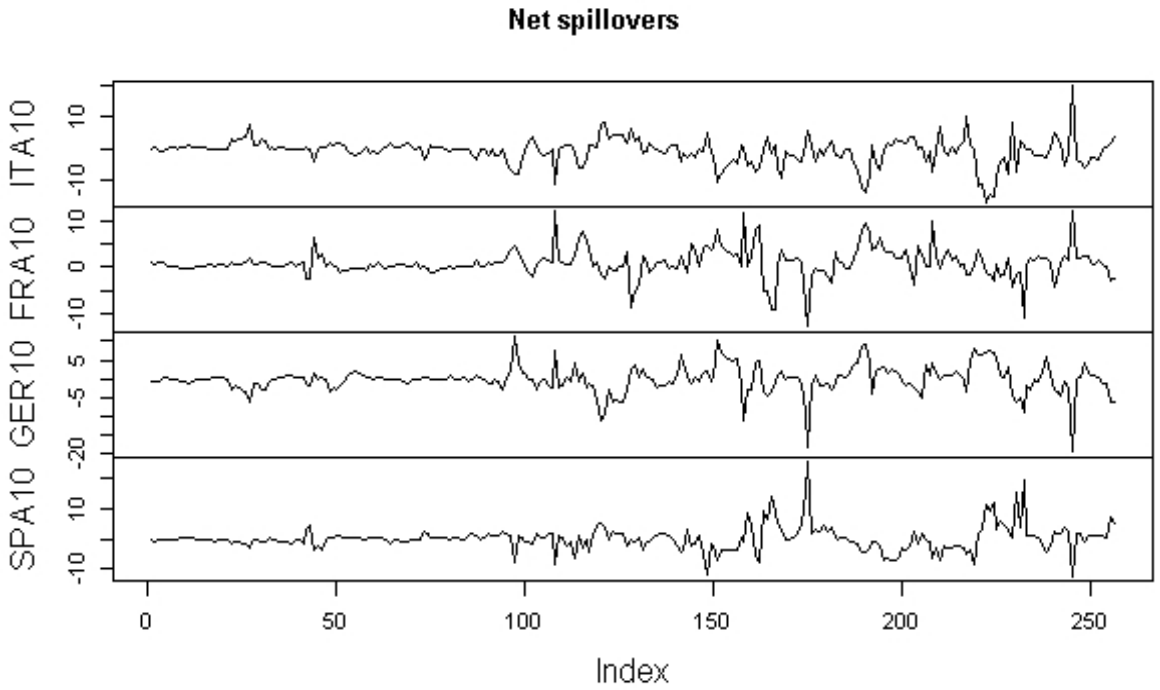
However, the level of connectedness seems to be smoother than before, but there are some parts where the pairwise directional connectedness reached high negative levels; for example, in the FRA-GER graph the trend is mainly stable, but around the Mid-2012 with the sovereign debt crisis, the strongest countries of the four suffered a deep period of separation in terms of connectedness, with a drop equal to -10, the lowest value touched by these two countries.

Another drop is in the graph ITA-SPA, the limits from Graph 44 moved to lower values, meaning that the maximum level is lower and the minimum value is deeper; looking at

the graph is noticeable that the level is highly volatile during the sample period, and around Mid-2012 started to show an even more presence of negative values, the most important peaks are around the just mentioned period equal to -6/-5, and the second one with a similar value but an unexpected drop at the beginning of 2017.

What is possible to notice from the description of these two graphs, is how the sovereign debt crisis leaded to a separation between the relationship of FRA-GER and ITA-SPA.

Graph 48: Net total directional connectedness of the four selected countries' 10-year yields in period 2000-2022



Source: Own production with Bloomberg data (2000-2022)

NB: Obs 0-50 equal to 01/2000-02/2004; obs 51-100 equal to 03/2004-04/2008; obs 101-150 equal to 05/2008-06/2012; obs 151-200 equal to 07/2012-08/2016; obs 201-266 equal to 09/2016-03/2022

In the description of Graph 48 on the net total directional connectedness, it is important to show again how the limits changed from Graph 45, in order to understand if also here the smoother trend is confirmed or not; at a first look, Germany increased its limits towards negative values, from (-10)-15 to (-20)-10, while France and Italy demonstrated a tightening of their range meaning that the net total directional connectedness that they registered in the sample period are more constant than before, finally Spain maintained the same range.

After analysing the change in limits, with the comparison of Graph 45 is evident how the yields created a more stable trend than before.

The country which showed the higher change is Italy, in fact its range has been reduced and around the period from 2008 till Mid-2012 the level of connectedness is more

balanced with relative small values; the only drop is present circa at 2018 reaching the lower limit of <-10, while right before the Covid-19 diffusion, Italy showed a sudden peak till the upper limit of 15 and the same thing happened also to France, while Spain and Germany suffered a drop (Germany reached the lowest value equal to -20).

Moving to the other countries, the situations are more stable than in Graph 45 with more contained volatility, but during 2014 there was a sudden change in volatility that for Spain was a positive peak equal to >15, while for France and Germany was a drop that reached in the first case <-10 and in the latter about -20.

Another case where countries took different directions is around the beginning of the pandemic, in fact in the previous graphs the Covid-19 period was an event that leaded to an increasing connectedness between the countries.

However, in this case for the peripherical countries, Italy and Spain, the final sample period showed an increasing trend, while for the core countries, France and Germany, the pandemic leaded to a reduction of the net total directional connectedness; this could mean that in Graph 48 Covid-19 implies reinforcing connectedness measure between the peripherical countries rather than the core one, even if Italy and Spain in the first period suffered a lot the pandemic for restrictions and high contagion numbers.

To sum up the dynamic analysis of the model, it is necessary to point out some features about the four countries that came out in Graphs 40-48:

-The first one is that the Graphs 40,43,46 highlighted how the measure is more stable as the maturity increased. In fact, in the first period till 2008 the level stayed even more stable around 75 increasing the maturity, while for the later period the negative reductions were more contained.

-Even if there were countries as Germany and France with better economic conditions than Italy and Spain, from the pairwise directional connectedness and the Net directional one is evident how during the sample period all countries suffered deep drop and highly volatile periods.

-Considering the economic shocks described in Chapter I, here is more evident how the period around 2001 with increment of oil prices, uncertainty due to the US economy after the Twin Tower's attack and the slow-down of EMU, they do not attach a lot the connectedness between the countries, maintaining the highest level reached during the 20 years. Another event that did not disturb the connectedness between countries is Covid-19, in fact during the first period of 2020 more or less all the four countries were at the same time in lockdown with similar restrictions, but later the government decisions were

different inside the euro area and some countries suffered difficult periods while others were better, nevertheless from the above graphs is evident how this pandemic leaded to a stronger connectedness between the euro area, even increasing the measure.

Conclusion

The main results of the thesis can be summarized as follows. The empirical analysis shows that the global financial crisis and the sovereign debt crisis changed the relationships between core and peripherical countries. In particular, the total connectedness measure became stronger and increasing with maturity.

In the analysis for subperiods, it is evident that the connectedness measures are more balanced in all countries, with values between 23-26 for the subperiod 2000-2005.

This shows that a "quiet" situation of the bond market was transformed into an equal connectedness between both peripherical and core countries. Probably in future periods, when the euro area situation will be again economically stable, it will be possible to see a common influence and equal degree of connectedness between core and peripherical countries.

On the opposite case, looking at the second subperiod analysed (2010-2016), the situation is inverted. In fact, the sovereign debt crisis implied higher volatility yields, with a strong trend difference between peripherical countries (high yields and increasing trend) and core countries (lower yields and stable/decreasing trend).

This inverse situation permits to highlight that even if events in 2001 and Covid-19 saw some economic shocks in terms of inflation, volatile oil prices and a pandemic, they did not attach the degree of connectedness of the bond market, maintaining the same levels of the previous periods. Thus, using this model it is possible to see that systemic risk did not move significantly in these two specific periods, even though Covid-19 effects in economy and everyday life are still present, and also that not always an economic shock leads to a weakening of the connectedness measures of the euro area.

Another feature that came out mainly inside the static analysis is the unexpected weak connectedness that Germany had in all the years analysed.

Evident since the connectedness measures of the model with all ten countries was, in particular, the weak connectedness towards Italy. In fact, in the static analysis with the four selected countries, Germany and Italy reached even a value equal to 0 in subperiod 2010-2016 with 5-year maturity yields, but the performances of Germany were not so different also with the other countries. In fact, in almost all the static analysis part, the level of the Net total directional connectedness was lower than the one of France and slightly higher than the measures of the peripherical countries.

An opposite performance was the one of France, which in almost all the connectedness measures of the static analysis collected the highest values on the "TO" and Net total directional connectedness measures, in the latter case the highest value reached was 9.79 in subperiod 2010-2016 with 10-year maturity yields.

The other interesting feature is the smoother behaviour of the connectedness measures in the dynamic analysis as the maturity of yields increased. This is evident due to a reduced volatility during the periods corresponding to the economic shocks of the euro area and between the pairwise directional connectedness measures of the countries.

In fact, in the pairwise directional connectedness graphs the limits are reduced as the yields move from 2- to 10-year maturity, showing also lower volatility and a more stable trend during the sample period. Inside the sovereign bond market this would lead to the conclusion that longer yields are riskier and higher but, at the same time, they seem to be less vulnerable to economic shocks than shorter term yields and are prone to increment the connectedness between countries.

One important point is that using the Diebold-Yilmaz model is possible to confirm that in periods of low total connectedness, like during the sovereign debt crisis, it is more evident the break between "strong" countries like Germany and France, characterized by stable and low yields, and "weak" countries like Italy and Spain with high yields.

Thus, during normal periods without significant shocks in yields the connectedness between Germany, France, Italy and Spain seems to be more balanced. Instead, during difficult periods and volatile yields, it is evident how the reaction of core and peripherical countries is different. Finally, core countries tend to have always a better reaction to these shocks, leading to lower damages inside the sovereign bond market and the economy.

In conclusion, the use of the Diebold-Yilmaz model to analyse the degree of connectedness within the euro area, has proven to be an efficient tool to examine in a very detailed way how "strong" and "weak" countries have reacted to different bond market situations.

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