MASTER'S DEGREE IN FINANCE

MASTER 2 FINANCE: MANAGEMENT DES RISQUES FINANCIERS

FINAL THESIS

THE EFFECT OF THE ECB QE ON THE GREEK BOND SPREAD

THE IMPLICATION OF THE ASSET PURCHASE PROGRAMME

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INTRODUCTION

This dissertation purpose is to analyse how the Quantitative Easing (QE) implemented by the European Central Bank (ECB) affected the 10-year Greek bond spread. The main intuition is that this expansionary monetary policy contributed to lower the sovereign spread in the long-run.

The study aims to provide a more nuanced understanding of the determinants of its movements during the period under investigation. Additionally, the findings will contribute to a more comprehensive assessment of the impact of the ECB's measures on the European market.

The forthcoming analysis covers the time window spanning November 2014 to July 2022, promising to offer valuable insights into the intricate relationship between unconventional monetary policy and the 10-year Greek bond spread. It coincides with the implementation Asset Purchase Programme (APP) by the ECB.

To support our thesis, we utilise of two main regression model which are partly based on previous the literature. The data has monthly frequency. The 10-year Greek bond spread is the dependent variable in both cases. The main control variable is the Cumulative Asset Purchases (CAP) made during the APP in all the Euroze. The two other important variables are the 10-year Credit Default Swap Spread and the Euro Stoxx 50, representing respectively the investor perception and the European market volatility.

The first model is the Ordinary Least Square (OLS). The second model is the Autoregressive Distributed Lag (ARDL) made of long- and short-run coefficients. In both, we notice that the control variable is significant.

In the OLS case we set the stationarity condition of all variables as mandatory, to obtain a robust analysis. After the CAPs growth rate, another significant coefficient is the dummy variable corresponding to the new purchase announcements during the APP. It is utilised only in this model and confirms the fact that the ECB’s statements are relevant in influencing the bond spread dynamics.

In the ARDL case this is not necessary to have stationary variables since cointegration was achieved. Here, the CAPs are considered in billion euros and their rise show to be significant in the long-run in lowering the sovereign spread. Moreover, there are significant coefficients in the short-run for the 10-year Credit Default Swap spread, the Euro Stoxx 50, the error correction term which displays a negative coefficient. This means that what affected most the sovereign spread decline are still the CAPs.

The dissertation is structured as follows. After a brief introduction, the previous literature is reviewed. Then, the dataset is fully analysed, and the methodology is chosen and explained according to the data characteristics. After that, the results are commented. The conclusion and the appendix precede the bibliography.

1. LITERATURE REVIEW

The analysis presented in this research draws upon various studies, which investigated the consequences of unconventional monetary policies implemented by central banks in the past 15 years. Each paper shed light on how these interventions have influenced short- and long-term bond yields, providing valuable insights into the dynamics of financial markets. A brief description of these studies follows.

Pieterse-Bloem and Eijffinger (2022) explore the transition of the ECB’s monetary policy from conventional to unconventional. They argue that the changes in bond spreads have become increasingly associated with market risk-based factors, and the decisions and measures taken by the ECB have gained significant relevance in influencing sovereign yields. This study explores how the shifts in the central bank's approach impact bond spreads in the euro area and contribute to the overall financial stability of the region.

Focusing specifically on the Security Market Programme (SMP) implemented by the ECB in 2010, Trebesch and Zettlemeyer (2016) examine the effects of the ECB’s purchases of Greek bonds on a weekly basis. Their findings reveal that the SMP had a notable impact on the prices of short- and medium-term maturity Greek bonds. The study also suggests that the ECB's intervention was strong but localised, aligning with the segmented market theory. By employing a model that considers bond yields' changes over the intervention period, the authors use the purchase amount of Greek bonds and their remaining maturity as regressors to better understand the bond yield dynamics during this period of central bank intervention.

Malliaropulos and Migiakis (2018) take a global perspective in their study by examining the impact of the balance sheet assets of four major central banks (the Federal Reserve, ECB, Bank of England, and Bank of Japan) on both developed and developing countries. Their research suggests that the massive purchases of securities made by these central banks led to a reduction in sovereign bond yields, particularly for countries with lower credit ratings. The study utilizes a monthly time window from 2009 to 2017 and builds a model with the yield to maturity as the dependent variable. The ratio between Central Bank Assets to GDP serves as the independent variable, allowing for a comprehensive analysis of the different quantitative easing programs worldwide.

Focusing on the ECB's Asset Purchase Programme (APP), Andrade et al. (2016) assess the program's impact on long-term sovereign yields and the share prices of banks with substantial sovereign holdings in their portfolios. Their study examines different subsamples on a weekly basis in 2015, covering the initial year of the program. Their research provides support for the significance of announcements in driving securities prices higher, reducing duration risk, and providing bank capital relief. They demonstrate that changes in the equity prices of a panel of European banks were influenced by shifts in the 10-year sovereign yield and national stock market indexes. Furthermore, the share of sovereign bonds in the central banks' balance sheets and a dummy variable reflecting undercapitalization of credit institutions serve as additional independent variables to capture the complexities of the relationship.

The reviewed studies contribute significantly to understand the effects of expansionary monetary policies on sovereign bond yields. By examining the consequences of various unconventional measures employed by central banks, these studies provide valuable insights into the dynamics of bond markets and the interplay between monetary policy decisions and bond spread movements. A common factor to all research is the expansion of the central banks' balance sheet which seems to be related to the reduction in the sovereign yields. Even if our research will deal with the sovereign spread, the intuition stays the same. Other factors presented in these studies concern investor perception, market volatility, and the announcement effect. This literature review brought to the two statistical models presented we constructed.

2. A GENERAL VIEW OF THE QE

The European Central Bank's (ECB) Quantitative Easing (QE) program has been one of the most significant monetary policy measures implemented in response to the global financial crisis of 2007-2008 and the subsequent eurozone sovereign debt crisis. This unconventional monetary policy tool involved the large-scale purchase of government bonds and other assets with the aim of injecting liquidity into the financial system and stimulating economic growth.

Greece, being one of the countries severely affected by the eurozone crisis, faced significant challenges in the years following the 2008 financial meltdown. The Greek economy experienced a deep recession, soaring public debt levels, and an escalating risk of sovereign default. The surge in Greek bond yields (versus German bond yields) during this period signified growing concerns about the country's solvency and increased perceived risk among investors.

2.1. Macroeconomic Context Leading to ECB QE

There were different factors which pushed the ECB to adopt new unconventional policies.

The first was the EU sovereign debt crisis that began around 2010 and exposed the vulnerabilities in the eurozone's economic and monetary union. Greece was facing a hard economic recession. From 2008 to 2016 the Greek GDP fell of 25%. At the same time, it had an unsustainable debt burden which amounted at about 180% of the GDP in the 2010s. This situation led the county to become one of the epicentres of the crisis. Investors worried that other heavily indebted Eurozone government might also face debt sustainability challenges, leading to increased risk aversion and higher borrowing costs.

As part of the bailout agreements. Greece was required to implement severe austerity measures to reduce its budget deficit and restore fiscal discipline. Still from 2008 to 2016, government expenditure was cut of 32%, retired people saw their pension reduced from 14% to 40%, and the minimum wage was lowered too. In the meantime, the unemployment rate skyrocketed: from the 8% in 2008 it almost reached the 30% in 2014.

These measures, while necessary, further aggravated the economic contraction, hindering the country's ability to meet debt obligations.

The escalating concerns about Greece's fiscal situation triggered fears of contagion, meaning that the crisis could spread to other vulnerable economies in the Eurozone. Investors started demanding higher yields on bonds issued by countries perceived as risky, indeed Moody’s rating for the Greek debt was Ca in 2011 meaning very near to default, which occurred. These led to increased bond spreads across the region.

Given the difficult scenario, as the crisis unfolded, the ECB initially responded with conventional monetary policy by cutting its policy interest rates. In December 2008 the rates on the Deposit Facility was 2%, and it was continuously reduced until the -0.50% reached in September 2019. The Marginal Lending Facility (from 3% to 0.25%) and the Main Refinancing Operations (from 2.50% to 0%) followed the same pattern.

However, the eurozone economy struggled to recover and inflation remained subdued, so these measures alone were insufficient to address the country crisis effectively.

2.2. ECB QE and its Objectives

To combat the crisis and address deflationary pressures, the ECB introduced QE in 2014. By injecting massive liquidity into the financial system, the ECB aimed to encourage lending to households and businesses, supporting consumption and investment, and ultimately fostering economic growth and job creation.

Indeed, persistently low inflation posed a threat to the Eurozone's economic stability. QE was intended to boost it, by increasing the money supply and its raising expectations.

In addition, The ECB's bond-buying program aimed to restore confidence in financial markets and reduce sovereign bond yields, especially in crisis-hit countries like Greece.

2.3. Impact on Greek Bond Spreads

The implementation of ECB QE had a notable impact on Greek bond spreads and borrowing costs. As the ECB purchased large quantities of Eurozone sovereign bonds, demand for these assets increased also by part of the investors, leading to higher bond prices and lower yields. Consequently, the spread between Greek and benchmark German bonds (the "risk-free" Eurozone asset) narrowed significantly.

The narrowing of Greek bond spreads was indicative of an improved market perception of Greece's creditworthiness and a reduction in perceived default risk. The program's success in reducing Greek borrowing costs provided some relief to the government, allowing to access capital markets at more affordable rates, which supported fiscal consolidation efforts.

However, it is essential to note that the impact of ECB QE on Greek bond spreads was also influenced by various other factors, such as the slow progress of fiscal reforms in Greece, political stability, and external economic conditions. Additionally, while QE helped lower borrowing costs, it did not address the underlying structural issues that the Greek economy faced, which required sustained reforms and policy efforts.

2.4. Implementation in 2014

In June 2014, the ECB announced the launch of its first APP, known as the Covered Bond Purchase Programme (CBPP3). This initiative aimed to enhance the liquidity and functioning of the covered bond market, which is a type of debt security backed by a specific pool of assets, primarily mortgage loans or public-sector loans. By purchasing these covered bonds from banks and other financial institutions, the ECB started to effectively inject liquidity into the financial system and promote lending to households and businesses as planned.

Subsequently, in September 2014, the ECB expanded its asset purchases to include private-sector asset-backed securities (ABS) through the Asset-Backed Securities Purchase Programme (ABSPP). Under this program, the ECB bought ABSs from banks, providing them with additional funding and encouraging more lending to households and small and medium-sized enterprises (SMEs). By supporting the ABS market, the ECB aimed to boost credit supply to the real economy and facilitate economic recovery.

2.5. Implementation After 2014

Building on the initial success of the CBPP3 and ABSPP, the ECB further expanded its program in subsequent years to combat persistently low inflation and stimulate economic growth in the Eurozone. In January 2015, the ECB launched its most prominent and comprehensive measure, the Public Sector Purchase Programme (PSPP).

The PSPP aimed to address the core issue of low inflation by purchasing a wide range of public-sector bonds issued by Eurozone governments, including sovereign bonds. By buying these bonds, the ECB increased demand for them, thereby reducing their yields (interest rates) and making borrowing cheaper for governments. This, in turn, was expected to lower borrowing costs for households and businesses, encourage investment, and support economic activity.

Under the PSPP, the ECB also implemented the Corporate Sector Purchase Programme (CSPP) in June 2016. This program involved the purchase of investment-grade corporate bonds issued by non-bank corporations in the Eurozone. By providing a further stimulus to corporate credit markets, the CSPP aimed to boost business investment and enhance overall economic conditions.

Additionally, the ECB implemented the Pandemic Emergency Purchase Programme (PEPP) in March 2020, in response to the severe economic impact of the COVID-19 pandemic. The PEPP was designed to provide additional flexibility in conducting asset purchases during the crisis, with a particular focus on supporting those sectors most affected by the pandemic.

3. DATA AND METHODOLOGY

3.1. Data Acquisition and Seasonal Adjustment

In this comprehensive analysis, an array of data sources was considered. The US Federal Reserve database provided the 10-year Greek and German bond yields, forming the basis for computing the critical 10-year Greek bond spread, the pivotal independent variable for this research. To facilitate accurate and standardized comparisons, the spread was converted into basis points by multiplying the corresponding vector by 10,000.

Moreover, to ensure robust analysis, time varying seasonal adjustments were applied to the time series data, effectively mitigating potential distortions due to recurring seasonal patterns. This was done by means of the R library *seasonal* and the function *seas*. With the default options, the function *seas* calls the automatic procedures of X-13 ARIMA-SEATS to perform the data adjustment.

3.2. Understanding the APP and the Control Variables

A vital aspect of this study involves comprehending the APP, the ECB's flagship unconventional monetary policy. Diving into the ECB's official website, the APP was observed to encompass four primary categories of securities (as mentioned before). We can briefly review them.

We have the Asset-Backed Securities purchases (ABSPP) and the Third Covered Bonds purchases (CBPP3).

Then, there are the Public Sector Securities purchases (PSPP), representing a significant portion (88%) of the overall APP, with 92% held by National Central Banks (NCBs).

Finally, there are also the corporate sector Securities purchases (CSPP), although not directly relevant to this specific analysis.

In this context, the PSPP, alongside the ABSPP and CBPP3, emerged as the primary control variable, serving as a key reference point for assessing the impact of unconventional monetary measures on sovereign bond spreads.

3.3. Additional Variables Influencing the Spread Behaviour

Recognizing the multifaceted nature of bond spread dynamics, this research accounts for other factors that may influence the spread behaviour. As a measure of investors' perception regarding Greek sovereign debt compared to German sovereign debt, the time series for the 10-year Credit Default Swap (CDS) for both Greece and Germany were obtained from the Refinitiv Eikon platform. The spread between these two CDSs provides valuable insights into investor risk perception during the analysed period.

Moreover, the analysis also considers the Euro Stoxx 50, sourced from the same database, as a measure of market volatility. This widely recognized index offers a comprehensive view of overall market sentiment and fluctuations during the APP period, further enriching the study's insights.

3.4. Main Variables

At the heart of this study lie two critical variables: the 10-year Greek bond spread and the Eurosystem Asset Purchases, which encompasses the ABSPP, the PSPP, and the CBPP3. These variables serve as the dependent and main control variables, respectively, and their time series plots offer an initial glimpse into their trends. Figure 1 presents the time series plot of the 10-year Greek bond spread, expressed in basis points, spanning the period from November 2014 to July 2022. On the other hand, Figure 2 showcases the Cumulative Asset Purchases (CAPs) in millions, covering the same period.

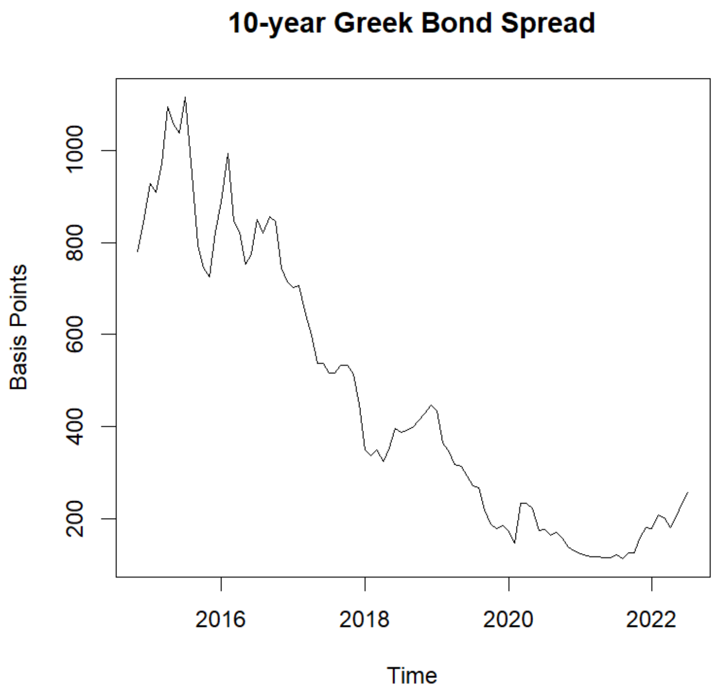

Figure 1. 10-year Greek bond spread in basis points

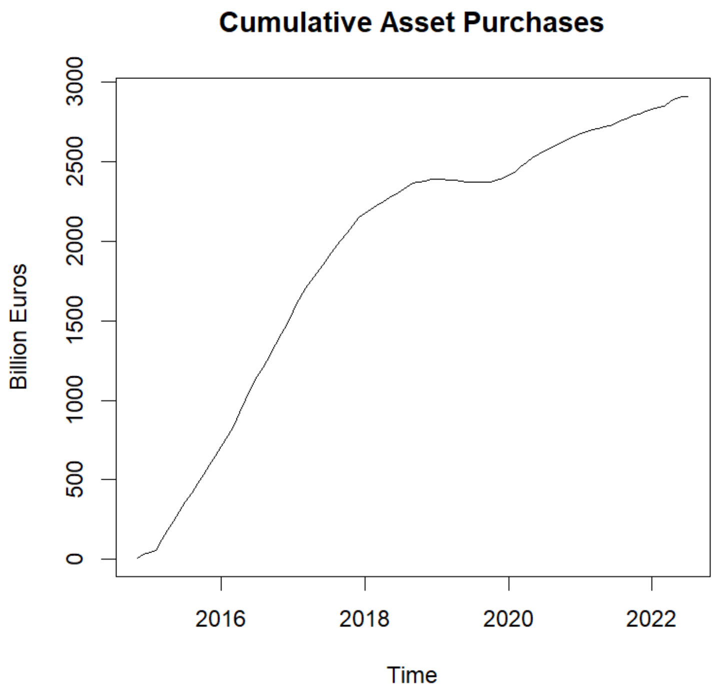

Figure 2. Cumulative Asset Purchases in billion euros

Upon first observation, it becomes evident that the two series exhibit an opposing trend. As the Eurosystem's asset purchases increase, the 10-year Greek bond spread tends to decline.

3.5. Stationarity Tests

To establish the existence of a long-run relationship between the Greek spread and the cumulative asset purchases, it is imperative to verify the stationarity condition of the second order. This entails ensuring that the mean, variance, covariance, and correlation remain constant across the same time lag. Augmented-Dickey Fuller (ADF) and Philippe-Perron (PP) tests, commonly used to detect unit roots, were employed for this purpose.

AUGMENTED DICKEY-FULLER TEST UNIT ROOT TEST		
TEST STATISTIC: 10-year Greek Spread	TEST STATISTIC: Cumulative Asset Purchases	
-1.6014	-0.1954	
CRITICAL VALUES FOR TEST STATISTICS		
1pct	5pct	10pct
-2.6	-1.95	-1.61

Table 1. ADF test for the 10-year Greek spread and the CAPs

PHILIPPE-PERRON UNIT ROOT TEST		
P-VALUE: 10-year Greek Spread	P-VALUE: Cumulative Asset Purchases	
0.47	0.99	
P-VALUES FOR THE TEST STATISTIC		
1pct	5pct	10pct
<0.01	0.01-0.05	0.05-0.1

Table 2. PP test for the 10-year Greek spread and the CAPs

Unfortunately, both time series, the 10-year Greek bond spread and the CAPs, exhibited test statistics greater than the critical value of -1.95. As a result, the stationarity condition did not hold in this case.

Despite the non-stationarity of the series, this research employs a methodology centred around a linear regression model. This model seeks to explain the decline in the 10-year Greek bond spread through the growth rate of the cumulative asset purchases, coupled with a dummy variable reflecting market announcements. The model is represented as follows.

Equation 1 $$\Delta Y_t = \alpha + \beta_1 X_1 t + \gamma dt + \varepsilon_t$$

In *Equation 1*, ΔY_t denotes the first difference of the 10-year Greek bond spread, $X_1 t$ represents the growth rate of the CAPs, dt corresponds to the dummy variable, and β and γ are coefficients. Both β and γ are expected to be negative, as each new purchase and announcement is anticipated to result in a decrease in the spread.

The stationarity of the spread change and the growth rate of the CAPs allow for dealing with the changes in these variables effectively, ensuring a robust analysis.

AUGMENTED DICKEY-FULLER TEST UNIT ROOT TEST		
TEST STATISTIC: Δ10-year Greek Spread	TEST STATISTIC: CAPS growth rate	
-6.0671	-4.1531	
CRITICAL VALUES FOR TEST STATISTICS		
1pct	5pct	10pct
-2.6	-1.95	-1.61

Table 3. ADF test for Δ10-year Greek spread and the CAPs growth rate

PHILIPPE-PERRON UNIT ROOT TEST		
P-VALUE: Δ10-year Greek Spread		P-VALUE: CAPs growth rate
<0.01		<0.01
P-VALUES FOR THE TEST STATISTIC		
1pct	5pct	10pct
<0.01	0.01-0.05	0.05-0.1

Table 4. PP test for the Δ10-year Greek spread and the CAPs growth rate

3.6. Extension of the Model

To incorporate additional factors influencing the spread behaviour, the initial model can be extended by including new variables. *Equation 2* represents the expanded model.

Equation 2 $$\Delta Y_t = \alpha + \beta_1 X_1 t + \beta_2 \Delta X_2 t + \beta_3 \Delta X_3 t + \gamma dt + \varepsilon_t$$

In *Equation 2*, $X_1 t$ retains the rate of growth of the cumulative asset purchases, while ΔX_2 represents the change in the 10-year CDSs spread. A positive sign of β_2, if significant, would indicate the influence of this variable on the spread behaviour. Similarly, $\Delta X_3 t$ reflects the change in the Euro Stoxx 50 monthly returns, with a positive sign expected if significant. These two variables will be included in the extended model, further enriching the analysis of sovereign bond spread behaviour, while dt still corresponds to the dummy variable.

The ADF and the PP tests confirm the stationarity of the first difference of the new variables.

AUGMENTED DICKEY-FULLER TEST UNIT ROOT TEST		
TEST STATISTIC: ΔCDS Spread	TEST STATISTIC: ΔEuro Stoxx 50 Returns	
-5.4473	-13.6012	
CRITICAL VALUES FOR TEST STATISTICS		
1pct	5pct	10pct
-2.6	-1.95	-1.61

Table 5. ADF test for the 10-year ΔCDS Spread and the ΔEuro Stoxx 50 Returns

PHILIPPE-PERRON UNIT ROOT TEST		
TEST STATISTIC: ΔCDS Spread	TEST STATISTIC: ΔEuro Stoxx 50 Returns	
<0.01	<0.01	
P-VALUES FOR THE TEST STATISTIC		
1pct	5pct	10pct
<0.01	0.01-0.05	0.05-0.1

Table 6. PP test for the 10-year ΔCDS Spread and the ΔEuro Stoxx 50 Returns

Although the original time series are non-stationary, the study adopts a robust methodology to analyse the dynamics of these variables and their impact on the spread behaviour. The extended model, incorporating additional influential factors, promises to offer valuable insights into the complexities of the European bond market and contribute to a better understanding of the implications of unconventional monetary policy on sovereign bond spreads.

Figure 4 showcases the 10-year Credit Default Swap (CDS) spread for Greece, reflecting investors' perception of risk concerning Greek sovereign debt compared to Germany's. Lastly, Figure 5 depicts the Euro Stoxx 50 returns, a measure of market volatility and sentiment.

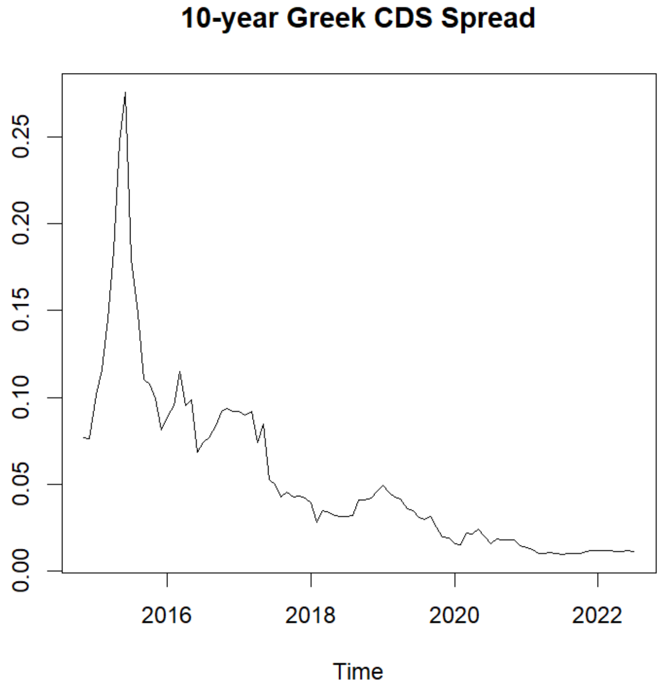

Figure 3. 10-year Credit Default Swap Spread for Greece

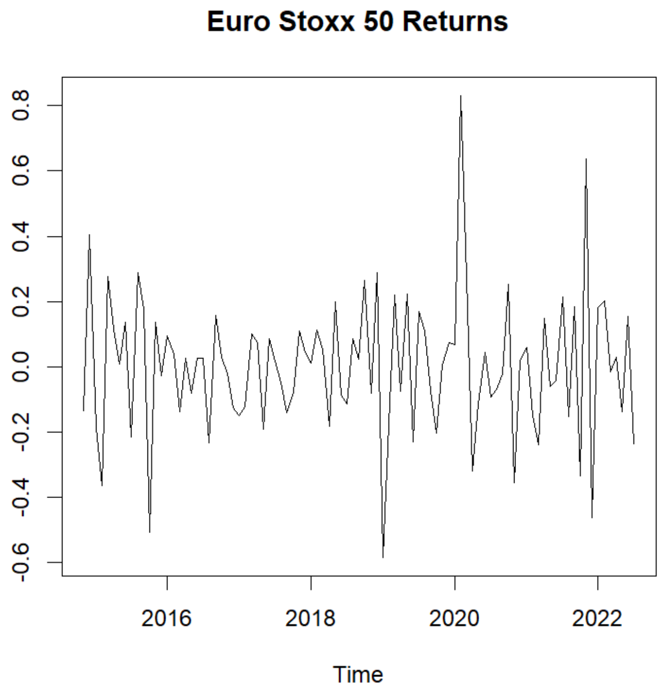

Figure 4. Euro Stoxx 50 Returns

4. OLS APPROACH: THE INTRICACIES OF THE LINEAR REGRESSION MODEL

The Ordinary Least Squares (OLS) approach, as presented in *Equation 2*, provides valuable insights into the relationship between the 10-year Greek bond spread and the various independent variables. To better see the results, only the spread in the regression analysis is expressed in basis points. Along with the corresponding statistics the coefficient estimates (Table 8 and 9), show the significance of the variables and the model's explanatory power.

COEFFICIENTS

Variable	Estimate	Std. Error	P-value
α	-0.67	5.22	0.90
X_1t	-11.56	5.72	0.05*
ΔX_2t	415.78	313.46	0.19
ΔX_3t	-6.54	14.58	0.65
dt	-49.54	19.09	0.01*

Table 7. OLS model coefficient estimates

MODEL PERFORMANCE

Statistics	Value
R^2	0.12
Adjusted R^2	0.08
P-value	0.02

Table 8. OLS model performance

4.1. Results and Interpretation

The results indicate that the growth rate of the CAPs (X_1t) and the dummy variable (dt) are statistically significant in explaining changes in the spread. Specifically, an increase in the CAPs growth rate corresponds to a decline in the spread change by 0.1156%, while each new purchase announcement corresponds to a decline of 0.4954%. However, the explanatory power of the model, as indicated by the adjusted R-squared value is relatively low, accounting for only 8% of the variability in the dependent variable behaviour.

4.2. Testing Residuals' Robustness

To ensure the robustness of the model, it is essential to test for the residuals' autocorrelation, normality, and heteroskedasticity.

The autocorrelation function (Figure 6) indicates no significant autocorrelation in the residuals. Additionally, the Box test suggests accepting the null hypothesis of no autocorrelation.

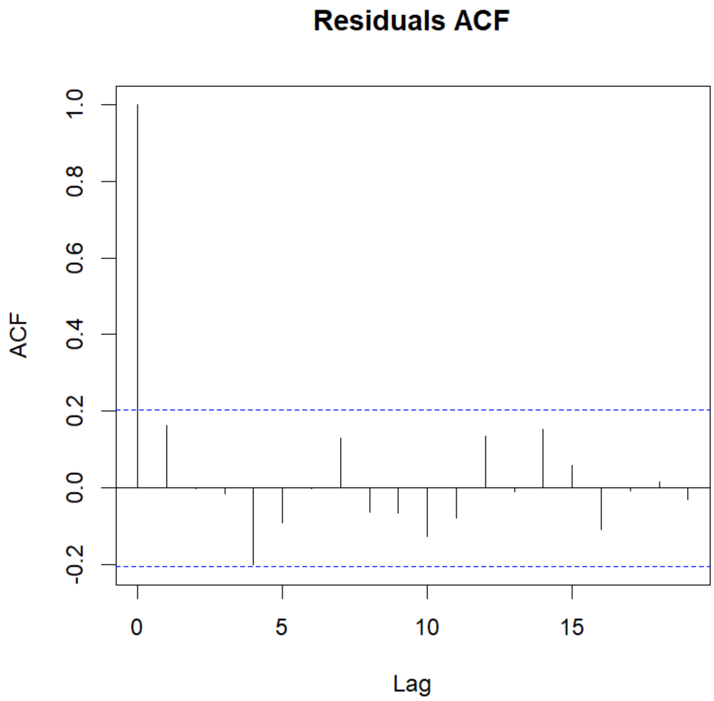

Figure 5. Residuals Autocorrelation for the OLS model

Test	P-value	Result
Box, type “Ljung”	0.1116	Not rejected

Table 9. OLS model residuals Box test

The Q-Q plot (Figure 7) is utilized to detect deviations from normality. However, the Shapiro-Wilk test indicates that the null hypothesis of normality should be rejected, implying some non-normality in the residuals.

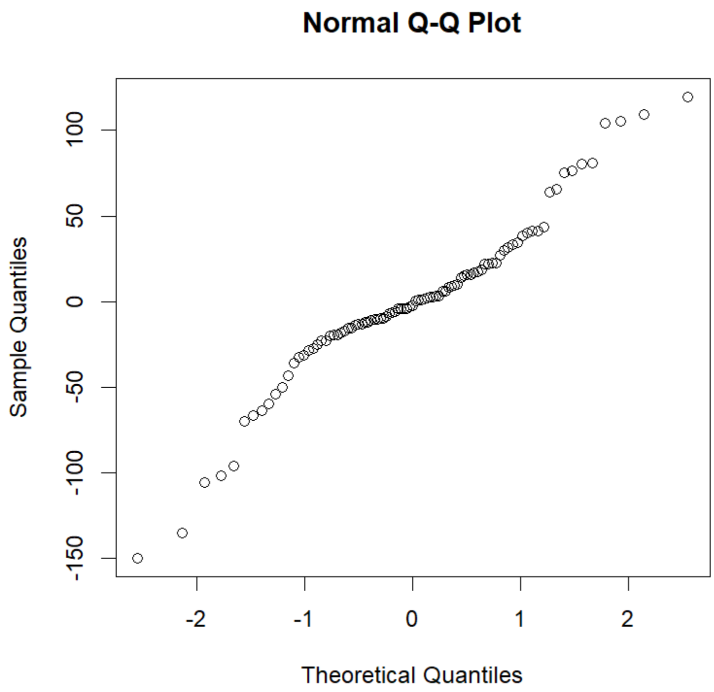

Figure 6. Q-Q normal plot for the OLS Residuals

Test	P-value	Result
Shapiro-Wilk	0.0009785	Rejected

Table 10. OLS model residuals Shapiro-Wilk test

The Breusch-Pagan test is employed to test for heteroskedasticity. The results (Figure 8) indicate that the null hypothesis of no heteroskedasticity should be accepted, confirming that the residuals exhibit homoscedasticity (constant variance).

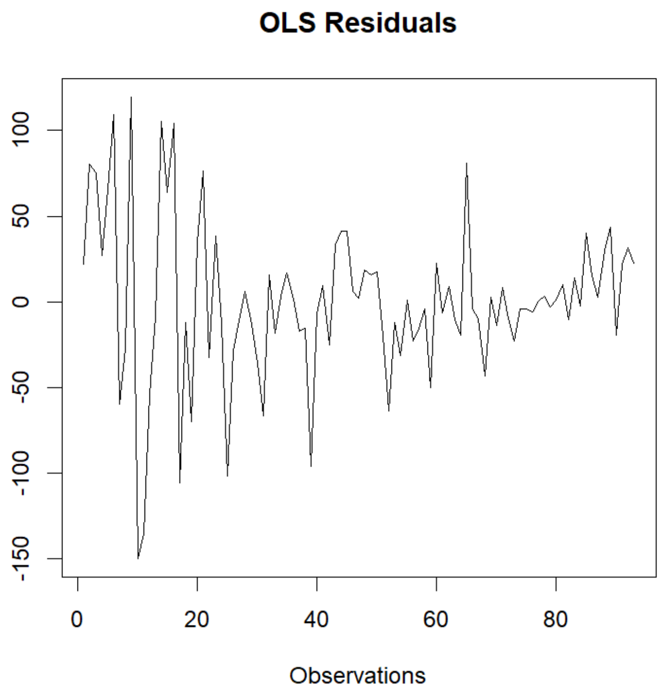

Figure 7. OLS Residuals plot

Test	P-value	Result
Breusch-Pagan	0.1515	Not rejected

Table 11. OLS model residuals Breusch-Pagan test

4.3. Addressing Our Model's Limitations

It is essential to acknowledge that the linear model may not fully capture the complex econometric relationship between the variables. The presence of outliers in the data could potentially contribute to the non-normality observed in the residuals. Additionally, the relatively low explanatory power of the model calls for further exploration of other factors that may influence the bond spread behaviour.

4.4. Future Directions

To enhance the model's robustness and explanatory power, future research may consider incorporating additional variables and exploring alternative regression approaches. The identification and treatment of outliers, if present, could also play a crucial role in refining the model's performance.

In conclusion, the OLS approach has provided valuable insights into the relationship between the 10-year Greek bond spread, the CAPs growth rate, and the announcement dummy variable. The significance of these variables emphasizes their role in influencing spread changes. However, the low explanatory power of the model, coupled with the non-normality observed in the residuals, calls for cautious interpretation of the results. Further investigation and refinement of the model are warranted to gain a more comprehensive understanding of the complex dynamics governing the European bond market.

By addressing the model's limitations and exploring new avenues of analysis, we can offer more robust insights that contribute to a deeper comprehension of the implications of unconventional monetary policy on sovereign bond spreads and financial stability in the Eurozone.

5. THE ARDL: COINTEGRATION AND LONG-TERM EQUILIBRIUM

In the pursuit of a more robust and comprehensive model, we explore the Autoregressive Distributed Lag (ARDL) approach, which has the potential to address issues related to cointegration and mixed order of integration among the variables. The ARDL model proves particularly valuable when dealing with variables of different integration orders, allowing us to detect potential long-term relationships that may not be apparent in the standard linear regression model.

Detecting the presence of cointegration signifies that two or more non-stationary variables can become stationary when combined in the same linear model or with the addition of suitable lags. A dynamic model can be obtained as a reparameterization of the ARDL model, possibly including an error correction term in case cointegration is present.

To assess the optimal lag structure for the dependent and independent variables and alleviate potential issues of serial correlation, the function *VAR select* in R is employed. This function provides us with the Shwartz Information Criteria (SC) to determine the ideal lags for each variable. The results indicate the following optimal lags.

Variable	Information Criteria	Optimal Lag
10-year GS	SC	2
CAPs	SC	1
10-year CDS Spread	SC	1
Euro Stoxx 50	SC	1

Table 12. Optimal lag selection

With the optimal lags identified, the Pesaran, Shin, and Smith test is performed to ascertain the presence of cointegration. The test yields critical values and an F-statistic, which lead to the rejection of the null hypothesis of no integration, thereby confirming the existence of cointegration among the variables.

Critical Values	I (0)	I (1)	F-statistic	Results
10%	2.72	3.77	4.64	Reject
5%	3.23	4.35	4.64	Reject
1%	4.29	5.61	4.64	Do not Reject

Table 13. the Pesaran, Shin, and Smith cointegration test outcome

Given the presence of cointegration, the ARDL model is then fitted in the error correction form (ECM). This facilitates the estimation of both long-run and short-run coefficients. The long-run coefficients reveal the cointegrating relationship between the variables, while the short-run coefficients describe the deviations from the long-term equilibrium for each specific time lag.

Equation 3 exemplifies the optimal lag structure of our ARDL model.

Equation 3 $$Y_t = \alpha + \sum_{j=1}^{2} Y_{(t-j)} + \sum_{k=0}^{1} X_{1(t-k)} + \sum_{k=0}^{1} X_{2(t-k)} + + \sum_{k=0}^{1} X_{3(t-k)} + \varepsilon_t$$

Here, Y_t represents the monthly 10-year Greek bond spread, $X_{1(t-k)}$represents t he monthly CAPs, $X_{2(t-k)}$ is the 10-year Greek CDS Spread, and $X_{3(t-k)}$ is the Eu-ro Stoxx 50 returns.

To better understand the implications of the estimated coefficients, their signific ance, and the overall model performance, we need to critically interpret the find ings. The outputs display the long run coefficients, the short-run coefficients, and finally the model performance.

5.1. A Critical Interpretation of the ARDL Results

LONG-RUN COEFFICIENTS

Variable	Estimate	Std. Error	P-value
10-year GS	-0.16	0.06	0.01*
CAPs	-0.06	0.02	0.0006***
10-year CDS Spread	-416.15	251.46	0.10
Euro Stoxx 50	13.24	47.08	0.77

Table 14. ARDL model long-run coefficient estimates

The 10-year GS (Greek Bond Spread) coefficient estimate of -0.16 with a p-value of 0.01* suggests that in the long run, there exists an inverse relationship between the 10-year Greek bond spread and itself. This implies that past changes in the bond spread have an impact on its current level, indicating some persistence in its behaviour.

The CAPs (Cumulative Asset Purchases) significant coefficient estimate of -0.06 with an extremely low p-value of 0.0006*** indicates that there is a negative long-run relationship between CAPs and the 10-year Greek bond spread. In other words, each rise in CAPs is associated with a reduction in the Greek bond spread of 6% of that increase. This finding implies that expansionary monetary policy measures, such as asset purchases by the central bank, have an effect on lowering the Greek bond spread.

The 10-year CDS Spread coefficient estimate of -416.15 with a p-value of 0.10 does not reach conventional levels of statistical significance. As a result, we cannot draw a robust conclusion regarding the long-run relationship between the 10-year CDS spread and the Greek bond spread.

The Euro Stoxx 50 with a coefficient estimate of 13.24 and a relatively high p-value of 0.77, does not appear to have a significant long-run relationship with the Greek bond spread too. This suggests that changes in the Euro Stoxx 50 do not have a substantial impact on the Greek bond spread over the long term.

SHORT-RUN COEFFICIENTS

Variable	Estimate	Std. Error	P-value
Intercept	202.34	47.34	5.20E-05***
Error correction	-0.16	0.04	3.40E-05***
Δ10-year GS (t-1)	0.32	0.10	0.002**
Δ10-year GS (t-2)	-0.15	0.10	0.13
ΔCAPs (t)	0.37	0.19	0.06’
ΔCAPs (t-1)	-	-	-
Δ10-year CDS Spread (t)	-757.64	309.24	0.02*
Δ10-year CDS Spread (t-1)	1532.56	294.82	1.48E-06***
ΔEuro Stoxx 50 (t)	35.56	15.44	0.02*
ΔEuro Stoxx 50 (t-1)	43.41	15.06	0.005**

Table 15. ARDL model short-run coefficient estimates

The intercept term of 202.34 with an extremely low p-value of 5.20E-05*** represents the short-run constant in the model. It indicates that the spread has a positive baseline level, regardless of the values of the independent variables.

The error correction coefficient estimate of -0.16 with a p-value of 3.40E-05*** is statistically significant. This term captures the speed of adjustment towards the long-run equilibrium after short-term deviations. A significant negative error correction coefficient suggests that any deviations from the long-run relationship will be corrected over time, leading the spread to converge back to its equilibrium level. This confirms the significance of the long-run coefficients trough time.

The two lagged 10-year Greek bond spread coefficients are 0.32 and -0.15, respectively. A positive coefficient (0.32) for the immediate lag (t-1) indicates that a previous period's increase in the spread is associated with a rise in the current period's spread. However, the coefficient for the second lag (t-2) is negative (-0.15), suggesting that the spread reverts to its long-term equilibrium following the first lag.

The short-run coefficient for CAPs (t) is 0.37, while the coefficient for CAPs (t-1) is not available (denoted as "-"). The positive coefficient for CAPs (t) indicates that an increase in the current period's cumulative asset purchases leads to a rise in the spread. However, the absence of a coefficient for CAPs (t-1) suggests that the impact of cumulative asset purchases diminishes after the immediate lag.

The current and lagged 10-year CDS spreads coefficients are -757.64 and 1532.56, respectively. The negative coefficient for 10-year CDS Spread (t) suggests that an increase in the current period's CDS spread corresponds to a decrease in the spread. However, the positive coefficient for 10-year CDS Spread (t-1) indicates that the impact of the CDS spread is stronger in the previous period than in the current one.

Finally, the current and lagged Euro Stoxx 50 returns coefficients are 35.56 and 43.41, respectively. Both coefficients are positive, indicating that an increase in the current or previous period's Euro Stoxx 50 returns is associated with a rise in the spread.

MODEL PERFORMANCE

Statistics	Value
R^2	0.40
Adjusted R^2	0.32
P-value	1.361E-05

Table 16. ARDL model performance

The R-squared value of 0.40 suggests that the model explains approximately 40% of the variability in the 10-year Greek bond spread. While this represents a moderate level of explanatory power, the adjusted R-squared value of 0.32 indicates that around 32% of the variation is explained when accounting for the model's degrees of freedom. The extremely low p-value of 1.361E-05*** for the overall model suggests that the model is statistically significant.

5.2. Testing Model Robustness

To ensure the model's robustness, various tests are conducted to evaluate the residuals' properties.

The autocorrelation function for the ARDL residuals (Figure 9) indicates no significant autocorrelation, with the Box test results corroborating this finding.

Test	P-value	Result
Box, type "Ljung"	0.5002	Not rejected

Table 17. ARDL model residuals Box test

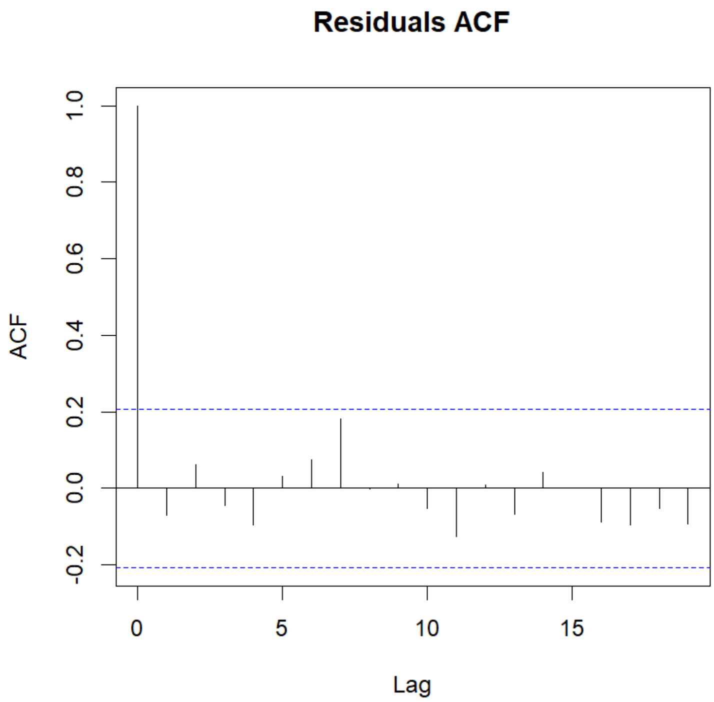

Figure 8. Autocorrelation function for the ARDL Residuals

The Shapiro-Wilk test results suggest that the ARDL residuals follow a normal distribution, which is further supported by the QQ residuals plot (Figure 10).

Test	P-value	Result
Shapiro-Wilk	0.2182	Not rejected

Table 18. ARDL model residuals Shapiro-Wilk test

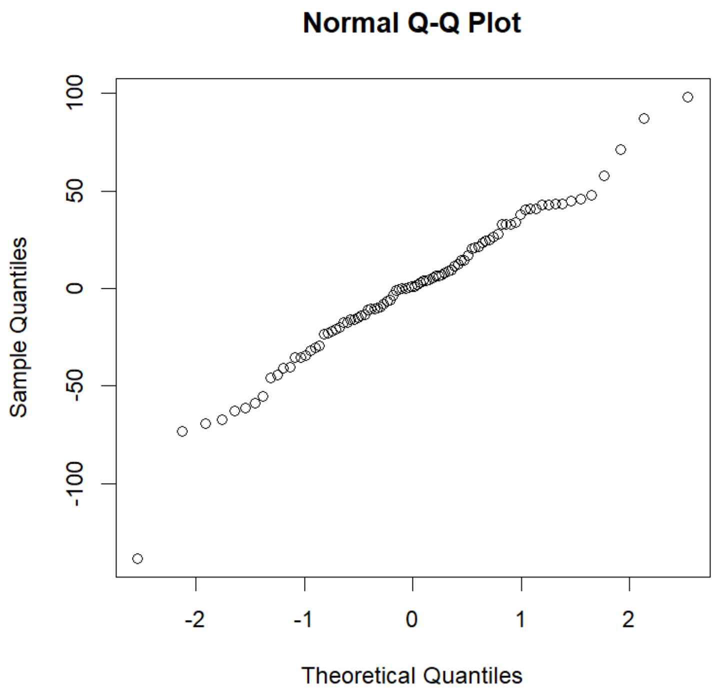

Figure 9. QQ Residuals plot for the ARDL model

The ARDL residuals (Figure 11) demonstrate homoscedasticity, as the Breusch-Pagan test does not reject the null hypothesis of no heteroskedasticity.

Test	P-value	Result
Breusch-Pagan	0.1118	Not rejected

Table 19. ARDL model residuals Breusch-Pagan test

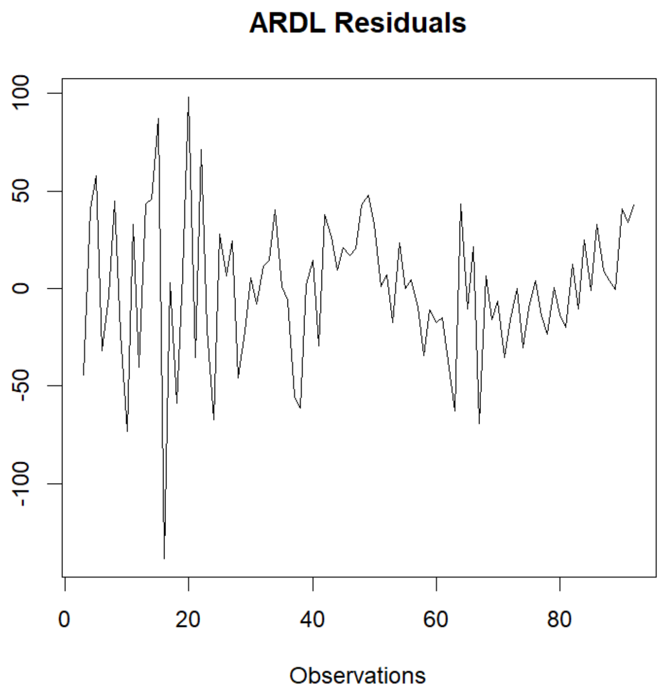

Figure 10. ARDL Residuals plot

Moreover, the ARDL model passes the structural break test (Figure 12), indicating the absence of structural changes within the analysed time window.

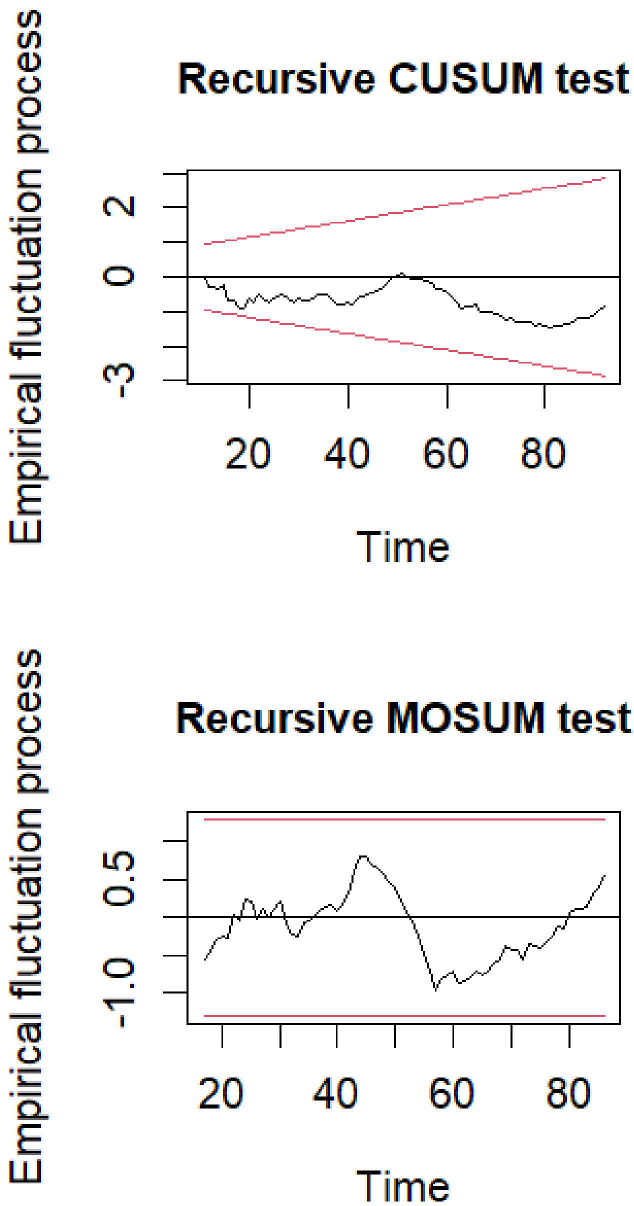

Figure 11. ARDL Structural Break Test

5.3. Final Considerations

The ARDL model results provide valuable insights into the dynamics governing the 10-year Greek bond spread and its relationship with the cumulative asset purchases, lagged bond spread, and other financial market indicators. The findings suggest a significant negative long-run relationship between the bond spread and cumulative asset purchases, indicating the effectiveness of expansionary monetary policy measures in reducing the same spread. Additionally, the short-run coefficients reveal the speed of adjustment towards the long-term equilibrium after any short-term deviations. While some variables, such as the Euro Stoxx 50, do not have a substantial impact on the bond spread, the model as a whole offers a meaningful framework for understanding the drivers of the Greek bond market. However, it is essential to consider the limitations of the model and the potential for further refinement and analysis to enhance the predictive power and accuracy of the findings.

In conclusion, the application of the ARDL model has enhanced the analysis, providing insights into the cointegrating relationship between the variables and their deviations from long-term equilibrium. The significant coefficients reveal the crucial role of CAPs in affecting the 10-year Greek bond spread within the specified time frame.

The model's robustness is reaffirmed through various tests, ensuring that the residuals meet the assumptions of the ARDL approach. These findings consolidate the credibility of the ARDL model's results and contribute to a more profound understanding of the intricate dynamics governing the European bond market.

CONLUSION

Our study delves into the dynamics of the 10-year Greek bond spread and its relationships with more key independent variables. Employing both the Ordinary Least Squares (OLS) approach and the Autoregressive Distributed Lag (ARDL) model, we aimed to gain comprehensive insights into the underlying factors influencing the bond spread behaviour.

Our findings from the OLS approach revealed that the growth rate of CAPs and the announcement dummy variable hold statistical significance in explaining changes in the bond spread. Notably, an increase in the CAPs growth rate corresponds to a decline of 0.1156% basis points in the spread change, while each new purchase announcement results in a decline of 0.4954%. However, the model's explanatory power, indicated by the adjusted R-squared value of 0.08, is relatively low, accounting for only 8% of the spread's variability.

As we turned to the ARDL model, it proved to be a valuable tool for handling variables with different integration orders and investigating potential long-term relationships among the variables. We discovered a significant negative long-run relationship between the bond spread and cumulative asset purchases, suggesting that expansionary monetary policies can effectively reduce the spread over time. Here, an increase in CAPs is associated with a reduction in the Greek bond spread of 6%. Nevertheless, other variables, such as the 10-year CDS spread and Euro Stoxx 50, did not demonstrate substantial impacts in the long-run.

Our analysis also provided crucial insights into short-run dynamics, showcasing the speed of adjustment towards the long-term equilibrium after short-term deviations. Notably, the ARDL model passed various tests for robustness, affirming the reliability of our results.

Despite the meaningful findings, we acknowledge the limitations of both models. The OLS approach's relatively low explanatory power and the ARDL model's potential complexities call for further investigation and refinements. To enhance the model's performance, future research may consider incorporating additional variables and exploring alternative regression approaches.

Our study contributes to the understanding of the European bond market and the implications of unconventional monetary policies. By addressing the model limitations and exploring new avenues of analysis, we pave the way for more robust insights that promote a deeper comprehension of financial stability in the Eurozone. Continued efforts in refining these models will undoubtedly foster more comprehensive and accurate assessments of the dynamic interactions governing the 10-year Greek bond spread.

APPENDICES

A1. Dataset for the OLS model

Table A1 contains the full dataset used for the OLS approach. Only the first difference in the 10-Greek bond spread is expressed in basis points.

Date	Δ10-year Greek Spread	CAPs growth	Δ10-year Greek CDS Spread	ΔEuro Stoxx 50 Returns	Dummy
01/11/2014	118.08	-8.31	0.00	-0.14	0
01/12/2014	62.02	1.22	0.00	0.54	0
01/01/2015	84.39	0.37	0.02	-0.59	0
01/02/2015	-18.90	0.27	0.01	-0.18	1
01/03/2015	63.78	0.80	0.03	0.64	0
01/04/2015	121.89	0.37	0.04	-0.16	0
01/05/2015	-36.93	0.28	0.06	-0.11	0
01/06/2015	-19.87	0.23	0.03	0.13	0
01/07/2015	79.63	0.17	-0.10	-0.35	0
01/08/2015	-168.71	0.15	-0.03	0.50	0
01/09/2015	-152.48	0.14	-0.04	-0.11	0
01/10/2015	-52.41	0.11	0.00	-0.68	0
01/11/2015	-18.45	0.10	-0.01	0.64	0
01/12/2015	97.40	0.09	-0.02	-0.16	0
01/01/2016	64.53	0.10	0.01	0.12	0
01/02/2016	105.73	0.08	0.01	-0.06	0
01/03/2016	-147.48	0.08	0.02	-0.18	1
01/04/2016	-22.72	0.09	-0.02	0.16	0
01/05/2016	-69.51	0.08	0.00	-0.11	0
01/06/2016	19.93	0.07	-0.03	0.11	0
01/07/2016	77.42	0.06	0.01	0.00	0
01/08/2016	-30.83	0.05	0.00	-0.26	0
01/09/2016	37.24	0.06	0.01	0.39	0
01/10/2016	-9.98	0.05	0.01	-0.13	0
01/11/2016	-102.11	0.05	0.00	-0.05	0
01/12/2016	-29.78	0.04	0.00	-0.11	0
01/01/2017	-12.17	0.05	0.00	-0.02	0
01/02/2017	4.03	0.05	0.00	0.03	0
01/03/2017	-64.80	0.04	0.00	0.22	1
01/04/2017	-44.10	0.03	-0.02	-0.03	0

01/05/2017	-61.56	0.03	0.01	-0.27	0
01/06/2017	-0.07	0.03	-0.03	0.28	0
01/07/2017	-19.94	0.03	0.00	-0.07	0
01/08/2017	-0.30	0.03	-0.01	-0.07	0
01/09/2017	17.76	0.02	0.00	-0.09	0
01/10/2017	-0.94	0.03	0.00	0.06	0
01/11/2017	-18.81	0.02	0.00	0.19	0
01/12/2017	-66.42	0.02	0.00	-0.07	1
01/01/2018	-97.87	0.01	0.00	-0.03	0
01/02/2018	-12.80	0.01	-0.01	0.10	0
01/03/2018	11.57	0.01	0.01	-0.06	0
01/04/2018	-24.56	0.01	0.00	-0.23	0
01/05/2018	29.39	0.01	0.00	0.38	0
01/06/2018	42.14	0.01	0.00	-0.29	0
01/07/2018	-8.75	0.01	0.00	-0.03	1
01/08/2018	4.46	0.01	0.00	0.20	0
01/09/2018	5.66	0.01	0.01	-0.06	0
01/10/2018	15.93	0.00	0.00	0.24	0
01/11/2018	17.68	0.00	0.00	-0.35	0
01/12/2018	15.79	0.01	0.00	0.37	0
01/01/2019	-13.56	0.00	0.00	-0.87	0
01/02/2019	-68.86	0.00	0.00	0.41	0
01/03/2019	-16.59	0.00	0.00	0.40	0
01/04/2019	-30.73	0.00	0.00	-0.29	0
01/05/2019	-3.77	0.00	-0.01	0.30	0
01/06/2019	-20.99	0.00	0.00	-0.45	0
01/07/2019	-20.49	0.00	0.00	0.40	0
01/08/2019	-4.83	0.00	0.00	-0.06	0
01/09/2019	-49.12	0.00	0.00	-0.18	0
01/10/2019	-29.28	0.00	-0.01	-0.13	1
01/11/2019	-10.82	0.01	-0.01	0.21	0
01/12/2019	7.78	0.01	0.00	0.07	0
01/01/2020	-12.57	0.01	0.00	-0.01	0
01/02/2020	-25.32	0.01	0.00	0.76	0
01/03/2020	86.83	0.02	0.01	-0.56	0
01/04/2020	-1.59	0.01	0.00	-0.59	0
01/05/2020	-10.79	0.01	0.00	0.21	0
01/06/2020	-46.88	0.01	0.00	0.16	0
01/07/2020	1.16	0.01	0.00	-0.14	0
01/08/2020	-13.58	0.01	0.00	0.02	0
01/09/2020	7.12	0.01	0.00	0.05	0
01/10/2020	-12.41	0.01	0.00	0.27	0

01/11/2020	-19.26	0.01	0.00	-0.61	0
01/12/2020	-8.89	0.01	0.00	0.37	0
01/01/2021	-5.45	0.01	0.00	0.04	0
01/02/2021	-5.35	0.01	0.00	-0.21	0
01/03/2021	-0.73	0.00	0.00	-0.09	0
01/04/2021	-0.27	0.00	0.00	0.39	0
01/05/2021	-2.37	0.00	0.00	-0.21	0
01/06/2021	-0.03	0.00	0.00	0.02	0
01/07/2021	7.24	0.01	0.00	0.26	0
01/08/2021	-8.57	0.01	0.00	-0.37	0
01/09/2021	10.91	0.00	0.00	0.34	0
01/10/2021	0.37	0.01	0.00	-0.52	0
01/11/2021	33.77	0.00	0.00	0.97	0
01/12/2021	21.73	0.01	0.00	-1.10	0
01/01/2022	-1.99	0.00	0.00	0.64	0
01/02/2022	28.91	0.00	0.00	0.02	0
01/03/2022	-5.34	0.00	0.00	-0.22	1
01/04/2022	-20.92	0.01	0.00	0.04	0
01/05/2022	22.45	0.01	0.00	-0.17	0
01/06/2022	29.19	0.00	0.00	0.29	0
01/07/2022	24.45	0.00	0.00	-0.39	0

Table A1. OLS model dataset

A2. Dataset for the ARDL model

Table A2 contains the full dataset used for the ARDL approach. Only the 10-Greek bond spread is expressed in basis points.

Date	10-year Greek Spread	CAPs (in billion)	10-year Greek CDS Spread	Euro Stoxx 50 Returns
01/11/2014	781.22	8.70	0.08	-0.14
01/12/2014	843.24	29.57	0.08	0.41
01/01/2015	927.63	42.90	0.10	-0.19
01/02/2015	908.73	56.02	0.12	-0.36
01/03/2015	972.52	124.37	0.14	0.28
01/04/2015	1094.41	180.69	0.18	0.11
01/05/2015	1057.48	239.79	0.25	0.01
01/06/2015	1037.61	301.44	0.28	0.14
01/07/2015	1117.24	358.46	0.18	-0.22
01/08/2015	948.53	417.08	0.15	0.29
01/09/2015	796.05	477.64	0.11	0.18
01/10/2015	743.64	534.22	0.11	-0.51
01/11/2015	725.19	592.57	0.10	0.14
01/12/2015	822.60	648.01	0.08	-0.03
01/01/2016	887.13	712.60	0.09	0.09
01/02/2016	992.86	775.80	0.10	0.04
01/03/2016	845.38	840.96	0.11	-0.14
01/04/2016	822.66	922.45	0.10	0.03
01/05/2016	753.14	1003.38	0.10	-0.08
01/06/2016	773.07	1078.40	0.07	0.03
01/07/2016	850.49	1148.48	0.07	0.03
01/08/2016	819.66	1207.43	0.08	-0.23
01/09/2016	856.90	1278.10	0.08	0.16
01/10/2016	846.92	1349.86	0.09	0.03
01/11/2016	744.81	1420.53	0.09	-0.02
01/12/2016	715.03	1479.51	0.09	-0.13
01/01/2017	702.86	1557.74	0.09	-0.15
01/02/2017	706.90	1631.19	0.09	-0.12
01/03/2017	642.10	1703.76	0.09	0.10
01/04/2017	598.00	1756.23	0.07	0.07
01/05/2017	536.44	1806.33	0.08	-0.19
01/06/2017	536.37	1856.14	0.05	0.09
01/07/2017	516.43	1907.96	0.05	0.02
01/08/2017	516.14	1957.19	0.04	-0.05

01/09/2017	533.89	2005.52	0.05	-0.14
01/10/2017	532.95	2057.12	0.04	-0.08
01/11/2017	514.15	2106.35	0.04	0.11
01/12/2017	447.72	2153.77	0.04	0.04
01/01/2018	349.85	2179.66	0.04	0.01
01/02/2018	337.05	2204.50	0.03	0.11
01/03/2018	348.62	2227.05	0.03	0.05
01/04/2018	324.06	2250.60	0.03	-0.18
01/05/2018	353.45	2272.68	0.03	0.20
01/06/2018	395.59	2293.27	0.03	-0.09
01/07/2018	386.84	2317.43	0.03	-0.12
01/08/2018	391.30	2343.33	0.03	0.08
01/09/2018	396.96	2364.14	0.04	0.02
01/10/2018	412.88	2372.99	0.04	0.27
01/11/2018	430.56	2378.97	0.04	-0.08
01/12/2018	446.36	2392.18	0.05	0.29
01/01/2019	432.80	2391.11	0.05	-0.58
01/02/2019	363.94	2391.36	0.05	-0.18
01/03/2019	347.35	2387.24	0.04	0.22
01/04/2019	316.62	2382.23	0.04	-0.07
01/05/2019	312.85	2378.39	0.04	0.22
01/06/2019	291.86	2374.68	0.04	-0.23
01/07/2019	271.37	2371.36	0.03	0.17
01/08/2019	266.54	2374.56	0.03	0.11
01/09/2019	217.42	2370.86	0.03	-0.07
01/10/2019	188.14	2370.67	0.03	-0.20
01/11/2019	177.32	2383.42	0.02	0.01
01/12/2019	185.10	2396.45	0.02	0.08
01/01/2020	172.53	2413.73	0.02	0.07
01/02/2020	147.21	2431.05	0.02	0.83
01/03/2020	234.05	2469.91	0.02	0.27
01/04/2020	232.46	2497.68	0.02	-0.32
01/05/2020	221.67	2526.45	0.02	-0.11
01/06/2020	174.79	2552.21	0.02	0.04
01/07/2020	175.95	2568.50	0.02	-0.09
01/08/2020	162.37	2585.59	0.02	-0.07
01/09/2020	169.49	2608.02	0.02	-0.02
01/10/2020	157.08	2626.43	0.02	0.25
01/11/2020	137.82	2644.08	0.02	-0.36
01/12/2020	128.93	2661.21	0.01	0.02
01/01/2021	123.48	2676.36	0.01	0.06
01/02/2021	118.13	2691.95	0.01	-0.15

01/03/2021	117.40	2701.45	0.01	-0.24
01/04/2021	117.13	2710.02	0.01	0.15
01/05/2021	114.76	2720.62	0.01	-0.06
01/06/2021	114.73	2730.02	0.01	-0.04
01/07/2021	121.97	2746.52	0.01	0.21
01/08/2021	113.40	2761.75	0.01	-0.15
01/09/2021	124.31	2773.91	0.01	0.18
01/10/2021	124.68	2792.04	0.01	-0.34
01/11/2021	158.45	2803.20	0.01	0.64
01/12/2021	180.18	2817.54	0.01	-0.46
01/01/2022	178.19	2831.65	0.01	0.18
01/02/2022	207.10	2844.51	0.01	0.20
01/03/2022	201.76	2852.28	0.01	-0.01
01/04/2022	180.84	2880.84	0.01	0.03
01/05/2022	203.28	2901.27	0.01	-0.14
01/06/2022	232.48	2913.62	0.01	0.15
01/07/2022	256.93	2913.07	0.01	-0.23

Table A2. ARDL model dataset

A3. Lag selection criteria for the ARDL

The ARDL lags are selected according to the Schwarz Criteria (SC):

$$SC = k\, ln(n) - 2\, ln\left(\hat{L}\right)$$

The Schwarz Criterion is a method used for model selection, particularly in the context of linear regression models. The SC balances the trade-off between model complexity and goodness of fit by incorporating a penalty for increasing model complexity.

It is almost the same as the Bayesian Information Criteria (BIC), although the strength of the penalty term is lower.

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Bayesian and Schwartz Information Criteria

URL:https://en.wikipedia.org/wiki/Bayesian_information_criterion

METHOD SELECTION FOR THE MODEL

M1. Selection process

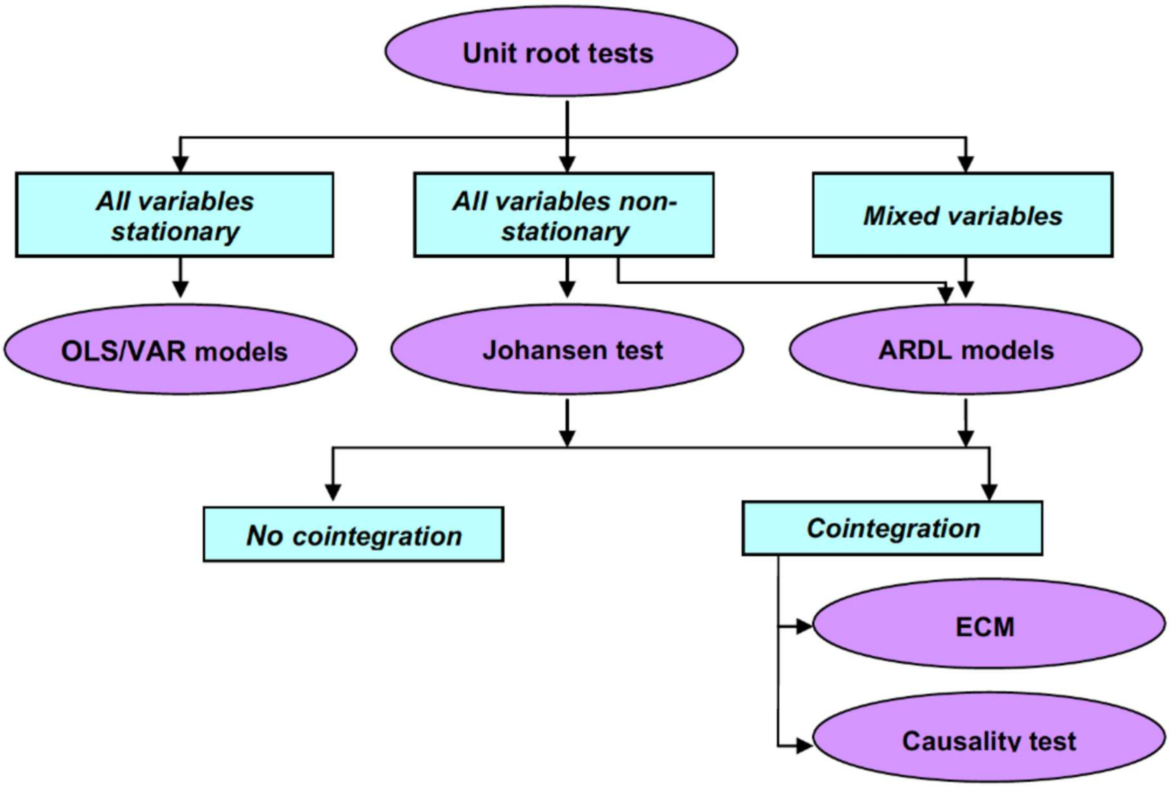

Figure M1. Model selection for time series data (Shrestha et al, 2018)