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Cointegration of EMU Government Bonds in Times of Financial Crises, COVID-19, and High Inflation – The Importance of Sovereign Debt for the European Insurance Industry

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Abstract

This paper is an empirical investigation of the long-term relationship between the yields of 10y sovereign bonds of Germany and ten European Monetary Union (EMU) member countries before, after, and during the most important financial and economic events since the Global Financial Crisis. Further, we investigate the long-term relationship of EMU bond yields in the most recent period of high inflation. We analyze daily 10y sovereign bond yields for both, sample and sub-samples, by implementing the Johansen parametric standard approach in cointegration testing in combination with two non-parametric test procedures suggested by Bierens (1997) and Breitung (2002), which are not dependent on nuisance parameters. The results indicate that there is strong evidence for cointegrating relationships in the sovereign bond yields in core and non-core Eurozone countries in the early period of the EMU. However, contradictory evidence is found in the sub-samples following the European Sovereign Debt Crisis, as well as in the more recent period of sharp increases in inflation which is experienced globally. The findings are especially relevant for the asset management of European insurance companies, predominantly with regard to the treatment of EMU sovereign debt within the European regulatory framework, namely the Solvency II Directive.

Zusammenfassung

Dieses Papier ist eine empirische Untersuchung der Langfristbeziehung der Renditen 10-jähriger Staatsanleihen Deutschlands und zehn weiteren Mitgliedsländern der Europäischen Währungsunion (EWU) vor, nach und während der wichtigsten finanziellen und wirtschaftlichen Ereignisse seit der globalen Finanzkrise. Darüber hinaus untersuchen wir die langfristige Beziehung der EWU-Anleiherenditen in der jüngsten Periode hoher Inflation. Wir analysieren die täglichen 10-jährigen Staatsanleiherenditen für alle Teilstichproben, indem wir den parametrischen Johansen-Standardansatz für Kointegra-

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tionstests in Kombination mit zwei von Bierens (1997) und Breitung (2002) vorgeschlagenen nichtparametrischen Testverfahren anwenden, die nicht von Störparametern abhängig sind. Die Ergebnisse deuten auf starke Evidenz für kointegrierende Beziehungen bei den Staatsanleiherenditen in den Core- und Non-Core Staaten der Eurozone in der Anfangszeit der EWU. In den Teilstichproben nach der europäischen Staatsschuldenkrise, sowie in der jüngeren Zeit des weltweit zu beobachten starken Inflationsanstiegs, werden jedoch widersprüchliche Belege gefunden. Die Ergebnisse sind insbesondere für das Asset Management europäischer Versicherungsunternehmen relevant, vor allem im Hinblick auf die Behandlung von Sovereign Debt der EWU innerhalb des europäischen Regulierungsrahmens Solvency II.

JEL classification: E44, G12, G15, G28.

Keywords: European Monetary Union, Non-Parametric Cointegration, Solvency II Directive, Sovereign Bond Market.

1. Introduction

Amid plumping stock prices, equity market volatility, and surging inflation rates paired with global central bank hikes in interest rates, investors' attention shifted towards government bonds due to their renewed attractive yield levels, amongst others. After years of low, even negative, interest rates in the US and the European Monetary Union (EMU) with sovereign bond yields in some cases trading at their all time lows, a trend of rising yield levels can be observed since the beginning of the year 2022. One explanatory factor for today's high inflation figures is connected to the flood of liquidity pumped into capital markets as a consequence of central banks' unconventional monetary policy in Western economies which took effect after the outbreak of the Global Financial Crisis in 2007 as well as the subsequent European Sovereign Debt Crisis in 2010 and even intensified in the aftermath of the COVID-19 pandemic. Other drivers of price increases and thus inflation can be attributed to supply chain bottlenecks as a consequence of the global lockdown measures introduced in the context of the the aforementioned pandemic since 2020. Moreover, surging energy prices as experienced after the outbreak of the Russian-Ukrainian war and the related sanctions on Russian oil and gas in 2022 have further fueled inflation. While some central banks, including the Bank of England (BoE) and the Federal Reserve (Fed) started to adjust interest rates to counter inflation already as early as December 2021, respectively March 2022, the European Central Bank's (ECB) first rate hike was announced later, in July 2022. Overall, the European monetary policymakers appeared to be more reluctant to increase borrowing costs as rising inflation rates were initially viewed as transitory triggered by short-term effects, such as rising energy costs. However, other explanatory factors for the ECB's more dovish behavior may be of a political nature and connected to the pronounced sovereign debt levels of some Southern European countries, including Italy (see, Basse/Reddemann/Rodriguez Gonzalez 2022). Even though bond yields of all EMU members increased during the global COVID-19 pandemic, the fear of additional financial stress connected to rising re-financing costs are particularly high in the case of highly indebted countries, including Italy and Greece, amongst others. Since the so-called "Covid Crash" in March 2020, 10y government bond yields in our daily data set reached a local maximum of over 5.05 % in the case of Greece on the 19th October 2022. These diverging yield levels in EMU government bonds, however, stand in sharp contrast to at least one of the underlying principles the EU insurance industry's regulatory framework is build on – namely Solvency II.

The European insurance industry's regulatory framework was already under review before the Global Financial and the Sovereign Debt Crisis as it did not adequately account for various types of risks. The crises then reinforced the need for reforms and triggered improvements of the solvency rules resulting in a substantial revision of the European insurance industry's regulatory and supervisory regime through the Solvency II Directive. Solvency II intends to make the European insurance industry more resilient to systemic risks and to harmonize regulatory requirements, including the introduction of capital buffers with a risk-based approach. Even though Solvency II became effective in 2016, its adequacy is still questioned, in particular with respect to its solvency capital requirements and its standard formula. To be more precise, government debt issued by any EMU member state is treated as a risk-free asset under the standard formula. This implies that EMU government bonds are associated the zero default risk, irrespective of the issuing government (Basse/Friedrich/Kleffner 2012; Ludwig 2014).

In the paper at hand, we investigate whether there is empirical evidence supporting the zero default risk assumption in conjunction with the risk-free treatment of EMU sovereign debt in the standard formula under Solvency II. To be more precise, we test whether the EMU sovereign bond yields of core and non-core member countries are cointegrated with a risk-free asset substitute. German government bonds are widely regarded as risk-free assets which is why we would expect to find cointegration between EMU members and German government bonds. This should confirm the assumption that EMU sovereign debt as a whole is risk-free. Therefore, we apply the Augmented Dickey-Fuller-Test (ADF) and the non-parametric method as suggested by Breitung (2002) to test for stationary in the samples before applying the Johansen trace test, the Max-L tests, and the non-parametric cointegration methodologies suggested by Bierens (1997) and Breitung (2002) to five core-countries (Austria, Belgium, Finland, France, the Netherlands) and five non-core countries (Greece, Italy, Ireland, Portugal, Spain) as well as the 10y German sovereign bond yields representing the risk-free interest rate.

Our results suggest that there is strong evidence for cointegrating relationships prior the Global Financial Crisis. Further, we find much stronger evidence for core countries than non-core countries. However, since then we only find limited evidence for cointegration within the data. Solely for the time after Draghi's famous "Whatever it takes" speech at the peak of the Sovereign Debt Crisis, we find strong empirical evidence for cointegration of German bond yields and core country counterparts in our parametric approach. Our results show even weaker to no evidence for non-core countries, also when applying the non-parametric models. For this reason, we conclude that long-term government bond yields of EMU member states cannot be considered as risk-free assets per se. Most importantly, the results suggests that sovereign default risk of EMU member states, especially for non-core countries, is not adequately reflected in the standard formula under the Solvency II Directive. Moreover, we cannot find any convincing evidence for cointegration since the outbreak of the COVID-19 pandemic at all, even in the case of core countries. This, in turn, raises doubts concerning the treatment of EMU government bonds under Solvency II.

The remainder of this paper is structured as follows. As the paper aims at a better understanding of the long-term relationships of EMU government bond yields in the context of the regulatory treatment under Solvency II, section 2 looks at the relevance of long-term government bonds for European life insurers as important long-term institutional investors, while section 3 highlights the regulatory treatment of these assets under the Solvency II regime. Subsequently, the data set and the cointegration methodologies are described in section 4. Our empirical results are presented in section 5. Finally, section 6 concludes.

2. The Importance of EMU Government Bonds for the European Insurance Industry

Our empirical analysis refers to 10y government bond yields in Germany and the ten EMU founding countries[1] which makes the results particularly important for long-term investors in EMU sovereign debt. According to the most recent asset management report by EFAMA (2022), European institutional asset managers invest roughly (36 %) of their assets under management in bonds, which confirms the relevance of this specific asset class for this type of investors. However, we analyze the results particularly with regard to the asset management of insurance companies which are of special relevance in this context (see,

[1] In fact, Greece is not a EMU founding country, but due to this country's unique role in the evolution of the European Sovereign Debt Crisis, we opted to include Greece instead of Luxembourg into our sample. This also allows us to have two identically sized study groups divided in core and non-core countries. Consequently, since Greece entered the EMU as late as January 1st 2001, all tests which included the pre-crisis subsample of Greece are based on data starting in 2001 accordingly.

most importantly, Basse/Friedrich/Kleffner 2012; Tholl/Basse/Meier/Rodriguez Gonzalez 2021; Rodriguez Gonzalez/Kunze/Schwarzbach/Dieng 2017).

Undoubtedly, in this context, the life insurance sector and pension funds are of particular relevance due to their long-term asset-liability matching which makes them, generally speaking, risk-averse investors. As government bonds generate secure and stable cashflows with a low return-risk profile, they match life insurers' investment objectives. Moreover, these bonds' regulatory treatment under the Solvency II Directive adds additional attractiveness. Table 1 highlights the high dependency of European life insurance companies' asset exposure to EMU sovereign debt within our core and non-core subsamples.[2] The data shows that the average exposure to EMU sovereign bonds issued by core countries is about 45 % of the total bond exposure and in the case of non-core countries even about 63 % on average. Taking into account the data of all current EMU member countries, the exposure to EMU sovereign bonds is on average about 47 %, which shows the high dependence of the industry to the EMU sovereign bond market.

More recently, EMU sovereign bonds also have attracted other financial market participants' attention due to their increasing yield levels, the rising interest rates and the underperformance of global equity markets following an exceptionally long period of a (ultra) low interest rates. The never seen and still continuing marathon of interest rate hikes at the central bank level, including the FED, BoE, and ECB, induced a stock market Baisse and resulted in rising sovereign bond yields. The recent plunge in equity prices paired with exceptionally high inflation rates, and rising government bond yields draw substantial investor interest to the sovereign bond market after years of low interest rates and government bond yield levels in the US and the EMU. The high inflation is often explained by the flood of liquidity due to the central banks' unconventional monetary policy in Western economies after the outbreak of the Global Financial Crisis in 2007, the subsequent European Sovereign Debt Crisis in 2010, as well as the COVID-19 pandemic. Other explanatory factors include price increases as a consequence of supply chain bottlenecks following the lockdown measures which were introduced to combat the COVID-19 pandemic since 2020 as well as rising energy prices due to the outbreak of the Russian-Ukrainian war and the sanctions on Russian oil and gas in 2022. Starting with the BoE in December 2021, most central banks started to hike interest rates as a measure to tame inflation at the end of 2021 and early 2022. However, the ECB was more hesitant to implement contractionary monetary policy measures. Consequently, the ECB did not announce changes in its interest rates before July 2022 as the

[2] Unfortunately, the data by Eiopa (2022) do not contain country-specific asset exposure information for life-insurance undertakings for Finland and Greece. Therefore, the countries are not reported in Table 1.

European monetary policymakers anticipated more short-lived inflation increases caused by shorter-term developments such as rising energy prices. Moreover, as higher interest rates could have caused stress for persistently heavily indebted Southern European countries, including Italy, as this would significantly push up these countries' borrowing costs (see, for example, Basse et al. 2022).

Table 1

Asset Exposure of European Life Insurers to Government Bonds in Q2/2022 in selected EMU Countries. Source: Own presentation based on Eiopa (2022).

	% = Government Bonds Exposure / Total Bonds Exposure				
Countries	Domestic	Core	Non-core	Sample	EMU total
Germany	23.31	13.47	4.21	40.99	41.70
Austria	18.19	28.19	6.43	38.38	41.60
Belgium	11.40	21.95	10.30	34.80	35.86
France	31.59	35.79	6.36	43.47	43.82
Netherlands	12.58	32.08	4.15	51.86	52.11
Core countries	35.15	35.15	6.06	44.62	44.98
Ireland	4.81	21.44	16.40	48.48	48.63
Italy	45.63	8.99	54.71	66.12	67.02
Portugal	33.22	7.36	52.37	64.48	64.48
Spain	50.72	5.38	60.83	66.89	66.98
Non-core countries	47.02	11.20	47.02	62.41	63.04
Sample countries	46.46	25.11	12.15	46.46	46.96
All EMU countries	46.97	25.10	12.15	46.45	46.97

In conclusion, government bonds are of special importance for institutional investors with a long-term investment horizon, such as life insurance companies and pension funds. In particular in the EU, government bonds are of great relevance as an asset class for insurers due to their regulatory treatment under Sol-

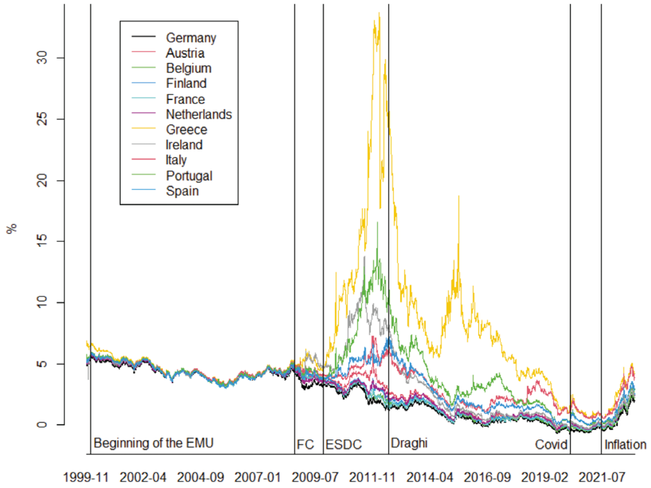

Fig. 1: Daily 10y government bond yields partitioned into several subsamples for selected EMU countries from 1999-11-03 to 2022-11-28.
Source: Own presentation based on Bloomberg Database.

vency II. Given the high exposure of European life insurers to government bonds and the uniform regulatory treatment of EMU government bonds under Solvency II, this study provides additional evidence as to whether the regulatory risk assumptions can be substantiated in a long-term view. In particular the assessment of the evolution of EMU government bond yields throughout periods of economic turning points and turmoil, such as economic crises, the ultra-low interest rate environment, inflationary pressure, and hawkish central bank policy will be insightful in this context. Efficient regulation of the insurance industry is indispensable due to its systemic relevance. Through risk transfers and investment activities, the insurance industry acts as important growth driver and long-term stabilizer of financial markets (see, for example, Rodriguez Gonzalez/Wegener/Basse 2022).

3. Regulatory Features of Government Bonds under the Solvency II Directive

The Global Financial Crisis emerged as a banking crisis. Yet, empirical evidence suggests it also transmitted to the insurance industry (see, most importantly, Eling/Schmeiser 2010; Marović/Njegomir/Maksimović 2010; Dungey/Gajurel 2015) which resulted in increasingly more voices calling for a reform of the European insurance industry's regulatory framework. Even though the regulation was already under review before the Global Financial and the Sovereign

Debt Crisis, it still did not adequately account for various types of risks (see, for example, Marović/Njegomir/Maksimović 2010; Ludwig 2014). In consequence, the crises reinforced the need for reform to improve the solvency rules and the EU regulatory and supervisory regime was significantly revised and modernized (see, for example, Quaglia 2011; Van Hulle 2011). In this context, the Solvency II Directive (2009/138/EC) was passed in 2009 but only became effective in 2016. To be more precise, the Omnibus II Directive (Directive 2014/51/EU) was passed in 2014, which, amongst others, aligned Solvency II with the EU's new supervisory structure (for further details on the revision process, please refer to Eling/Schmeiser 2010; Jones 2014; Peleckienė/Peleckis 2014).

Solvency II is based on a three pillar structure (see, for example, Gatzert/Wesker 2012; Wagner 2014). The first pillar stipulates the quantitative requirements, such as equity provisions, while Pillar 2 targets qualitative needs, including the monitoring and governance process. Moreover, the third pillar enforces transparency and disclosure requirements. As outlined by Basse (2020), the quantitative components of Pillar 1 harmonize the capital requirements for European insurance companies based on a market-consistent calculation of assets and risk-based estimates of capital applicable to all insurers operating in the European insurance sector. Pillar 2 stipulates the principles and methods of supervision, including details on the supervision review process and the assessment of quantitative and qualitative requirements as well as the internal governance processes, the fit and proper requirements, the "own risk and solvency assessment" (known as ORSA), as well as internal controls and internal audits. Notably, the ORSA tool is supposed to account for company-specific risks not adequately reflected in the Pillar 1 calculations, for example, reputation, contagion, liquidity, and environmental risks (see, for instance, Elderfield 2009; Lindberg/Seifert 2015). However, details on the implementation of these risks are not provided (see, for example, Doff 2016). Pillar 3 details disclosure requirements concerning reporting to the supervisory authority to enhance transparency. In this context, particular emphasis is placed on the provision of all relevant data in a meaningful format to the supervisory authority and to the general public (see, for example, Lindberg/Seifert 2015; Doff 2016; Basse 2020).

As government bonds are exposed to credit and default risk, it is interesting to understand how the revised supervisory and regulatory regime Solvency II treats government bonds and sovereign credit and default risk.

Concerning Pillar 1, insurers are required to maintain sufficient eligible own funds amounting to at least their Solvency Capital Requirements (SCR) (see, Directive 2009/138/EC, Art. 100 (1)). The SCR is a formula-based figure which aggregates exposure to specific risks and stipulates the total amount of funds insurers should hold to withstand a crisis or default with a 99.5 per cent probability (see, Directive 2009/138/EC, Art. 104 (4)). Insurers can calculate the SCR either by applying a tailor-made internal model or by opting for the European standard formula (see, Directive 2009/138/EC, Art. 100 (2)). The internal model requires approval by the supervising authority and should account for sovereign credit risk in a realistic manner (see, for example, Ludwig 2014). However, when the SCR is calculated based on the standard formula, government bonds issued by member states of the European Economic Area and denominated in their domestic currency are treated with a zero risk weight (see, for example, Ludwig 2014; Basse 2020; Tholl/Basse/Meier/Rodriguez Gonzalez 2021). In consequence, when applying the standard formula, sovereign credit risks are not sufficiently accounted for under Pillar 1 in Solvency II's quantitative risks assessment.

Concerning Pillar 2, insurers are supposed to conduct the so-called "own risk and solvency assessment" (ORSA) (see, Directive 2009/138/EC, Art. 45). This includes an analysis of an insurer's risk profile and its risk management approach with the results published as a qualitative report. Moreover, insurers should evaluate whether the standard formula sufficiently addresses their risks. Notably, risks not adequately reflected under the standard formula should be disclosed under ORSA (see, for example, BaFin 2016; Gründl/Gal 2013). This implies risks associated with the exposure to government bonds which are, as outlined above, treated with zero risk weight under the standard formula. Consequently, sovereign credit risks should be disclosed in the ORSA report, and thus, be integrated into stress test scenarios (see, for example, BaFin, 2016). However, as Gründl/Gal (2013) convincingly argue, even though ORSA is strongly linked to the quantitative assessment under Pillar 1, it remains ill-defined, mainly because of the interplay with the SCR calculations in Pillar 1.

To summarize, the zero risk weight of sovereign bonds under the standard formula results in preferential treatment of sovereign EEA debt as opposed to other debt instruments. Insurers may opt for an internal model that adequately reflects sovereign debt and its associated risks. However, the time and cost-intensive process related to the development of such an internal model constitutes significant constraints making the applicability of the standard formula more practicable and straightforward. Ludwig (2014) argues that the standard formula is likely the preferred choice. Technically, the ORSA will require insurers to assess and manage risks associated with government bonds sufficiently. Still, the ORSA remains ill-defined, thus raising justifiable doubts regarding the efficiency of the qualitative assessment.

One particular challenge jeopardizing the solvency situation of European insurance companies is related to the treatment of sovereign bonds under Solvency II. The risk free treatment of sovereign bonds irrespective of the issuer's fiscal position and the associated default risk may result in regulatory arbitrage when insurers opt to invest in sovereign bonds of EEA member states with greater fiscal imbalances as the implied risk premiums is commonly reflected in higher bond yields (see also Basse/Friedrich/Kleffner 2012; Tholl/Basse/Meier/Rodriguez Gonzalez 2021). Evidence shows that sovereign credit risk plays a significant role for investors when determining the price of bonds (see, amongst others, Gruppe/Basse/Friedrich/Lange 2017). While market participants price the associated higher default risks, these are not reflected in insurers' risk provisions as the capital requirements treat all sovereign bonds with zero risk weight (see, for example, Basse/Friedrich/Kleffner 2012; Ludwig 2014; Rodriguez Gonzalez/Basse/Tholl 2019; Tholl/Basse/Meier/Rodriguez Gonzalez 2021). In short, sovereign credit risk and default differentials of European Economic Area (EEA) member states are not accounted for under the Solvency II capital requirements.

The Sovereign Debt Crisis indubitably demonstrates that even EEA member states' sovereign credit risks cannot be lumped together and that sovereign credit risk may significantly threaten financial stability (see, for example, Basse 2014; Düll/König/Ohls 2017; Ludwig 2014; Meier/Gonzalez/Kunze 2021). Following the Great Financial Crisis and the subsequent economic recession, fiscal imbalances in most member states of the European Monetary Union (EMU) significantly increased. Consequently, different fiscal positions were reflected in government bond yield differentials as market participants priced sovereign credit risks. Hence, fiscally weaker member states were confronted with significantly greater risk premiums and thus rising government bond yield spreads. Notably, countries with disproportionate sovereign debt faced difficulties with refinancing their debt, eventually requiring external assistance. Thus, the Sovereign Debt Crisis demonstrated that sovereign credit risk could significantly threaten financial stability (see, for example, Düll/König/Ohls 2017; Afonso/Jalles/Kazemi 2020; Meier/Gonzalez/Kunze 2021).

In this context, Basse/Friedrich/Kleffner (2012) study German and Italian government bonds yields and find that market participants assign increased risk premiums to Italian government bonds during the Sovereign Debt Crisis when worries about the Italian fiscal situation and default risk emerged while German government bonds have been regarded as "safe haven" assets with minimal risk premiums. Thus, both countries' government bond yields mirrored the respective sovereign credit risks associated with the issuer at the time. Against this background, the risk-free and equal regulatory treatment of both issuers' bonds is regarded as problematic. In other words, government bonds issued by Italy were associated with higher credit risks compared to those issued by Germany (see, Basse/Friedrich/Kleffner 2012; Sibbertsen/Wegener/Basse 2014; Basse/Reddemann/Rodriguez Gonzalez 2022). However, as explained above, the sovereign credit risk differentials are not reflected in the solvency capital requirements calculations. The empirical evidence presented by Düll/König/Ohls (2017) supports this conclusion and shows that there are transmission effects from sovereign risk to insurers during the Sovereign Debt Crisis. To be more precise, it is found that insurers' default risk increases when they hold riskier sovereign debt. Thus, the authors conclude that sovereign bond portfolios' risks drive insurers' risk exposur. This, however, is not adequately reflected in the regulatory capital requirements. To summarize, empirical evidence suggests that a country's fiscal position, as well as sovereign credit risks, are reflected in sovereign bond yields, which is why the equal and risk-free treatment of sovereign bonds under Pillar 1 of the Solvency II Directive is regarded as problematic. Consequently, these findings point towards flaws in the design of the Solvency II framework and chiefly in the calculation of capital requirements under Pillar 1.

4. Data and Methodology

This paper aims at testing the long-term relationships between German and EMU member countries' government bond yields since 2000, roughly when the Euro was introduced as as a common currency for the EMU. This motivates the employment of theory and methodology rooted in the field of cointegration (see, for an intuitive illustration of cointegration, Murray 1994). In general, two time series – $X_{1,t}$ and $X_{2,t}$ – are said to be cointegrated if each of the series taken individually is integrated of order d – hereafter, denoted as $I(d)$ – while some linear combination (for example, $X_{1,t} - \beta' X_{2,t}$ with $\beta \neq 0$) is integrated of order $I(b)$ with $b < d$. Phrased somewhat differently, the resulting linear combination (hereafter, equilibrium error) is less persistent than the underlying time series. Hence, both variables share a common stochastic trend and are at least unidirectional Granger-Causal (see, Engle and Granger, 1987). Here, we rely on the classic $I(0)/I(1)$ framework – this means that we only allow integer values for b and assume that $d = 1$.

Consequently, we test for cointegration relationships between 10y government bond yields of EMU member states and Germany by applying parametric and non-parametric cointegration techniques. Statistical evidence for cointegration between two yield series is understood as the risk of two cointegrated bonds to share a common stochastic trend, and thus, both assets are sharing a common risk profile and being similarly priced by market participants over time. We empirically investigate the long-term relationship of 10y German government bond yields to the yields of five EMU member core countries (Austria, Belgium, Finland, France, and Netherlands) and five non-core countries (Greece, Ireland, Italy, Portugal, and Spain). The usage of this classification is for example discussed in Basse (2014). More specifically, we inspect daily 10y government bond yields starting from January 1st, 2000 until November 28th, 2022. As a result there is a total of 5, 973 obervations for each time series to be analyzed. The data is taken from Bloomberg. Some few missing values of the data series are estimated based on the average daily percentage changes of the other core, respectively non-core, countries.

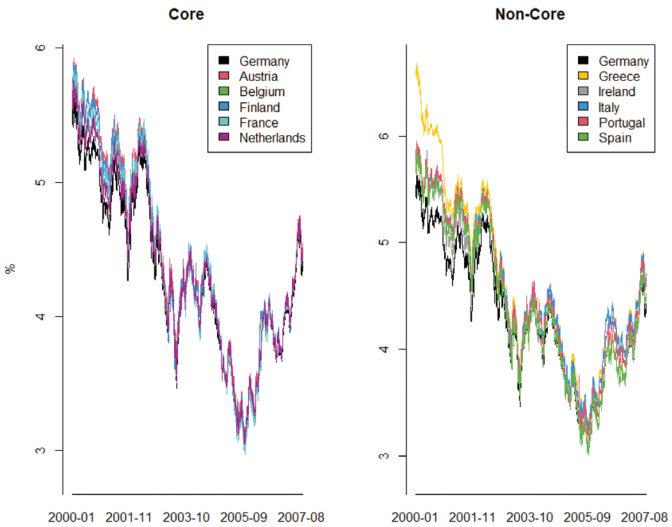

Fig. 2: Daily 10y government bond yields in the subsample "Pre-Crisis" for selected core and non-core-countries.
Source: Own presentation based on Bloomberg Database.

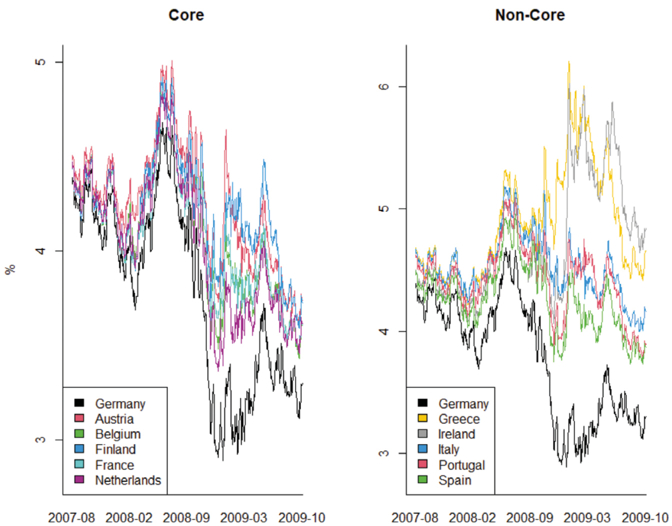

Fig. 3: Daily 10y government bond yields in the subsample "Global Financial Crisis" for selected core and non-core-countries.
Source: Own presentation based on Bloomberg Database.

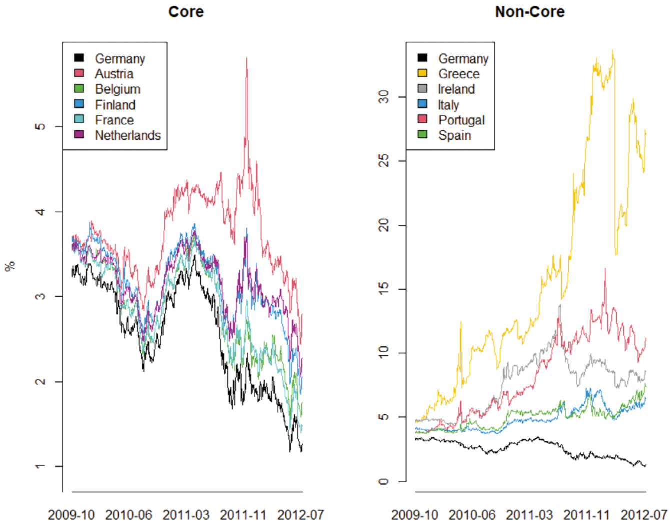

Fig. 4: Daily 10y government bond yields in the subsample "European Sovereign Debt Crisis" for selected core and non-core-countries.
Source: Own presentation based on Bloomberg Database.

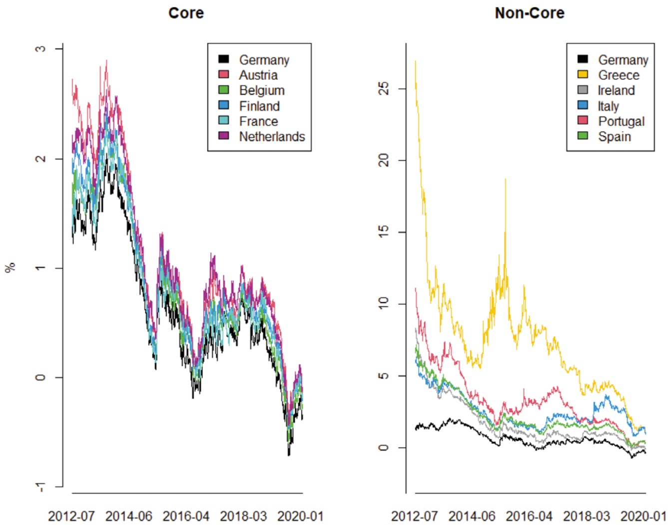

Fig. 5: Daily 10y government bond yields in the subsample "Draghi-Effect" for selected core and non-core-countries.
Source: Own presentation based on Bloomberg Database.

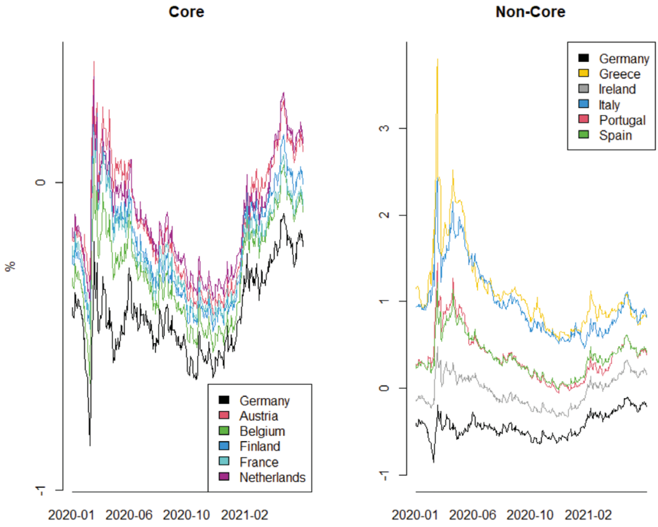

Fig. 6: Daily 10y government bond yields in the subsample "COVID Crash" for selected core and non-core-countries. Source: Own presentation based on Bloomberg Database.

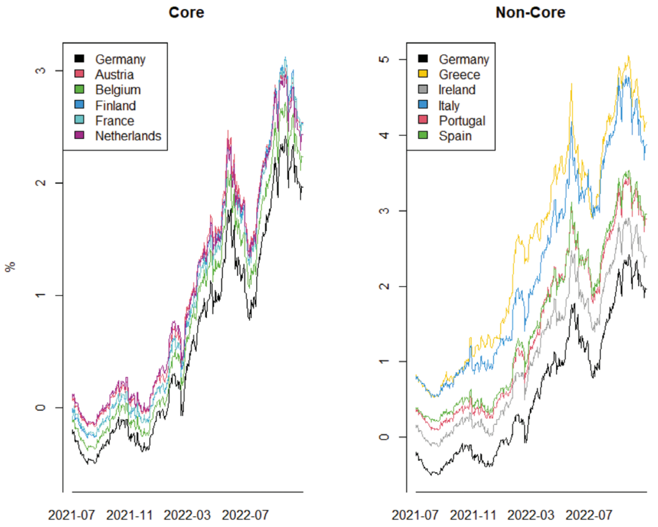

Fig. 7: Daily 10y government bond yields in the subsample "Above Target Inflation" for selected core and non-core-countries. Source: Own presentation based on Bloomberg Database.

For methodological reasons we divide the dataset into six smaller subsets. Even though, the tests for the whole sample are conducted, the results are not reported due to the issue of structural breaks. According to the prevailing view, shortening the sample can help to minimize problems with structural breaks (see, most recently, Kunze/Basse/Rodriguez Gonzalez/Vornholz 2020; Basse/Wegener 2022). Therefore, the statistical outcomes for smaller sized samples should be more conclusive. Due to the enormous impact of financial and economic crises on global financial markets during our sample period, it makes sense to divide the data set into smaller subsamples that correspond to these events. As highlighted in Figure 1, we divide the data set in line with the timings of some major financial "black swan" events on the European bond market since the founding of the EMU. The assumption that these events correlate with a changing behaviour of the yield series make them suitable fit after visually inspecting the whole data set as shown in Figure 1 as well as the resulting subsample series of core and non-core countries (see Figure 2–7). These figures are decisive when it comes to the selection of meaningful model assumptions when obtaining contradictory test decisions.

As a result, we define the first subsample as the "*Pre-Crisis*" period ranging from the January 1st, 2000 until the beginning of the Global Financial Crisis (GFC) on August 9th, 2007 with a total of 1,982 observations (see Figure 2). The second subsample starts with the beginning of the GFC and lasts until the beginning of the European Sovereign Debt Crisis (ESDC). The beginning of the ESDC is defined as October 20th, 2009, the date when the Greek government disclosed a budget deficit double the amount of whats has been communicated previously. Clearly, these turmoils triggered EMU sovereign bond spreads to widen sharply. Thus, the subsample "*Global Financial Crisis*" comprises a total of 573 observations (see Figure 3). Undoubtedly, there is strong evidence for the effects of the former ECB president Mario Draghi's famous "Whatever it takes" speech on July 26th, 2012 on the EMU bond market. Due the strong commitment to Europe and the euro area expressed and the related calming effects, this speech marks the end of this crisis. Therefore, the third subsample "*European Sovereign Debt Crisis*" contains 721 observations (see Figure 4). The following subsample named "*Draghi-Effect*" ends with the financial market crash triggered by the outbreak of the global COVID-19 pandemic on March 9th, 2020. Accordingly, this subsample contains 1,959 observations. The last breakpoint is the beginning of above target inflation north of the 2 % threshold in the Eurozone, starting on July 1st, 2021 according to the monthly published Harmonized Index of Consumer Prices (HCIP) data of Eurostat (2022). Consequently, the resulting sub-sample "*COVID Crash*" comprises 370 observations in total, and the observations included in subsample "*High Inflation*" amount to 368.

One of the most common standard approaches to test for cointegration is the Johansen test (see, Johansen 1988; Johansen/Juselius 1990; Johansen 1991, 1994). Therefore, we apply the two suggested test procedures, the Johansen trace test and the Johansen Lambda-Max test, in bivariate and multivariate cointegration models under different model assumptions to each subsample and EMU member country, respectively to the group of core and non-core countries in the multivariate case. Since most cointegration tests are sequential tests, the null hypothesis of $r = 0$ cointegration relationships is tested first, before the null hypothesis of $r = 1$ cointegration relationship (r is the number of the cointegration vector) is tested in a second step. For multivariate models, this test is run until the null hypothesis is rejected the first time. This approach is parametric, since the deterministic part of the Vector Error Correction Model (VECM) of the Johansen procedure needs to be determined. In our case, three model assumptions were implemented, tested and compared: 1. VECM including an intercept with restrictions on the intercept parameters imposed (in case the time series run parallel without drift), 2. VECM including an intercept without cointegrating restrictions on the interecept parameters (in case the time series run parallel with drift), and 3. intercept and time trend with restrictions on the intercept parameters imposed (in case the time series run apart with drift).

In addition to this well-known parametric standard approach, we also apply two non-parametric procedures to identify more robust results. Using different cointegration techniques to test for consistent results is a common procedure in the academic literature (see, for instance, Chang/Caudill 2006; Liow, 2008). Therefore, we apply the non-parametric cointegration techniques suggested by Bierens (1997) and Breitung (2002) to the selected time series and Germany. The latter two testing procedures – in particular their limiting distributions – are not depending on nuisance parameters. This is an enormous advantage of non-parametric over parametric time series procedures for empirical researches, because non-parametric methods are more robust against misspecifications. To exemplify, as reported by Breitung (2002), the test statistic has a nondegenerate limiting distribution, and most importantly, the asymptotic properties do not depend on transitory components. In other words, this test is robust against misspecification of short-run dynamics. In contrast, employing the most widely used cointegration test by Johansen requires the specification of a Vector AutoRegressive (VAR) model. Most importantly, Bierens (1997) non-parametric approach is superior over Johansen's standard method when the data generating process is non-linear. Bierens' method extends the approach by Johansen in that the two test statistics, based on the trace test and the lambda-max test, and the associated solution of the generalized eigenvalue problem is independent of the data generating process. Even though the test by Bierens (1997) is also non-parametric, the test procedure involves the determination of a model constant c. We follow Bierens (1997)'s suggestion and do not change c which default value equals 1. Also the test procedure allows to standardize the variables involved. However, for better test results, the data should be implemented in log values. In our specific case, yields can be interpreted as percentage, so that log values make no sense as also discussed by Dale/Haldane (1995), for instance.

However, since the underlying time series have to be stationary, we have to apply some unit root tests to each sub-sample first. This step is crucial to investigate the above mentioned methodological prerequisites for the cointegration tests. Therefore, we apply the well-established ADF test (see, Fuller 1976; Dickey/Fuller 1979, 1981; Said/Dickey 1984) using the asymptotic critical values as reported by Davidson, MacKinnon, et al. (1993). Moreover, we apply also a non-parametric unit root tests as suggested by Breitung (2002). The advantage of this approach is that there is no need to specify the short-run dynamics using statistical information criteria. We apply both methodologies to each study period allowing for different model assumptions. Consequently, we test for stationarity without any assumptions, as well as a demeaned and a demeaned plus detrended model.[3] In the parametric ADF test, we include various information criteria for determining the optimal lag-length. These are the Akaike information criteria, Hannan-Quinn, Final Prediction Error and Schwarz criterion. To conclude, the test results are independent of the selected information criterion, hence, Table 2 only presents the results using the Schwarz criterion. The results of the unit root tests and the three different cointegration models are all reported in section 5.

To conclude, finding empirical evidence for cointegration would imply the existence of a long-run equilibrium relationship between non-stationary variables which share common stochastic trends. In the next section, we present the results of the Johansen test and the two non-parametric procedures to test for cointegration. Hereafter, the extension of this procedure to cointegration by Bierens (1997) and the extension by Breitung (2002) are presented. In total, we examine 360 bivariate tests in the parametric case, and 60, resp. 120, tests in the non-parametric models as suggested by Bierens (1997) and Breitung (2002). Further, we examine 30 multivariate tests in the parametric case and ten multivariate tests in each of the non-parametric approaches.

5. Empirical Evidence

When analyzing time series for cointegrating behavior, it is essential to understand their statistical properties with regard to mean reversion first. Thus, we apply some unit root tests to the data. Testing for stationarity in the context of cointegration analysis is a well-known problem in econometric time series anal-

[3] However, to conserve space we do not report the results of none model assumptions in the ADF and the Breitung test. Nevertheless, the results presented in this paper are confirmed when not including a constant, or time trend respectively.

ysis. Even though many financial and economic time series, like stock prices or bond yields, are said to be non-stationary per se (as discussed for instance by Sarno 2007), it is still crucial to investigate the time series dynamics to obtain valid and robust empirical evidence.

ADF Unit Root Tests:

To test this methodological precondition of cointegration analysis, we employ multiple unit root tests to all countries under study and for each sub-sample period we defined above. First, we apply the commonly used ADF test to assess the (non-)stationary behavior of the time series. The results of the ADF test, as presented in Table 2, indicate that all time series in our analysis are nonstationary for each model specification. Nevertheless, there are two exceptions to this general finding in the parametric ADF test results: In the case of Greece and Ireland, two non-core EMU countries, the empirical outcome indicates some kind of stationarity within the time series. In the "Draghi-Effect" sub-sample, the null hypothesis of no unit root is accepted for both countries for all model assumptions. This suggests that the behavior of these yields time series might exhibit different dynamics than the other countries under study.

Breitung Unit Root Tests:

Other than the ADF test, we also apply a non-parametric unit root test in addition to a standard parametric procedure, as we do for the subsequent cointegration tests. Therefore, we apply the test according to Breitung (2002) to all time series and all study periods. By analyzing further empirical evidence with additional model assumptions and methods related to the issue of unit roots, we can obtain a broader picture of the statistical properties of the time series. The aim of this approach is to obtain more robust results and implications derived from them. In the case of Breitung's (2002) nonparametric tests, our above results of the ADF test are confirmed, and even further strengthened in the case of Ireland and Greece, where we now can confirm unit roots even in the Draghi sample for both time series. Therefore, the results presented in Table 3 further indicate that the time series are non-stationary across all samples which implies no behavior of mean reversion. This means, long-run relationships between the yield time series may also be present.

Based on the robust evidence that the time series are I(1) variables, the bivariate and multivariate cointegration tests are then performed. The investigation of cointegrating relationships among the yield time series allows us to obtain empirical evidence on possible long-term interrelationships in the EMU government bond market.

Johansen Cointegration Tests:

In the *"Pre-Crisis"* subset we find strong empirical evidence for cointegrating relationships in all three models for each core country (with Belgium being the only exception). For the non-core EMU countries the performance of the Johansen cointegration test delivers no empirical evidence. Additionally, there is little evidence for cointegrating relationships within the multivariate model of non-core countries, which emphasizes that the sovereign bond yields of these countries do not seem to share common risk valuations by investors. Furthermore, we find clear evidence for cointegrating relationships in the multivariate model of core countries under all model assumptions.

When considering the subset covering the *"Global Financial Crisis"* period, our test results are straightforward. The results clearly suggest that there are no cointegrating relationships in any of the core and non-core countries. Similarly, in the multivariate case, we find no evidence for cointegration for the non-core countries sample and limited evidence in the core countries sample.

The Johansen trace test and Lambda-Max test results for *"The European Sovereign Debt Crisis"* subset suggest that the time series for all countries included in the analysis show no evidence for cointegration under all model assumptions. Hence, we find no clear sign for cointegration relationships for each EMU member country.

Following the Sovereign Debt Crisis, we consider the impact of Draghi's "whatever it takes speech" and look at the *"Draghi-Effect"* subset for which we identify clear evidence for cointegration in all core countries, except for Finland. In this specific case, we can only reject the null hypothesis in model 2. Nevertheless, this seems to be the most realistic assumption when inspecting the yields of Finland and Germany in this sub-sample (see Figure 5). Moreover, we find strong evidence for cointegration in the multivariate model of core countries, and again, few indications for cointegration in the non-core countries.

For the subset lasting throughout the *"COVID Crash"*, the results also yield strong evidence for no cointegration in all countries included in the analysis. Moreover, there is only little evidence in the cases of France and Ireland. However, as the visual examination of Figure 6 suggest, model 1 seems to be a better fit for the case of Ireland.

When considering the most recent observation period defined in this work, namely, the *"Above Target Inflation"* subset, a pattern in line with our results presented for the "*COVID Crash*" subset becomes evident. We find even stronger evidence for no cointegration in the bivariate and multivariate models.

For the whole observation period, we identify strongest evidence for cointegration for the core countries when assuming model 3 (constant and trend).

Overall, we find strong evidence for cointegration within the core countries. Moreover, when looking at the non-core multivariate model, we find evidence for cointegration relationships, however, the results also suggest that there is no cointegration of each bivariate test of the non-core countries and Germany.

Bierens Cointegration Tests:

The results of the non-parametric procedures following the approach presented by Bierens (1997) are presented in Table 7. The test results point at evidence for cointegration of most core-countries. However, in line with the results found when applying the Johansen test, the findings are less conclusive for the EMU members Austria and Belgium. Similarly, we find no clear evidence for cointegration in the subsets *"Global Financial Crisis"* and *"European Sovereign Debt Crisis"*. However, for the following subset covering the *"Draghi-Effect"*, our results suggest that there is some evidence for cointegration in the core countries. Overall, we find clear evidence for no cointegration for the non-core countries in the three subsets *"Global Financial Crisis"*, *"European Sovereign Debt Crisis"*, and *"Draghi-Effect"*. It is striking, however, that there is strong evidence for cointegration for the core countries in the *"COVID Crash"* and *"Above Target Inflation"* samples. Additionally, similar results are found for some non-core countries.

Breitung Cointegration Tests:

The other non-parametric test procedure we are applying to the data is the test by Breitung (2002). This test follows another non-parametric approach compared to Bierens (1997). The results in Table 8 are less compelling when compared to the results of the non-parametric Bierens test. Depending on the assumption of a drift in the time series, we can only confirm strong evidence for cointegrating relationships within the core countries.

Table 2

Results of the Augmented Dickey Fuller Test by Fuller (1976); Dickey/Fuller (1979, 1981); Said/Dickey (1984) for the EMU core and non-core countries. Model 1 includes constant and Model 2 constant and trend. The triple asterix denotes statistically significant difference with $p < 0.01$. Source: Own presentation and calculations.

Core Countries

Period	Austria		Belgium		Finland		France		Netherlands		Core	
	Mo.1	Mo.2	Mo.1	Mo.2	Mo.1	Mo.2	Mo.1	Mo.2	Mo.1	Mo.2	Mo.1	Mo.2
Pre-Crisis	*I* (1)***	*I* (1)***	*I* (1)***	*I* (1)***	*I* (1)***	*I* (1)***	*I* (1)***	*I* (1)***	*I* (1)***	*I* (1)***	*I* (1)***	*I* (1)***
FC	*I* (1)***	*I* (1)***	*I* (1)***	*I* (1)***	*I* (1)***	*I* (1)***	*I* (1)***	*I* (1)***	*I* (1)***	*I* (1)***	*I* (1)***	*I* (1)***
ESDC	*I* (1)***	*I* (1)***	*I* (1)***	*I* (1)***	*I* (1)***	*I* (1)***	*I* (1)***	*I* (1)***	*I* (1)***	*I* (1)***	*I* (1)***	*I* (1)***
Draghi	*I* (1)***	*I* (1)***	*I* (1)***	*I* (1)***	*I* (1)***	*I* (1)***	*I* (1)***	*I* (1)***	*I* (1)***	*I* (1)***	*I* (1)***	*I* (1)***
Covid-19	*I* (1)***	*I* (1)***	*I* (1)***	*I* (1)***	*I* (1)***	*I* (1)***	*I* (1)***	*I* (1)***	*I* (1)***	*I* (1)***	*I* (1)***	*I* (1)***
Inflation	*I* (1)***	*I* (1)***	*I* (1)***	*I* (1)***	*I* (1)***	*I* (1)***	*I* (1)***	*I* (1)***	*I* (1)***	*I* (1)***	*I* (1)***	*I* (1)***

Non-core Countries

Period	Greece		Ireland		Italy		Portugal		Spain		Non-core	
	Mo.1	Mo.2	Mo.1	Mo.2	Mo.1	Mo.2	Mo.1	Mo.2	Mo.1	Mo.2	Mo.1	Mo.2
Pre-Crisis	*I* (1)***	*I* (1)***	*I* (1)***	*I* (1)***	*I* (1)***	*I* (1)***	*I* (1)***	*I* (1)***	*I* (1)***	*I* (1)***	*I* (1)***	*I* (1)***
FC	*I* (1)***	*I* (1)***	*I* (1)***	*I* (1)***	*I* (1)***	*I* (1)***	*I* (1)***	*I* (1)***	*I* (1)***	*I* (1)***	*I* (1)***	*I* (1)***
ESDC	*I* (1)***	*I* (1)***	*I* (1)***	*I* (1)***	*I* (1)***	*I* (1)***	*I* (1)***	*I* (1)***	*I* (1)***	*I* (1)***	*I* (1)***	*I* (1)***
Draghi	*I* (0)	*I* (0)	*I* (0)	*I* (0)	*I* (1)***	*I* (1)***	*I* (1)***	*I* (1)***	*I* (1)***	*I* (1)***	*I* (1)***	*I* (1)***
Covid-19	*I* (1)***	*I* (1)***	*I* (1)***	*I* (1)***	*I* (1)***	*I* (1)***	*I* (1)***	*I* (1)***	*I* (1)***	*I* (1)***	*I* (1)***	*I* (1)***
Inflation	*I* (1)***	*I* (1)***	*I* (1)***	*I* (1)***	*I* (1)***	*I* (1)***	*I* (1)***	*I* (1)***	*I* (1)***	*I* (1)***	*I* (1)***	*I* (1)***

Table 3

Results of the non-parametric Breitung Unit Root Test by Breitung (2002) for the EMU core and non-core countries. Model 1 includes constant and Model 2 constant and trend. The triple asterix denotes statistically significant difference with $p < 0.01$. Source: Own presentation and calculations.

Core Countries

Period	Austria		Belgium		Finland		France		Netherlands		Core	
	Mo.1	Mo.2	Mo.1	Mo.2	Mo.1	Mo.2	Mo.1	Mo.2	Mo.1	Mo.2	Mo.1	Mo.2
Pre-Crisis	I (1)***	I (1)***	I (1)***	I (1)***	I (1)***	I (1)***	I (1)***	I (1)***	I (1)***	I (1)***	I (1)***	I (1)***
FC	I (1)***	I (1)***	I (1)***	I (1)***	I (1)***	I (1)***	I (1)***	I (1)***	I (1)***	I (1)***	I (1)***	I (1)***
ESDC	I (1)***	I (1)***	I (1)***	I (1)***	I (1)***	I (1)***	I (1)***	I (1)***	I (1)***	I (1)***	I (1)***	I (1)***
Draghi	I (1)***	I (1)***	I (1)***	I (1)***	I (1)***	I (1)***	I (1)***	I (1)***	I (1)***	I (1)***	I (1)***	I (1)***
Covid-19	I (1)***	I (1)***	I (1)***	I (1)***	I (1)***	I (1)***	I (1)***	I (1)***	I (1)***	I (1)***	I (1)***	I (1)***
Inflation	I (1)***	I (1)***	I (1)***	I (1)***	I (1)***	I (1)***	I (1)***	I (1)***	I (1)***	I (1)***	I (1)***	I (1)***

Non-core Countries

Period	Greece		Ireland		Italy		Portugal		Spain		Non-core	
	Mo.1	Mo.2	Mo.1	Mo.2	Mo.1	Mo.2	Mo.1	Mo.2	Mo.1	Mo.2	Mo.1	Mo.2
Pre-Crisis	I (1)***	I (1)***	I (1)***	I (1)***	I (1)***	I (1)***	I (1)***	I (1)***	I (1)***	I (1)***	I (1)***	I (1)***
FC	I (1)***	I (1)***	I (1)***	I (1)***	I (1)***	I (1)***	I (1)***	I (1)***	I (1)***	I (1)***	I (1)***	I (1)***
ESDC	I (1)***	I (1)***	I (1)***	I (1)***	I (1)***	I (1)***	I (1)***	I (1)***	I (1)***	I (1)***	I (1)***	I (1)***
Draghi	I (1)***	I (1)***	I (1)***	I (1)***	I (1)***	I (1)***	I (1)***	I (1)***	I (1)***	I (1)***	I (1)***	I (1)***
Covid-19	I (1)***	I (1)***	I (1)***	I (1)***	I (1)***	I (1)***	I (1)***	I (1)***	I (1)***	I (1)***	I (1)***	I (1)***
Inflation	I (1)***	I (1)***	I (1)***	I (1)***	I (1)***	I (1)***	I (1)***	I (1)***	I (1)***	I (1)***	I (1)***	I (1)***

Table 4:

Results of the Johansen trace test and Lambda-Max test (Model 1: intercept included with cointegrationg restrictions on the intercept parameters) by Johansen (1988); Johansen/Juselius (1990); Johansen (1991, 1994) for the EMU core and non-core countries. The double asterix denotes statistically significant difference with $p < 0.05$. Source: Own presentation and calculations.

	Core Countries											
Period	Austria		Belgium		Finland		France		Netherlands		Core	
	Trace	LMax	Trace	LMax	Trace	LMax	Trace	LMax	Trace	LMax	Trace	LMax
Pre-Crisis	r=1**	r=1**	r=0**	r=0**	r=1**	r=1**	r=1**	r=1**	r=1**	r=1**	r=3**	r=3**
FC	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=1**	r=1**
ESDC	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=1**
Draghi	r=1**	r=1**	r=1**	r=1**	r=0**	r=1**	r=1**	r=1**	r=1**	r=1**	r=3**	r=3**
Covid-19	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=1**	r=1**
Inflation	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=2**	r=2**

	Non-core Countries											
Period	Greece		Ireland		Italy		Portugal		Spain		Non-core	
	Trace	LMax	Trace	LMax	Trace	LMax	Trace	LMax	Trace	LMax	Trace	LMax
Pre-Crisis	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=2**	r=2**
FC	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**
ESDC	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**
Draghi	r=1**	r=1**	r=1**	r=1**	r=1**	r=1**	r=1**	r=1**	r=1**	r=1**	r=1**	r=1**
Covid-19	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=1**	r=1**
Inflation	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=2**	r=1**

Table 5

Results of the Johansen trace test and Lambda-Max test (Model 2: intercept included without cointegrationg restrictions on the intercept parameters) by Johansen (1988); Johansen/Juselius (1990); Johansen (1991, 1994) for the EMU core and non-core countries. The double asterix denotes statistically significant difference with $p < 0.05$.
Source: Own presentation and calculations.

Core Countries

Period	Austria		Belgium		Finland		France		Netherlands		Core	
	Trace	LMax	Trace	LMax	Trace	LMax	Trace	LMax	Trace	LMax	Trace	LMax
Pre-Crisis	r=1**	r=1**	r=0**	r=0**	r=1**	r=1**	r=1**	r=1**	r=1**	r=1**	r=4**	r=3**
FC	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=1**	r=1**
ESDC	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=1**	r=0**	r=1**
Draghi	r=1**	r=1**	r=1**	r=1**	r=1**	r=1**	r=1**	r=1**	r=1**	r=1**	r=4**	r=4**
Covid-19	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=1**	r=0**	r=0**	r=1**	r=1**
Inflation	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=2**	r=1**

Non-core Countries

Period	Greece		Ireland		Italy		Portugal		Spain		Non-core	
	Trace	LMax	Trace	LMax	Trace	LMax	Trace	LMax	Trace	LMax	Trace	LMax
Pre-Crisis	r=1**	r=0**	r=0**	r=1**	r=1**	r=0**	r=0**	r=0**	r=0**	r=0**	r=2**	r=2**
FC	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**
ESDC	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**
Draghi	r=1**	r=1**	r=1**	r=1**	r=1**	r=1**	r=1**	r=1**	r=1**	r=1**	r=1**	r=1**
Covid-19	r=1**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=2**	r=2**
Inflation	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=2**	r=1**

Table 6

Results of the Johansen trace test and Lambda-Max test (Model 3: intercept and time trend included with cointegrationg restrictions on the intercept parameters) by Johansen (1988); Johansen/Juselius (1990); Johansen (1991, 1994) for the EMU core and non-core countries. The double asterix denotes statistically significant difference with $p < 0.05$.
Source: Own presentation and calculations.

Core Countries

Period	Austria		Belgium		Finland		France		Netherlands		Core	
	Trace	LMax	Trace	LMax	Trace	LMax	Trace	LMax	Trace	LMax	Trace	LMax
Pre-Crisis	r=0**	r=1**	r=0**	r=0**	r=0**	r=1**	r=1**	r=1**	r=1**	r=1**	r=3**	r=3**
FC	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=1**	r=1**
ESDC	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=1**	r=1**	r=2**
Draghi	r=1**	r=1**	r=0**	r=1**	r=0**	r=0**	r=1**	r=1**	r=1**	r=1**	r=2**	r=2**
Covid-19	r=0**	r=0**	r=0**	r=1**	r=0**	r=0**	r=1**	r=1**	r=1**	r=1**	r=1**	r=1**
Inflation	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=2**	r=2**

Non-core Countries

Period	Greece		Ireland		Italy		Portugal		Spain		Non-core	
	Trace	LMax	Trace	LMax	Trace	LMax	Trace	LMax	Trace	LMax	Trace	LMax
Pre-Crisis	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=2**	r=2**
FC	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**
ESDC	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=1**	r=1**
Draghi	r=1**	r=1**	r=1**	r=1**	r=1**	r=1**	r=1**	r=1**	r=1**	r=1**	r=1**	r=1**
Covid-19	r=1**	r=1**	r=1**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=2**	r=1**
Inflation	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=1**	r=1**

Table 7

Results of the bivariate and multivariate tests by Bierens (1997) for the EMU core and non-core countries. The double asterix denotes statistically significant difference with $p < 0.05$. Source: Own presentation and calculations.

Core Countries

Period	Austria		Belgium		Finland		France		Netherlands		Core	
	Trace	LMax	Trace	LMax	Trace	LMax	Trace	LMax	Trace	LMax	Trace	LMax
Pre-Crisis	r=1**	r=0	r=1**	r=0	r=1**	r=1	r=1**	r=1	r=1**	r=1	r=4**	r=2
FC	r=0**	r=0	r=0**	r=0	r=0**	r=0	r=1**	r=0	r=0**	r=0	r=1**	r=1
ESDC	r=0**	r=1	r=0**	r=0	r=1**	r=1	r=0**	r=0	r=1**	r=1	r=0**	r=0
Draghi	r=0**	r=0	r=0**	r=0	r=0**	r=0	r=1**	r=0	r=1**	r=1	r=2**	r=1
Covid-19	r=1**	r=1	r=1**	r=1	r=1**	r=1	r=1**	r=1	r=1**	r=1	r=4**	r=3
Inflation	r=1**	r=1	r=1**	r=1	r=1**	r=1	r=1**	r=1	r=1**	r=1	r=4**	r=3

Non-core Countries

Period	Greece		Ireland		Italy		Portugal		Spain		Non-core	
	Trace	LMax	Trace	LMax	Trace	LMax	Trace	LMax	Trace	LMax	Trace	LMax
Pre-Crisis	r=1**	r=0	r=1**	r=1	r=0**	r=0	r=0**	r=0	r=1**	r=0	r=2**	r=1
FC	r=0**	r=0	r=0**	r=1	r=0**	r=0	r=0**	r=0	r=0**	r=0	r=0**	r=0
ESDC	r=0**	r=0	r=0**	r=0	r=0**	r=1	r=0**	r=0	r=0**	r=0	r=0**	r=0
Draghi	r=0**	r=0	r=0**	r=0	r=0**	r=0	r=0**	r=0	r=0**	r=0	r=0**	r=0
Covid-19	r=0**	r=0	r=1**	r=1	r=0**	r=0	r=0**	r=1	r=0**	r=1	r=1**	r=1
Inflation	r=0**	r=0	r=1**	r=1	r=0**	r=0	r=0**	r=1	r=0**	r=1	r=1**	r=1

Table 8

Results of the bivariate and multivariate tests by Breitung (2002) for the EMU core and non-core countries. The double asterix denotes statistically significant difference with $p < 0.05$. Source: Own presentation and calculations.

Core Countries

Period	Austria		Belgium		Finland		France		Netherlands		Core	
	no drift	drift	no drift	drift	no drift	drift	no drift	drift	no drift	drift	no drift	drift
Pre-Crisis	r=0**	r=0**	r=1**	r=0**	r=1**	r=0**	r=1**	r=0**	r=1**	r=1**	r=2**	r=2**
FC	r=0	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**
ESDC	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**
Draghi	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=1**	r=2**	r=1**
Covid-19	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**
Inflation	r=0**	r=0**	r=0**	r=0**	r=1**	r=1**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**

Non-core Countries

Period	Greece		Ireland		Italy		Portugal		Spain		Non-core	
	no drift	drift	no drift	drift	no drift	drift	no drift	drift	no drift	drift	no drift	drift
Pre-Crisis	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=1**	r=0**	r=0**	r=0**
FC	r=0**	r=0**	r=1**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=1**	r=0**
ESDC	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=1**
Draghi	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**
Covid-19	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**
Inflation	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**	r=0**

6. Conclusion

We look at the long-term relationship between the yields of 10y sovereign bonds of Germany and ten EMU member countries, which we divide in two samples of equal size, namely core and non-core countries, since the founding of the EMU. Special emphasize is placed on how this relationship evolves before, after, and during the past decade's most pressing crises events, including the Global Financial Crisis, the Sovereign Debt Crisis and the COVID-19 Crash. Furthermore, we consider most recent data covering the period of increasing inflation and central bank rate hikes. In this context, we analyze cointegrating relationships of 10y sovereign bond yields for both, sample and sub-samples, by implementing parametric and non-parametric unit root tests, as well as the Johansen parametric standard approach in cointegration testing in combination with two non-parametric test procedures being not dependent on nuisance parameters. These non-parametric cointegration techniques have been suggested by Bierens (1997) and Breitung (2002). Generally, cointegration describes the long-term relationship of two assets and can be interpreted as two assets sharing identical risk exposure profiles.

Empirical evidence from the ADF unit root test, Breitung's non-parametric unit root test, and the three implemented cointegration methodologies according to Johansen, Breitung and Bierens, enabled us to carry out a detailed and far-reaching analysis of the long-term relationships of EMU government bond yields since the emergence of the EMU. The application of multiple parametric and non-parametric investigation methods to various relevant episodes of the European government bond market over the last 20 years allows a detailed interpretation of the dynamics of government bond yields over time.

Our results suggest that there is strong evidence for cointegrating relationships prior the Global Financial Crisis. However, contradictory evidence is found in the sub-samples following the European Sovereign Debt Crisis as well as in the more recent period of sharp increases in inflation experienced globally. In this context, the results of the Johansen tests show that the impact of Draghi's famous "Whatever it takes"-speech appears to be rather short-lived. Due to the experience of the European Sovereign Debt Crisis, capital markets only temporarily assessed the default risk of government bonds uniformly still accounting for a certain north-south divide. Particularly since the Covid-19 Crash, it appears that this effect completely fizzled out. Still, when considering the results of the two non-parametric methods, the results are less compelling (at the least when considering the model proposed by Breitung (2002)).

To summarize, since the tests applied in the paper at hand do not provide evidence for cointegration of EMU long-term sovereign bond yields with a risk-free asset substitute in the crises sample as well as in the subsets after Draghi's popular statement, the equal and risk free treatment of EMU member states' sovereign debt under the Solvency II regulatory regime seems to be more than questionable from a risk perspective. To be more precise, we do not find empirical evidence supporting the zero default risk assumption in conjunction with the risk free treatment of EMU sovereign debt in the standard formula under Solvency II. These findings are especially relevant for the asset management desks of European insurance companies, predominantly with regard to the treatment of EMU sovereign debt within the European regulatory framework, namely the Solvency II Directive. Nonetheless, the academic debate on the long-term relationship between EMU government bond yields is still of vital importance. While the Great Financial Crisis and the European Sovereign Debt Crisis have already been studied more intensively, the behavior of the long-term relationship of government bond yields during the recent period of very restrictive central bank policy worldwide in the wake of inflation targeting offers great potential for more in-depth analysis.

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