Charles University in Prague

Faculty of Social Sciences

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Central Bank Communication and Correlation between Financial Markets: Evidence from the Euro Area

Master's Thesis

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Declaration of Authorship

The author hereby declares that he compiled this thesis independently, using only the listed resources and literature, and the thesis has not been used to obtain a different or the same degree.

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Prague, January 4, 2019

Signature

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Bibliografický záznam

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Abstract

The aim of this thesis is to assess the effect of ECB's communication on financial market co-movements between Italy, Spain, Germany and France using MGARCH family of models. Author addresses partially the potential problem of endogeneity of central bank communication by using Composite indicator of systemic stress and excess liquidity. The author estimates the impact of ECB's communication on correlations of government bond yield changes using daily data from 2008 to 2014. For this purpose author employs bivariate diagonal BEKK(1,1) and bivariate scalar BEKK(1,1) with surprises of macroeconomic announcements under control. The results are consistent and robust for all models, the results suggest that communication does not have statistically significant effect on financial market correlations in the Euro area. Furthermore, author defines delta functions which describe and quantify the immediate and full effect of explanatory variables on conditional correlations in bivariate diagonal BEKK(1,1) and bivariate scalar BEKK(1,1). To the best of author's knowledge this thesis is the only one in the literature which examines this effect of ECB's communication by MGARCH models.

Keywords: Financial markets, central bank communication, correlation, MGARCH, BEKK

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Abstrakt

Cílem této práce je posoudit dopad komunikace ECB na společné pohyby finančních trhů mezi Itálií, Španělskem, Německem a Francií použitím MGARCH modelů. Autor částečně řeší potenciální problém s endogenitou komunikace centrální banky použitím Složeného ukazatele systémového stresu a přebytečnou likviditou. Autor odhaduje dopad komunikace ECB na korelace změn ve výnosech vládních dluhopisů použitím denních dat pro období 2008-2014. Pro tenhle účel autor používá diagonální BEKK(1,1) a skalární BEKK(1,1) modely se dvěma závislými proměnnými při zahrnutí překvapení v makroekonomických oznámeních. Výsledky jsou konzistentní a robustní pro všechny modely, ukazují, že komunikace nemá statisticky významný dopad na korelace finančních trhů v Eurozóně. Navíc autor definuje delta funkce, které popisují a vyčíslují okamžitý a plný efekt vysvětlujících proměnných na podmíněné korelace v diagonálním BEKK(1,1) a skalárním BEKK(1,1) modelu se dvěma závislými proměnnými. Podle nejlepšího autorova vědomí je toto jediná práce zkoumající tento efekt komunikace ECB pomocí MGARCH modelů v literatuře.

Klíčová slova: Finanční trhy, komunikace centrální banky, korelace, MGARCH, BEKK

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Acronyms

ACF	Autocorrelation function
ADF	Augmented Dickey-Fuller
AIC	Akaike information criterion
CESI	Citigroup Economic Surprise index
CISS	Composite indicator of systemic stress
CNB	Czech National Bank
ECB	European Central Bank
EMH	Efficient market hypothesis
GARCH	Generalized autoregressive conditional heteroskedasticity
GO-GARCH	Generalized orthogonal – Generalized autoregressive conditional heteroskedasticity
HQIC	Hannan-Quinn information criterion
KPSS	Kwiatkowski–Phillips–Schmidt–Shin
MGARCH	Multivariate Generalized autoregressive conditional heteroskedasticity
O-GARCH	Orthogonal - Generalized autoregressive conditional heteroskedasticity
PACF	Partial autocorrelation function
SIC	Schwarz information criterion
S&P	Standard & Poor´s
UK	United Kingdom
US	United States
USA	United States of America

Master's Thesis Proposal

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Proposed Topic:

Central bank communication and correlation between financial markets: Evidence from the Euro Area

Motivation:

For the purposes of monetary policy and policy actions is very important to know about the influence of central bank communication on financial market correlations. The importance of examining these effects has increased as central bank communication practices have changed and well as the fact that the integration of financial markets has increased. Central banks now tend to be more transparent about their policies, decisions and actions to the public.

Hayo et al. (2010) examine the effects of Federal Open Market Committee members' communications on European and Pacific equity market returns, while both of them respond to US Fed events.

However, to the best of my knowledge there are only two studies focused on the effect of central bank communication on financial market comovements. Beck et al. (2012) focus on US and Canadian bond and stock markets and examine the effect of central bank communication on the correlation between these two markets. Gertler et al. (2017) examine the effects of ECB's communication on the financial market comovements using financial data for Germany, France, Italy, Spain and the UK. Therefore, there is a scarcity of literature examining this field and motivation to contribute to fill this gap is strong.

Hypotheses:

1. Hypothesis #1: The effect of ECB's communication should be the same across the Euro Area.
2. Hypothesis #2: The ECB's communication affects the conditional comovement of financial markets in the Euro Area

Methodology:

The first step of the econometric analysis is collecting data from national stock markets (or government bonds if available). Gertler and Horvath (2018) will serve as a source of the daily data of ECB's Governing Council members, in short referenced as ECB's communication.

The analysis will focus on pairs of markets using the multivariate GARCH family of models. The most likely filtered series will be used to be able to estimate the model without including all variables. The most appropriate model will be chosen based on information criteria and robust convergence. Beck et al. (2012) found that diagonal-BEKK(1,1) proposed by Engle and Kroner (1995) could be a good compromise for this purpose. However, the model will be selected and discussed later after examining and evaluating the models and results.

Expected Contribution:

I will examine whether ECB's communication affects the financial market co-movements. The scarcity of literature focused on this topic provides an opportunity to widen the research to the areas where this field has not been examined yet. I will provide similar analysis as Beck et al. (2012) on the data for the Euro Area, but this will differ from Gertler et al. (2017), because they employed quantile regressions. Therefore, it will bring another result and probably very interesting implications for ECB's policy as well.

Outline:

1. Introduction and motivation: I will briefly introduce the reader to the topic and give my motivation for studying this field
2. Literature review: I will provide a literature background and their findings relevant to this topic
3. Data: I will explain how the data was compiled and collected etc.
4. Econometric model: I will describe the appropriate model for the analysis and provide reasoning why this is the most suitable
5. Results: In this section, the results of the analysis will be described as well as the robustness of the checks
6. Concluding remarks: I will summarize my findings and their implications for policy and future research.

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Author **Supervisor**

1. Introduction

Financial markets are indisputably of great importance in economics. Financial markets play an important role for the economy and are one of the factors of long-term economic growth (Levine, 2005). Thus analysing the determinants of the evolution of financial markets and the determinants of its fluctuations are useful for both private sector and policy makers. In recent years, the integration and interdependence of financial has increased (see e.g. Ayuso and Blanco (2001) for evidence). Using data from 1800 to 2000, Lothian (2002) reached the conclusion that the globalisation of financial markets is not a new phenomenon. Once financial markets are highly interdependent, it limits the possibility for investors to diversify their portfolios, thus limiting the benefits of diversification.

It is crucial for central banks to know about the consequences of their actions for financial markets as their interdependence. The importance of examining these effects of central bank's action on financial markets has increased during recent years as Gertler et al. (2017) argue that central bank communication practices have changed. Central banks now tend to be more transparent about their policies, decisions and actions to the public (see Dicher and Eichengreen, 2014 or Horvath and Vasko, 2016).

Although we can find a large theoretical background in the literature examining how economic or financial fundamentals influence the financial market co-movements and whether these co-movements cannot be explained only by fundamentals (e.g. Bekaert et al., 2014, Longin and Solnik, 2001), the effects of policy news on co-movements have been examined much less.

To the best of the author's knowledge there are only two studies examining the effect of central bank communication on the co-movements of financial markets (Beck et al., 2012, Gertler et al., 2017). Jonášová (2016) examined the effect of central bank communication on the contagion among countries. More details about recent research in this field can be found in literature review. Therefore, there is scarcity of literature examining this field and the motivation to contribute to the current academic discussion is strong as the contribution is substantial.

This thesis uses the verbal unscheduled communication of the European Central Bank (ECB)'s Governing Council Members from Gertler and Horvath (2018) for examining the ECB's communication influences on financial market co-movements in the Euro area countries – Italy, Spain, Germany and France in particular.

The results of regressions show no statistically significant effect of central bank communication on conditional correlations of government bond yield changes among Euro area countries. The results are in line with the results of Beck et al. (2012) for the impact of speeches between US and Canada; however author uses macroeconomic surprise indices which allow for controlling of the size and side compared to Beck et al. (2012). Further author at least partially predicts the tone of central bank communication and therefore addresses the potential endogeneity. This thesis is to the best of author's knowledge the only work studying the effect of ECB's communication on financial market co-movements in the Euro area using

MGARCH family of models. Further author creates delta functions which describes and quantifies the impact of explanatory variables on conditional correlations in bivariate diagonal BEKK(1,1) and bivariate scalar BEKK(1,1). These functions are also one of the uniqueness of this work.

This thesis consists of six parts. A Literature review follows after the Introduction, where a brief survey of what has already been done in this field will be presented. It will provide the theoretical background for the empirical part of this thesis. Attention will also be paid to different theories about how financial markets function. The next section, Data description, describes the sources of the data, the dataset itself and the necessary transformations of the data that have been made. The fourth section, Empirical methodology, focuses on various methods that could be used for estimating the model, with their advantages and their drawbacks. A discussion about choosing the most appropriate approach will be provided. The fifth part of the thesis, Results, highlights the outcomes and their interpretation. Finally, the Conclusion summarizes the main findings of the thesis together with discussion and recommendation about possible future research in this field.

2. Literature review

This section will provide literature review for the impact of central bank communication on financial markets, however also some of the related topics relevant for this thesis. Therefore, author provides brief theoretical discussion about financial markets generally, including discussion about complexity of ex ante impact of various variables on financial market correlations.

One of the questions that emerged during the changing nature of central bank communication has been the optimal level of transparency of communication. Horvath and Vasko (2016) constructed an index of central bank transparency and showed that there is an optimal level of transparency to promote financial stability.

Kahveci and Odabaş (2016) used a semantic examination of monetary policy statements from the US Federal Reserve and the ECB for period from 2001 to 2015 and the Central Bank of the Republic of Turkey for period from 2002 to 2015 and found no evidence of tone differences in certainty, optimism and the realism over time for ECB as well as for the Central Bank of the Republic of Turkey. The optimistic tone of the US Federal Reserve decreased during the period observed and the tone of certainty has increased.

The main goal of the ECB's monetary policy is to sustain price stability across the whole Euro area. The ECB can achieve this goal by different instruments of monetary policy. One of these ways influencing financial markets are unscheduled speeches and interviews. Gertler et al. (2017) proposed that the ECB's communication will probably increase the financial market co-movements if communication is clear and with respect to the whole Euro area, because financial markets in particular countries will respond equally. Although Gertler et al. (2017) highlight some unconventional policy instruments focused on helping in specific countries, the communication linked to these instruments can also have heterogeneous effect and decrease co-movements of the financial market.

A brief discussion about these hypotheses will be useful. There are three possible outcomes of the influence of ECB's communication on financial market co-movements. Firstly, as mentioned above, the most intuitive outcome observed is that ECB's communication increases the financial market co-movements. In this case the homogenous effect among countries prevails in the Euro area. This can be also interpreted as investors do not distinguish very much between particular countries as the financial markets react mostly the same. The second case is when there is no observed effect of ECB's communication on the co-movements of financial markets. This can be interpreted in different ways. Firstly, the ECB has no effect on financial market co-movements via this channel, because this channel of central bank communication does not represent news for financial markets as the information is already included in prices. Conversely, the financial markets differ between messages e.g. according to the content of the message and to which monetary policy instrument the message is linked to. Another case is when the financial markets can behave differently in times that are more volatile. In both cases, the homogeneous and heterogeneous effects can rule each other and as a result no effect can be observed. The last possible outcome is the heterogeneous effect of

ECB's communication. This can also reflect a negative signal about the financial stability of the Euro as a currency in the event of a financial crisis. The intuition behind this is not trivial. Regarding the geographically focused unconventional policy instruments mentioned in Gertler et al. (2017), when there is a need to use these instruments by the ECB to help some particular countries, it reflects a negative signal about these countries. It can also support the idea about stability or even imperfections in the construction of the Euro area.

A related field in the literature focuses on examining the effects of macroeconomic news on domestic countries and their impact on financial markets in foreign countries. There is an extensive body in literature examining this field and strong evidence is given. However, Connolly and Wang (2001) have tested one interesting hypothesis. They test the hypothesis if the financial market co-movements are driven by economic fundamentals or contagion. They used data from 1985 to 1996 from the US, UK and Japan and found the effect of macro news is too small to account for any economically important part of the return co-movement. The previous foreign market returns show a significant effect on subsequent domestic market returns and obviously contain different information than economic fundamentals. They propose further research in analysing the private information and contagion as results show that equity market co-movements cannot be explained by public information or economic fundamentals. The contagion hypothesis is also supported by the results of King and Wadhwani (1990), and Karolyi and Stulz (1996).

2.1. The effect of central bank on domestic financial markets

The literature provides a great deal of evidence on the significant effect of the communication of central bank on domestic financial markets. The significant effect of central bank communication on financial markets is commonly proven in the literature, regardless of whether data are daily or intraday, or the communication is scheduled or unscheduled.

Gertler and Horvath (2018) used high-frequency data to examine the effect of the ECB's communication on financial markets (interest rates, the exchange rate as well as stock market). Their results show that communication by the central bank affects financial market systematically, especially the interest rates; the evidence for the stock market and the exchange rate is weaker. They also made some interesting checks of robustness and found that the financial markets react differently according to who is talking. The response of financial market was much higher when speeches were made by Draghi as compared to Trichet (using data only for their tenures as President). This was most likely due to their different management styles. They also highlight the fact that ECB's monetary policy committee is comprised of a significantly higher number of members than in typical central banks, thus increasing the probability of referencing the same message to geographically different audiences. Therefore, Gertler and Horvath (2018) claimed that searching for evidence in case of ECB communication can be harder compared to other central banks as the effect might be smaller due to the reason just mentioned.

Similarly, using high-frequency data on currency, stock and bond markets, Ranaldo and Rossi (2009) find a significant effect on the price on financial markets of both monetary policy announcements (representing scheduled central bank communication communication) and speeches and interviews (unscheduled communication) made by the Swiss National Bank. Blinder et al. (2008) provide evidence of a significant effect of central bank communication on financial markets using data for developed countries as does Andersen et al. (2007) with respect to macroeconomic announcements.

Guthrie and Wright (2000) find that the announcements made by the Reserve Bank of New Zealand have a significant effect on interest rate changes and these changes cannot be explained by open market operations. Using data for communication for the Federal Reserve, the Bank of England and the ECB, Ehrmann and Fratzsher (2007) find speeches and interviews to have significant effect on the interest rate in the financial market; this effect has been found to be the largest for the ECB.

Using the data for exchange rates of three Central and Eastern European countries against the Euro, Egert and Kocenda (2012) show that the exchange rates during a pre-crisis period do not react significantly, but during a crisis all exchange rates responded to the verbal actions given by the central bank.

Born et al. (2014), using data from 1996 to 2009 found that speeches and interviews have had a substantial effect during a financial crisis, but do hot help to reduce volatility during tranquil times. On the other hand, Financial Stability Reports reduce financial market volatility and affect stock market returns in the expected way. Using daily data for Fed communication, Kohn and Sack (2003) provided evidence that market rate variance increases on a given day when the Fed makes speeches. Examining the effect of ECB statements on the mean and volatility of the euro-dollar exchange rate, Jansen and de Haan (2003) find evidence that influenced are mainly volatility. However, in some cases there are also effects of the statements on the level of euro-dollar rate itself. Using data from 1997 to 2004, Reeves and Sawicki (2007) analysed the impact of communication by the Bank of England, both scheduled and unscheduled, on the variance of financial markets. They found significant evidence for the effect of scheduled communication; however the unscheduled communication does not show a significant effect on the variance.

Musard-Gies (2006) shows that financial markets react more the change in tone of ECB's communication in comparison with the effect of tone itself. Rosa (2011), using high-frequency data, examines the effect of Federal Reserve's decisions and statements on US stock market indices. The surprise component of Fed has been found to be the significant determinant of stock market indices, for example, 90 % of the explainable variation in S&P 500 is due to it. The US stock markets also incorporate surprises within 40 minutes window after the announcement. Using high-frequency data for the period of 1998-2004, Wongswan (2009) investigated the effect of scheduled US monetary policy announcements on equity indices in Asia, Europe and Latin America. The indices respond to an unexpected change in the target federal funds rate and incorporate this news very quickly (i.e. in a 15 minutes window, which is the shortest period allowed to measure the response).

Siklos and Bohl (2007) support evidence that policy deeds are still more influential than policy words and that statistical evidence of the effect of central bank communication on financial markets can be found for daily data due to aggregation that is too high.

2.2. The effect of central bank communication on foreign financial markets

The effect of central bank communication on foreign financial markets is covered in the literature much less.

Hayo et al. (2010) found that US monetary communications matter significantly for both European and Pacific equity market returns, while European reaction is stronger. Hayo and Neuenkirch (2012) found an evidence of international spillovers for Canadian financial markets in reaction on US macroeconomic shocks and US Federal Reserve actions and communications.

Beck et al. (2012) analysed the conditional co-movement of financial markets between Canada and the USA. They relied on both scheduled and unscheduled central bank communication. For this purpose they used diagonal-BEKK models and found that good compromises between conducting a multivariate analysis and still achieving robust convergence are bivariate diagonal-BEKK(1,1) models originally proposed by Engle and Kroner (1995). The results show that conditional correlation increases following actions taken by central banks.

Jonasova (2016) analyzed the effect of ECB's communication on contagion on financial markets in four countries – Germany, Greece, France and UK. She employed an ordered logit model to estimate the effects of the variables chosen, including the nature of the communication, on the probability of extreme returns joint occurrence. She rejects the hypothesis that ECB's communication affects contagion immediately based on the results.

Using daily data in 2008-2014 for Germany, France, Italy and Spain, Gertler et al. (2017) find that central bank communication contributes to greater co-exceedances, but only in the presence of extreme events in the financial markets. For this purpose, they employed a measure of co-exceedances developed by Baur and Schulze (2005) in order to capture their possible nonlinear structure. Baur and Schulze (2005) extended the work on co-exceedances originally made by Bae et al. (2003). They both used least squares and quantile regression in the estimation framework.

2.3. General theories about financial markets

This thesis will now focus on a brief summary of general theories about financial markets, as it is also crucial, thus concluding the theoretical background.

Firstly, Kocenda (2017) presents four views about what causes financial crises and economic recessions: a fundamental view, an animal spirit view, a banking view and a household debt view. Kocenda (2017) says that in the fundamental view the causes are fundamental shocks to the economy (e.g. natural disasters, technology shock), while in the animal spirit view, the economy fluctuates because of irrational and volatile beliefs. However, the lack of liquidity causes recessions in the banking view (the cessation of the flow of credit in severely weakened financial sectors. Finally, recessions are driven by a drop in consumption according to the household debt point of view.

Similarly, this thesis could discuss theories on the efficiency of the financial markets or behavioural finance. However, the examples of evidence and mostly the discussion about this evidence and its connection to co-movements of financial markets is also useful for revealing some limitations of this thesis and its study of the influence of central bank communication on financial market co-movements.

Beirne and Fratzscher (2013) analysed the determinants of the price of sovereign risk. They find that during the EU debt crisis, there was a sharp rise in sovereign risk due to a deterioration of fundamentals and fundamentals contagion among countries. This was combined with the fact that financial markets overreacted to fundamentals and overpriced sovereign risk during crisis for countries that were underpriced in a pre-crisis period.

Edmans et al. (2007) found evidence of the influence of sport results on stock market returns. Their results suggest decrease in stock returns after the loss of a national soccer team, no significant effect after a win and the effect is stronger for small cap indices.

Doyle and Chen (2009) provided evidence for the presence of a wandering weekday effect from 11 major stock markets, but still they argue that it is hard to use this evidence for finding abnormal returns.

The three examples mentioned above serve only to illustrate the complexity of examining the co-movements of financial markets. As there is no study examining the effect of sport results on financial market co-movements, or similarly for the other two studies, as far as the author knows, the suggestions proposed based on the studies are only hypotheses with no evidence. These examples have been chosen just for demonstration purposes, still author suggests them to be useful part of the analysis.

Based on the results by Edmans et al. (2007) sport results can have both positive and negative effect on the co-movements of financial markets. On the particular day the national teams of the two analysed countries can lose, then in both countries are expect to have negative effect on stock market returns, so in this case it can have positive effect on financial market co-movement. Similar argument can be used in the opposite case when one of the national team wins (or they do not play at all on that particular day, as it is proposed to be the same, because win has no effect on stock market returns) and the second one loses, then it can have negative effect on financial market co-movements. Based on Beirne and Fratzscher (2013) there is again no a priori known effect on financial market co-movements, because once the financial markets overreact during crisis for sovereign risk underpriced countries in pre-crisis period, there can be two opposite effects on financial market co-movements. Firstly, because of the deterioration of fundamentals and fundamentals contagion market are likely to move more in the same direction, so it can increase the financial market co-movements. On the other hand, the overreaction of the financial markets between sovereign risk underpriced country in pre-crisis period and country which its sovereign risk was correctly priced to fundamentals even in pre-crisis period can be so high that it will decrease the financial market co-movements. Based on the wandering weekday effect examined by Doyle and Chen (2009) there can be also both effects on financial market co-movements observed. When a positive weekday effect emerges in both countries it can increase the correlations of financial markets, but in presence only in one of the examined countries, the effect can also be negative.

All of these examples were discussed to show the possible presence of other factors that can create noise in financial market co-movements and that is the reason why it can be more difficult to observe the effect of ECB's communication on financial market co-movements. For sure we could find other examples that could create noise on financial markets, but for imagination it is sufficient.

Based on the literature review the effect of central bank communication on financial market co-movements should be present. The markets incorporate the information contained in this channel and the reaction is more pronounced during extreme events on financial markets. This supports also a theory of herding behaviour of investors.

3. Data description

This section is divided into two subsections, first one describes data for ECB's communication and the second one is devoted to financial market variables.

3.1. The ECB communication

The central bank communication can take various forms as speeches, interviews, publish minutes or reports. This thesis uses data for communication from Gertler and Horvath (2018). Gertler and Horvath (2018) focused on speeches and interviews made by the ECB's Governing Council Members following Ehrmann and Fratzscher (2007). The dataset for ECB's communication covers the period from 1st July 2008 to 21st January 2014.

Gertler and Horvath (2018) coded the data for ECB's communication based on their nature. The communication is coded by 1 if it has hawkish tone. Then the 0 is used for communication with neutral tone and finally value -1 is assigned when the communication has a dovish tone.

Similar classification was used by Musard-Gies (2006), but softer as also 2 for very hawkish and -2 for very dovish tone have been also employed. Siklos and Bohl (2007) proposed that the coding of the communication is essential for results. The communication can be also classified based on the frequencies of characteristic words. The most important words for the classification in the articles can be classified artificially or based on neural network. Both approaches would lead to interesting and softer classification of the nature of communication compared to used classification -1, 0, 1. But the classification used by Gertler and Horvath (2018) has also its advantages as it is specified in clear way. The classification of communication has been revised by both authors independently so the probability of wrongly classified message has significantly decreased. The classification based on the frequencies of the words can be more precise reflection of the nature of communication, but still it does not have to be better approach compared to classification made by experts. Anyway it is one of the ways for future research.

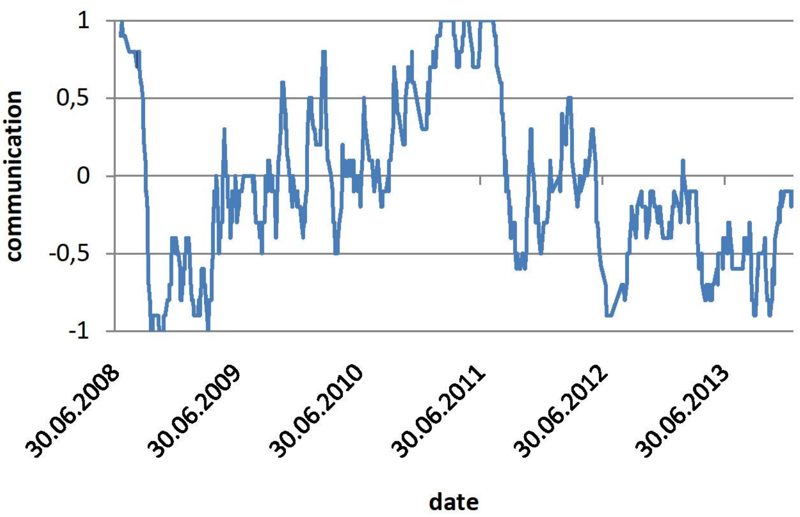
Since there are many cases in the original dataset (Gertler and Horvath, 2018) when more than one speech or interview was published during that particular day and our data for financial variables have daily form as noted in the next subsection, the transformation of the data has to be made. In case of more than one speech or interview the average value of their nature has been assigned to that particular day. For example on 1st July 2008 two speeches were made – one by Liebscher about monetary policy with hawkish tone and one by Smaghi about economic outlook with dovish tone. Therefore, value 0 for neutral tone is assigned to the communication variable for this day. Another case may be that there are three speeches on the particular day – two with hawkish tone and one with dovish tone. Author used common approach of rounding, so the value 0 will be assigned in this particular case. Finally, value -1 is assigned when there is for example one statement with dovish tone and one with neutral tone.

The main reasons behind choosing daily form of the data are availability, clarity and also the theoretical background for methodology. Transformation of the original dataset (Gertler and Horvath, 2018) had to be made also for assignment of the communication to the particular day. In other words in case the communication has been published after the stock exchange trading hours (e.g. 10pm), it does not make any sense to assign this communication on the same day. But obviously one has to assign this communication to the next trading day as financial markets did not have chance to incorporate this new information before. The same argument holds for communication during weekends, so the similar approach was applied for the assignment of the communication to the particular day.

Also regarding to the assignment of the communication to the particular day it is important to discuss the dependence of the results and evidence on choice of the time window in the analysis. Gertler and Horvath (2018) found no significant differences in the results between using 15, 30, 60 or 120 minutes time windows. Clearly longer time after announcement of the central bank communication means higher chance that the financial market reaction is distorted by other news and information, and that is why it can be harder to find a significant evidence of the effect of central bank communication on financial market co-movements from the daily basis. Born et al. (2014) proposed that even if the higher frequency data might have been desirable for eliminating most of the noise created by other events, common approach in the literature examining the effect of monetary policy on stock markets is usage of daily data; see Rigobon and Sack (2004) or Bernanke and Kuttner (2005).

Figure 1 shows the nature of communication in time, it depicts moving average of last 10 communication tones. We can identify three most obvious clusters from the graph. Firstly, from the end of year 2008 until half of 2009 ECB communicated mostly in dovish tone. The second cluster contains mostly hawkish tone communication and cover the first three quarter of 2011. The last cluster of dovish tone communication is during 2013.

Figure 1: ECB's communication tone time series



Source: Author's calculations

Table 1 depicts that in the original dataset (Gertler and Horvath, 2018) the tones of communication were approximately balanced as well as in adjusted data. No significant changes have been made during the transformation from high frequency to daily data. The total number of observations decreased almost by one half.

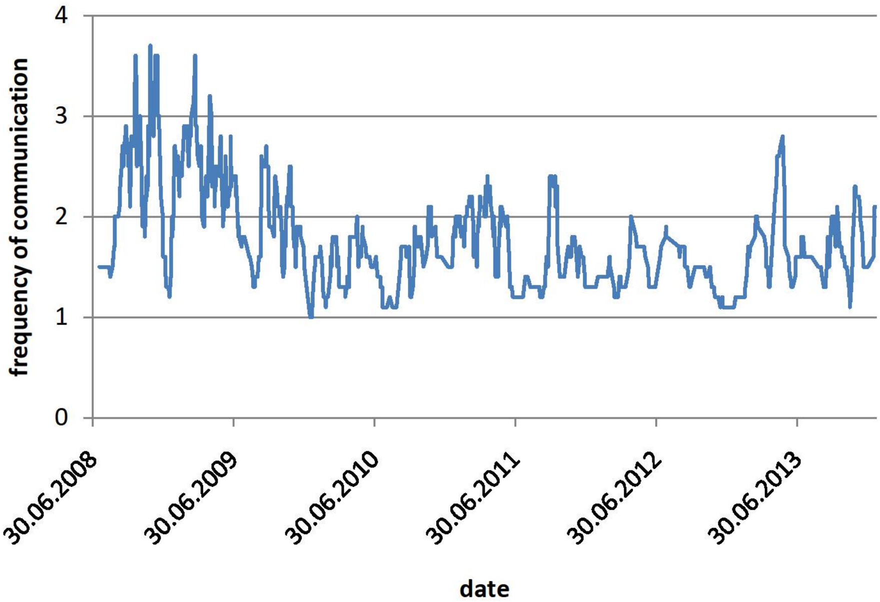
Table 1: Statistics of the nature of the communication

Nature of the statement		Dovish	Neutral	Hawkish	Total
Original data	Total	539	416	429	1384
	Percentage	38,95	30,05	31,00	100,00
Adjusted data	Total	278	227	223	728
	Percentage	38,19	31,18	30,63	100,00

Source: Author's calculations

Figure 2 shows moving average of last 10 frequencies of communication. We can identify cluster from the end of year 2008 until half of 2009 ECB communicated more frequently, for similar time period cluster for dovish tone has been found also in Figure 1. This is in line with hypothesis that ECB communicates more frequently during times with negative signals to financial markets. The rest of the time, the frequency of communication dropped and remained relatively stable.

Figure 2: Frequency of daily communication

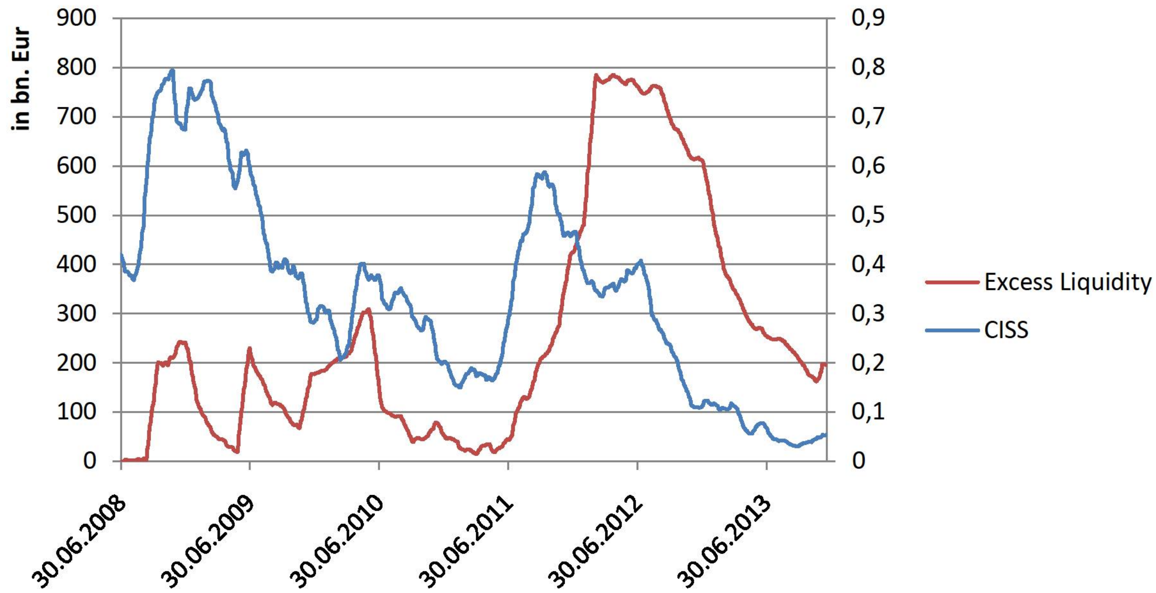


Source: Author's calculation

The author follows Gertler and Horvath (2018) to control for possible endogeneity of communication using data for excess liquidity and CISS – Composite indicator of systemic stress. The excess liquidity and CISS will serve as partially prediction of the communication tone. This approach will serve as one of the robustness checks. They suppose that shock could generate a larger response with higher excess liquidity in financial system and also that higher market uncertainty could be associated with higher volatility, both of the issues can lead to misleading results about the effect of central bank communication on financial markets. The endogeneity of the central bank communication is a crucial issue that one has to deal with. The weekly data for CISS are available at ECB's website, author computed the weekly values for excess liquidity in the Eurosystem in bn EUR based also on ECB's data. Author used most recently known data for both series. Under the EMH only unexpected change in central bank communication should influence financial markets, since it is hard to observe true expectation in most cases for the whole financial market. Possible solution to filter fully the endogeneity of the ECB's communication could be to evaluate surprise of each particular message separately based on professional expertise, but the author fears that this approach is not feasible retrospectively. The author is aware of the imperfections of filtering the central bank communication tone based only on CISS and excess liquidity, but still it is better to filter endogeneity at least partially since it is hard to find a better and feasible approach for now.

$$Excess\ Liquidity = \ Current\ account - Minimum\ reserve\ requirements$$
$$+Deposit\ facility - Marginal\ lending\ facility$$

Figure 3: Excess liquidity and CISS



Source: Author's calculation based on ECB data

Note: Monthly moving averages of CISS and excess liquidity were used for better readability of the graph. CISS refers to the right hand axis and excess liquidity to the left hand axis.

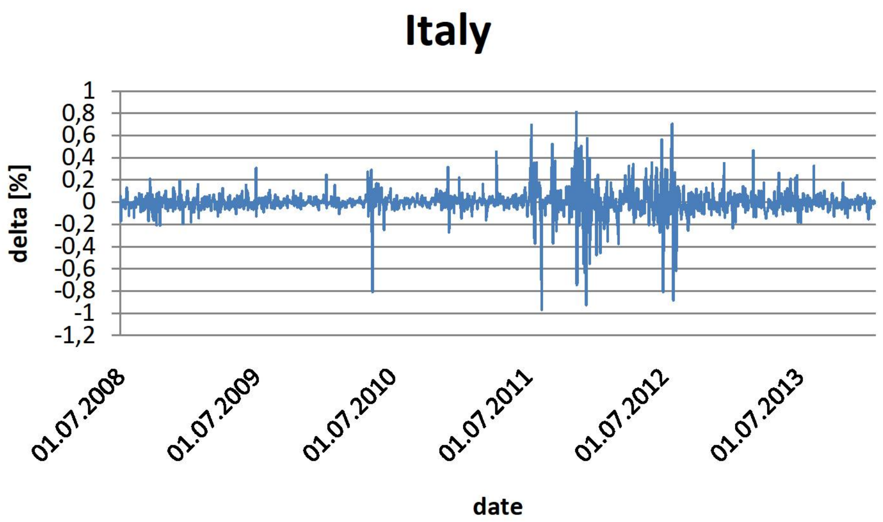
3.2. Data for financial market variables

The author used generic yields for 2-year government bonds from Bloomberg for 4 euro area countries – Germany, Italy, France and Spain. The author presents graphs for sovereign bond yields in Figures A1-A4 in the Appendix. From the Figures A1-A4 we can identify that there might be a trend in government bond yields series, which leads to non-stationarity. Since

GARCH modelling generally requires stationarity, which is described more in the next section, the original bond yield series were tested for stationarity as described in the next section and transformed to time series presented in Figures 4-7.

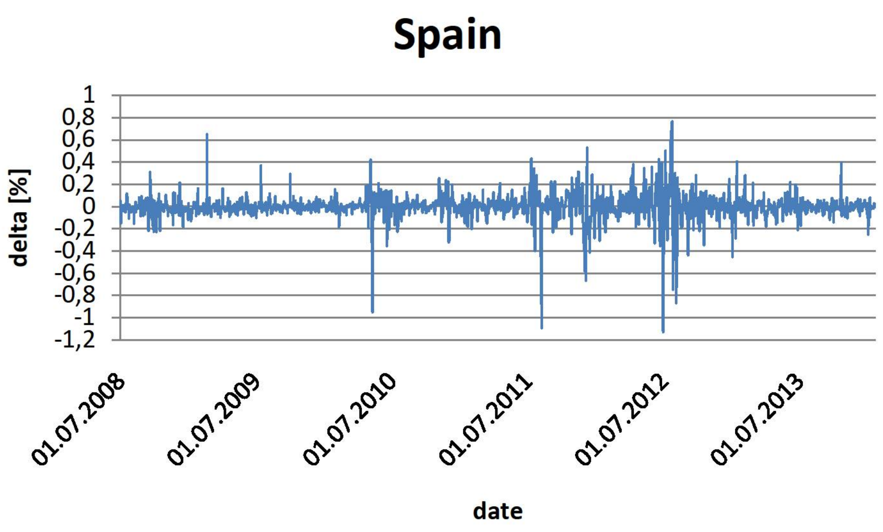
The author follows Beck et al. (2012) and uses daily closing yield changes for financial market variables. Figure 4 illustrates daily yield changes for Italy and Figure 5 for Spain. The minimums of 0,974 percentage point decrease for Italy and 1,093 percentage point decrease for Spain were reached on August 2011. There was a period when the USA was downgraded by S&P to AA+ and warned that it could go further. Italy and Spain announced new measures and reforms in the areas of fiscal and structural policies and the ECB welcomed it. In November 2011, Italy's borrowing cost reached a record high following the maximum of 0,81 percentage point increase as fears grew of escalating the European sovereign debt crisis. The maximum of 0,764 percentage point increase was reached on 23 July 2012 as fears about the need for a full scale bail-out for Spain, even after Spain's Economy minister Luis de Guindos rejected it in Reuters. The author decided to set the same scale for y axis for all of the figures depicting the daily yield changes due to illustrative reasons. We can identify a similar pattern for Italy and Spain.

Figure 4: Italy, daily yield changes



Source: Author's calculation

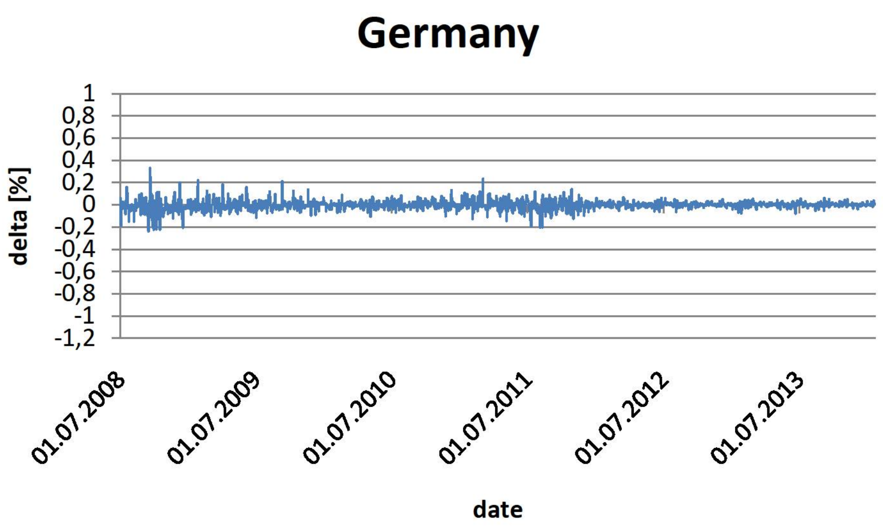
Figure 5: Spain, daily yield changes



Source: Author's calculation

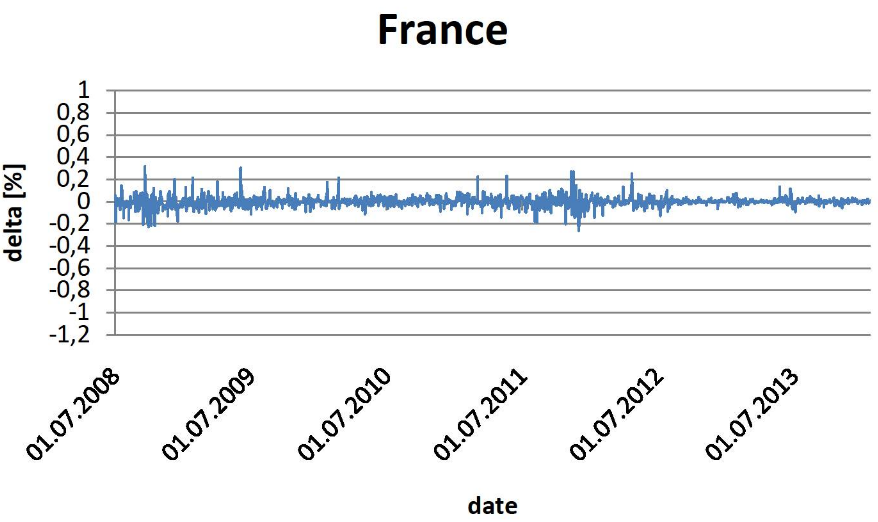
Figure 6 shows the daily yield changes for Germany and Figure 7 for France. The daily volatility of the yields for Germany and France is obviously much lower than for Italy and Spain, as Germany and France were not among the countries under financial stress. Like Italy and Spain, we can identify the similarities also for Germany and France.

Figure 6: Germany, daily yield changes



Source: Author's calculation

Figure 7: France, daily yield changes



Source: Author's calculation

3.3. Control variables

Following Beck et al. (2012), the author used macroeconomic news as control variables. They used only dummy variables for macroeconomic surprises assigned by 1 when the actual release differs from the Bloomberg survey of financial market experts and sum it up to price and macroeconomic announcements of indicators for each country. According to the author, this is one of the ways how to deal with macroeconomic surprises. The author differs in this way as macroeconomic data are released every day and under the EMH market participants react only to the unexpected part of the macroeconomic releases (for a survey see Gürkaynak and Wright, 2013). The author decided to use one of the macroeconomic surprise indices, Citigroup Economic Surprise index (CESI) as it allows for control of the size and side of the surprise. According to Bloomberg relevancy indicator, it is the most pronounced and followed by most Bloomberg users macroeconomic surprise index for the US. Wambeke (2013) used this index to explain the effect of macroeconomic surprises on asset returns. Several studies have tried to construct similar macroeconomic surprise indices and compare them. Scotti (2012) compares the CESI for US with self-created macroeconomic surprise index and provides a survey of several other macroeconomic surprise indices. Wambeke (2013) argues that the method of calculating CESI is also under criticism because Citigroup's weights are calculated based on the reaction of foreign exchange markets to macro news surprise; it can be subjective as it might leave out otherwise important macroeconomic news. Wambeke (2013) used this index in estimation despite criticism.

Bloomberg defines CESI as:

"The Citigroup Economic Surprise Indices are objective and quantitative measures of economic news. They are defined as weighted historical standard deviations of data surprises (actual releases vs Bloomberg survey median). A positive reading of the Economic Surprise Index suggests that economic releases have on balance been beating consensus. The indices are calculated daily in a rolling three-month window. The weights of economic indicators are derived from relative high-frequency spot FX impacts of 1 standard deviation data surprises. The indices also employ a time decay function to replicate the limited memory of markets."

The author adds additional concerns as the weights are calculated based on forex market reactions on macroeconomic announcements and this thesis uses government bond yields as dependent variables. There is no evidence that the calculated weights in CESI are the same for bond yields as the first issue. The second issue is that the weights are derived from relative high-frequency data and the author uses daily data. Therefore, the results can differ. Using data for government bond yields for each particular country and availability of the CESI only for whole Euro area implies an additional drawback, as the weights do not differ for different countries of interest. Even if we consider that the macroeconomic surprises have international spillovers to other countries, it does not make sense to consider that for example the macroeconomic surprise for German data have the same impact on German government bond yields and France government bond yields. There are also advantages of using this approach compared to Beck et al. (2012) as it controls for the positive or negative surprise, as well as its size and weights for the particular macroeconomic surprise. The approach used by Beck et al. (2012) can result in these problems, which can lead to misleading results. They give the same value for all the surprises, small and large, but once the surprise is very small and the market reaction will be limited, one outweighs the surprise in index compared to the actual value. The second problem is that Beck et al. (2012) assign a value of 1 to all surprises, regardless whether they are positive or negative. Imagine positive and negative surprises both of them being the same size in terms of actual response of the market. These two effects rule each other out and there is no actual effect to observe even if according to Beck et al. (2012), one would assign the value 2 for 2 surprises. The third problem is the weighting of the particular macroeconomic announcements; one should assign the weights to particular macroeconomic announcement based on their importance for financial markets; otherwise this could lead to overweighting of less important variables and underweighting of more valued ones.

There is also one available approach to addressing the issues mentioned above. One could take a Bloomberg survey for each particular macroeconomic announcement and standardize it following Balduzzi et al. (2001). This would allow macro surprise index for each particular country to be computed. The issue is how to assign weights for each particular macroeconomic announcement and which macroeconomic variables should be included in the regression. One could follow rich literature focusing on the impact of macroeconomic surprises on financial markets to choose the variables, estimate the coefficients and assign the weights.

Despite the issues surrounding CESI that have been mentioned, the author uses CESI for US and Euro area as a proxy to capture for macroeconomic surprises. According to the author, the advantages of CESI outweigh its disadvantages and should be better approach than Beck et al. (2012) due to the reasons mentioned.

The evidence of international transmission to other financial markets can be found e.g. Funke and Matsuda (2002), Ehrmann and Fratzscher (2005) and Wongswan (2009), although author admits that the evidence on the daily basis may be much lower.

Andersen et al. (2007) find significant effects of U.S., German and British stock, bond and foreign exchange markets on U.S. macroeconomic news using high-frequency data. Altavilla et al. (2017) study the joint reactions of U.S. macroeconomic announcements on U.S. and Europe financial markets. Their results show no time variation in responses and remarkable consistency of the results. They also claim that the effect is at maximum at about 2 years.

Another concern could be raised if the Bloomberg survey of macroeconomic announcement is unbiased. We can argue that the Bloomberg survey is not perfect, but still it is a good proxy of macroeconomic surprises. The properties of the forecasts have been tested, for example by Pearce and Roley (1985) and McQueen and Roley (1993). Although Campbell and Sharpe (2009) argue that most of the studies and tests were focused only on bias or auto-correlated errors and provided only limited insight into the behaviour behind inefficient forecasts. They provide evidence that the MMS survey suffers from an anchoring bias. Their results show that financial markets react significantly only to residual, or unpredictable, component of surprise and not to the expected part induced by anchoring. They estimate anchoring bias for each macro announcement separately. This approach is not feasible in CESI, but it is another reason for concern, as the weights were calculated based only on macro surprise following Balduzzi et al. (2001). Therefore, these weights can be misleading. Still, it is common approach in literature to use the Bloomberg survey as a proxy of market expectations despite its drawbacks.

The first differencing was applied to CESI and then a 2-sided t-test was performed that CESI for US and for Euro area are statistically different from 0. The results are displayed in Table 2, we cannot reject null hypothesis that mean of CESI indices are different from zero at none of the generally accepted p-value. The results indicate that CESI for US and Euro area are unbiased, analogically weightings of the macro announcements did not change unbiasedness of the Bloomberg survey.

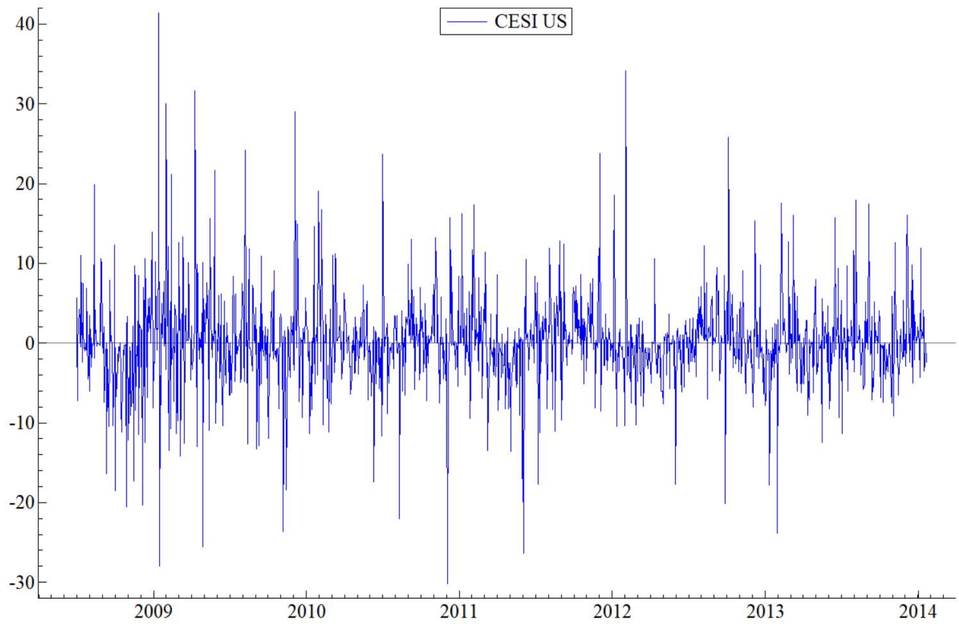
Table 2: Results of t-tests for CESI

Variable	**p-value**
CESI_us	0,8096
CESI_eu	0,6891

Source: Author's calculations

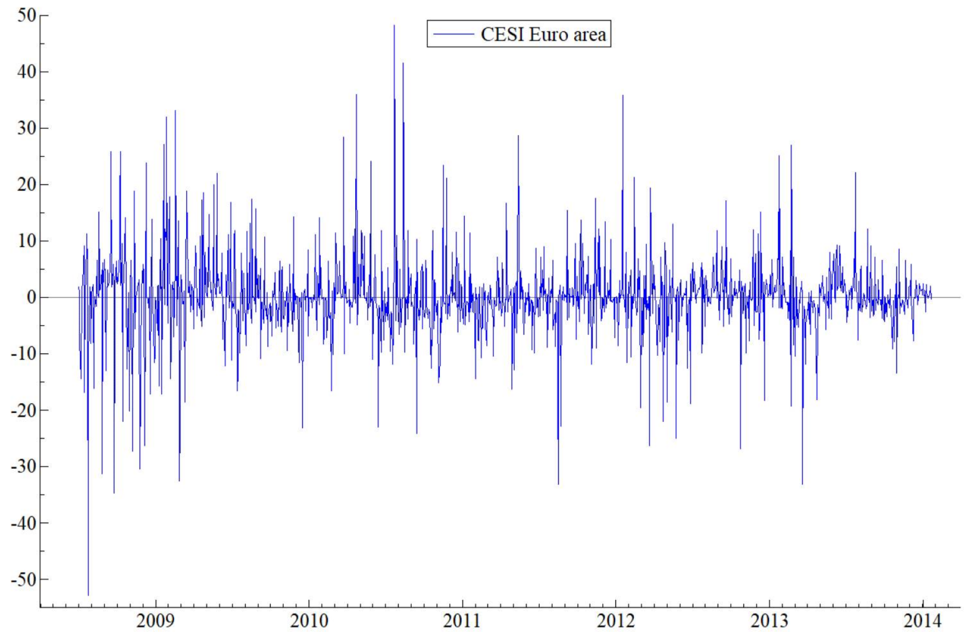
The transformed series of CESI for US and Euro area are displayed in Figures 8 and 9. There is constant mean over the sample and no volatility clusters.

Figure 8: Citigroup Economic Surprise Index for US



Source: Author's calculations

Figure 9: Citigroup Economic Surprise Index for Euro area



Source: Author's calculations

4. Empirical methodology

In this section author will describe methodology used in this thesis. It includes description of transformation used for variables, tests of government bond yields, regression results of central bank communication tone on CISS and excess liquidity and finally descriptive statistics of all variables employed in models. Further author describes MGARCH models which he used in the estimations, particularly diagonal BEKK(1,1) and scalar BEKK(1,1). Author also discusses potential problems with interpretation of the impact of explanatory variables on financial market correlations and creates delta functions which could help with these problems.

Daily yield changes, first differencing, can be expressed as:

$$\Delta_t = yield_t - yield_{t-1}$$

As it was mentioned in the description of the dataset GARCH modelling requires stationarity. Since the original time series of 2 year government bond yields were under suspicion of non-stationarity, these series were tested for stationarity using ADF and KPSS tests. Test results can be found in Table 3. Author used ADF test for 1 lag optimizing AIC with constant and trend, KPSS test was performed for 1 lag with trend. For visual examination of the time series ACF and PACF were also performed. Author reports plots of both original time series as well as of the transformed one in the Appendix Figure A5-A6, but only for Germany. Plots for other countries looked quite similar and the conclusions are the same. In the graph, it can be seen that the process is suspect from a random walk as the ACF declines extremely slowly and the PACF drops immediately after 1 lag. For the original series, p-values for ADF test were higher than any generally accepted p-values; we cannot reject the null hypothesis of unit root (non-stationarity). For KPSS test the situation is quite different as we can reject the null hypothesis of stationarity at very low p-value. The concerns about non-stationarity of the original time series were confirmed by both ADF and KPSS tests as they have different null hypothesis. In order to make process stationary the data were transformed into daily closing yield changes (1st differencing) and then ACF, PACF and both ADF and KPSS test were performed to prove that we avoided the potential issue of spurious regression resulting from the non-stationary nature of the dataset. For the transformed series, ADF test rejected null hypothesis of unit root (non-stationarity) at the very low p-value and for KPSS we cannot reject the null hypothesis of stationarity at none of the generally accepted p-values. Author concludes from both tests and ACF and PACF that the transformation of the data ruled out the problem of non-stationarity for all countries of our interest. This new dataset has constant mean, constant unconditional variance and is weakly dependent. The results are sample specific.

Table 3: Results of ADF and KPSS tests

	2 year government bond yields		Daily bond yield changes (1st differencing)	
	ADF	KPSS	ADF	KPSS
Country	p-value	statistics	p-value	statistics
Italy	0,458	6,88694	8,022e-059	0,0389885
Spain	0,1684	7,14584	2,78e-061	0,0299165
Germany	0,9997	4,53539	2,109e-030	0,0566424
France	0,9981	4,66327	1,62e-030	0,0541372

*1% critical value 0,218 *10% critical value 0,119

Source: Author's calculations

Author tests of daily government bond yield changes for normality using Jarque-Bera test. Results of these tests are presented in Table 4. We can reject null hypothesis of normality at very low p-value for all countries.

Table 4: Results of Jarque-Bera test

	Skewness	Kurtosis	Jarque-Bera
Country	p-value	p-value	p-value
Italy	1,9498e-34	0,00000	0,00000
Spain	9,4856e-74	0,00000	0,00000
Germany	0,45923	5,2557e-161	8,4255e-159
France	2,4785e-6	4,6343e-229	3,8924e-231

Source: Author's calculations

Author presents regression results for communication series based on CISS and excess liquidity in Table 5.

Table 5: Regression results of communication tone based on CISS and excess liquidity

Variable	Coefficient
CISS	-0,958 ***
Excess liquidity	-0,001 ***
constant	0,507 ***

Source: Author's calculations

Note: * 10% significance level, ** 5% significance level, *** 1% significance level

Descriptive statistics of all variables used in regressions are presented in Table 6. None of the daily government bond yield series are statistically different from 0. Filtered series of communication tone based on regression presented in Table 5 have lower standard deviation than original time series.

Table 6: Descriptive statistics

Variable	Mean	St. deviation
it_2y	-0,0027294	0,11784
ge_2y	-0,0043393	0,047417
fr_2y	-0,0029313	0,053034
sp_2y	-0,0044986	0,11401
code2	-0,075549	0,82612
CISS	0,37221	0,22806
excess_liquidity	2,0625e+05	2,0293e+05
CESI_us	-0,010027	6,0824
CESI_eu	0,16223	7,3118
surprise_tone	-4,1209e-09	0,77657

Source: Author's calculations

Note: it_2y stands for daily yield changes for Italy's 2 year government bond, similarly ge_2y for Germany, fr_2y for France and sp_2y for Spain, further code2 represents daily ECB's communication tone, CISS, excess_liquidity, CESI_us and CESI_eu are self explaining as it was described earlier, then surprise_tone are saved residuals from the regression with results presented in Table 4.

Surprise_tone will be referred further as surprise communication tone and code2 representing daily ECB's communication as original communication tone.

4.1. Multivariate GARCH modelling

Author follows Beck et al. (2012) modelling conditional correlations among government bond yields for 4 countries – Italy, Spain, Germany and France. Author proposes only bivariate MGARCH models rather than focusing on full system. Bauwens et al. (2006) discussed MGARCH models, their complexity and convergence problems. The reason behind choosing only bivariate specifications is also high number of parameters. Bauwens et al. (2006) argued that BEKK model is rarely used with number of series larger than 3 or 4. They divide MGARCH models in three categories: generalization of the univariate GARCH model, linear combinations of univariate models and conditional correlation models.

The general mean equation of the following form is estimated:

$$y_t = \mu + Z_t\beta + cH_t + \varepsilon_t,$$

where y_t is a vector of N time series, μ is the mean, ε is a white-noise error, Z is the matrix of f explanatory variables and β is vector of parameters, H is the conditional variance covariance matrix of y and c is a parameter.

The differences among models are contained in specifying the variance equation.

Since results of regressions show that bivariate diagonal BEKK(1,1) and bivariate scalar BEKK(1,1), both proposed by Engle and Kroner (1995), provide a good compromise between conducting multivariate analysis and still achieving robust convergence. Therefore only methodology for these models has been proposed in this section. The diagonal BEKK and scalar BEKK show robust convergence and superiority based on information criteria compared to O-GARCH and GO-GARCH (van der Weide, 2002).

Parametrization of H_t in BEKK model (Engle and Kroner, 1995) ensures its positivity, since it is required for variance matrix to be positive definitive. General form of BEKK(p,q) with additional variables is defined as:

$$H_t = C^{'}C + \sum_{i=1}^{q} A'_i\, \varepsilon_{t-i}\varepsilon'_{t-i}A_i + \sum_{j=1}^{p} G'_j\, H_{t-j}G_j + F \cdot diag|Z_t| \cdot F^{'},$$

where C, the A's and the G's matrices are of dimension N × N but C is upper triangular, N is number of series, F is a N × f matrix, where f represents number of explanatory variables and Z is the of explanatory variables itself.

As this thesis works with bivariate GARCH models N=2. Engle and Kroner (1995) proposed also diagonal BEKK model to reduce number of parameters to be estimated. In diagonal BEKK matrices A's and G's are diagonal. Another specification of BEKK model which reduces number of parameters is Scalar BEKK, where A's and G's matrices are equal to scalar times the identity matrix.

Bivariate diagonal BEKK(1,1) then simplifies to:

$$H_t = \begin{pmatrix} c_{11} & c_{12} \\ 0 & c_{22} \end{pmatrix}^{'} \begin{pmatrix} c_{11} & c_{12} \\ 0 & c_{22} \end{pmatrix} + \begin{pmatrix} a_{11} & 0 \\ 0 & a_{22} \end{pmatrix}^{'} \begin{pmatrix} \varepsilon_{1,t-1}^2 & \varepsilon_{1,t-1}\varepsilon_{2,t-1} \\ \varepsilon_{1,t-1}\varepsilon_{2,t-1} & \varepsilon_{2,t-1}^2 \end{pmatrix} \begin{pmatrix} a_{11} & 0 \\ 0 & a_{22} \end{pmatrix}$$

$$+ \begin{pmatrix} g_{11} & 0 \\ 0 & g_{22} \end{pmatrix}^{'} H_{t-1} \begin{pmatrix} g_{11} & 0 \\ 0 & g_{22} \end{pmatrix} + F \cdot diag|Z_t| \cdot F^{'}.$$

The model is covariance stationary in our case if $a_{11}^2 + g_{11}^2 < 1$ and $a_{22}^2 + g_{22}^2 < 1$.

The financial market conditional covariances are then described by:

$$h_{12,t} = c_{11}c_{12} + a_{11}a_{22}\varepsilon_{1,t-1}\varepsilon_{2,t-1} + g_{11}g_{22}h_{12,t-1} + \sum_{k=1}^{f} f_{1k}f_{2k}|z_{k,t}|$$

Then we can derive financial market correlation:

$$\rho_{12,t} = \frac{Cov_{12,t}}{\sigma_{1t}\sigma_{2t}}$$

$$= \frac{c_{11}c_{12} + a_{11}a_{22}\varepsilon_{1,t-1}\varepsilon_{2,t-1} + g_{11}g_{22}h_{12,t-1} + \sum_{k=1}^{f} f_{1k}f_{2k}|z_{k,t}|}{\sqrt{c_{11}^2 + a_{11}^2\varepsilon_{1,t-1}^2 + g_{11}^2 h_{11,t-1} + \sum_{k=1}^{f} f_{1k}^2|z_{k,t}|}\sqrt{c_{22}^2 + a_{22}^2\varepsilon_{2,t-1}^2 + g_{22}^2 h_{22,t-1} + \sum_{k=1}^{f} f_{2k}^2|z_{k,t}|}}$$

Bivariate scalar BEKK(1,1) is defined as:

$$H_t = \begin{pmatrix} c_{11} & c_{12} \\ 0 & c_{22} \end{pmatrix}^{'} \begin{pmatrix} c_{11} & c_{12} \\ 0 & c_{22} \end{pmatrix} + \alpha^2 \begin{pmatrix} \varepsilon_{1,t-1}^2 & \varepsilon_{1,t-1}\varepsilon_{2,t-1} \\ \varepsilon_{1,t-1}\varepsilon_{2,t-1} & \varepsilon_{2,t-1}^2 \end{pmatrix} + \gamma^2 H_{t-1} + F \cdot diag|Z_t| \cdot F^{'}$$

The model is covariance stationary if $\alpha^2 + \gamma^2 < 1$.

The financial market conditional covariances are then described by:

$$h_{12,t} = c_{11}c_{12} + \alpha^2\varepsilon_{1,t-1}\varepsilon_{2,t-1} + \gamma^2 h_{12,t-1} + \sum_{k=1}^{f} f_{1k}f_{2k}|z_{k,t}|$$

Similarly as for diagonal BEKK(1,1) we can derive conditional financial market correlation for scalar BEKK(1,1):

$$\rho_{12,t} = \frac{Cov_{12,t}}{\sigma_{1t}\sigma_{2t}}$$
$$= \frac{c_{11}c_{12} + \alpha^2\varepsilon_{1,t-1}\varepsilon_{2,t-1} + \gamma^2 h_{12,t-1} + \sum_{k=1}^{f} f_{1k}f_{2k}|z_{k,t}|}{\sqrt{c_{11}^2 + \alpha^2\varepsilon_{1,t-1}^2 + \gamma^2 h_{11,t-1} + \sum_{k=1}^{f} f_{1k}^2|z_{k,t}|}\sqrt{c_{22}^2 + \alpha^2\varepsilon_{2,t-1}^2 + \gamma^2 h_{22,t-1} + \sum_{k=1}^{f} f_{2k}^2|z_{k,t}|}}$$

Author decided to formally show difficult interpretation of f parameters for explanatory variables in the variance equation. Firstly we start by simplifying the equation for conditional financial market correlation. For simplicity author denotes $x = c_{11}c_{12} + a_{11}a_{22}\varepsilon_{1,t-1}\varepsilon_{2,t-1} + g_{11}g_{22}h_{12,t-1}$ ($x = c_{11}c_{12} + \alpha^2\varepsilon_{1,t-1}\varepsilon_{2,t-1} + \gamma^2 h_{12,t-1}$), $y = c_{11}^2 + a_{11}^2\varepsilon_{1,t-1}^2 + g_{11}^2 h_{11,t-1}$ ($y = c_{11}^2 + \alpha^2\varepsilon_{1,t-1}^2 + \gamma^2 h_{11,t-1}$) and $z = c_{22}^2 + a_{22}^2\varepsilon_{2,t-1}^2 + g_{22}^2 h_{22,t-1}$ ($z = c_{22}^2 + a_{22}^2\varepsilon_{2,t-1}^2 + g_{22}^2 h_{22,t-1}$) for bivariate diagonal BEKK(1,1), respectively for bivariate scalar BEKK(1,1), further we assume only one explanatory variable. The logic is the same for more explanatory variables as we can include other explanatory variables into x, y and z. Then equation for conditional financial market correlations becomes:

$$\rho_{12,t} = \frac{x + f_1 f_2|z_t|}{\sqrt{y + f_1^2|z_t|}\sqrt{z + f_2^2|z_t|}}$$

The only thing we can say about the parameters f_1 and f_2 is that the explanatory variable reduces (or has no effect in case $z_t = 0$) the correlation between the series if the signs of f_1 and f_2 differ and estimated conditional correlation at time t is positive. If signs of f_1 and f_2 are the same, then the interpretation of the coefficients f_1 and f_2 is not so straightforward, because conditional variances and covariance, equivalently numerator and denominator, in the correlation equation increase. Therefore, there is no ex ante known effect on the correlation. This is crucial since Beck et al. (2012) argues that the common sign of the coefficients of f_1 and f_2 are decisive in interpretation of the parameters, according to them if f_1 and f_2 are both negative then it means that corresponding explanatory variable reduces the conditional correlation. Author demonstrates this on the following example, the logic behind is that we know the values of $y + f_1^2|z_t|$, $z + f_2^2|z_t|$ and $x + f_1 f_2|z_t|$, further the estimates of f_1 and f_2 are also known from the results of model and finally we know $|z_t|$. We can subtract the estimated impact of the explanatory variable and compare if it is positive or negative other things equal. Therefore, once we know the estimated values we can derive the impact of central bank communication other things equal. Author defines delta functions - $\Delta_{k,t}^{immediate}$ and $\Delta_{k,t}^{full}$, firstly $\Delta_{k,t}^{immediate}$ function describing the impact of explanatory variable k in time t:

$$\Delta_{k,t}^{immediate} = \widehat{\rho_{all,12,t}} - \frac{\widehat{Cov_{all,12,t}} - \widehat{f_{1k}}\widehat{f_{2k}}|z_{k,t}|}{\sqrt{\widehat{Var_{all,1,t}} - \widehat{f_{1k}^2}|z_{k,t}|}\sqrt{\widehat{Var_{all,2,t}} - \widehat{f_{2k}^2}|z_{k,t}|}},$$

where $\widehat{\rho_{all,12,t}}$ stands for stored value of conditional correlation between first and second country in time t, $\widehat{Cov_{all,12,t}}$ stands for stored value of conditional covariance between first and second country in time t, $\widehat{Var_{all,1,t}}$ and $\widehat{Var_{all,2,t}}$ stands for stored value of conditional variance for the first country in time t, respectively for the second country, $\widehat{f_{1k}}$ and $\widehat{f_{2k}}$ denotes estimated parameters for explanatory variable k for the first and second country, $|z_{k,t}|$ is the actual absolute value of explanatory variable k at time t.

But this would be only the partial estimate of the impact of explanatory variables, representing only immediate transition into conditional covariance. Let us denote $\delta_t = \widehat{f_{1k}}\widehat{f_{2k}}|z_{k,t}|$. We can then subtract whole impact of the explanatory variable by redefining $\Delta_{k,t}^{immediate}$ function to $\Delta_{k,t}^{full}$ for bivariate diagonal BEKK(1,1).

$$\Delta_{k,t}^{full} = \widehat{\rho_{all,12,t}} - \frac{\widehat{Cov_{all,12,t}} - \delta_t - \sum_{i=1}^{n}\widehat{g_{11}^i}\widehat{g_{22}^i}\,\delta_{t-i}}{\sqrt{\widehat{Var_{all,1,t}} - \widehat{f_{1k}^2}|z_{k,t}|}\sqrt{\widehat{Var_{all,2,t}} - \widehat{f_{2k}^2}|z_{k,t}|}}$$

or equivalently

$$\Delta_{k,t}^{full} = \widehat{\rho_{all,12,t}} - \frac{\widehat{Cov_{all,12,t}} - \sum_{i=0}^{n}\widehat{g_{11}^i}\widehat{g_{22}^i}\,\delta_{t-i}}{\sqrt{\widehat{Var_{all,1,t}} - \widehat{f_{1k}^2}|z_{k,t}|}\sqrt{\widehat{Var_{all,2,t}} - \widehat{f_{2k}^2}|z_{k,t}|}}.$$

We had to redefine $\Delta_{k,t}^{immediate}$, because we had to subtract δ_{t-1} also from the lagged $h_{12,t-1}$ and further because $h_{12,t-1}$ contains inside itself also $h_{12,t-2}$. Similarly we can define $\Delta_{k,t}^{full}$ for bivariate scalar BEKK(1,1):

$$\Delta_{k,t}^{full} = \widehat{\rho_{all,12,t}} - \frac{\widehat{Cov_{all,12,t}} - \sum_{i=0}^{n}\widehat{\gamma^{2i}}\,\delta_{t-i}}{\sqrt{\widehat{Var_{all,1,t}} - \widehat{f_{1k}^2}|z_{k,t}|}\sqrt{\widehat{Var_{all,2,t}} - \widehat{f_{2k}^2}|z_{k,t}|}}.$$

The $\Delta_{k,t}^{immediate}$ and $\Delta_{k,t}^{full}$ will be crucial in interpretation of the impact of central bank communication tone. Obviously delta functions can take only values from $\langle -2; 2\rangle$.

5. Empirical results

This section presents results of regression of government bond yields on ECB's communication, CESI for US and CESI for EU. All models have been estimated in OxMetrics employing package G@RCH. Table 7 shows which model is favoured based on which information criterion employing bivariate diagonal BEKK(1,1), bivariate scalar BEKK(1,1), bivariate O-GARCH(1,1) and bivariate GO-GARCH(1,1), these models use original communication tone as explanatory variable. Author prefers particular model to others when this model is favoured at least by 2 from 3 information criteria. For pairs Italy-Spain, Italy-Germany, Italy- France and Spain-France bivariate diagonal BEKK(1,1) have been favoured. Bivariate scalar BEKK(1,1) have been favoured for pairs Spain-Germany and Germany-France.

Table 7: Favoured models based on information criteria for models using original communication tone

Countries	SIC	HQIC	AIC
Italy-Spain	OGARCH	Diagonal BEKK	Diagonal BEKK
Italy-Germany	Diagonal BEKK	Diagonal BEKK	Diagonal BEKK
Italy-France	Diagonal BEKK	Diagonal BEKK	Diagonal BEKK
Spain-Germany	Scalar BEKK	Scalar BEKK	Scalar BEKK
Spain-France	Diagonal BEKK	Diagonal BEKK	Diagonal BEKK
Germany-France	Scalar BEKK	Scalar BEKK	Diagonal BEKK

Source: Author's calculations

Table 8 presents favoured model by information criteria employing the same models as mentioned above, but this time using surprise communication tone. For all pairs of countries bivariate diagonal BEKK(1,1) has been favoured except Germany-France pair for which information criteria prefers scalar BEKK(1,1). Since the information criteria show consistent result of preferred models, author presents only regression results for these models. Author includes only 2 countries in MGARCH models, otherwise models sometimes suffer from problems with convergence because of high number of parameters.

Table 8: Favoured models based on information criteria for models using surprise communication tone

Countries	SIC	HQIC	AIC
Italy-Spain	Diagonal BEKK	Diagonal BEKK	Diagonal BEKK
Italy-Germany	Diagonal BEKK	Diagonal BEKK	Diagonal BEKK
Italy-France	Diagonal BEKK	Diagonal BEKK	Diagonal BEKK
Spain-Germany	Diagonal BEKK	Diagonal BEKK	Diagonal BEKK
Spain-France	Diagonal BEKK	Diagonal BEKK	Diagonal BEKK
Germany-France	Scalar BEKK	Scalar BEKK	Diagonal BEKK

Source: Author's calculations

Beck et al. (2012) argues that diagonal BEKK models are still too computationally demanding to include all explanatory variables in the mean and variance equations at the same time. However once this thesis uses only 1 explanatory variable for central bank communication and

2 macroeconomic indices, this approach is feasible and also preferable rather than using Beck et al.(2012) 2 step approach. Both diagonal and scalar BEKK models allow for variables that influence variances of the time series as well as their correlations. All regressions have been tested against reduced model with no explanatory variables and all tests for all countries favour full models against the reduced ones at 1% significance level. Statistical significance of parameters for surprise communication tone in the variance equations are quite similar for models employing all explanatory variables as well as for models using only surprise communication variable. Further correlations between explanatory variables are very low, it means 0,03 for daily changes of CESI US and CESI EU, 0,00 for daily changes of CESI US and surprise communication tone and finally -0,04 for daily changes of CESI EU and surprise communication tone; therefore we do not need to worry about multicollinearity. Tables 9, 10, 11, 12, 13 and 14 show regression results of estimating bivariate diagonal BEKK(1,1) or bivariate scalar BEKK(1,1) for 6 pairs of countries. The reasons for choosing bivariate diagonal BEKK(1,1) and bivariate scalar BEKK(1,1) is mentioned earlier. All of the models are covariance stationary as $a_{11}^2 + g_{11}^2 < 1$ and $a_{22}^2 + g_{22}^2 < 1$ conditions hold for all bivariate diagonal BEKK(1,1) models and $\alpha^2 + \gamma^2 < 1$ condition holds for all bivariate scalar BEKK(1,1) models. Since some of the parameters are not the point of interests, author will only briefly discuss these parameters. The parameters c_{11} and c_{22} can be interpreted as long term volatilities for the first and the second country in models. Author skips interpretation of remaining constants at all. Next parameters a_{11}, a_{22}, g_{11} and g_{22} are statistically significant at 1% level in all bivariate diagonal BEKK(1,1) models employing original communication tone as well as surprise communication tone. For bivariate scalar BEKK(1,1) for Spain-Germany employing original communication tone parameters α and γ are statistically significant at 1% level, for Germany-France γ is also significant at 1% level for both original and surprise communication tone, but parameter α is significant at 5% level only with original communication tone. All of the parameters a_{11}, a_{22}, α, g_{11}, g_{22} and γ are positive. Parameters a_{11}, a_{22} and α can be interpreted that current news has a positive impact on current market volatility, compared to parameters g_{11}, g_{22} and γ that represent impact of historical volatility on current market volatility. The estimates of parameters a_{11}, a_{22} and α vary between 0,23 and 0,78 and are lower than corresponding parameters g_{11}, g_{22} and γ except the model for Italy-Spain with original communication tone. Therefore, a positive impact of current news on current market volatility is smaller than positive impact of historical volatility and the smaller the difference is between the a_{11} and g_{11}, respectively a_{22} and g_{22}, α and γ, the smaller is the difference in the impacts. We already know that conditions for covariance stationarity of the models are always satisfied but the values of $a_{11}^2 + g_{11}^2$, $a_{22}^2 + g_{22}^2$ and $\alpha^2 + \gamma^2$ indicate persistency of shock in volatility. The lowest value about 0,90 implies that the volatility shocks have long memory and die very slowly.

Table 9: Results of regressions for Italy-Spain

Parameters	Original communication tone		Surprise communication tone	
	Mean equation			
	Italy	Spain	Italy	Spain
μ	-0,001113	-0,004794	-0,004571	-0,009215 **
communication	0,002552	0,003548	0,001644	0,000451
CESI US	0,001065 **	0,000997 ***	0,000613	0,000726 **
CESI EU	0,001159	0,000490	0,000446	0,000147
Parameters	Variance equation			
c_{11}	0,044147 ***		0,000000	
c_{12}	0,026494 ***		-0,003307	
c_{22}	0,000054		0,015009 **	
	Italy	Spain	Italy	Spain
a	0,778230 ***	0,579586 ***	0,348159 ***	0,536651 ***
g	0,588728 ***	0,810284 ***	0,929499 ***	0,843799 ***
|communication|	0,013317	0,007382	0,000017 *	0,000009
|CESI US|	-0,000010	-0,000008	0,000013	0,000034
|CESI EU|	0,001956	-0,008301	-0,007802 ***	-0,009568 ***

Source: Author's calculations

Note: Coefficients a_{11} and a_{22} stands for parameters in row with parameter a for Italy respectively Spain, similar logic is applied to rows with parameters μ and g to conserve space. Regarding to notation *, ** and *** indicate statistical significance at a 10 %, 5 % and 1 % level.

Table 10: Results of regressions for Italy-Germany

Parameters	Original communication tone		Surprise communication tone	
	Mean equation			
	Italy	Germany	Italy	Germany
μ	-0,003495	-0,001459	-0,003386	-0,001677
communication	0,000694	0,001197	0,001038	0,000387
CESI US	0,000821 **	0,000816 ***	0,000846 **	0,000800 ***
CESI EU	0,000165	0,000369	0,000191	0,000381
Parameters	Variance equation			
c_{11}	0,000119		0,007154	
c_{12}	-0,000080		-0,002320 *	
c_{22}	0,000186		0,000032	
	Italy	Germany	Italy	Germany
a	0,501744 ***	0,225713 ***	0,503741 ***	0,229503 ***
g	0,865011 ***	0,967262 ***	0,863849 ***	0,966185 ***
|communication|	0,000146	-0,000077	-0,000013 **	-0,000001
|CESI US|	0,002069	0,002412 **	0,001578	0,001624
|CESI EU|	0,008813 ***	0,000692	0,008187 **	0,001451

Source: Author's calculations

Note: Coefficients a_{11} and a_{22} stands for parameters in row with parameter a for Italy, respectively Germany, similar logic is applied to rows with parameters μ and g to conserve space. Regarding to notation *, ** and *** indicate statistical significance at a 10 %, 5 % and 1 % level.

Table 11: Results of regressions for Italy-France

Parameters	Original communication tone		Surprise communication tone	
	Mean equation			
	Italy	France	Italy	France
μ	-0,001634	0,000266	-0,001417	0,000244
communication	0,003484	0,004995 **	0,004376	0,004364 **
CESI US	0,001119 ***	0,000938 ***	0,001104 ***	0,000922 ***
CESI EU	0,000606	0,000581 *	0,000604	0,000562 *
Parameters	Variance equation			
c_{11}	0,015706 ***		0,015704 ***	
c_{12}	-0,002943		-0,002937	
c_{22}	0,000004		0,000029	
	Italy	France	Italy	France
a	0,508568 ***	0,288099 ***	0,509572 ***	0,287296 ***
g	0,861016 ***	0,909076 ***	0,860422 ***	0,911334 ***
|communication|	-0,000768	-0,001191	-0,000001	0,000011
|CESI US|	-0,000023	-0,000032	-0,000002	-0,000005
|CESI EU|	-0,005296 *	-0,007509 ***	-0,005322 *	-0,007382 ***

Source: Author's calculations

Note: Coefficients a_{11} and a_{22} stands for parameters in row with parameter a for Italy, respectively France, similar logic is applied to rows with parameters μ and g to conserve space. Regarding to notation *, ** and *** indicate statistical significance at a 10 %, 5 % and 1 % level.

Table 12: Results of regressions for Spain-Germany

Parameters	Original communication tone		Surprise communication tone	
	Mean equation			
	Spain	Germany	Spain	Germany
μ	-0,007908 *	-0,001992	-0,009059 **	-0,001809
communication	0,000542	-0,000604	-0,001168	-0,000617
CESI US	0,000632 **	0,000705 **	0,000664 **	0,000713 ***
CESI EU	-0,000165	0,000205	-0,000034	0,000247
Parameters	Variance equation			
c_{11}	0,014232		0,013991	
c_{12}	-0,002912		-0,001291	
c_{22}	0,000061		0,000004	
	Spain	Germany	Spain	Germany
α/a	0,435014 ***		0,567093 ***	0,257832 ***
γ/g	0,893408 ***		0,823648 ***	0,955038 ***
|communication|	0,000029	0,000038	0,000011	0,000003
|CESI US|	-0,003446 *	-0,004627 *	0,004516	0,002454
|CESI EU|	-0,006523	-0,003412	0,008473 *	0,002187 ***

Source: Author's calculations

Note: The row with parameters α/a denotes common parameter α for the regression with the original communication tone employing bivariate scalar BEKK(1,1) and parameters a_{11} and a_{22} in bivariate diagonal BEKK(1,1) for Spain, respectively for Germany. Similar logic applies for row with parameters γ/g. Regarding to notation *, ** and *** indicate statistical significance at a 10 %, 5 % and 1 % level.

Table 13: Results of regressions for Spain-France

Parameters	Original communication tone		Surprise communication tone	
	Mean equation			
Parameters	Spain	France	Spain	France
μ	-0,007951 *	-0,000849	-0,007622 *	-0,000792
communication	0,003096	0,003576	0,001825	0,003051
CESI US	0,000712 **	0,000986 ***	0,000859 ***	0,000922 ***
CESI EU	0,000492	0,000779 ***	0,000390	0,000693 **
Parameters	**Variance equation**			
c_{11}	0,000094		0,021092 ***	
c_{12}	-0,000128		-0,002852	
c_{22}	0,000000		0,002488	
	Spain	**France**	**Spain**	**France**
a	0,622740 ***	0,239781 ***	0,629105 ***	0,272418 ***
g	0,782421 ***	0,927475 ***	0,777314 ***	0,908013 ***
|communication|	-0,000242	-0,000311	0,000083 *	0,000025
|CESI US|	-0,012027	-0,000099	0,000523	0,000399
|CESI EU|	-0,008773	-0,007206	-0,010474 **	-0,007901 ***

Source: Author's calculations

Note: Coefficients a_{11} and a_{22} stands for parameters in row with parameter a for Spain, respectively France, similar logic is applied to rows with parameters μ and g to conserve space. Regarding to notation *, ** and *** indicate statistical significance at a 10 %, 5 % and 1 % level.

Table 14: Results of regressions for Germany-France

Parameters	Original communication tone		Surprise communication tone	
	Mean equation			
Parameters	Germany	France	Germany	France
μ	0,000732	0,001153	0,000390	0,001340
communication	0,001919	0,000021	0,001810	-0,000397
CESI US	0,000285	0,000323	0,000256	0,000283
CESI EU	0,000405	0,000359	0,000380	0,000334
Parameters	**Variance equation**			
c_{11}	0,000001		0,000012	
c_{12}	0,000016		0,000010	
c_{22}	0,000002		0,000005	
	Germany	**France**	**Germany**	**France**
α	0,489656 **		0,468994	
γ	0,871910 ***		0,883196 ***	
|communication|	0,003526	-0,009645 *	-0,004563	0,008859
|CESI US|	0,003034	0,001601	0,002558	0,001877
|CESI EU|	0,000988	0,000885	0,000826	0,000902

Source: Author's calculations

Note: Regarding to notation *, ** and *** indicate statistical significance at a 10 %, 5 % and 1 % level.

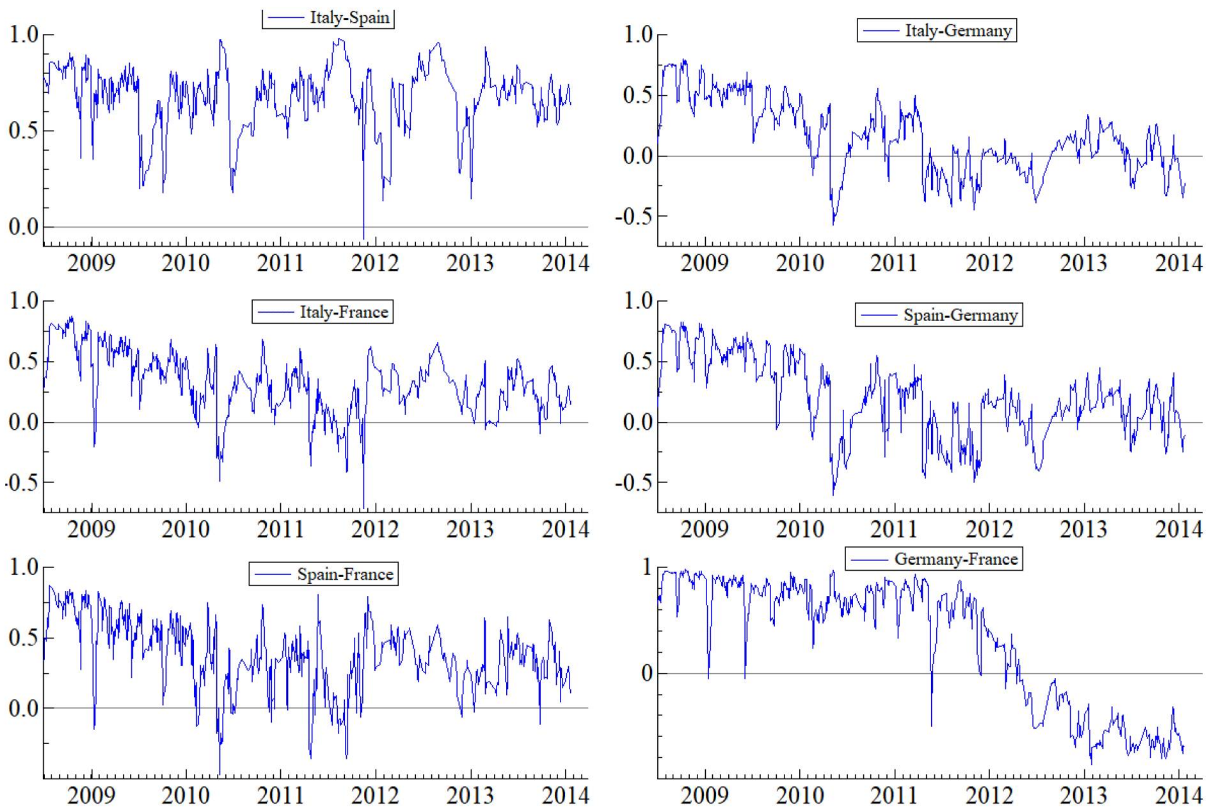
In the mean equations, CESI for US shows quite robust and statistically significant results at some of the generally accepted levels, except for both models for Germany-France and for Italy in model for Italy-Spain employing surprise communication tone. The significance levels vary across the models but all of them are positive, which means that unexpected positive surprise in macroeconomic announcements in US represented by CESI is expected to increase 2 year government bond yields of our countries of interest by the estimated value of parameter, e.g. in the model for Italy-Spain employing original communication tone the estimated value of parameter for Spain is 0,000997, then 1 (percentage) point increase in CESI US is expected to increase Spain 2-year government bond yield by 0,000977 percentage point other things equal. This is in line with theory as positive economic surprise, it means macroeconomic announcements indicate stronger than expected economy, will increase interest rates, equivalently reduce bond and bill price, for negative surprise vice versa. In the mean equations, CESI for EU have positive estimated values, but compared to CESI for US the statistical evidence is poor. These parameters are positive in all employed models except models for Spain-France where there is negative estimate for Spain in both models. The statistical significance of these parameters varies and parameters are statistically significant at 10 % level for Italy-France models for Italy, at 5 % level for France in Spain-France model employing surprise communication tone and finally at 1 % level also for France in Spain-France model but employing original communication tone. These results are in line with results of Ehrmann and Fratzscher (2005) and Andersen et al. (2007). In the mean equations parameters for communication are not statistically significant at none of the generally accepted levels, except models for Italy-France with positive parameter statistically significant at 5% level.

Author further continues in interpretation only with models employing surprise communication tone as models with original communication tone show quite similar results.

Author plots conditional correlations of 2-year government bond yields for pairs of euro area countries of interest in Figure 10. Author plots long-term interest rates for chosen euro area countries in Figure 11 using data downloaded from ECB website. We can identify that the 2 year government bond yields for all our pairs of countries were highly correlated before European debt financial crisis. However we cannot say one particular date for the start of European debt financial crisis, we can highlight at least some important events for the beginning. In October 2008 the Iceland's banking system has collapsed, in late 2009 new Greek government revealed that previous governments had been misreporting government budget data and rise or we might even say collapse of spread primarily to Portugal, Italy, Ireland, Greece and Spain later. We can see this pattern in Figure 11, there is well known and well described in the literature nonsense convergence in government bond yields among euro area countries before the crisis. Once the European debt financial crisis emerges investors started to distinguish between the risks for particular euro area countries, they started to demand higher risk premium or equivalently higher yield especially for countries under financial stress – e.g. Greece, Italy, Spain, Portugal, and Iceland. Author reports also average values of conditional correlations: 0,68 for Italy-Spain, 0,20 for Italy-Germany, 0,35 for Italy-France, 0,25 for Spain-Germany, 0,40 for Spain-France and 0,41 for Germany-France. However these values can be very misleading as we can see especially for Germany-France in Figure 10, where in the first part of the sample particularly from July 2008 to late 2011 there is quite stable and very high conditional correlation, sometimes even very close to 1. However since 2012, the correlation between

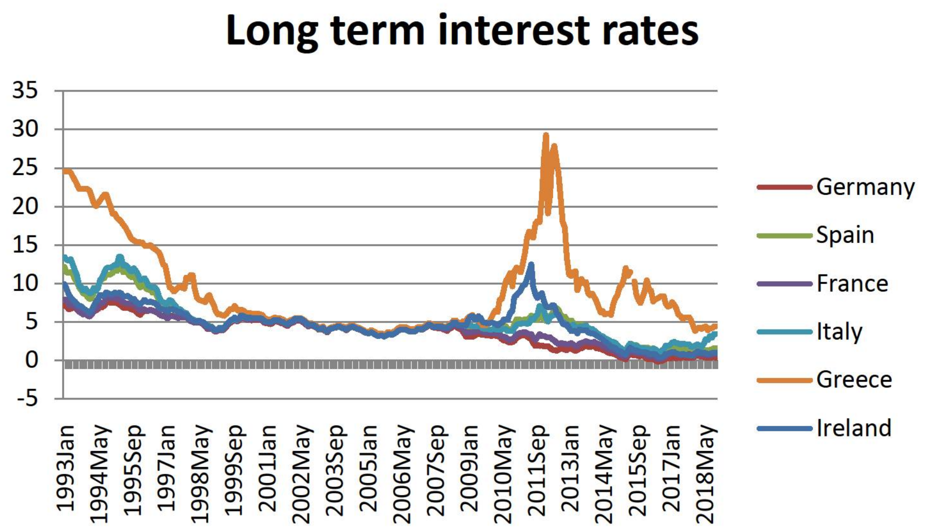
Germany and France started to decrease and the time series became highly negatively correlated later. For Italy and Spain, the correlation has some falls but overall the correlation is high and remains relatively stable over the whole observation period. The reasons for this high correlation with occasional falls are bidder, Italy and Spain were both countries under financial stress during European sovereign debt crisis and therefore despite some short term volatilities in one or the other country investors evaluate risks for these two countries quite similar and connected. Italy and Spain faced similar problems during European debt sovereign debt crisis therefore we can use similar reasoning to describe the pattern in the graphs for Italy-Germany and Spain-Germany. The conditional correlations decline especially in the first half of 2010 and then oscillated around zero for rest of the observed period. The reasons behind are that Germany contrary to Italy and Spain did not belong to countries under financial stress and was considered as safe haven compared to those countries. We can identify similar but lower decline in conditional correlations also in Italy-France and Spain-France, the reasoning is quite similar. In the Appendix Figure A7 depicts conditional variances for pairs of Euro area countries, every row depicts two plots for each particular country in that pair.

Figure 10: Conditional correlations between euro area countries



Source: Author’s calculations

Figure 11: Long term interest rates for selected euro area countries

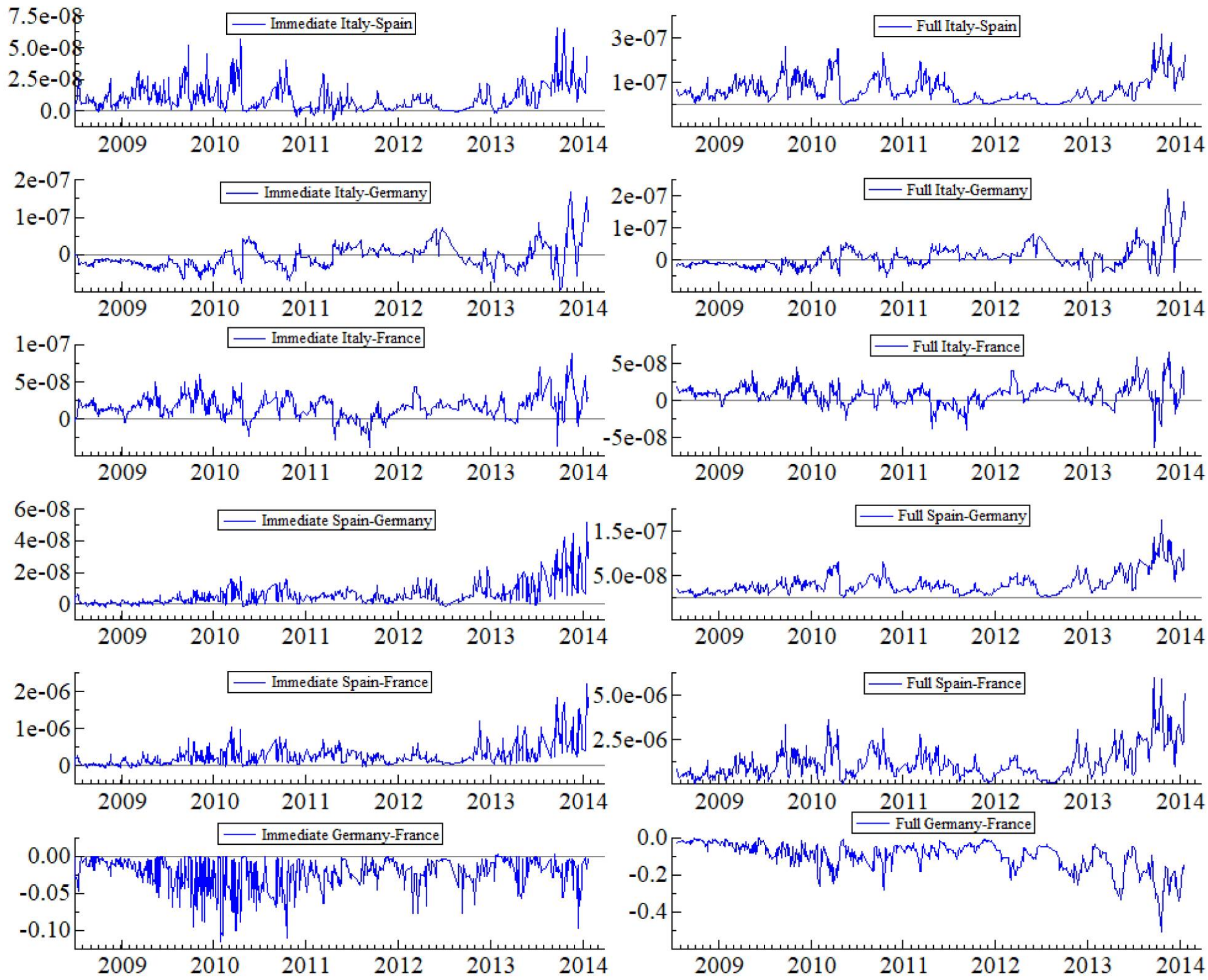


Source: Author's calculations

Finally, we can interpret and quantify the impact of ECB's communication on financial market correlations for 4 euro area countries. In Figure 12 author depicts delta functions as defined in section Empirical methodology by $\Delta_{k,t}^{immediate}$ and $\Delta_{k,t}^{full}$. Author uses general form of $\Delta_{k,t}^{full}$ with n=10 as $g_{11}<1$, $g_{22}<1$ and $\gamma<1$ the results will be very close to $\Delta_{k,t}^{full}$ with n<N. Obviously number of lags we include in computation of $\Delta_{k,t}^{full}$ equals to the first number of observations for which we cannot compute $\Delta_{k,t}^{full}$. The graphs on the left side of Figure 12 depict immediate effect or contemporaneous effect of central bank communication tone on financial market correlations. The plots on the right side of Figure 12 depict full effect of central bank communication tone on financial market correlations, it means including the effect transmitted through $h_{12,t-1}$ contained in every equation for $h_{12,t}$. Unfortunately the evidence of the impact of ECB's communication on financial market co-movements is poor as only coefficient for Italy in Italy-Spain model is statistically significant at 10 %, further for Italy in Italy-Germany model at 5 % and finally for Spain in Spain-France model at 10 %. Altogether only 3 out of 12 estimated parameters are statistically significant at some of the generally accepted levels; therefore, the computed impact represented by delta functions of ECB's communication is also not statistically significant, even though author comments Figure 12. For Italy-Spain, we can identify that ECB's communication increases the financial market co-movements, however the size is negligible. For Italy-Germany and Italy-France there is not obvious pattern for the impact of ECB's communication as both delta functions oscillates around 0. Plots for Spain-Germany and Spain-France share similar pattern and ECB's communication increases the financial market correlations between these countries, but as well as for Italy-Spain the absolute size of this increase is negligible. The last pair of plots in Figure 12 belongs to Germany-France. There is an obvious pattern that ECB's communication decrease financial market correlation between these two countries, the impact is more pronounced for full delta function and the absolute size of the impact on the financial market correlation is remarkable. The ECB's communication data, created by Gertler and Horvath

(2018) and transformed by author, contains only speeches and interviews made by ECB's Governing Council members following Ehrmann and Fratzscher (2007); therefore author compares the results of regressions for the impact of ECB's communication with results of Beck et al. (2012) estimating bivariate financial market correlations for 10 year yields Canada and US. In their model speeches contemporaneously do not show statistically significant coefficients in the variance equations for Canada nor for US. This is in line with the results of author's models, even author differs in process. As suggested by Gertler and Horvath (2018) significantly higher number of ECB's Governing Council member compared to typical other central bank monetary policy committees increases the probability that an identical message is transferred to geographically dispersed audiences; therefore ECB's communication could have on average weaker effect on financial markets compared to other central banks. The results are also in line with results of Gertler et al. (2017), they examined the effect of verbal unscheduled ECB's communication using quantile regressions. Gertler et al. (2017) found that financial markets co-movements increase following the central bank communication only in case of extreme returns in financial markets. The first hypothesis of this thesis that the effect of ECB's communication should be the same across the Euro area cannot be rejected at none of the generally accepted levels as estimated coefficients are not statistically significant from 0. There is no statistically significant effect of ECB's communication on financial market co-movements, so we also cannot reject that the effect is the same across the whole Euro area. For the second hypothesis that the ECB's communication affects the conditional co-movements of financial markets in the Euro area, there has not been found statistically significant evidence supporting it.

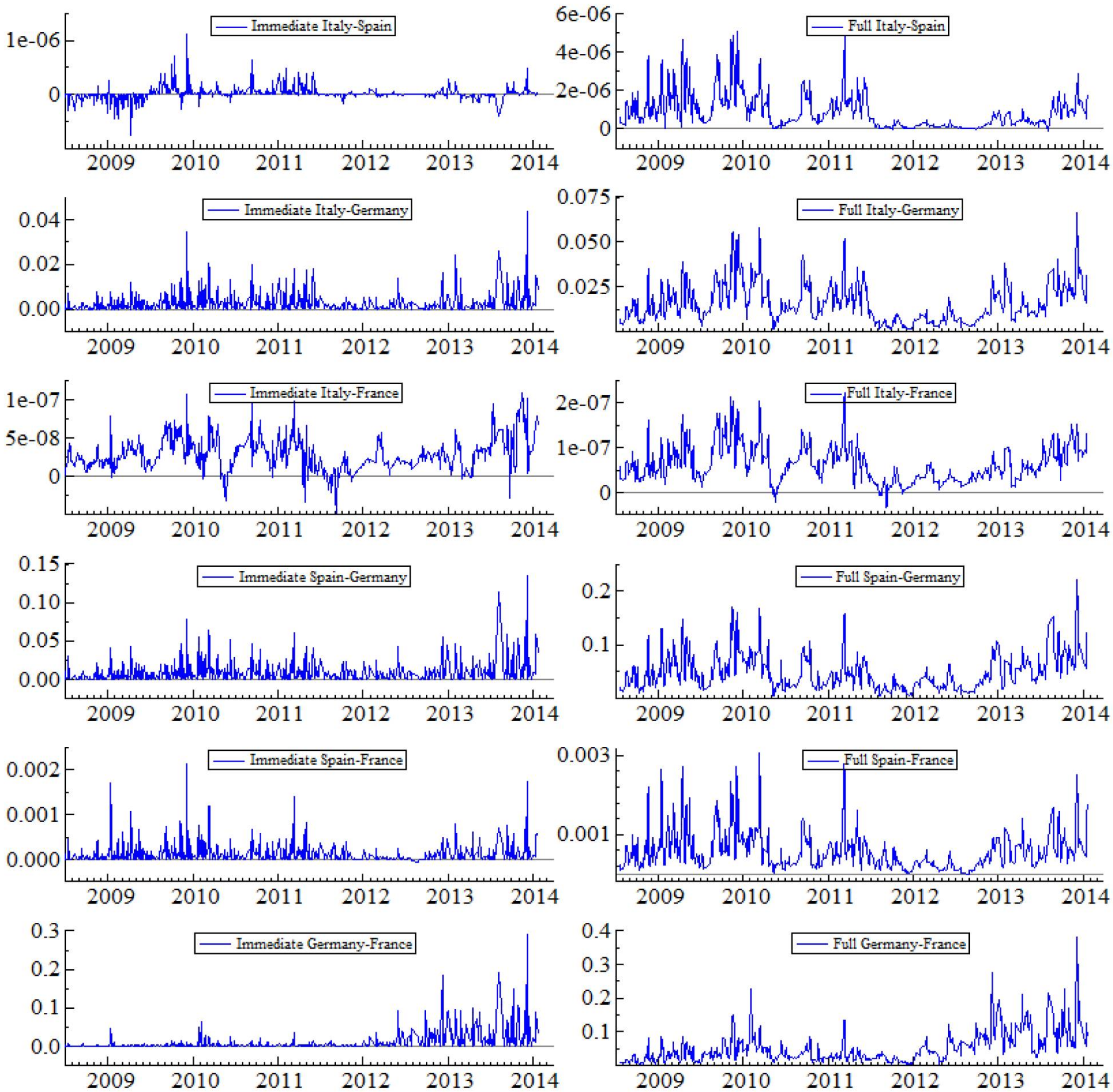
Figure 12: Delta functions for surprise communication tone



Source: Author's calculations

Furthermore, there is no statistically significant evidence of the impact of US macroeconomic announcements on financial market co-movements after controlling for the size of surprise in the mean equations for none of the models employing surprise communication tone. Since as it was described earlier one cannot interpret coefficients directly, author provides Figure 13 depicting delta functions for CESI US. All plots show that CESI for US increases financial market correlations between all of our focused Euro area countries, except for immediate delta function for Italy-Spain, where the impact is oscillating around 0, but full delta function for Italy-Spain shows also that CESI for US negligibly increases financial market correlations between them. From Figure 13 we can identify that CESI for US remarkably affects – increases financial market correlations for Italy-Germany, Spain-Germany and Germany-France. The estimated effect of CESI for US is the largest in absolute values for Germany-France for the second part of the estimated period. Even though we cannot say that these effects are statistically significant at some of the generally accepted levels, we can say that the results coincide with intuition and theory. As financial markets and financial systems are today highly interconnected then it is not surprising that surprises of US macroeconomic announcements increase financial market correlations among euro area countries on which this thesis focuses on.

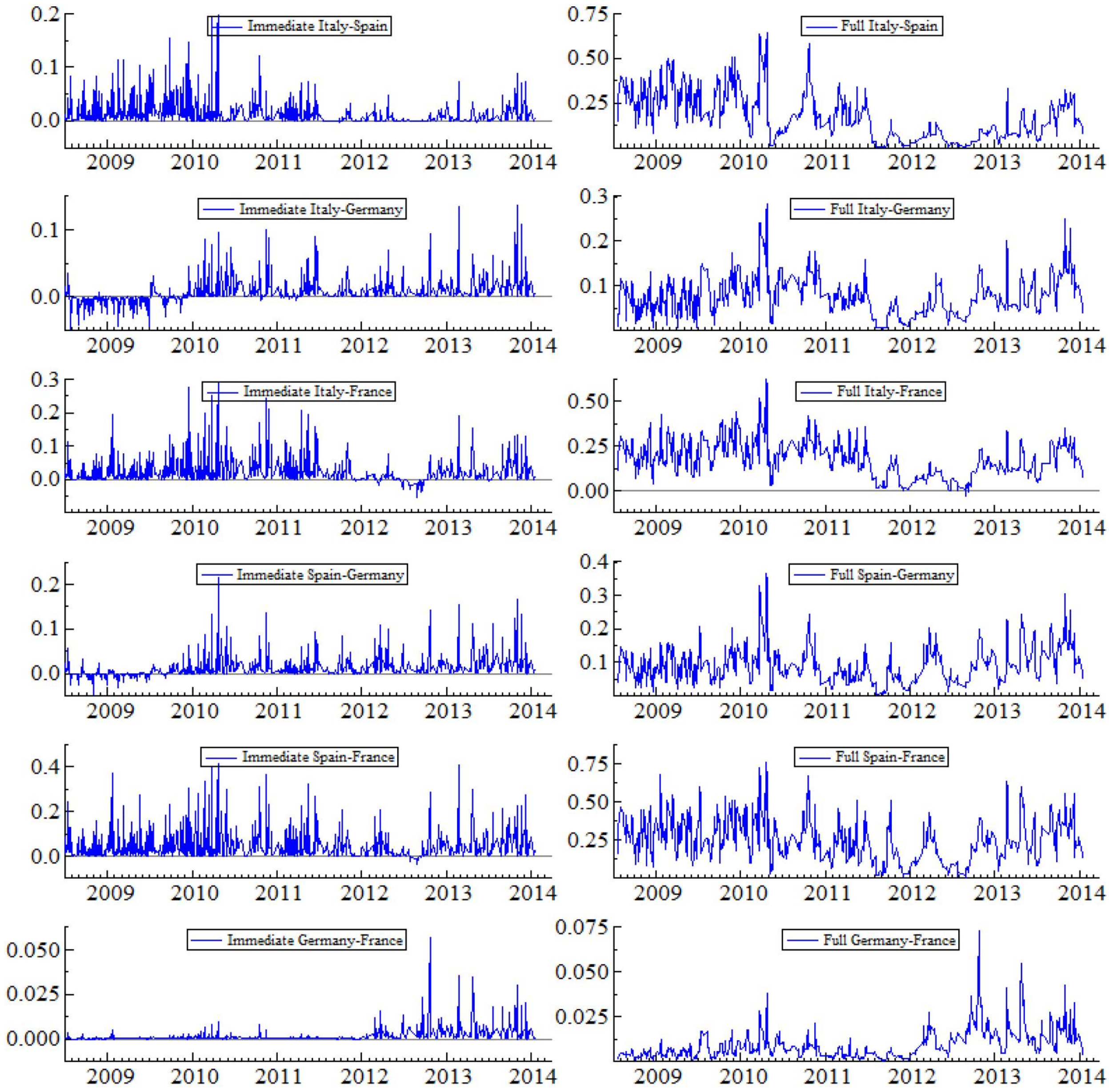
Figure 13: Delta functions for CESI US



Source: Author's calculations

The situation is different for the impact of CESI for EU on financial market correlations; Figure 14 depicts delta functions describing these effects on Euro area countries. Contrary to the statistical significant evidence for ECB's communication and CESI for US the estimated coefficients for CESI EU are mostly statistically significant, altogether 9 out of 12 parameters at some of the generally accepted levels. Particularly author reports 1% statistical significance for Italy-Spain for both countries, further for France in Italy-France and Spain-France and for Germany in Spain-Germany model. Coefficients are statistically significant at 5% level for Italy in Italy-Germany model, for Spain in Spain-France model and finally coefficients for Italy in Italy-France and Spain in Spain-Germany model are statistically significant at 10% level. Except for Germany-France model, the coefficients are jointly statistically significant. The same reasoning as it was used for CESI US that financial markets, financial systems and economies are interconnected today, it is reasonable to suggest that macroeconomic surprises increase financial market correlations among Euro area countries. The results show that the effect of Euro area macroeconomic surprises represented by CESI EU is stronger than for CESI US. After we control for the macroeconomic surprises for US and for Euro area and the results for mean equations are in line with results of Ehrmann and Fratzscher (2005) and Andersen et al. (2007), there are several reasons why Euro area macroeconomic surprises should affect financial market correlations more than US macroeconomic surprises. The first reason is that our observation period contains substantial part of European sovereign debt crisis; therefore, investors started to look more at economic fundamentals in Euro area and started to price risks for each particular country differently. Beirne and Fratzscher (2013) argue that the financial markets overreacted during the European sovereign debt crisis for countries that their sovereign risks were underpriced in the pre-crisis period, due to the deterioration of fundamentals, equivalently negative macroeconomic surprises and fundamentals contagion financial markets are likely to move more in the same direction; however, the widening spread between countries under financial stress and regular one will probably decrease financial market correlations. The Figures 13 and 14 quantifies this effect among Euro area countries. Delta functions depicted in Figure 14 confirms that the CESI EU increase financial market correlations between euro area countries substantially in terms of absolute value. Immediate responses takes maximum values about 0,4, but full effect peaks almost for 0,75 value. The increase of financial market correlations driven by macroeconomic surprises for EU is the largest between Italy and Spain and between Spain and France. In case we consider only models with jointly statistically significant coefficients, it means except the last one for Germany-France, the plots for full delta functions show quite similar pattern, the only differences between them are the absolute values.

Figure 14: Delta functions for CESI EU



Source: Author's calculations

5.1. Contribution and suggestions for further research

This thesis follows mainly Beck et al. (2012) as it is to author's best knowledge the only literature studying the effect of central bank communication on financial market correlations employing MGARCH models. Although the results of this thesis and results of Beck et al. (2012) coincide with no statistical significance at generally accepted levels for speeches, author differs substantially in some steps and interpretations of results.

Firstly, author uses CESI for US and CESI for EU compared to Beck et al. (2012) who constructed their own macro surprise indices. The problem lies in the construction of the index; they assign value 1 to each macroeconomic announcement when it differs from Bloomberg survey and then sum it up to price and macro surprise index. It does not make sense to assume that the financial markets will react equally for the surprise decrease of GDP by 0,1 percentage point and by 1 percentage point. The approach of Beck et al. (2012) does not allow controlling for the size and side of macroeconomic surprise; therefore, the author uses CESI US and CESI EU, because these indices weigh each macroeconomic surprise by the high-frequency reaction on foreign exchange markets when macroeconomic surprises differ by 1 standard deviation. However, this approach has also its limitations as the weights have been assigned based on foreign exchange markets reaction rather than on bond market reactions, still author considers this approach as better way to deal with the data.

The second difference is that author filtered the central bank communication series at least partially from expectations following Gertler and Horvath (2018).

The third difference is that author involves all explanatory variables in mean and variance equations at the same time, since number of explanatory variables used in the thesis allowed him to do that compared to Beck et al. (2012), who used two-step estimation.

The fourth difference and very crucial one is in the interpretation of the models. Once Beck et al. (2012) correctly suggest that explanatory variable affects financial market correlations statistically significantly if both of its coefficients are statistically significant for both countries. But author disagrees that these coefficients have to have same signs, further coefficients which share the same sign do not have to increase for plus or decrease for minus the financial market conditional correlations; therefore author derived directly delta functions describing and quantifying the impact of each explanatory variable on financial market correlations. This is also one of uniqueness of this thesis as to author's best knowledge there does not exist such a function for interpretation of the coefficients in variance equations for bivariate diagonal BEKK(1,1) nor for bivariate scalar BEKK(1,1) in recent literature. These functions can be extended for more lags or modified for other models.

Although author tried to do his best to provide the best available approach, there exist also some limits of this thesis. Further research could use classification of central bank communication which uses more categories, e.g. very hawkish, hawkish, neutral, dovish, very dovish, or one could create neural network for classifying the central bank communication tone, or one could try to classify which ECB's news contain new information based on professional expertise. Another improvement can be made in construction of macroeconomic surprise indices as it was highlighted earlier CESI uses weights based on foreign exchange market reaction, one could evaluate these weights for bond markets or create macroeconomic index for each particular country separately, but this approach would need a long time series to estimate it properly. The availability of the data increases every day, so it could be valid approach in the future. Further research could also try to filter Bloomberg survey for macroeconomic announcements as Campbell and Sharpe (2009) argue that it suffer from anchoring bias. The theory behind MGARCH family of models evolves and new models are also created, so in the future there could be available better approach for estimating the impact of central bank communication on financial market correlations. Author would imagine MGARCH model which could allow using quantile regression as Gertler et al. (2017) found that the financial markets co-movements increase only in case of extreme returns. One can also use high frequency data instead of data with daily frequency; this could lead to more robust results as it lower the chance of jointly occurrence with another important event.

6. Conclusion

This thesis has been focused primarily on finding and quantifying the effect of ECB's communication on financial market co-movements for 4 Euro area countries – particularly Italy, Spain, Germany and France. Evaluating this effect is important for private sector and also for central bank policymakers. Author uses ECB's communication data, created by Gertler and Horvath (2018) and transformed by author into the daily frequency, the original dataset contains only speeches and interviews made by ECB's Governing Council members in 2008-2014 following Ehrmann and Fratzscher (2007). Further data for 2-year government bond yields for Italy, Spain, Germany and France were used as dependent variables. Finally, author uses macroeconomic surprise indices following Beck et al. (2012) for filtering the impact of macroeconomic fundamentals. Particularly author uses CESI for US and CESI for EU, contrary to Beck et al. (2012), who constructed their own price and macroeconomic surprise indices. According to author, these macroeconomic surprise indices have several pros compared to those constructed by Beck et al. (2012) as CESI uses weights for each particular announcement based on high frequency reaction of foreign exchange market. The price and macro surprise indices constructed by Beck et al. (2012) does not allow controlling for neither the size nor the side of the surprise. However also drawbacks or limits of using CESI are well-known to the author, ideally the weights for macro surprises should be evaluated based on bond market reactions as this thesis works with government bond yields. Further Campbell and Sharpe (2009) argue that Bloomberg survey suffers from anchoring bias; one could try to correct the Bloomberg survey from anchoring bias. Finally, it does not make sense, even though the Euro area economies are highly interconnected, that e.g. Italy macroeconomic surprise slowdown in GDP will have the same effect on Italy's government bond yields as well as on Germany's government bond yields especially during European sovereign debt crisis. Beirne and Fratzscher (2013) provide evidence that financial markets overreacted during European sovereign debt crisis for countries that their sovereign risks were underpriced in pre-crisis period. Author also controls at least partially for possible endogeneity of ECB's communication following Gertler and Horvath (2018) and filters the central bank communication time series by CISS and excess liquidity in the Euro area. However, possible endogeneity of ECB's communication is serious problem that one has to deal with it, under EMH financial markets react only to unexpected part of news. Gertler and Horvath (2018) discuss the potential endogeneity and highlight that significant higher number of ECB's governing council could lead to higher probability of delivering the same message to geographically dispersed audiences; therefore, the effect of ECB's communication could have on average weaker effect compared to that of other central banks. Possible solution could be to evaluate surprise of each particular message delivered by ECB's Governing Council members separately based on professional expertise, but author concerns that this approach is not feasible retrospectively.

Author employs MGARCH models for this purpose, particularly diagonal BEKK, scalar BEKK (Engle and Kroner, 1995), O-GARCH and GO-GARCH (van der Weide, 2002), following Beck et al. (2012), then evaluates which one fits the data best based on information criteria and chooses that one. The final models reported in regression results were bivariate diagonal BEKK(1,1) for most of pairs of countries and bivariate scalar BEKK(1,1) for the rest. Author focuses on pairs of countries rather than employing full possible system (for survey of reasons see Bauwens et al., 2006), the choice of bivariate diagonal BEKK(1,1) model coincides with choice of Beck et al. (2012). Further author included all explanatory variables in mean and variance equations at the same time as the number of explanatory variables allow him to do that. Author differs here from Beck et al. (2012); they firstly eliminate impact of explanatory variables in the mean equations and then use residuals as filtered series to conserve the degrees of freedom. The final models for each pair of countries have been tested of nested models against the ones with none of the explanatory variables.

The results show that financial market conditional correlation were relatively high and positive between each pair of Italy, Spain, Germany and France, but since fears of investors due to European sovereign debt crisis were rising the financial market conditional correlations started to decrease. The most pronounced reduction in financial market co-movements can be found between countries under financial stress (Italy and Spain) and Germany as country considered as safe haven in the Euro area. The reduction is smaller for countries under financial stress and France and negligible between Italy and Spain together with only short term deviation from high correlation, as those countries faced quite similar risks during the crisis. The results for mean equations show quite robust and statistically significant positive coefficients for US macroeconomic surprises, on the other hand statistical significance of the coefficients for Euro area macroeconomic surprises is poor. However, these results are in line with the results of Ehrmann and Fratzscher (2005) and Andersen et al. (2007) and also with theory as positive economic surprise. This means macroeconomic announcements indicate a stronger than expected economy, will increase interest rates, equivalently reduce bond and bill price, for negative surprise vice versa. There is poor evidence that the ECB's unscheduled verbal communication affects government bond yields of Italy, Spain, Germany or France in the mean equation at all.

Furthermore, the author had to define delta functions as described in the section Methodology to interpret and quantify the impact of explanatory variables on the financial market conditional correlations, since from the estimated coefficients itself one cannot say nothing about the estimated impact of explanatory variable of the financial market conditional correlations. This is crucial since Beck et al. (2012) suggest that the explanatory variable increases the financial market correlations since it is positive and statistically significant in both conditional variance equations, alternatively reduces for negative coefficients. Author shows, describes in the section Methodology why this is misleading interpretation and that this does not have to hold. The delta functions are also one of the uniqueness of this thesis since to author's best knowledge there is no described function in recent literature interpreting the impact of the explanatory variable on the financial market correlations in bivariate diagonal BEKK(1,1), respectively bivariate scalar BEKK(1,1). The results show poor evidence for the impact of US macroeconomic surprises on the variance and financial market conditional correlations and quite robust and economically also remarkable impact of Euro area macroeconomic surprises on government bond yields conditional correlations, except for model for Germany and France. This is in line with Beirne and Fratzscher (2017) that due to deterioration of fundamentals or equivalently negative macroeconomic surprises and fundamentals contagion financial markets are likely to move more in the same direction; therefore financial market correlations should increase, however the widening spread between countries under financial stress and regular one will probably deteriorate this effect on financial market correlations. This pattern can be identified from the results, the impact of Euro area macro surprises on government bond yields conditional correlations is larger and statistically most significant between countries under financial stress – Italy and Spain rather than rest of pairs. Finally, there is poor evidence that ECB's unscheduled verbal communication affects government bond yields' financial market conditional correlations. For none of the pairs of countries there were both coefficients statistically significant and altogether only 3 out of 12 coefficients show significant results at some of the generally accepted levels. This is however is line with results of Beck et al. (2012) estimating bivariate financial market correlations for 10 year yields Canada and US, including central bank communication contemporaneously in form of speeches there has not been found any statistically significant coefficient in the variance equations neither for Canada nor for US. Further Gertler et al. (2017) found that financial markets co-movements increase following the central bank communication only in case of extreme returns in financial markets.

There is no statistically significant effect of ECB's communication on financial market co-movements, so we cannot reject the first hypothesis of this thesis that the effect is the same across the whole Euro area. For the second hypothesis that the ECB's communication affects the conditional co-movements of financial markets in the Euro area, there has not been found statistically significant and robust evidence supporting it.

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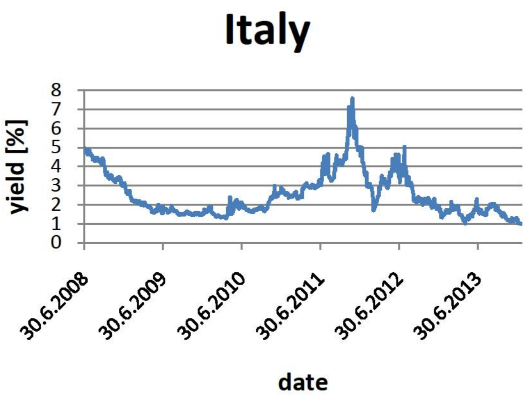
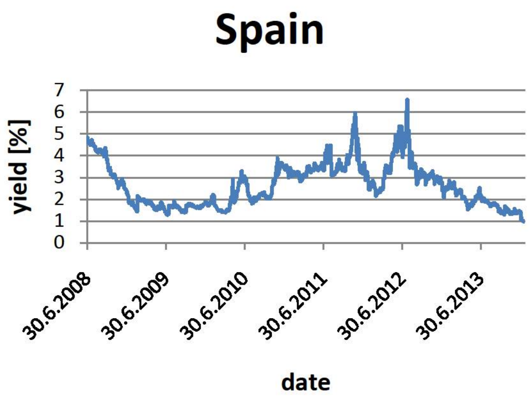
Appendix

Figure A 1: Italy 2y yield



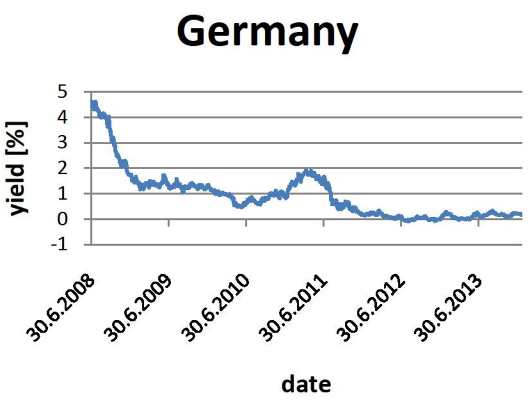
Source: Author's calculation

Figure A 2: Spain 2y yield



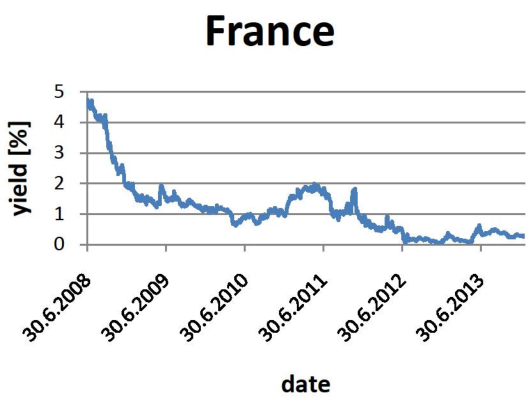
Source: Author's calculation

Figure A 3: Germany 2y yield



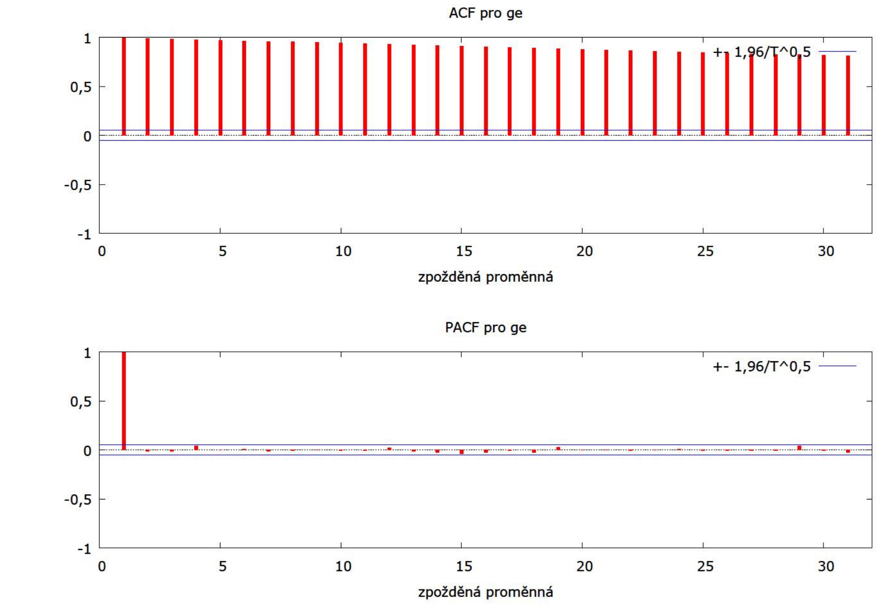
Source: Author's calculation

Figure A 4: France 2y yield



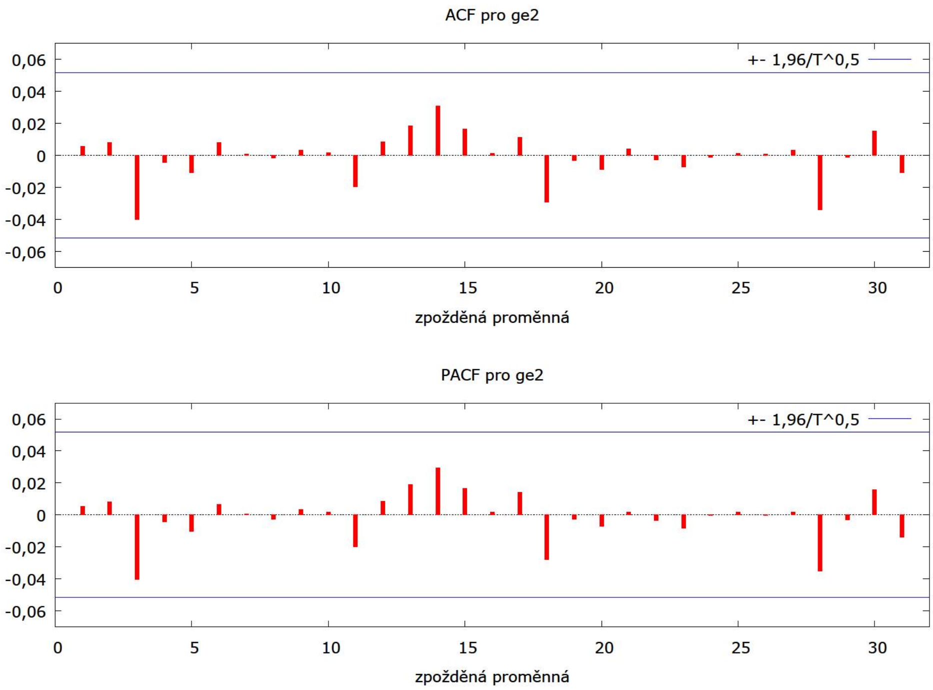
Source: Author's calculation

Figure A 5: ACF and PACF for German 2 year government bond yield series



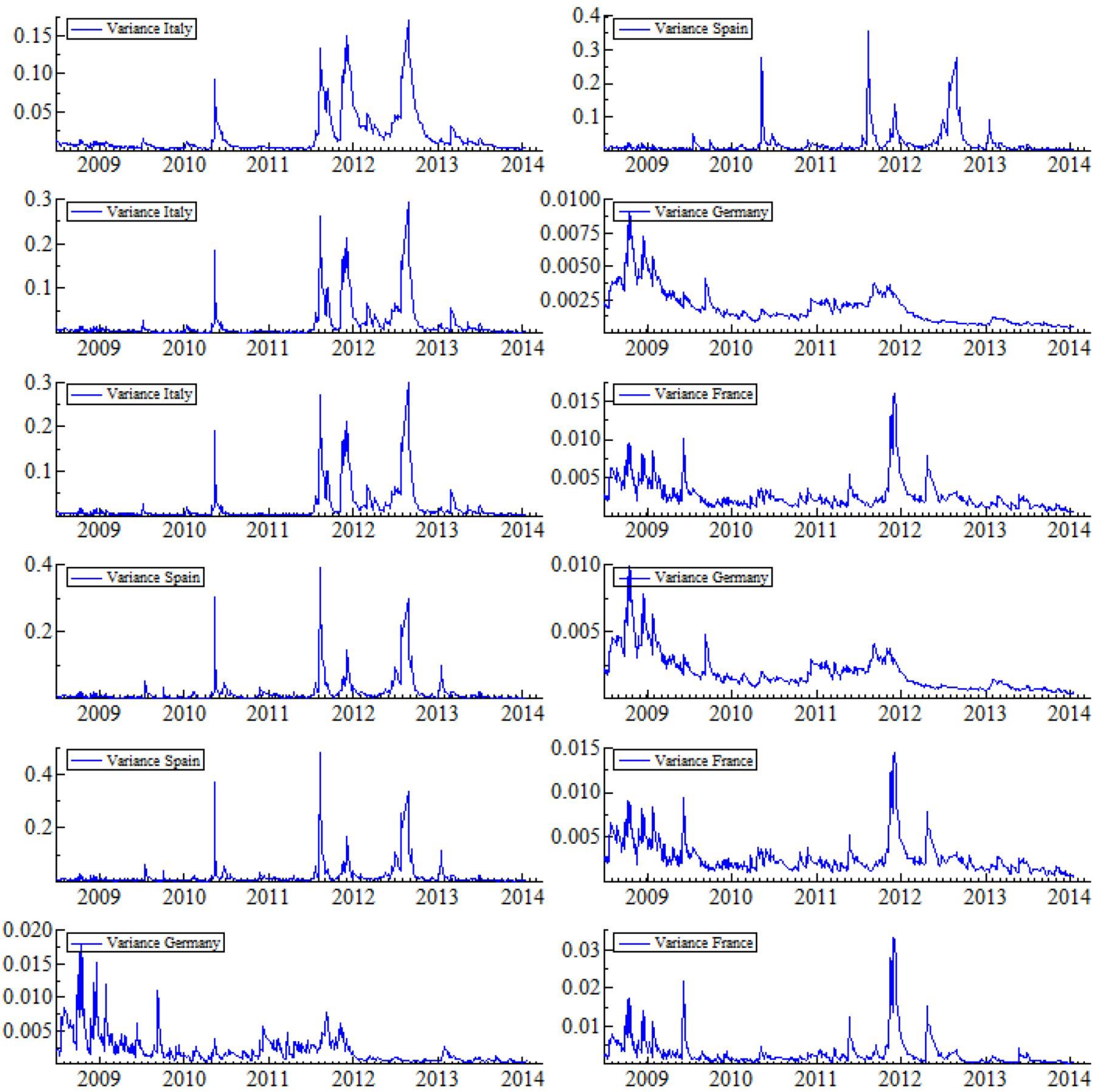
Source: Author’s calculations

Figure A 6: ACF and PACF for the transformed series – daily yield changes for Germany



Source: Author’s calculations

Figure A 7: Conditional variances for pairs of euro area countries



Source: Author’s calculations