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Carlos Alberto Piscarreta Pinto Ferreira

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Portugal

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Rua Miguel Lúpi, 20
1249-078 LISBOA
Portugal

Telephone: +351 - 213 925 912
E-mail: rem@iseg.ulisboa.pt

https://rem.rc.iseg.ulisboa.pt/

REVISITING THE DETERMINANTS OF SOVEREIGN BOND YIELD VOLATILITY

By Carlos Alberto Piscarreta Pinto Ferreira[1]

KEYWORDS

Volatility, Bond Market, Public Debt, Sovereign Risk, Panel Data, Fixed Effects.

JEL CODES

C23, E44, G11, G15, H63

ABSTRACT

Although there is an extensive literature regarding volatility in the financial markets, to our knowledge, few empirical studies specifically focus on the drivers of volatility of sovereign bond yields. This empirical paper aims to fill part of this gap and to provide more up to date empirical insights. We add to previous work by examining the issue simultaneously in a broad number of advanced economies. Our analysis shows that sovereign bond unconditional volatility exhibits mean-reversion and persistence. Bond yield volatility responds to proximate market movements and global risk. However, that response is found to be uneven across geographies, asymmetric in some cases and possibly time-varying. Macro and policy uncertainty impact depends on the specific uncertainty measures used and rarely is very meaningful.

[1] ISEG - Lisbon School of Economics & Management, Universidade de Lisboa; REM/UECE. R. Miguel Lupi 20, 1249-078 Lisbon, Portugal. Email: cpferreira@phd.iseg.ulisboa.pt; cferreira@iseg.ulisboa.pt. The views expressed are the author's and all errors are his responsibility. I am very grateful for comments from Miguel St. Aubyn and José Cardoso da Costa.

1. INTRODUCTION

News headlines are once more calling the public attention to volatility in the sovereign bond markets. Headlines such as: ”The bond market has been volatile over the past week as corporate earnings and economic readings have given conflicting signals to investors and global central banks have begun to chart their separate paths to tighter policy” (10-year Treasury yield dips as bond market volatility continues, CNBC, October 21, 2021); or “Fixed income markets have been jolted by fears that rising inflation will force monetary policymakers into scaling back stimulus programmes, (…) ” (US bond tumult risks triggering stock market volatility, analysts warn, FT, Robin Wigglesworth and Nicholas Megaw November 2, 2021). More recently, “The MOVE gauge of volatility has surged to its highest since the Covid crash of March 2020 as investors navigate conflicting cross-currents in the economic outlook.”(Bond Volatility Soars In Tug-Of-War Between Recession, Fed Risks, Financial Advisor, July 6, 2022).

Previous news illustrates the fact the occasionally bouts of volatility sweep the sovereign bond market. This raises the issue of why it happens, and what are the underlying driving forces?

Although there is an extensive literature regarding volatility in the financial markets, to the best of our knowledge, few recent empirical studies focus explicitly on the drivers of volatility of sovereign bond yields. This empirical paper aims to review several features of volatility in sovereign bond markets and provide new empirical insights. In this respect we investigate (i) the degree of mean-reversion present in the data and whether it can be related to time-varying means across the sample period; (ii) whether volatility is affected by market cycles, namely if bear markets are associated with higher volatility; (iii) the type of relationship between volatility and bond yield movements and; (iv) how sovereign bond market volatility relates with macroeconomic and economic policy uncertainty, a connexion underlying the above news headlines.

We add to the existing knowledge base on sovereign bond yield volatility by examining the issue simultaneously in a broad number of advanced economies, by combining different levels of analysis, and working with a sample period that encompassing the Great Financial Crisis (GFC) and the Euro Area (EA) sovereign debt crisis allow us to observe the aftermath of those two important and related financial crises.

Our analysis shows that sovereign 10-year yields unconditional volatility exhibits mean-reversion and persistence. Persistence remains statistically significant when we account for crisis-related structural breaks in the mean, indicating that it is not entirely due to the presence of time-varying means in the data. We are unable to reject the hypothesis of identical volatilities across bear and bull markets, conditional on our definition of market cycles based on the US market. Bond yield volatility responds to proximate bond market movements unevenly across geographies, corroborating the results of Sheppard et al. (2003), and possibly in a time-varying fashion. We also find evidence of volatility response to global risk. Although macro and policy uncertainty have an impact on bond yield volatility, this impact depends on the specific uncertainty measures used and, when significant, rarely is very meaningful.

The remainder of the paper is structured as follows. Section 2 reviews the relevant literature covering the general determinants of bond market volatility. Section 3 introduces the data, some descriptive statistics, and the time-series properties and tests. Sections 4 describes the general modelling and econometric approach. Section 5 details the empirical strategy and presents the results. A summary of the study main findings is given, and conclusions are drawn in Section 6. The Appendix provides more comprehensive information, namely description of data sources, time-series tests, and econometric results.

2. LITERATURE REVIEW

Volatility is stationary, persistent, and heteroskedastic. Volatility seems to respond to market movements, but the response is diverse across countries and possibly asymmetric (larger response to negative market movements). The slim evidence on causality points to market movements Granger causing volatility but not the reverse. The relation between the two is explained by the asymmetric impact of price movements on investors' equity capital and on levered positions, the asymmetric presence of issuers, compounded in high volatility periods by volatility feedback effects. Theoretically, it is suggested that in periods of higher fundamental uncertainty, news will induce higher asset price volatility. High frequency data studies suggest that the surprise component of all macroeconomic announcements have an impact on bond volatility, but that the effect dissipates quickly. The empirical evidence of other studies is less clear. In the US, monetary policy uncertainty is often found to have a positive impact on volatility and causality to be unidirectional, running from monetary policy uncertainty to bond volatility. This result stands even recognizing that 10-year yield volatility is associated more with the volatility of the term premia and less to the volatility of short-rate expectations. The impact of monetary policy uncertainty is not universal, however. It shows up in the UK, Germany, and the Netherlands but not in other advanced economies. Evidence regarding other fundamentals such as real GDP or inflation uncertainty is mixed in the US and fails to prove significant in other countries.

Borio & McCauley (1996) investigate the time series properties of bond yield volatility, the link between volatility and market movements, and the fundamental determinants of volatility using a data set of weekly observations on implied yield volatility for 3-month over the counter at-the-money options on 10-year benchmark government bonds in 13 major markets. Regarding time series properties, they find (unconditional) bond yield volatility to be stationary, heteroskedastic, and displaying persistence. Persistence means that if a shock drives volatility above or below its average it takes a long time to return to its mean value. OLS estimates of the persistence parameter range from 0.77 in Spain to 0.97 in the Netherlands.

The relation between volatility and market movements is examined in two perspectives: medium-term and short-term; with results supporting the latter link as being the strongest. The first perspective looks at the differences in volatility between bull and bear markets. Two tests are conducted: a difference-in-means statistical test, and an econometric test on the change of both the mean and the persistence parameter to account for the autocorrelation of volatility over time. The first test's results support the view that is unlikely that volatilities are equal in bear and bull markets. However, the second test's results are less clear. The null of the joint test of equal mean and persistence parameter is rejected only in 4 out of 13 countries (Japan, France, UK, and Denmark). A test on the equality of means conditional on the same persistence parameter[2] across market cycles rejects the null hypothesis in 7 out of 13 cases. All the 7 markets are European: Germany, France, the UK, Italy, Belgium, Denmark, and Sweden, including both countries in and out of the Exchange Rate Mechanism thereby dismissing any apparent influence of the exchange rate regime. The difference between bull and bear markets is not statistically significant in all non-European countries in the sample: US, Canada, Japan, and Australia. The second perspective examines the explanatory power of short-term market movements[3] and possible asymmetric effects. Bond yield volatility react to market movements[4] in all markets but the US and Canada. The relation is symmetric in Japan, Spain, and Sweden, and asymmetric in the remaining 8 countries, where only increases in yields have an impact on volatility.

In their view, the relationship between market movements and volatility may be explained by two main factors: wealth effects resulting from changes in market prices that affect market-makers capital and risk tolerance[5] and leverage, understood as both debt-financing and duration mismatches between assets (long duration) and liabilities (short duration). Depletion of capital during bear markets reduces risk tolerance and promotes re-allocation of capital to other activities reducing market liquidity, whereas in a bull markets effects tend to be more muted. Leverage, by magnifying losses, may force liquidation of open positions in adverse market conditions, amplifying price changes. In the bond market the effect of leverage relates to the ability to take losses, differently from the stock market where share price declines increase quoted firms' debt-to-equity ratios changing the risk of the underlying asset (Black, 1976 and Christie, 1982). A third complementary explanation relates with the asymmetric behaviour of issuers, that take advantage of strong markets to increase supply and thereby moderate demand pressure, but seldom are available to retire debt when demand is weak. Curiously, no role is envisaged for the volatility feedback effect proffered by Campbell & Hentschel (1991) according to which large shocks feed expectations of more large shocks due to news/volatility persistence and this increase in future expected volatility drives the required rate of return up and lowers asset prices. In case of positive news, the volatility feedback effect dampens the increase in prices; in case of negative news, the feedback effect compounds the news negative impact on prices. In the equity

[2] The equality of the persistence parameter is rejected only in 2 countries, Japan, and Spain.

[3] Given that short-term asset returns are largely unpredictable, forecast errors, a measure of 'news', are basically the market movements themselves, if we admit that "noise trading" has little significance.

[4] Percentual change in yields proxied by the first difference of the logarithm of yields.

[5] This explanation mirrors the intermediary asset pricing theory where frictions lead to marginal pricing by intermediaries when their equity constraints binds and to non-linear equilibrium asset prices (see for example He & Krishnamurthy (2018)).

market this effect is large during volatile periods, but secondary to other market dynamics when market conditions are stable (Wu, 2001).

The fundamental determinants of volatility are investigated, first, by looking at the relation between volatility and the bond yield level. Their rational is that higher yield levels reflect higher inflation expectations and, following Milton Friedman, higher inflation expectations are more volatile. The same argument is applied to fiscal policy as higher bond yield levels are associated with higher debt levels and riskier debt is more volatile. The evidence of a positive relation between volatility and the yield level, however, fails to materialize when looking at the G3 bond markets and even in the European markets the relation even if statistically significant has an unstable explanatory power. A second approach tries to relate bond yield volatility to revisions and dispersion of measures of short-term inflation and growth expectations. Again, these fundamental macro factors fail to account for the short-term behaviour of volatility. Due to the lack of similar measures for fiscal policy indicators the swap spread is used as a proxy and only for the case of Italy, the country with the largest debt level. Only positive changes in the swap spread are statistically significant at a 10% significance level, indicating asymmetry, but the size of the effect is not very large: a swap spread widening of 100 bps accounts for a 2.9 percentage point increase in volatility. The relation with money-market volatility is also investigated, and though remarked the possible two-way causality[6], the endogeneity problem is left unaddressed in the econometric analysis. Using historical money-market volatility measured as the standard deviation of the implied 3-month LIBOR 3-months forward a positive statistically significant relation is found in 4 out of 10 countries in the whole sample, the US, Germany, the UK, and the Netherlands. The US results is further confirmed using implied money-market volatility derived from interest rate caps.

Cappiello (2000) estimates a multivariate asymmetric GJR-GARCH to capture asymmetric effects for both the conditional variance and covariance of three US assets: stocks, T-bills and 10-year government bonds; employing monthly data over 1960M1 – 1998M12. As part of the diagnostic tests he estimates a model that has as dependent variable the square of demeaned returns taken as a rough measure of unconditional volatility and as regressors: (1) an intercept, (2) an interaction of the intercept with an indicator variable that takes the value 1 when previous period demeaned return is negative, (3) an interaction of previous period demeaned return and the previously referred indicator variable, and (4) an interaction of previous period demeaned return and an indicator variable that takes the value 1 when previous period demeaned return is positive. He then carries out the sign bias test, the negative size bias test and the

[6] Higher money-market volatility indicating higher uncertainty regarding monetary policy and short-term rates has an impact on bond yield volatility. Higher bond yield volatility, that may be linked either to higher inflation expectations or changes in short-term funding in association with the use of leverage in bonds positions, can also have an influence in money-market volatility. Empirical evidence of a feedback effect of past bond market volatility into short term yield volatility is provided by Steeley (2006) under a GARCH framework and using UK data between 1984:6 - 2004:6, although the variable used to represent short term rates is an index of less than 5-year bonds.

positive size bias test proposed by Engle and Ng (1993) on the parameters of variable (2) to (4), respectively. As far as bonds are concerned, the tests fail to reject the hypothesis of different volatility means in periods of positive and negative returns and point to the fact that only negative returns have an impact on volatility. The former but not the latter results match those of Borio & McCauley (1996) for the US. Having estimated the proper multivariate GJR-GARCH model, Cappiello (2000) results show that a Wald test rejects the null hypothesis that positive and negative past return shocks have the same effect on government bond conditional volatility and that the news impact curve plots a higher response to past negative than positive return shocks of the same magnitude, confirming the asymmetry of responses suggested by the diagnostics.

Sheppard et al. (2003), using weekly returns on 5-year average maturity government bond indices for 13 countries[7] between January,2 1987 and February 15, 2001, find variances of bond returns to be higher after negative shocks in 9 cases of which only one is statistically significant. Having fitted different univariate GARCH models to the series, they only find asymmetric effects in 3 out of 13 countries. Canadian bond returns conditional volatility displays a large response to negative shocks, while Swiss bond returns conditional volatility has exactly the opposite reaction, increasing substantially in face of positive shocks. The US model parameter coefficients suggest a similar behaviour to the Canadian market, but no information is available on their statistical significance. Most of the European countries fitted models are of the symmetric variety. The paper also finds strong linkages in bond return volatilities among EMU member states (0.80) and even between all European countries (0.53), whereas the US volatility is basically uncorrelated with every other market volatility except for the neighbouring Canada.

Andritzky et al. (2005) examine the effects of macroeconomic announcements[8] on the volatility of spreads for sovereign bonds included in the EMBI index of 12 countries, over the period January 5, 1998 to July 12, 2004, using a variety of approaches. Their ANOVA results show significant differences in variances across announcement and non-announcement days for GDP, fiscal balance, and the US interest rate. Country level GARCH estimates find significant effects from announcements in many countries, though only GDP and trade balance announcement produce consistent effects across sample countries. The first reduces volatility, whereas the second tend to increase it. Panel GARCH results confirm the significance of announcements for volatility of the daily change in spreads. Moreover, they indicate that GDP, fiscal balance, and US interest rate announcements tend to reduce volatility, while trade balance and rating actions tend to do the opposite. The difference in impacts is attributed to more consensual views of investors regarding the consequences for country risk of the first group of

[7] The countries covered are the US, Canada, Japan, Austria, Belgium, Denmark, France, Germany, Ireland, the Netherlands, Sweden, Switzerland, and the UK.

[8] These include real GDP; industrial production; consumer prices; trade balance; fiscal balance; changes in the domestic policy interest rate; changes in the US federal funds rate; and rating actions.

announcements. When a control for the surprise content of news is introduced[9] and a distinction is made between positive and negative surprises, GARCH regressions show that all macroeconomic announcements influence the volatility of spreads. When the sample is divided in two, distinguishing between investment and non-investment grade credit ratings, it is found that for non-investment grade countries announcements of domestic interest rate changes and fiscal policy have stronger effects on the volatility of spreads, and that rating actions matter less. Redefining the event window to cover the preceding and following day of the announcement results in a same sign but smaller magnitude of the effects, suggesting that they dissipate over time.

Arnold & Vrugt (2010) explore the fundamental determinants of volatility in the US Treasury bond market using quarterly data for the period 1969Q1 – 2005Q4. They build on the work of Veronesi (1999) and David and Veronesi (2004) on the relation between financial market volatility and macroeconomic uncertainty, according to which investors make inferences about asset prices based on the unobservable path of macroeconomic fundamentals. In periods of higher fundamental uncertainty, news will induce higher asset price volatility. Thus, a positive relation between asset market volatility and fundamental uncertainty is to be expected. The uncertainty measure used is the cross-sectional dispersion of individual forecasts from the Survey of Professional Forecasters, following the positive conclusions of Giordani and Söderlind (2003) and Bomberger (1996) regarding its quality. This indicator is complemented by a macroeconomic volatility measure, first proposed by Bansal et al. (2005), that uses the absolute value of residuals of an AR(1)-model[10]. Both variables are introduced in an AR(1) model for volatility for 4 different maturities of Treasury bonds (1, 5, 10 and 30 years). Their empirical results establish a significant relation between bond volatility and dispersion-based uncertainty[11] about the monetary policy rate, inflation, and measures of real activity when taken individually. Once the relation is estimated including the uncertainty about monetary policy, all other measures of macroeconomic volatility are dwarfed by this variable. The only other uncertainty measure that remains significant for 10-year bond volatility and considering a forecast horizon of 4 quarters is inflation but has an unexpected negative sign. A test on Granger causality finds that causality is unidirectional and runs from monetary policy to bond volatility, in accordance with the theoretical model of Veronesi (1999). All these results where first obtained using volatility on bond returns. Using the volatility of changes in bond yields does not change in any significant way the previous conclusions, even the odd negative significance of inflation uncertainty.

[9] In mature markets announcement effects on volatility tend to be detected only after controlling for the surprise content of news.

[10] The paper also uses an alternative AR(1)-GARCH(1,1) approach but conclusions are similar.

[11] The contemporaneous relation between bond volatility and macroeconomic volatility is found to be weak, confirming earlier studies such as Schwert (1989) and David & Veronesi (2004), and when both uncertainty and volatility measures are included in the same regression the former usually outperforms in explaining bond volatility.

Cieslak & Povala (2013) decompose bond yield implied volatility into three components: short-term rates expectations volatility, term premium volatility and the covariance between short-term rates expectations and the term premium. Using high-frequency data for the US covering the period January 1992 to December 2010, their results show that: (i) the volatility of the 10-year bond is mostly determined by the term premium component; (ii) the term premium component of volatility is more persistent with a half-life of about the double of the short-term rate expectations component[12]; and (iii) long-end volatility remains relatively contained before recessions and during periods of distress when short-end volatility rises, exhibiting more pronounced fluctuations at the exit from recessions.

Regarding the (realized) volatility-yield link, they find this relationship to be nonlinear (asymmetrical U-shaped pattern), a sort of middle ground between the affine models' implicit assumption of a direct relationship due to common determinants and the 'unspanned stochastic volatility' models' prediction of a weak link between volatility factors and the contemporaneous cross-section of yields.

Conditional covariance between shocks to the term premia and short rate expectations point, on average, for low positive[13] values, that from time-to-time change signs, suggesting a persistent but time-varying relationship. The relation of the term premia volatility with macroeconomic expectations and uncertainties shows a positive link to revisions in real GDP forecasts four quarters ahead, the degree of dispersion of those forecasts, and an index of policy uncertainty[14] for the all-sample period. When the crisis time-interval of 2007-10 is removed, two other variables become statistically significant: revisions to the Fed Funds Rate and the dispersion of inflation forecasts. The fist has an expected positive sign. The second has a surprisingly negative sign since we would expect higher uncertainty regarding inflation to translate into higher long-term volatility. The impact of volatility changes on the 10-year yield is found to be quantitatively small[15] and almost entirely driven by the term premium component of volatility.

Ribeiro et al. (2017) does not address specifically the subject of volatility, but volatility dynamics are incorporated into their panel-GARCH model that aims to explain the behaviour of sovereign bond yield spreads of six EA countries over 2007M1 – 2016M6. They find conditional volatility to be quite persistent. Bond yield spread conditional volatility responds positively to shocks in spread changes, without evidence of a statistically significant presence of asymmetric or leverage effects[16].

[12] Their half-lives estimates are 47 weeks for the short-end volatility and above 1.5 years for the long-end volatility.

[13] Positive values mean the correlation increases during easings and declines during tightening periods.

[14] The economic policy uncertainty index from Baker et al. (2013).

[15] A two standard deviation shock to volatilities has a total (negative) impact on the 10-year yield of about 8 basis points.

[16] Asymmetry regards the unexpected component or innovation of the sovereign bond yield spread process.

3. BOND YIELD VOLATILITY

3.1 Data Description

Financial market volatility is not a directly observable variable (Bollerslev & Zhou, 2006). The scope of the present work and data availability constraints determined our use of historical volatility as a suitable proxy, taking stock of the observed close relationship between historical volatility and implied volatility over the long-term (Borio & McCauley, 1996). Bond yield volatility is computed as the annualized standard deviation of the changes in daily yields of 10-year benchmark bonds over each quarter. Since price returns can be approximated by the product of changes in yields times modified duration, our volatility measure is commensurate to bond returns volatility, an alternative measure often found in empirical studies. Although using logs of yields would ensure better comparability of market movements, we did not use it due to the presence of negative rates later in the sample, and to avoid having a volatility measure whose link to asset return volatility is dependent on the level of yields.

The data covers 23 advanced economies (countries are listed in Appendix, Table A - I) over the period 2000Q1 - 2019Q2. Other variables and their respective sources are listed in Table A - II. Further details on the variables used can be found in Appendix B.**Erro! A origem da referência não foi encontrada.Erro! A origem da referência não foi encontrada.**

3.2 Descriptive Statistics

3.2.1 Volatility Analysis

Table I shows descriptive statistics for bond yield volatility across the entire data sample and for several sub-periods, as well as for the sample period for which we have data on all relevant variables. Starting at 2000Q1 or 2004Q1 does not significantly change the results. Average volatility stands at 0.8% with a standard deviation slightly above 1%. We slice the sample period into three broadly defined periods: a pre-crises period ending in 2007Q4, the period covering the GFC and the EA sovereign debt crisis between 2008Q1 and 2013Q4, and the following post-crises period. We can observe in Table I that the mean of bond yield volatility increased in the crises' period.

TABLE I – BOND YIELD VOLATILITY DESCRIPTIVE STATISTICS

In %

	2000Q1-2019Q2		2000Q1-2007Q4		2008Q1-2013Q4		2014Q1-2019Q2		2004Q1-2019Q2	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Overall	0.79	1.04	0.65	0.31	1.07	1.60	0.68	0.85	0.80	1.14
Between		0.42		0.19		0.89		0.52		0.53
Within		0.95		0.25		1.35		0.67		1.02
Decomposition of SS Deviations										
Between		15.60		34.60		29.60		36.60		20.30
Within		84.40		65.40		70.40		63.40		79.70

Notes: SS = Sum of squared. The between standard deviation measures variation of the variable's means across countries and is calculated as the square root of SSDB/(T_i(N-1)) where SSDB = $\sum_{i=1}^{N} T_i(\bar{X}_i - \bar{\bar{X}})^2$, T_i is the sample period of each country i, $\bar{X}_i$ is the country mean, $\bar{\bar{X}}$ is the total sample mean, and N is the number of countries. The within standard deviation measures variation of the variable in each country over time and is calculated as the square root of SSDW/(NT_i-N), where SSDW = $\sum_{i=1}^{N}\sum_{t=1}^{T_i}(X_{it} - \bar{X}_i)^2$ and X_{it} is the value of the variable of country i at time t. Because the computation of the different standard deviations uses distinct degrees of freedom the sum of between and within standard deviations do not add up to total standard deviation. Thus, the decomposition is carried out over the sum of squared deviations, being presented the percentage of the overall sum of squared deviations due to between and within variability. Source: Author own calculations on data from Bloomberg.

Before and after this period of market turmoil average volatility ranges 0.65%-0.68%. A difference-in-means t-test confirms that we do not reject the null of identical mean volatilities in the pre- and post-crisis periods, but we do reject the null when comparing the pre-crises with the crises' period (see Table II).

TABLE II – DIFFERENCE-IN-MEANS T-TEST

H_0: Mean of 2000Q1-2007Q4 equal to mean of

2008Q1-2013Q4		2014Q1-2019Q2	
t-stat	p-value	t-stat	p-value
6.2677	0	0.796	0.4264

Source: Author's calculations

Besides the mean, the variation of volatility has also increased during the EA sovereign debt crisis particularly during the years of 2010, 2011 and 2012, but also later in 2015, at the start of the ECB's PSPP (see Figure 1). This last impact may be partially associated with Greece which experienced then a bout of high volatility.

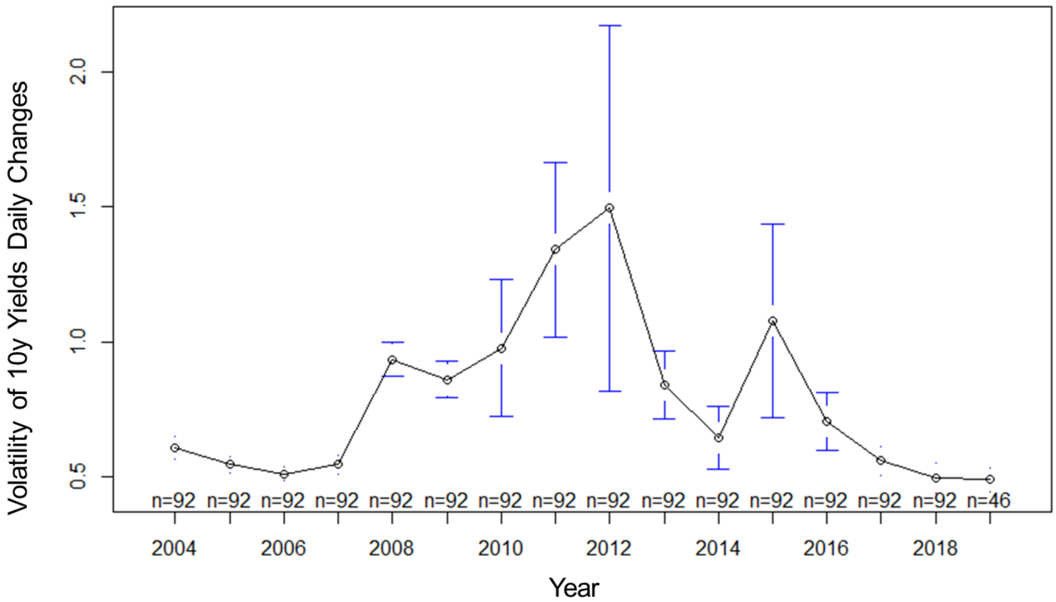


FIGURE 1 – HETEROGENEITY ACROSS TIME OF VOLATILITY VARIATION

In our last sub-period, the variation of volatility has not yet come down entirely to its pre-crises level and this can be attributed to both higher dispersion among countries (between effect) and within each domestic market (within effect) – note however the similarity of the variation decomposition in the pre- and post-crises periods. A difference-in-standard deviations χ^2-test confirms the previous observation as we reject the null of identical standard deviations in the pre- and post-crises periods.

TABLE III - DIFFERENCE-IN-STANDARD DEVIATIONS χ^2-TEST

H_0: Std.Dev. of 2000Q1-2007Q4 equal to Std.Dev. of

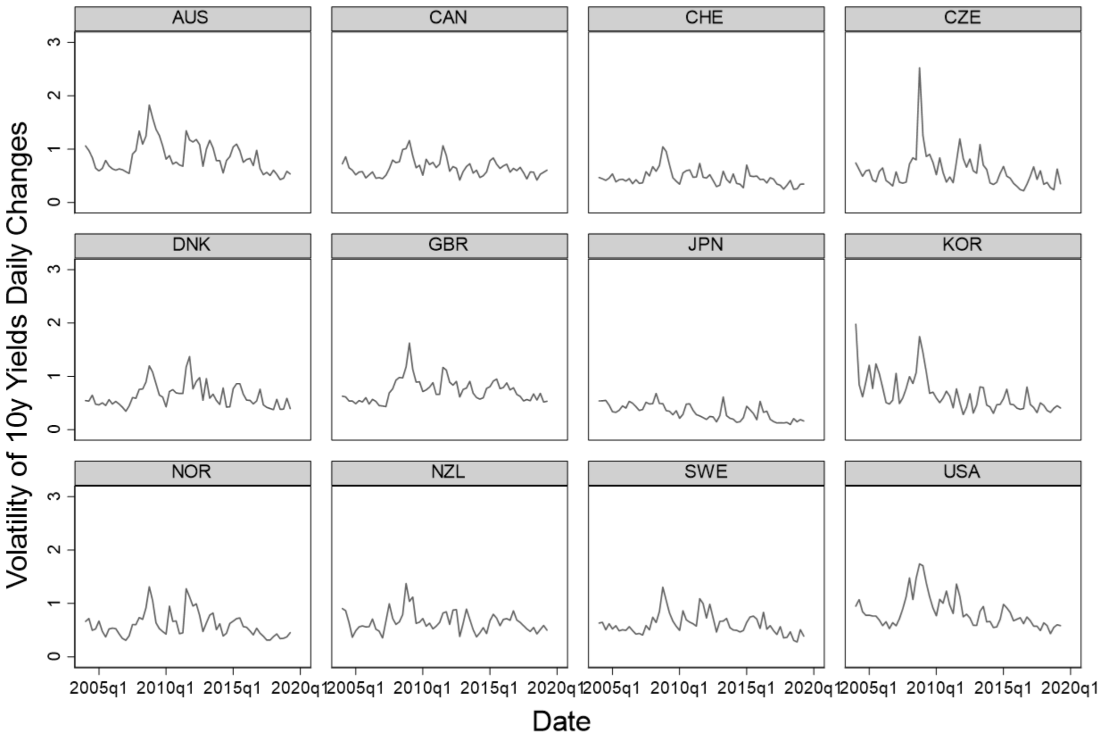
2008Q1-2013Q4		2014Q1-2019Q2	
χ^2-stat	p-value	χ^2-stat	p-value
15000	0	3800	0

Source: Author's calculations

In general, outside the EA, volatility only briefly flares above 1.5% during periods of market turmoil. Japan stands apart in this respect with volatility consistently below 0.7%.

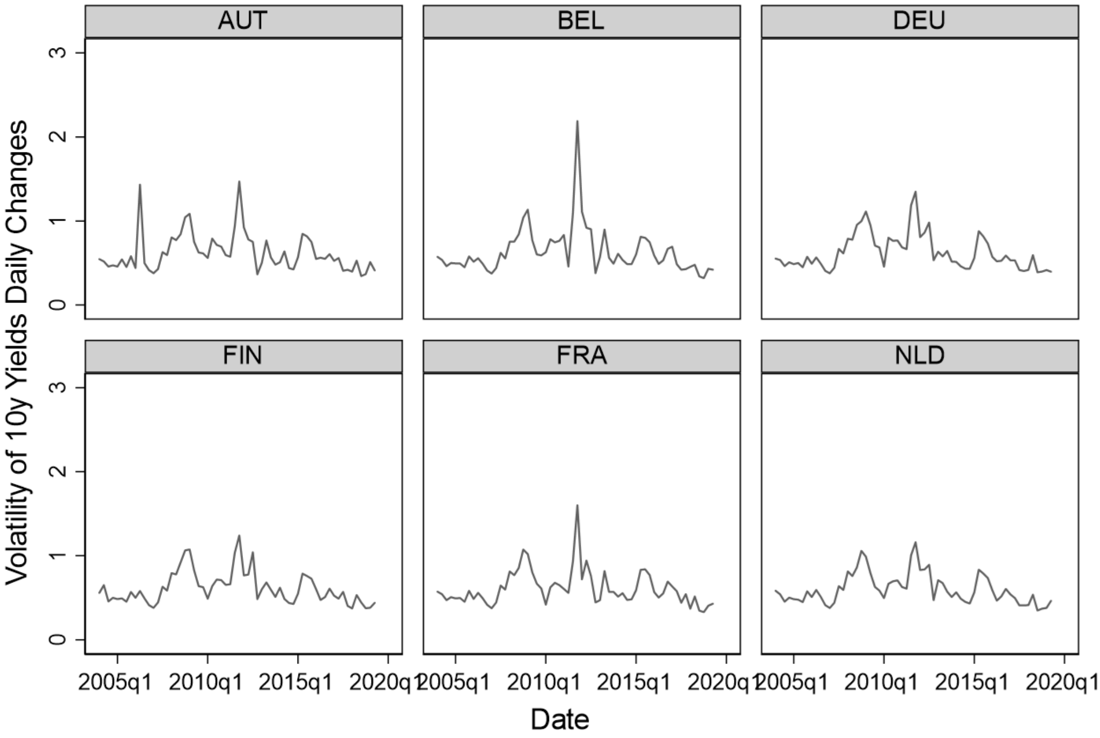
In core EA countries volatility seldom goes above the 1% mark (see Figure 3). The short-lived periods when is possible to observe such elevated levels of volatility coincide with the GFC and the EA sovereign debt crisis.

When we focus our attention in Italy and Spain, we observe that volatility stays above the 1% mark for extended periods of time, and in the case of Ireland and Portugal, even above 2% which represents about 2 standard deviations when we consider the all sample (see Figure 4). The case of Greece is unique, not only in what regards the extraordinarily high levels reached by volatility around the date of the Greek sovereign debt restructuring in March/April 2012 but also by its persistence, since volatility had not yet returned to its pre-crisis level by 2019Q2 (see Figure 5).



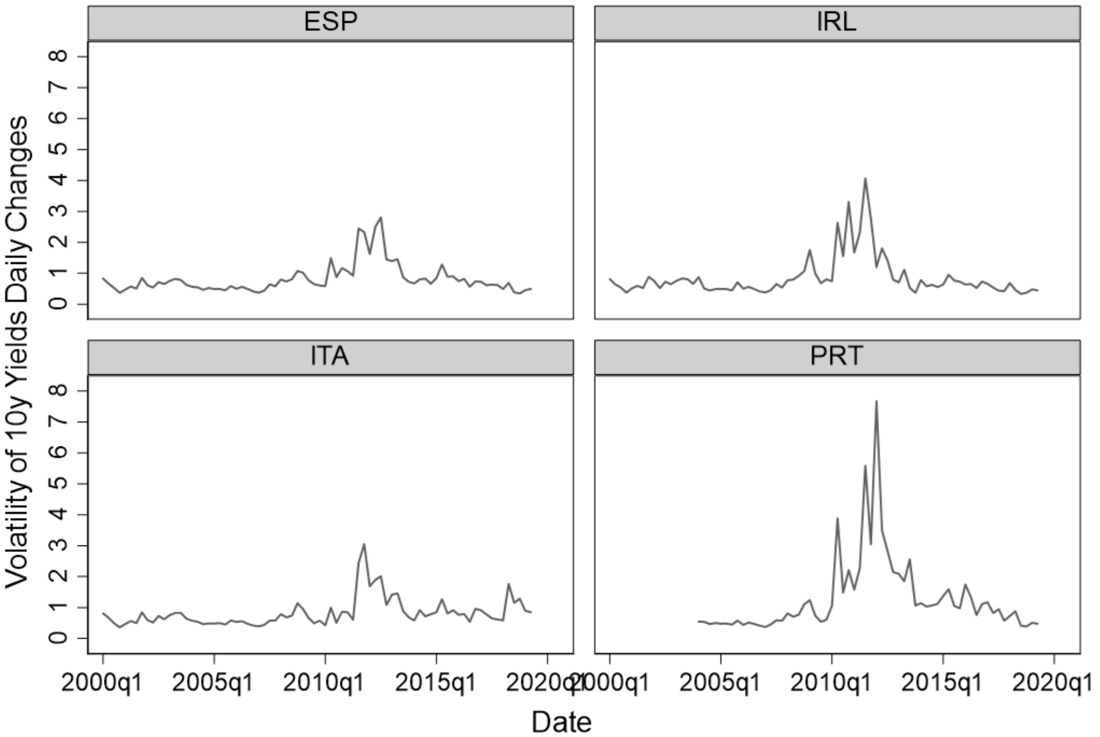
Source: Author's calculations based on data from Bloomberg.

FIGURE 2 – BOND YIELD VOLATILITY IN NON-EURO AREA COUNTRIES



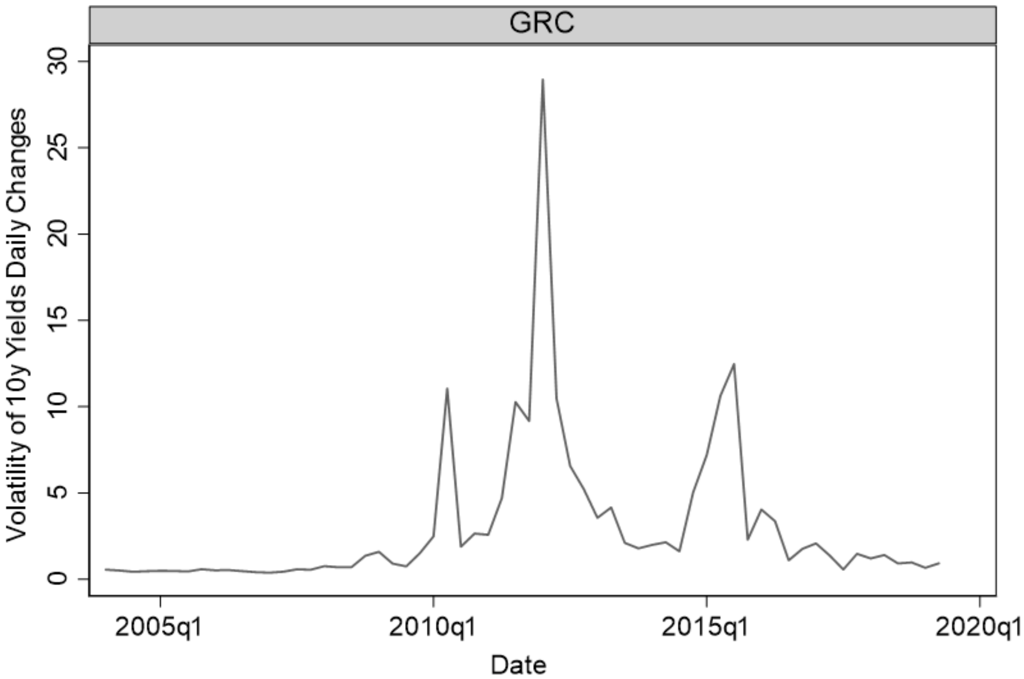
Source: Author’s calculations based on data from Bloomberg.

FIGURE 3 - BOND YIELD VOLATILITY IN CORE EURO AREA COUNTRIES



Source: Author’s calculations based on data from Bloomberg.

Figure 4 - BOND YIELD VOLATILITY IN IRELAND, ITALY, PORTUGAL, AND SPAIN



Source: Author's calculations based on data from Bloomberg.

FIGURE 5 – BOND YIELD VOLATILITY IN GREECE

Recomputing volatility descriptive statistics and our previous difference-in-means and difference-in-standard deviations statistical tests excluding Greece (Table IV to Table VI), we now find that the mean volatility is lower in the post-crises period compared with pre-crises levels, possibly a reflection of a market heavily influenced by central banks' asset purchase programmes. Furthermore, the same occurs with its standard deviation, since a one-sided test rejects the null in favour of the alternative of lower dispersion, while it does not reject the null when the alternative is higher dispersion. These results indicate that Greece has a strong bearing on the analysis even if it is only 1 in 23 sample countries.

TABLE IV - BOND YIELD VOLATILITY DESCRIPTIVE STATISTICS EXCLUDING GREECE

In %

	2000Q1-2019Q2		2000Q1-2007Q4		2008Q1-2013Q4		2014Q1-2019Q2		2004Q1-2019Q2	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Overall	0.71	0.44	0.65	0.31	0.90	0.62	0.57	0.22	0.70	0.45
Between		0.17		0.20		0.36		0.16		0.19
Within		0.40		0.25		0.51		0.16		0.41
Decomposition of SS Deviations										
Between		14.50		34.40		32.70		46.90		17.60
Within		85.50		65.60		67.30		53.10		82.40

Notes: SS = Sum of squared. The between standard deviation measures variation of the variable's means across countries and is calculated as the square root of SSDB/(T_i(N-1)) where SSDB = $\sum_{i=1}^{N} T_i\left(\bar{X}_i - \bar{\bar{X}}\right)^2$, T_i is the sample period of each country i, $\bar{X}_i$ is the country mean, $\bar{\bar{X}}$ is the total sample mean, and N is the number of countries. The within standard deviation measures variation of the variable in each country over time and is calculated as the square root of SSDW/(NT_i-N), where SSDW = $\sum_{i=1}^{N}\sum_{t=1}^{T_i}(X_{it} - \bar{X}_i)^2$ and X_{it} is the value of the variable of country i at time t. Because the computation of the different standard deviations uses distinct degrees of freedom the sum of between and within standard deviations do not add up to total standard deviation. Thus, the decomposition is carried out over the sum of squared deviations, being presented the percentage of the overall sum of squared deviations due to between and within variability. Source: Author own calculations on data from Bloomberg.

TABLE V - DIFFERENCE-IN-MEANS T-TEST

H_0: Mean of 2000Q1-2007Q4 equal to mean of

2008Q1-2013Q4		2014Q1-2019Q2	
t-stat	p-value	t-stat	p-value
9.3821	0	-7.7936	0

TABLE VI - DIFFERENCE-IN-STANDARD DEVIATIONS χ^2-TEST

H_0: Std.Dev. of 2000Q1-2007Q4 equal to Std.Dev. of

2008Q1-2013Q4		2014Q1-2019Q2	
χ^2-stat	p-value	χ^2-stat	p-value
2000	0	247	0

Source: Author's calculations.

Excluding Greece does not change much the decomposition of the variability of volatility in the pre-crises period, but during the crises and in the following period it is possible to observe an increase of the importance of variability across countries relative to variations over time within each country. Moreover, the decomposition does not seem to have change significantly between the pre-crises and crises period, it is rather the last period that now exhibits a different structure, brought about by a lower variability of variations over time within each country. It is hard not to posit that these is a result of central banks active presence in the government bond market.

3.2.2 Volatility and Yields

Volatility exhibits a positive relationship with yields (see Figure 6), but this relationship becomes looser as we move up the yield level scale to countries such as GIIPS[17] or the Asia-Pacific countries, or down to Japan.

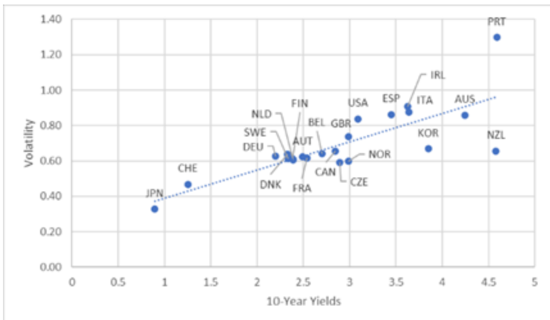


FIGURE 6 – VOLATILITY AND 10-YEAR YIELDS

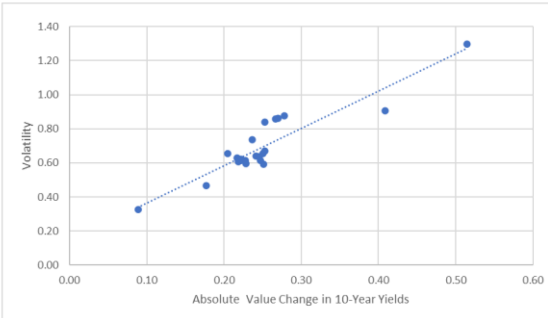


FIGURE 7 – VOLATILITY AND ABSOLUTE VALUE OF CHANGES IN 10-YEAR YIELDS

Note: Cross-section of average sample values of annualized volatility of 10-year yields daily changes over each quarter and 10-year yields over 2004q1 to 2019q2, excluding Greece, in Figure 6. Cross-section of average sample values of annualized volatility of 10-year yields daily changes over each quarter and of the absolute value of quarterly changes in 10-year yields over 2004q1 to 2019q2, excluding Greece, in Figure 7. Source: Author's calculations based on data from Bloomberg.

The relation between the cross-section of mean volatilities and yield changes is conditioned by the presence or exclusion of Greece, Ireland, and Portugal (GIP). The slope of the linear relationship is positive and statistically significant in the presence of those three countries, but changes sign and becomes statistically insignificant once they are excluded. Focusing solely on GIP, a positive relationship is confirmed, and it stands the inclusion of Italy and Spain, although at a cost of a lower 10% significance level for the slope parameter.

[17] GIIPS stands for Greece, Italy, Ireland, Portugal, and Spain.

TABLE VII – VOLATILITY AND CHANGE IN YIELDS

	dY	t Stat.	P>|t|	R^2	F Stat.
All countries	14.66	2.26	0.035	0.196	5.10**
All countries except GIP	-0.33	-0.16	0.876	0.001	0.030
Greece, Ireland and Portugal	46.04	54.88	0.012	1.000	3012**
GIP, Italy and Spain	40.64	2.58	0.082	0.690	6.67*

TABLE VIII - VOLATILITY AND ABSOLUTE VALUE OF CHANGE IN YIELDS

	I dY I	t Stat.	P>|t|	R^2	F Stat.
All countries	2.56	29.21	0.000	0.975	853.2***
All countries except Greece	2.19	10.22	0.000	0.831	104.53***
All countries except GIP	2.74	6.71	0.000	0.698	45.00***

TABLE IX – VOLATILITY AND POSITIVE CHANGE IN YIELDS

	dY>0	t Stat.	P>|t|	R^2	F Stat.
All countries	3.22	24.35	0.000	0.966	592.9***
All countries except GIP	3.17	5.19	0.000	0.600	26.96***

TABLE X – VOLATILITY AND NEGATIVE CHANGE IN YIELDS

	dY<0	t Stat.	P>|t|	R^2	F Stat.
All countries	-1.86	-20.35	0.000	0.952	414.2***
All countries except GIP	-2.22	-6.17	0.000	0.679	38.01***

Note: Regressions using country means. dY = yields' first difference; |dY| = yields' first difference in absolute value. dY<0 = negative values of yields' first differences; dY>0 = positive values of yields' first differences. R^2 is the between R^2. The asterisks ***, **, * indicate significance at the 1, 5, and 10% level, respectively. Source: Author's calculations based on data from Bloomberg.

If we take yield changes in absolute values the relation becomes positive again, and robust to the inclusion or exclusion of GIP. Allowing for possible asymmetric effects by conditioning the results on positive and negative changes in yields results in substantially different slope parameters, both statistically significant. According with these results, volatility seems to be relatively more responsive to increases in bond yields. Removing GIP does not change this conclusion.

3.3. Time Series Properties

A series of unit root and stationarity tests with different specifications, since tests are sensitive to treatment of serially correlated errors, means and trends, were conducted and details can be found in Appendix B. Across the different unit root tests volatility of 10-year bond yields, the real GDP growth rate and VIX consistently prove to be stationary in levels. Although the evidence is less clear cut for inflation expectations, we also treat this variable as stationary in levels. Test results for all other variables point to the presence of unit-roots in levels but not after differentiation. Therefore, these variables will be used in first differences.

4. ECONOMETRIC METHODOLOGY

In exploring the drivers of bond yield volatility (V_t) we combine single country regressions with a panel approach where in all cases we will have present a lagged dependent variable. The basic single country model is an autoregressive distributed lag ARDL (1,0) model:

(1) $V_t = \alpha + \beta V_{t-1} + U_t$,

where U_t is the random disturbance term. Estimation is conducted using OLS, which continues to be an efficient and consistent estimator as long as the disturbance does not exhibit autocorrelation. Newey-West standard errors are computed to account for a heteroskedastic error structure.

We use a dynamic panel data version of the previous specification - equation(2) - to assess whether the data is poolable, and whether there are no country-specific effects either in the regressors (fixed effects) or in the composite error term (random effects);

(2) $V_{it} = \alpha_i + \beta_i V_{it-1} + U_{it}$; i = 1, …, N ; t = 1, …, T,

where N stands for the number of countries and T the number of quarters. The detail of these tests as well as the ones mentioned next in this subsection are available in Appendix C. We conclude from them that the data is poolable and that country fixed effects in the regressors are present.

We also test for heteroskedasticity and for autocorrelation on the residuals. Considering the tests' results and the fact that the volatility series exhibit cross-sectional dependence, we decide to use Driscoll and Kraay (1998) standard errors for the coefficients of the regression model, since they assume an error structure that is heteroskedastic, autocorrelated up to some lag and allow for cross-sectional dependence.

Since the fixed effects estimator is biased, we estimate the size of the fixed effects within estimator bias at less than 5%, which we considered reasonable enough against the problems of the alternative econometric approaches and proceed with this estimator.

5. EMPIRICAL STRATEGY AND RESULTS

5.1 Persistence

Time series tests provided indication that volatility is stationary. To investigate the degree of mean-reversion we proceed to estimate the following fixed effects dynamic panel data model using the within-estimator:

(3) $V_{it} = \alpha_i + \beta V_{it-1} + U_{it}$; i = 1, …, N ; t = 1,…,T

Regression results presented in Table XI confirm that persistence in bond yield volatility can be found in low frequency data of advanced economies. The 'All countries' persistence point estimate of 0.57 is below the pooled SURE estimates of Borio & McCauley (1996) of 0.89 obtained using implied volatility and weekly data. Part of this difference may be explained by the different data frequency, as their estimates drop when they use monthly data (no pooled estimates are presented, but the average country estimates is 0.75 for month-end data). Other part may be due to differences in sample countries and severity of the bond market turmoil.

TABLE XI – PERSISTENCE: PANEL REGRESSIONS

Variables		All Countries		All countries ex Greece				All countries ex GIP			
		(1) AR(1)		(2) AR(1)		(3) AR(2)		(4) AR(1)		(5) AR(3)	
		Coef.	t Stat	Coef.	t Stat	Coef.	t Stat	Coef.	t Stat	Coef.	t Stat
Constant	α	0.338 ***	3.83	0.251 ***	5.91	0.179 ***	4.15	0.223 ***	7.32	0.17 ***	4.88
AR Parameter	β	0.574 ***	5.77	0.636 ***	12.42	0.463 ***	7.36	0.656 ***	13.43	0.59 ***	9.69
F Stat. - Overall Significance		33.27		154.25		62.76		180.27		77.18	
(p-value)		0.0000		0.0000		0.0000		0.0000		0.0000	
R^2		0.330		0.404		0.449		0.431		0.449	
$\chi^2(4)$ Stat. - Serial Correlation		4.489		11.473		1.612		19.768		6.19	
(p-value)		0.3439		0.0217		0.8067		0.0006		0.1854	

Notes: GIP = Greece, Ireland, and Portugal; higher order models, AR(2) and AR(3) restricting lag 2 to zero, are used due to the presence of serial correlation in the base AR(1) model; higher order parameters' values are not reported for the sake of conciseness; the sum of all autoregressive parameters for the panel excluding Greece is 0.74 and for the panel excluding GIP is 0.73; Driscoll-Kraay (1998) standard errors; F Stat. is the statistic of the F-test of overall significance (p-values below); R^2 is the within R^2; $\chi^2(4)$ is the statistic of the Cumby-Huizinga heteroskedasticity robust test of serial correlation up to lag 4 with a null hypothesis of no serial correlation (p-values below).The asterisks ***, **, * indicate significance at the 1, 5, and 10% level.

Once we exclude from the panel regressions Greece or all the countries that received financial assistance during the EA sovereign debt crisis - Greece, Ireland, and Portugal – the sum of the autoregressive parameters inches up to 0.73-0.74, a figure closer to Borio & McCauley (1996) month-end results. The difference between observed volatilities and parametric volatilities may also play a role here. Cieslak & Povala (2013) find for the US a persistence parameter of 0.83 using implied volatility of options on 10-year Treasuries, a figure comparable with the 0.85 of Borio & McCauley (1996), but only 0.42 when using realized volatility[18]. It is also noteworthy that as we remove Greece, or GIP, the persistence parameter increases 0.16, a result that mirrors the one obtained by Borio & McCauley (1996) when they remove Italy and Spain (+0.06). A rise in persistence and a lower estimate of short-run mean volatility combine to drive long-run mean volatility to 0.64 from 0.79 once we exclude the GIP countries.

ARDL (1,0) country models show that at a low data frequency mean-reversion is somewhat swifter than with high frequency data. Our individual AR parameter estimates range from 0.43 in Australia to 0.79 in the US, which compares to 0.49 in Australia to 0.87 in Germany (month-end data) in Borio & McCauley (1996)[19]. We reject the null hypothesis of an insignificant AR parameter in all cases at a 5% significance level, including when using bootstrapped standard errors as suggested by Arnold & Vrugt (2010). Based on R^2, explanatory power varies between 0.17 in Australia to 0.62 in the US, not far from the range of 0.23 in Australia to 0.79 in Germany of Borio & McCauley (1996)[20]. Panel results suggested higher short-run mean volatility and lower persistence in GIP countries. Country-by-country findings confirms that suggestion on what concerns higher short-run mean volatility. However, lower persistence is only significant in Greece (0.53) whose short-run volatility is extremely high. Persistence estimates for Portugal (0.79) and Ireland (0.77) point instead for an above-average period of time for bond yield volatility to return to its long-run mean value.

High levels of persistence, in association with low mean values, place the UK, the US and Australia in the second quartile of long-term mean volatility, right after the GIIPS – see Figure 8. Core EA countries rank at the bottom, only above the low-volatility markets of Japan and Switzerland. In general, the ARDL (1,0) country models do not show signs of the presence of systematic unaccounted factors, exhibiting no residual serial correlation. Exceptions are Belgium, Spain, Ireland, and Portugal for which extra lags are needed to eliminate the residual serial correlation (5, 4, 2 and 2, respectively). In all cases the sum of AR coefficients increases, but the long-term volatility estimates remain unaffected.

Heteroskedasticity is present in almost all cases, a reflection of volatility clustering with sequences of periods of either high or low volatility. Low volatility countries as Switzerland, Japan and Norway are the only countries with homoscedastic residuals. This may be due to identification problems due to the low volatility level rather than any specific characteristic of these sovereign bond markets.

[18] Both Cieslak & Povala (2013) estimates use overlapping monthly data sampled at weekly frequency.
[19] Their weekly data results range between 0.77 in Spain to 0.97 in the Netherlands.
[20] Month-end data

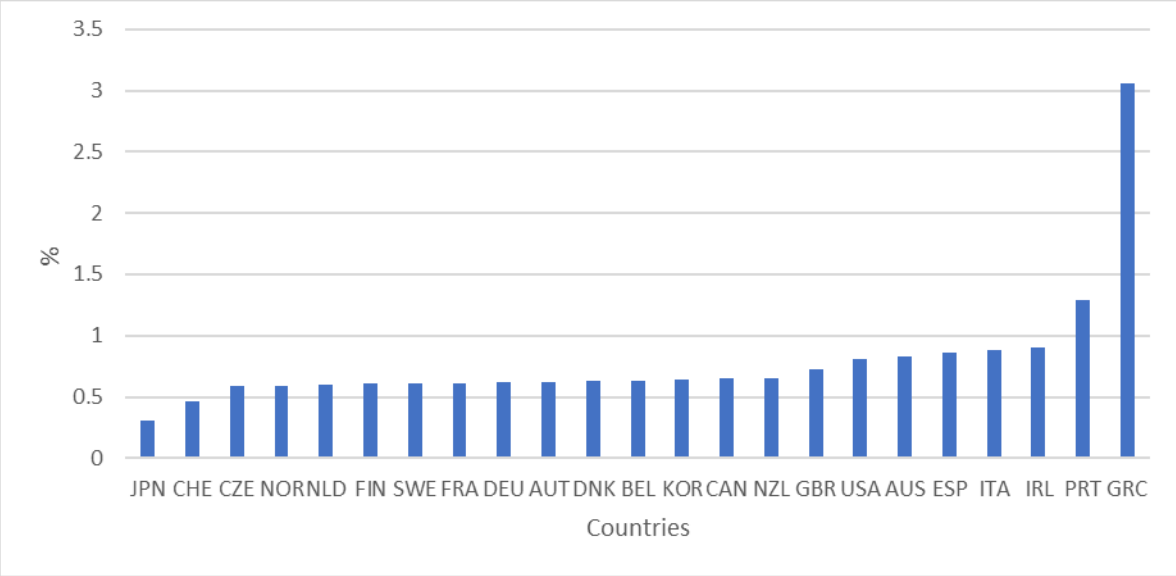


FIGURE 8 – IMPLICIT LONG-TERM MEAN VOLATILITY

Note: Implicit long-term mean volatility computed as $\hat{\alpha}/(1-\hat{\beta})$ from ARDL(1,0) country models estimates using OLS and data from 2004 Q1 to 2019 Q2. The estimates from serial correlation free models for Belgium, Spain, Ireland, and Portugal are, respectively, 0.63, 0.85, 0.89 and 1.28. These values are computed using the sum of the autoregressive parameters to obtain $\hat{\beta}$.

5.2 Persistence and time-varying mean volatility

The deepness of the GFC, the extremes of the EA sovereign debt crisis, the break of the zero low bound in some countries, all are profound changes that may have had a structural impact during the period under analysis. To investigate the possibility that volatility persistence is due to time-varying means across our sample period, we start by conducting a simple difference-in-means test (see Table A - VIII). Most of the structural break dates identified are related with the GFC. Exceptions are GIIPS, with break-dates more closely related with the EA sovereign debt crisis period, and Japan/Korea, whose breaking period starts post-GFC, hence relatively later than other countries, and persists until the end of the sample period. All tests point to a statistically significant difference in means at the 5% significance level or lower except New Zealand's, which is only statistically significant at the 10% significance level. Since this test does not consider persistence in volatility, we move to perform an econometric test by including a structural break time-dummy (D_{sb}) in our dynamic panel data model:

(4) $V_{it} = \alpha_i + \beta V_{it-1} + \delta D_{sb} + U_{it}$; i=1, …, N; t=1, …, T.

Since the identified structural break dates vary from country to country, we grouped them according to the closest break-dates (see Table A - IX). Three groups were formed: (1) core EA, Denmark, and Norway (break period: 2007Q4-2012Q1); (2) a US related bloc consisting of Australia, Canada, UK, New Zealand, Sweden, and the US itself (break period: 2007Q3-2012Q4); (3) a GIIPS bloc but without Greece whose break-dates were very country-specific (break period: 2010Q2-2013Q2). The models are estimated with and without dummy to allow us to compare the results.

TABLE XII – PERSISTENCE AND TIME-VARYING MEAN VOLATILITY

Variables		Core EA, DNK, NOR								AUS, CAN, GBR, NZL, SWE, USA								IIPS							
		(1)				(2)				(1)				(2)				(1)				(2)			
		Coef.		t Stat		Coef.		t Stat		Coef.		t Stat		Coef.		t Stat		Coef.		t Stat		Coef.		t Stat	
Constant	α	0.265	***	4.21		0.315	***	5.66		0.235	***	4.63		0.267	***	6.78		0.323	**	4.24		0.426	***	8.57	
Break	δ					0.135	**	2.97						0.090	*	2.13						0.867	**	4.10	
AR Parameter	β	0.564	***	6.86		0.443	***	5.75		0.677	***	9.71		0.599	***	11.61		0.651	***	11.35		0.377	***	6.54	
F Stat		30.19				29.50				94.26				69.05				128.76				64.33			
(p-value)		0.0004				0.0002				0.0002				0.0002				0.0015				0.0034			
R^2		0.344				0.417				0.462				0.490				0.422				0.534			
$\chi^2(4)$ Stat.		2.218				3.207				8.39				8.014				7.368				3.025			
(p-value)		0.6958				0.5238				0.0783				0.091				0.1177				0.5536			

Notes: IIPS = Ireland, Italy, Portugal, and Spain; Core EA, DNK, NOR models are AR(4) models with the second lag restricted to zero due to the presence of serial correlation in the base model; the sum of parameters for 3rd and 4th lags sum is close to zero, parameters' values are nor reported for the sake of conciseness; Driscroll-Kraay (1998) standard errors; F Stat. is the statistic of the F-test of overall significance (p-values below); R^2 is the within R^2; $\chi^2(4)$ is the statistic of the Cumby-Huizinga heteroskedasticity robust test of serial correlation up to lag 4 with a null hypothesis of no serial correlation (p-values below). The asterisks ***, **, * indicate significance at the 1, 5, and 10% level.

In all three cases is possible to confirm an increase in short-term mean volatility during the crisis period considered, although only at the 10% significance level for the US related bloc. Long-term mean volatility increases around 43% in core EA related countries, and 34% in the US block. These figures are not that different among themselves but quite apart from the 204% increase observed in IIPS - in Greece the change is even bigger at 638%. In all cases, persistence falls but remains statistically significant. The drop is more expressive in the case of GIIPS (ex-Greece), pointing to swifter reversion to the mean in periods of extraordinary shocks to volatility. The fact that persistence remains statistically significant indicates that it is not entirely due to the presence of time-varying means in the data.

In individual country results (see Table A - VII), we find the structural break to be non-statistically significant at 10% significance level only for New Zealand, a small open economy that seems to have been immune to what went on in the world bond market. Japan and Korea are the only countries where the structural-break parameter estimate is negative, suggesting a post-crisis switch to a lower volatility regime and highlighting the idiosyncrasy of Asia-Pacific markets. Mean volatility drops about the same 42-43% below the pre-break period levels in both Japan and Korea, although volatility levels are very different in the two countries. The persistence parameter of Ireland and Portugal are the only ones that are non-statistically significant at the 10% significance level. The Greek persistent parameter is significant under Newey-West standard errors but not under bootstrapped standard errors. The fact that these countries underwent an unparallel change in the means of more than 200% may explain why persistence non-associated with time-varying means fades away from a statistical point of view. Results for Spain and Italy show changes in mean volatility between periods of 114% and 167%, respectively, which is somewhat lower than the IIPS panel estimates, most probably influenced by higher values associated with Ireland and Portugal. Czechia is the European country where mean volatility increases the most outside the GIIPS bloc, possibly still a reminiscence of its link to emerging market portfolios. The increase in Switzerland comes second and well above the Nordic countries or core EA where Germany suffers the highest increase. The sudden search for safe havens may explain this volatility. Within the US bloc increases in mean volatility are widely dispersed. It is noteworthy the fact the US shows the highest increase (68%), higher than Australia's 57%, and far above Canada's 35%. Considering UK's increase of 50% and Sweden's of 44%, previous panel estimates of 36% seem downward biased.

5.3 Volatility and Market Cycles

According with Loyes(1994), cited by Borio & McCauley (1996), "looking over 10 of the major bond markets across the world over the last 9 years, bond yield volatility is on average 1/3 higher during bear markets than in bull markets. Out of 38 transitions between bear and bull markets, volatility was higher in the bear market during 32 transitions". However, the econometric results of Borio & McCauley (1996) are unclear, as they reject the equality of means across market regimes for 7 European countries, but do not reject the null for 6 countries, namely non-Europeans as the US, Canada, Japan, and Australia

To investigate the issue, we have defined a bear/bull market cycle when yields consecutively change in the same direction with a maximum of 2 quarters of opposite signs. Using this definition for the US, we have identified 3 bear market phases (2004Q1-2007Q2; 2012Q4-2014Q1; 2017Q4-2019Q2) and 2 bull market phases (2007Q3-2012Q3; 2014Q2-2017Q3). Due to the importance of the US financial market, we take its market cycles as a reference for all countries. Difference-in-means t-test results show (1) massive rejection of equal volatility between bull and bear markets against an alternative of different volatilities (only exceptions are Czechia, Japan, and Korea), but (2) no rejection of the null hypothesis of equality whenever the alternative is higher volatility during bear markets. Since the GFC may have change the dynamics of bond markets beyond its usual drivers we exclude the period of statistically significant higher average volatility found in our sample for the US bloc: 2007Q3–2012Q4. Results become more balanced: in 8 out of 23 countries we do not reject the null of equal volatilities, but still only in 3 cases is the null rejected against the alternative of higher volatility in bear than in bull markets (Czechia, Japan, and Korea).

Since the foregoing test does not account for persistence in volatility, we tested econometrically whether bond yield volatility is higher during bear markets by including a dummy variable (D_{bear}) taking value 1 during bear markets and 0 otherwise, affecting both the intercept and the lagged dependent variable parameter.

(5) $V_{it} = \alpha_i + \delta D_{bear} + \beta V_{it-1} + \lambda D_{bear} V_{it-1} + U_{it}$; i=1, …, N ; t=1, …, T.

A panel regression (see Table XIII) shows negative parameters for the bear market dummy interactions with both the intercept and the lagged dependent variable, but neither is statistically significant. Removing the US highest volatility period does not change the statistical significance of the previous results.

Excluding GIIPS due to their idiosyncratic crisis dynamics, and Japan and Korea due their own specific trends, the dummy interaction with the lagged dependent variable becomes statistically significant. The implied lower persistence during bear markets translates into a lower long-term mean volatility during that market cycle. Short-term mean volatility is not affected by market cycles. Thus, conditional on the definition of market cycles used, we fail to find evidence of higher mean volatility in bear markets.

TABLE XIII – VOLATILITY IN BEAR/BULL MARKETS: PANEL REGRESSIONS

Variables		All countries			All ex 2007Q3-2012Q4			All ex GIIPS, JPN, KOR		
		Coefficient		t-Stat.	Coefficient		t-Stat.	Coefficient		t-Stat.
Constant	α	0.432	***	4.20	0.213	*	1.74	0.311	***	5.24
Bear Market	δ	-0.149		-1.65	0.009		0.08	-0.042		-0.64
AR Parameter	β	0.563	***	5.51	0.714	***	3.72	0.582	***	7.56
AR x Bear Market	λ	-0.074		-0.57	-0.117		-0.63	-0.347	***	-3.70
AR3 Parameter								0.003		0.05
AR3 x Bear Market								0.217	**	2.58
F Stat		51.59			46.29			28.32		
(p-value)		0.0000			0.0000			0.0000		
R^2		0.339			0.515			0.460		
$\chi^2(4)$ Stat.		4.288			2.406			8.336		
(p-value)		0.3684			0.6615			0.080		

Notes: GIIPS = Greece, Ireland, Italy, Portugal, and Spain; JPN = Japan; KOR = Korea; Bear is a dummy variable taking value 1 in the following periods and 0 otherwise: 2004Q1-2007Q2; 2012Q4-2014Q1; 2017Q4-2019Q2. All ex GIIPS, JPN, KOR model is an AR(3) model with the second lag restricted to zero due to the presence of serial correlation in the base model. Driscroll-Kraay (1998) standard errors; ; F Stat. is the statistic of the F-test of overall significance (p-values below); R^2 is the within R^2; $\chi^2(4)$ is the statistic of the Cumby-Huizinga heteroskedasticity robust test of serial correlation up to lag 4 with a null hypothesis of no serial correlation (p-values below). The asterisks ***, **, * indicate significance at the 1, 5, and 10% level.

Country regressions (see Table A - XII) mostly point for non-statistically significant differences between bear/bull market cycles, outside lower persistence, namely if we consider a 5% significance level. Exceptions are (i) Austria and Finland, where short-term mean volatility is higher during bear markets[21], but since at the same time persistence declines, long-term mean volatility is still lower across periods of falling markets; (ii) Greece and Portugal, where short-term mean volatility drops during bear markets, but since this is accompanied by a rise in persistence[22], long-term mean volatility ends-up being higher than during bull markets. Belgium, Germany, Denmark, Spain, Ireland, and the Netherlands, all exhibit no change in the short-term mean but lower persistence[23] during bear markets, which translates into lower long-term mean volatility in this market cycle.

[21] Using bootstrapped standard errors (unreported for conciseness), we cannot reject the null of equal short-term mean volatilities in both these countries at any of the conventional levels of significance. However, the main conclusion of lower long-term volatility in bear markets remains valid due to the sole effect of lower persistence.

[22] Using bootstrapped standard errors (unreported for conciseness), in both countries we cannot reject the null for the interaction between bear markets and persistence parameter at any of the conventional levels of significance. Hence, in bear markets mean volatility is lower than in bull markets, as observed in most of the other countries.

[23] Using bootstrapped standard errors (unreported for conciseness), lower persistence is statistically significant only in Germany and the Netherlands, at a 10% significance level.

5.4 Volatility and Market Movements

The link between volatility and proximate market movements is investigated focusing on possible asymmetries between upward and downward markets. We estimate three models – Equations (6) to (8) – that distinguish among themselves by the treatment of market movements represented by the change in the average yield vis-à-vis the previous quarter (dY_{it}).

(6) $V_{it} = \alpha_i + \beta V_{it-1} + \gamma dY_{it} + U_{it}$; i=1, …, N ; t=1, …, T ;

(7) $V_{it} = \alpha_i + \beta V_{it-1} + \gamma_a |dY_{it}| + U_{it}$; i=1, …, N ; t=1, …, T ;

(8) $V_{it} = \alpha_i + \beta V_{it-1} + \gamma^- (1-I_t) dY_{it} + \gamma^+ I_t dY_{it} + U_{it}$; i=1, …, N ; t=1, …,T ;

where I_t is an indicator variable defined as: $I_t = \begin{cases} 1 \; if \; dY_{it} \geq 0 \\ 0 \; if \; dY_{it} < 0 \end{cases}$.

The variable enters unadjusted in the first model, and in absolute values in the second one. The third model introduces the possibility of different reactions to positive and negative changes in yields. Note that volatility is measured within the quarter, while the change in yields measures the difference of average yields between the current and the previous quarter.

The estimation results from the first two models indicate that market movements matter as in both cases the change in yields is statistically significant at the 1% significance level and improves the explanatory power of the initial ARDL (1,0) model. The estimate of the change in yields' parameter is positive and almost identical in the two models[24]. This points to either directionality, in which case volatility moves in the same direction as yields, or symmetry, where all changes have a positive impact on volatility proportional to their absolute value size.

The estimation of the third model suggests asymmetry of responses, more specifically semi-directionality, since only positive changes in yields have a statistically significant impact on volatility. A Wald test rejects the null of both coefficients associated with the positive and negative changes in yields being zero at the 1% significance level. It also rejects the possibility of the two coefficients being identical at the 10% significance level, as well as one being the symmetric of the other at the 1% significance level.

Adding as control variable the change in the VIX (dVIX), taken as a proxy of global risk, the previous results hold. The control variable has a positive impact, suggesting contagion of volatility shocks across markets. Although statistically significant, the variable adds little explanatory power.

[24] The change in the persistence parameter, however, is very different. It increases in the first model and declines in the second. Consequently, the long-term unconditional volatility is higher in the directional model than in the symmetric one. The improvement in R^2 is higher in the first model.

TABLE XIV - VOLATILITY AND MARKET MOVEMENTS

Variables		All Countries (1) Coef.	(1) t Stat	(2) Coef.	(2) t Stat	(3) Coef.	(3) t Stat	(4) Coef.	(4) t Stat
Constant	α	0.341 ***	4.13	0.287 ***	3.67	0.298 ***	3.93	0.298 ***	3.83
AR Parameter	β_1	0.601 ***	7.13	0.483 ***	4.79	0.521 ***	4.87	0.532 ***	4.87
Change in Yields	Υ	0.443 ***	3.37						
Absolute Value of Change in Yields	Υ_a			0.428 ***	2.85				
Negative Change in Yields	Υ^-					0.055	0.21	0.093	0.34
Positive Change in Yields	Υ^+					0.782 ***	4.05	0.771 ***	3.89
dVIX								0.011 *	2.05
Wald Tests									
1: $\Upsilon^+ = \Upsilon^-$						3.210 *		2.65	
2: $\Upsilon^+ = -\Upsilon^-$						12.55 ***		14.50 ***	
F Stat		27.32		28.68		36.96		31.80	
(p-value)		0.0000		0.0000		0.0000		0.0000	
R^2		0.384		0.352		0.400		0.405	
ΔR^2		0.05		0.02		0.07		0.07	
$\chi^2(4)$ Stat.		5.328		4.982		5.994		6.008	
(p-value)		0.2553		0.2891		0.1996		0.1985	

Notes: Panel fixed effects within regressions of equations (6) to (8), the latter also with the addition of dVIX in regression (4); Driscroll-Kraay (1998) standard errors; Wald tests use a F-Statistic; F Stat. is the statistic of the F-test of overall significance (p-values below); R^2 is the within R^2; the change in the R^2 is measured against the results of the base ARDL(1,0) model; $\chi^2(4)$ is the statistic of the Cumby-Huizinga heteroskedasticity robust test of serial correlation up to lag 4 with a null hypothesis of no serial correlation (p-values below). The asterisks ***, **, * indicate significance at the 1, 5, 10% level.

Having already verified the impact of Greece when estimating the initial ARDL model, we run another regression excluding this country – see Table XV. Due to the presence of first-order autocorrelation in the residuals an additional autoregressive term is added to the regression. Again, results change, and now both negative and positive responses are statistically significant. The response is asymmetric. Positive changes in yields have higher impact than negative changes.

A Wald test rejects the null of absence of impact of both negative and positive change in yields at the 1% significance level, as well as the equality of both parameters. The symmetry of the associated parameters is also rejected at the 5.6% significance level.

Controlling for global risk, we find the change in the VIX to have a positive and statistically significant impact on bond yield volatility. This VIX direct effect reduces the indirect effect through the change in yields, which is reflected in lower responses of bond yield volatility to proximate market movements, namely declining yields. It is somehow puzzling, however, that when one allows for VIX asymmetric effects, only positive movements turn out statistically significant. Negative changes in VIX, that seemingly have a more dampening effect on the impact of negative changes in yields on bond volatility, end up being not statistically significant.

Overall, the control variable does not change the main results, but its contribution to the explanatory power is more material in the specification without Greece among the sample countries.

TABLE XV- VOLATILITY AND MARKET MOVEMENTS EX-GREECE

Variables		All Countries ex Greece								
		(1)			(2)			(3)		
		Coef.		t Stat	Coef.		t Stat	Coef.		t Stat
Constant	α	0.150	***	3.60	0.131	***	3.05	0.118	**	2.77
AR Parameter	β_1	0.391	***	6.98	0.421	***	7.34	0.396	***	7.48
AR2 Parameter	β_2	0.235	***	3.47	0.264	***	3.83	0.247	***	3.76
Negative Change in Yields	Υ^-	-0.279	**	-2.66	-0.161	*	-1.97	-0.157	*	-1.98
Positive Change in Yields	Υ^+	0.653	***	4.68	0.602	***	4.89	0.621	***	4.99
dVIX					0.013	***	3.35			
dVIX negative								-0.004		-0.67
dVIX positive								0.020	***	3.52
Wald Tests										
1: $\Upsilon^+ = \Upsilon^-$		32.28	***		42.030	***		40.020	***	
2: $\Upsilon^+ = -\Upsilon^-$		4.10	*		6.550	**		7.570	**	
F Stat		46.15			38.50			43.21		
(p-value)		0.0000			0.0000			0.0000		
R^2		0.518			0.553			0.568		
ΔR^2		0.11			0.15			0.16		
$\chi^2(4)$ Stat.		1.184			3.304			4.263		
(p-value)		0.8807			0.5083			0.3716		

Notes: Panel fixed effects within regressions of equations (7) with a second lag on the dependent variable due to the presence of serial correlation in the base model, where dVIX has been added in the second regression; Driscroll-Kraay (1998) standard errors; Wald tests use a F-Statistic; F Stat. is the statistic of the F-test of overall significance (p-values below); R^2 is the within R^2; the change in the R^2 is measured against the results of the base ARDL(1,0) model; $\chi^2(4)$ is the statistic of the Cumby-Huizinga heteroskedasticity robust test of serial correlation up to lag 4 with a null hypothesis of no serial correlation (p-values below). The asterisks ***, **, * indicate significance at the 1, 5, 10% level.

To better understand the underlying relations, we estimate the following country model:

$$(9) \quad V_t = \alpha + \beta V_{t-1} + \gamma^+ I_t \, dY_t + \gamma^- (1-I_t) \, dY_t + U_t \, .$$

Country results (see Table A - XIII and Figure 9) point to three groups of countries: (1) semi-directionality seems to be a feature of GIIPS[25] and Belgium[26], countries where bond yield volatility only reacts to positive changes in yields; (2) core EA and Asia exhibit symmetric reactions; (3) Australia, Switzerland, UK, Norway, Sweden, and the US have a (weak[27]) asymmetric reaction, but in opposition to previous panel results, volatility is more sensitive to downward movements in yields.

[25] The semi-directional response from Portugal is less clear but it is confirmed by a model with a structural break in 2010Q2-2013Q2. The response to negative yield changes is -0.0745, with a t-statistic of -0.28 (p-value = 0.78). The response to positive yield changes is 1.004, with a t-statistic of 2.28 (p-value = 0.027). Cumby-Huizinga serial correlation up to lag 4 test yields 2.883 (p-value = 0.5775).

[26] The semi-directional response is also less clear for Belgium and results from the initial ARDL (5,0) model with a structural break in 2007Q4-2012Q1 and proximate market movements. The response to negative yield changes is 0.03, with a t-statistic of 0.26 (p-value = 0.795). The response to positive yield changes is 0.321, with a t-statistic of 0.172 (p-value = 0.091). Cumby-Huizinga serial correlation up to lag 4 test yields 1.573 (p-value = 0.8137).

[27] In Australia, Switzerland, U.K. and namely the US, the response to positive changes in yields is only statistically significant at the 10% significance level. Symmetry is rejected in Australia, Norway, and Sweden only at the 10% significance level.

Υ

1	2 AUS CHE GBR NOR SWE USA	3
4 CAN	5 AUT DEU DNK FIN FRA JPN KOR NLD NZL	6
7 CZE	8 BEL ESP GRC IRL ITA PRT	9

Υ^+

FIGURE 9 – RELATIONSHIP BETWEEN VOLATILITY AND MARKET MOVEMENTS

Notes: Dark grey area: both negative and positive market movements are not statistically significant at the 10% level. Light grey area: either negative (squares 8 and 9) or positive (squares 1 and 4) market movements are not statistically significant. Square 5 shows countries where negative and positive market movements are symmetric from the statistical point of view. Square 2 indicates countries where the impact of negative changes in yields are higher than the impact of positive changes (asymmetrical relationship).

Idiosyncratic cases are Czechia (no relation) and Canada, although the latter semi-directional reaction to negative changes in yields seems to be just a more extreme version of the type of asymmetry observed in the US.

The greater impact of downward movements in yields is puzzling, but not new as it had already been documented by Sheppard et al. (2003) for Switzerland.

Running rolling regressions over a 30 quarters window for some of these countries (see Figure A - 1) we find the relation to be unstable with the most recent results pointing to a move towards a more symmetric relationship in Australia, Canada, US and possibly the UK, although in the latter case joining the semi-directional relationship group of countries seems more likely. The results for Switzerland confirm the stronger impacts of decreasing yields and even suggest a totally semi-directional relationship instead of a less extreme asymmetrical one.

In GIIPS the volatility response to 1 p.p. increase in 10-year yields is the highest and ranges between 70 to 100 bps, being Portugal the most extreme case. Belgium's response is considerably lower, amounting only to 32 bps. In the case of asymmetric responses, the impact of a 1 p.p. decrease in yields ranges between 46 to 64 bps. Core EA symmetric responses to a 1 p.p. change in yields lies mostly around 30 bps, with Germany's response being slightly higher. Asia-Pacific countries' response is either similar or even higher than Germany's response, with Japan showing a value around 60 bps. Persistence decreases on average 0.06 when we account for market movements.

Explanatory power increases measured by both R^2 and the Akaike Information Criterion[28].

The difference between the previous country results and the findings of Borio & McCauley (1996) with month-end data is noteworthy. Just Italy, Japan, and Spain exhibit the same behaviour. The heavy representativity of semi-directional relationships showing a response of volatility only to rising yields may result from the coincidence of rising volatility only with periods of rising or flat yields in their sample (October 1993 to August 1994). The size of impacts is not directly comparable. However, taking a yield of 6% as a reference, their impact response ranges between 55 to 83 bps, not far from our own values.

ϒ

1	2 USA	3
4 CAN CHE GBR	5 AUS DEU DNK FIN JPN KOR NLD NOR NZL SWE	6
7 AUT BEL CZE	8 ESP FRA GRC IRL ITA PRT	9

$ϒ^+$

FIGURE 10 – RELATIONSHIP BETWEEN VOLATILITY AND MARKET MOVEMENTS WHEN CONTROLLING FOR THE DIRECT IMPACT OF GLOBAL RISK CHANGES

Notes: Dark grey area: both negative and positive market movements are not statistically significant at the 10% level. Light grey area: either negative (squares 8 and 9) or positive (squares 1 and 4) market movements are not statistically significant. Square 5 shows countries where negative and positive market movements are symmetric from the statistical point of view. Square 2 indicates countries where the impact of negative changes in yields are higher than the impact of positive changes (asymmetrical relationship).

The introduction of the change in the VIX as a control variable in country regressions allows us to confirm, first, the statistical significance of the variable, which is observed in 16 out of 23 countries at a 10% significance level. The exceptions are GIIPS ex Italy, Germany, Denmark, and the UK. Secondly, the instability of some of the relationships between sovereign bond yield volatility and market movements, as 8 countries change positions – see Figure 10. Most of the changes involve the asymmetric relationship sub-panel of countries where only the US subsists, with 3 moves to the symmetrical relationship sub-panel and 2 moves to the negative semi-directional position previously occupied just by Canada.

[28] Czechia is an exception with no improvement registered in both measures.

5.5 Volatility and Macro and Policy Uncertainty

Andersen & Benzoni (2007) and Jones et al. (1998) show that relative to other liquid asset markets, bond prices tend to provide clear and pronounced reactions to economic news. On the other hand, Schwert (1989) finds a limited role for conditional volatility of macroeconomic factors on the conditional volatility of corporate bonds. A theoretical treatment of the relation between financial market volatility and macroeconomic uncertainty can be found in Veronesi (1999) and David & Veronesi (2004).

To test the response of volatility we need measures of economic uncertainty that are as much as possible independent of the variable to be explained. We started by using WEO forecast revisions regarding real GDP growth, inflation, budget balance (in % of GDP), and current account balance (in % GDP). We compute the absolute revision between semi-annual reports. We assign to Q4 of year T the revision between the October and the April reports of year T regarding forecasts for year T+1; to Q1 of year T+1 the revisions of the same T+1 forecasts between the reports of April T+1[29] and October T; to Q3 of year T+1 the revisions between the two reports of year T+1 of that same year forecasts. The Q2 value is an interpolation between the values of Q1 and Q3. An absolute value z-score is then computed to normalize each variable. The expectation is that in times of greater uncertainty large revisions in fundamental forecasts may have a positive impact on government bond market volatility.

Following the literature, market movements are first excluded because they too may be affected by the economic uncertainty variables and its presence could act as a filter and make difficult to identify the potential effect of uncertainty regarding fundamentals.

Adjusting our dynamic panel data model without market movements by adding a matrix of macro and policy uncertainty variables (F_{it}) we obtain the following equation:

(10) $V_{it} = \alpha_i + \beta V_{it-1} + F_{it}\Theta + U_{it}$; i=1, …, N ; t=1, …, T.

Using specification (10) and excluding Greece, the only variable whose forecast revisions we find significant is the current account balance[30]. However, the incremental explanatory power is meaningless (change of R^2 = 0.002 to a R^2 of 0.450 – see Table XVI).

[29] We assume here financial markets tend to anticipate changes in released forecast figures.

[30] CONSIDERING THAT EMPIRICAL CORRELATIONS BETWEEN ECONOMIC UNCERTAINTY VARIABLES AND MARKET MOVEMENTS ARE LOW (LESS THAN 0.11 IN ABSOLUTE VALUE), WHEN WE CONTROL FOR THE LATTER THE CURRENT ACCOUNT BALANCE IS REPLACED BY REAL OUTPUT GROWTH. HOWEVER, THIS VARIABLE ALSO HAS A MEANINGLESS IMPACT IN THE REGRESSION'S EXPLANATORY POWER. ALL OTHER RESULTS HOLD (

Next, we consider the different country sub-panels according with the relationship between volatility and market movements. We are unable to find statistically significant macro uncertainty variables, except for Czechia. In this country's case, uncertainty regarding both fiscal policy and the external balance has a significant impact on bond yield volatility and the additional explanatory power is relevant (an additional 0.138 in Adjusted R^2 – see Table XVII).

TABLE XVI - VOLATILITY AND WEO MACRO FORECAST REVISIONS

Table A - XV).

Variables	All Countries (1)		(2)		All Countries ex GRC (3)		(4)	
	Coef.	t Stat	Coef.	t Stat	Coef.	t Stat	Coef.	t Stat
GDP Unc	0.099	1.17	0.062	1.13	0.006	0.38		
Inf Unc	-0.014	-0.29			0.009	0.80		
Bdg Unc	-0.047	-0.74			-0.002	-0.08		
CA Unc	-0.008	-0.51			0.021 *	1.75	0.026 **	2.65
F Stat	11.55		26.00		49.69		43.38	
(p-value)	0.0000		0.0000		0.0000		0.0000	
R^2	0.332		0.331		0.457		0.450	
$\chi^2(4)$ Stat.	4.426		4.483		1.503		1.637	
(p-value)	0.3514		0.3445		0.826		0.8021	

Notes: Panel fixed effects within regressions; Driscroll-Kraay (1998) standard errors; constant and AR parameter estimates not reported for the sake of conciseness; ; F Stat. is the statistic of the F-test of overall significance (p-values below); R^2 is the within R^2; $\chi^2(4)$ is the statistic of the Cumby-Huizinga heteroskedasticity robust test of serial correlation up to lag 4 with a null hypothesis of no serial correlation (p-values below). The asterisks ***, **, * indicate significance at the 1, 5, 10% level.

TABLE XVII - VOLATILITY AND WEO MACRO FORECAST REVISIONS: SUB-PANELS

Variables	Semi-directional Panel (1)		Asymmetrical Panel (2)		Symmetrical Panel (3)		Czechia (4)		(5)	
	Coef.	t Stat	Coef.	t Stat	Coef.	t Stat	Coef.	t Stat	Coef.	t Stat
GDP Unc	0.181	0.82	0.018	0.67	0.029	0.97	-0.150	-1.09		
Inf Unc	-0.084	-0.56	0.011	0.85	0.012	1.01	-0.043	-0.50		
Bdg Unc	-0.070	-0.65	0.008	0.46	-0.018	-0.60	0.074 **	2.50	0.085 ***	3.23
CA Unc	-0.062	-1.17	0.019	1.61	-0.001	-0.12	0.154 *	1.85	0.134 **	2.09
F Stat	9.00		48.21		31.27		16.35		27.15	
(p-value)	0.0154		0.0001		0.0000		0.0000		0.0000	
R^2	0.330		0.515		0.374		0.345		0.359	
$\chi^2(4)$ Stat.	4.024		7.325		5.992					
(p-value)	0.4028		0.1197		0.1998					
Durbin F Stat.										
Lag 1							3.318 *		2.432	
Lag 2							1.913		1.528	
Lag 3							1.378		0.997	
Lag 4							1.927		1.670	

Notes: Panel fixed effects within regressions; Driscroll-Kraay (1998) standard errors; constant and AR parameter estimates not reported for the sake of conciseness; ; F Stat. is the statistic of the F-test of overall significance (p-values below); R^2 is the within R^2 in panel regressions and adjusted-R^2 in Czechia regressions; $\chi^2(4)$ is the statistic of the Cumby-Huizinga heteroskedasticity robust test of serial correlation up to lag 4 with a null hypothesis of no serial correlation (p-values below); in the Czechia regression the test of serial correlation is the Durbin's alternative test that does not require all regressors to be strictly exogenous, its F-statistic has a distribution F(p, T-K-p-1), where K = number of parameters, T = number of observations, p = lag order. The asterisks ***, **, * indicate significance at the 1, 5, 10% level.

In a second approach we resort to the Survey of Professional Forecasters conducted by the Federal Reserve Bank of Philadelphia and the ECB. In the former, we use the Interquartile Dispersion of forecasts (75th Percentile Minus 25th Percentile of the forecasts) over 1 quarter and 4 quarters ahead of the survey date. The forecasted variables are the 3-month T-bill rate, the inflation rate, the real GDP growth rate (quarter-on-quarter) and the quarterly growth rate of federal government consumption and investment. In the case of the ECB's survey, we use two measures of dispersion: the interquartile dispersion and the standard deviation of rolling horizon forecasts one year ahead of the latest available data. Giordani & Söderlind (2003) and Bomberger (1996) argue that the cross-section standard deviation of point forecasts is a good representation of uncertainty. The selected horizon was chosen among the six possible horizons to have a measure comparable with the one used for the US. The forecasted variables are the HICP inflation rate and the real GDP growth rate.

TABLE XVIII – US VOLATILITY AND DISPERSION OF PROFESSIONAL FORECASTS

Variables	1 Quarter ahead				4 Quarters ahead					
	(1)		(2)		(3)		(4)		(5)	
	Coef.	t Stat	Coef.	t Stat	Coef.	t Stat	Coef.	t Stat	Coef.	t Stat
3m T-bill IQD	0.139	0.67			0.156	1.73	0.169	1.67		
Inflation IQD	0.174	1.57	0.276 *	1.94	0.327	1.97	0.332 **	2.09	0.369 **	2.26
GDP IQD	0.160	1.63			0.077	0.56				
Fed Gov IQD	-0.010	-0.38			-0.012	-0.34				
F Stat	53.14		62.73		27.44		29.13		36.55	
(p-value)	0.0000		0.0000		0.0000		0.0000		0.0000	
Adj. R^2	0.686		0.670		0.683		0.681		0.663	
Durbin F Stat.										
Lag 1	0.013		0.050		0.095		0.008		0.208	
Lag 2	0.797		0.473		0.336		0.341		0.188	
Lag 3	0.543		0.312		0.273		0.280		0.125	
Lag 4	0.554		0.322		0.259		0.261		0.108	

Notes: OLS regressions with Newey-West standard errors to account for a heteroskedastic error structure possibly autocorrelated up to the fourth lag; 3m T-bill = 3-month Treasury-bill rate; Inf = inflation rate; GDP = GDP q-o-q growth rate; Fed Gov = Federal government consumption and investment; IQD = inter-quartile dispersion; constant and AR parameter estimates not reported for the sake of conciseness; constant and AR parameter estimates not reported for the sake of conciseness; F Stat. is the statistic of the F-test of overall significance (p-values below); R^2 is the adjusted-R^2 ; the test of serial correlation is the Durbin's alternative test that does not require all regressors to be strictly exogenous, its F-statistic has a distribution F(p, T-K-p-1), where K = number of parameters, T = number of observations, p = lag order. The asterisks ***, **, * indicate significance at the 1, 5, 10% level.

Estimation results for the US in a model without market movements indicate that solely the dispersion measures of inflation rate forecasts 1 and 4 quarters ahead are statistically significant (at 10% and 5% significance levels, respectively). Improvements in explanatory power are around 7-8%[31] over the R^2 of the base ARDL (1,0) model. Contrary to Arnold & Vrugt (2010), we do not find US monetary policy uncertainty proxied by the 3-month Treasury bill rate forecast dispersion to be statistically significant. This result may stem from the large representativeness of the period during which rates were at the zero low bound in our sample.

In the EA, interquartile dispersion measures of inflation and output growth are not statistically significant, when we consider all the eleven countries of our sample that are part of the EA. Once we drop out Greece, interquartile dispersion of inflation forecasts becomes significant, even if only at a 10% significance level. The additional explanatory power is feeble[32], however.

TABLE XIX– EA VOLATILITY AND DISPERSION OF PROFESSIONAL FORECASTS

[31] This improvement is very close to the 8% improvement observed by Arnold & Vrugt (2010) on their regression using just the inflation uncertainty variable. Controlling for market movements, only the 4 quarters ahead dispersion measure remains significant, and the explanatory power improvement is reduced to 1.6%. This suggest that uncertainty regarding inflation may affect bond yield volatility through two channels, a direct one and indirectly through its effect on bond yields.

[32] In the order of 1-2% over the base model adjusted R squared, both in regressions with and without market movements.

Variables	Standard Deviation of Individual Forecasts						Interquartile Dispersion of Individual Forecasts					
	All Countries				All Countries ex GRC		All Countries				All Countries ex GRC	
	(1)		(2)		(3)		(4)		(5)		(6)	
	Coef.	t Stat	Coef.	t Stat	Coef.	t Stat	Coef.	t Stat	Coef.	t Stat	Coef.	t Stat
Inf Std	2.509	2.98	1.891	1.70	0.766 *	1.99						
GDP Std	-0.469	-0.99					0.177	0.31	0.742	1.54	0.385 *	1.87
Inf IQD							0.610	0.85				
GDP IQD												
F Stat	18.30		22.17		83.35		13.38		20.68		73.42	
(p-value)	0.0002		0.0002		0.0000		0.0008		0.0003		0.0000	
R^2	0.342		0.341		0.416		0.336		0.331		0.409	
$\chi^2(4)$ Stat.	4.090		4.027		7.241		4.079		4.051		7.195	
(p-value)	0.3939		0.4024		0.237		0.3954		0.3991		0.1259	

Notes: Panel fixed effects within regressions; Driscroll-Kraay (1998) standard errors; Std = standard deviation of rolling horizon forecasts one year ahead of the latest available data; IQD = interquartile dispersion of individual forecasts; Inf = EA HICP inflation rate; GDP = EA real GDP growth rate; constant and AR parameter estimates not reported for the sake of conciseness; F Stat. is the statistic of the F-test of overall significance (p-values below); R^2 is the within R^2; $\chi^2(4)$ is the statistic of the Cumby-Huizinga heteroskedasticity robust test of serial correlation up to lag 4 with a null hypothesis of no serial correlation (p-values below). The asterisks ***, **, * indicate significance at the 1, 5, 10% level.

The use of the cross-sectional standard deviation confirms the relevance of inflation uncertainty, namely once we remove Greece. The improvement in explanatory power is more meaningful but still small[33]. In the EA we do not find significant differences in the results with and without market movements in what regards the impact of inflation uncertainty, probably because inflation forecast revisions do not have an impact on bond yields, as show the panel results of Afonso & Nunes (2015). Thus, inflation uncertainty plays a modest but direct role in explaining bond yield volatility.

A third approach to this subject uses Bansal et al. (2005) macro volatility measures for the 3-month money market rate (3m rate Vol.), the real GDP growth (GDP Vol.), the inflation rate (Inflation Vol.), the budget balance[34](Budget Vol.), and the current account balance (Cur. Acc. Vol.) – see Table XX and Table XXI. For each one of these variables, an ARDL (1,0) model is estimated, and the residuals collected. The volatility measure is calculated taking the absolute value of the z-score of the residuals[35].

The 'All countries' panel results show that only uncertainty regarding GDP real growth is statistically significant[36] but the additional explanatory power is again meagre (0.332 against 0.330). However, this result changes when Greece is excluded. Then, the only variable that remains statistically significant[37] is the volatility of short-term interest rates. The improvement in explanatory power continues to be minor though (0.004 in within R^2).

TABLE XX- BOND YIELD AND MACRO VOLATILITIES I

[33] The size of the effect is 3.6% (3.7%) in a model without (with) market movements.
[34] We also use debt-to-GDP instead of the budget balance in percentage of GDP, but it never changed the results first obtained using the latter fiscal variable.
[35] We differ slightly from Bansal et al. (2015) by not taking the log of the residuals because it could produce negative values for the volatility and by using an absolute value z-score instead of just dividing the residuals by its standard deviation, taking the same approach used for the WEO forecast revisions measure.
[36] This result is robust to the exclusion of market movements.
[37] At a 10% (1%) significance level without (with) market movements.

Variables	All Countries				All Countries ex GRC				Semi-directional Panel	
	(1)		(2)		(3)		(4)		(5)	
	Coef.	t Stat	Coef.	t Stat	Coef.	t Stat	Coef.	t Stat	Coef.	t Stat
3m rate Vol.	-0.004	-0.24			0.025 *	1.87	0.033 *	1.97	-0.131	-1.13
GDP Vol.	0.065 ***	2.96	0.074 ***	3.03	0.023	0.97			0.156 *	2.13
Inflation Vol.	0.042	0.91			0.016	1.05			0.172	0.84
Budget Vol.	-0.008	-0.38			-0.023	-1.29			-0.018	-0.31
Cur. Acc. Vol.	0.010	0.48			-0.003	-0.27			0.024	0.28
F Stat	14.66		33.54		91.13		80.87		11.17	
(p-value)	0.0000		0.0000		0.0000		0.0000		0.0090	
R^2	0.333		0.332		0.456		0.453		0.333	
$\chi^2(4)$ Stat.	4.560		4.536		1.875		1.806		4.333	
(p-value)	0.3354		0.3383		0.7587		0.7713		0.3628	

Notes: Panel fixed effects within regressions; Driscroll-Kraay (1998) standard errors; constant and AR parameter estimates not reported for the sake of conciseness F Stat. is the statistic of the F-test of overall significance (p-values below); R^2 is the within R^2; $\chi^2(4)$ is the statistic of the Cumby-Huizinga heteroskedasticity robust test of serial correlation up to lag 4 with a null hypothesis of no serial correlation (p-values below). The asterisks ***, **, * indicate significance at the 1, 5, and 10% level.

TABLE XXI- BOND YIELD AND MACRO VOLATILITIES II

Variables	Asymmetrical Panel				Symmetrical Panel				Czechia			
	(6)		(7)		(8)		(9)		(10)		(11)	
	Coef.	t Stat	Coef.	t Stat	Coef.	t Stat	Coef.	t Stat	Coef.	t Stat	Coef.	t Stat
3m rate Vol.	0.055 ***	6.63	0.061 ***	7.43	0.024	1.31	0.032 **	2.48	-0.188 *	-1.73	-0.111 **	-2.29
GDP Vol.	0.033	1.71			0.022	0.82			0.164	1.04		
Inflation Vol.	0.026	1.40			0.009	0.91			0.070	1.60		
Budget Vol.	-0.013	-1.04			-0.018	-1.00	0.019 *	1.97	0.036	1.18		
Cur. Acc. Vol.	-0.007	-0.55			0.009	0.73			-0.003	-0.07		
F Stat	75.20		91.28		74.51		75.58		43.80		81.07	
(p-value)	0.0000		0.0000		0.0000		0.0000		0.0000		0.0000	
R^2	0.565		0.548		0.414		0.409		0.313		0.247	
$\chi^2(4)$ Stat.	16.724		12.994		4.680		5.410					
(p-value)	0.0022		0.0113		0.3217		0.2477					
Durbin F Stat.												
Lag 1									0.403		0.245	
Lag 2									0.196		0.208	
Lag 3									0.662		1.618	
Lag 4									0.568		1.412	

Notes: Panel fixed effects' within regressions with Driscroll-Kraay (1998) standard errors; Czechia - OLS regressions with Newey-West standard errors to account for a heteroskedastic error structure possibly autocorrelated up to the fourth lag; constant and AR parameter estimates not reported for the sake of conciseness; 'All countries ex Greece' is a AR(2) model; the symmetrical panel regression is a AR(4) model with lags 2 and 4 restricted to equal zero; F Stat. is the statistic of the F-test of overall significance (p-values below); R^2 is the within R^2 in panel regressions and adjusted-R^2 in Czechia regressions $\chi^2(4)$ is the statistic of the Cumby-Huizinga heteroskedasticity robust test of serial correlation up to lag 4 with a null hypothesis of no serial correlation (p-values below); in the Czechia regression the test of serial correlation is the Durbin's alternative test that does not require all regressors to be strictly exogenous, its F-statistic has a distribution F(p, T-K-p-1), T = number of observations, p = lag order. The asterisks ***, **, * indicate significance at the 1, 5, and 10% level.

When we divide the sample countries according with the found relationship between volatility and market movements, we find the same result for the asymmetrical[38] and symmetrical panels. In Czechia the same result holds but with a 'wrong' negative sign[39]. In the semi-directional panel, no uncertainty variable is significant, even when excluding Greece.

The significance of monetary policy uncertainty using the measure of Bansal et al. (2005) matches the findings of Arnold & Vrugt (2010) for the US in a sample over 1981Q4-2005Q4. In their tests this variable dominates inflation uncertainty and several

[38] The persistent presence of autocorrelation in this panel requires its results to be taken as merely indicative.

[39] Debt is also statistically significant at a 10% significance level but also with a 'wrong' negative sign.

measures of economic activity uncertainty in explaining Treasury bond volatility. Cieslak & Povala (2013) results for the US over 1992-2006 also find revisions of the median of Fed Funds rate forecasts to be a significant variable in explaining the model-implied long-end volatility factor[40]. However, when the sample is extended to 2010, covering the GFC period, monetary policy revisions loose statistical significance. On the other hand, real GDP growth revisions and uncertainty, as well as the Baker et al. (2013) measure of economic policy uncertainty, remain significant across sample periods. Borio & McCauley (1996), using a wider panel of countries but in a more dated study, fail to find any meaningful relationship between bond yield volatility and revisions in GDP growth and inflation forecasts as well as the dispersion of expectations regarding the same variables, except for Japan, where output growth revisions and dispersion were statistically significant and carried the expected sign.

Overall, the different results suggest that uncertainty regarding inflation, short-term interest rates, output growth, fiscal and external balances have an impact on bond yield volatility, but this impact tends to depend on the uncertainty measures used and, when significant, rarely is very meaningful.

6. CONCLUSIONS

The aim of this paper is to provide empirical insights on the drivers of volatility of long-term sovereign bond yields across advanced economies.

Our analysis shows that in the bond market unconditional volatility exhibits mean-reversion and persistence. Persistence seems to be a feature that is present independently of using high-frequency data, as is often the case in studies concerning financial assets volatility, or low frequency data, as in our case. Volatility shocks have an estimated half-life of about two quarters. Although we have found evidence of changes in the means during the sample period, we have also concluded that persistence is not a mere reflexion of those time-varying means as it remains statistically significant throughout the all period. In general, persistence drops slightly at the different country-specific breaking-points in the mean. In the countries most affected by the EA sovereign debt crisis the reduction is more expressive pointing to a quicker adjustment in face of significant volatility shocks. Thus, peaks of high volatility entail a swifter reversion to the mean.

Bond yield volatility responds to proximate market movements. However, that response is found to be uneven across geographies, corroborating the results of Sheppard et al. (2003), and possibly time-varying. Once added to the model, the VIX index has a positive impact, suggesting contagion of volatility shocks across markets. Although statistically significant, the variable adds little explanatory power. The VIX direct effect on bond yield volatility reduces the indirect effect through the change in yields, which is reflected in lower responses of bond yield volatility to proximate market movements, namely

[40] However, their dispersion measure, the median of absolute deviation of individual forecasts, is not statistically significant.

declining yields. In face of this result, it is somehow puzzling that when one allows for VIX asymmetric effects, only positive movements turn out statistically significant.

Three major volatility response patterns to proximate market movements can be identified. A semi-directional response when only increases or decreases in yields affect volatility. This pattern can be found in GIIPS, Belgium and Canada. An asymmetric response pattern where both increases and decreases in yields have an impact, but the volatility response is stronger in the latter case. This pattern is observed in a diversified group of countries encompassing the US, UK, Switzerland, and with a lower degree of confidence also in Norway, Sweden, and Australia. This puzzling relationship is in most cases unstable and seems to be evolving towards either a symmetric or positively sloped semi-directional relationship. Once we account for the VIX's impact only the US continues to display this type of relationship, with 3 moves to the symmetrical relationship sub-panel and 2 moves to the negative semi-directional position previously occupied just by Canada. Finally, a symmetric response pattern characteristic of most of core EA and Asia-Pacific countries. Within the EA, it is noteworthy the differences between core and periphery on what concerns the response of volatility to changes in yields which poses a challenge for the smooth operation of sovereign bond markets. Like Cappiello (2000) we find no difference in volatility across market cycles when these are defined by the developments in the US market.

Macro and policy uncertainty have an impact on bond yield volatility, but this impact depends on the specific uncertainty measures used and, when statistically significant, rarely has a very meaningful explanatory power across all sample countries.

The empirical analysis could be extended in several ways. In what concerns data, the country panel could be enlarged to cover emerging markets and the use of higher frequencies would allow modelling realized volatility. The role of both non-official and official investors could also be envisaged. A panel GARCH approach, eventually over a simplified model, would allow to model conditional volatility and provide further insights on correlations across markets.

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APPENDIX A

TABLE A - I - SOVEREIGN DEBT INVESTOR BASE COUNTRY LIST

#	Advanced Economies	Country Codes
1	Australia	AUS
2	Austria	AUT
3	Belgium	BEL
4	Canada	CAN
5	Czech Republic	CZE
6	Denmark	DNK
7	Finland	FIN
8	France	FRA
9	Germany	DEU
10	Greece	GRC
11	Ireland	IRL
12	Italy	ITA
13	Japan	JPN
14	Korea	KOR
15	Netherlands	NLD
16	New Zealand	NZL
17	Norway	NOR
18	Portugal	PRT
19	Slovenia	SVN
20	Spain	ESP
21	Sweden	SWE
22	Switzerland	CHE
23	United Kingdom	GBR
24	United States	USA

TABLE A - II - VARIABLES DATA SOURCES

Data	Source	Observations
Current Account	OECD and IMF	
Forward Exchange Rates (1 and 2 years)	Bloomberg	
GDP	OECD and IMF	
General Government Budget Balance and Gross Debt to GDP	Eurostat, OECD and IMF	Exceptions are: Australia - Budget Balance sourced from Australia Statistics; Canada - Budget Balance sourced from Canada Statistics; New Zealand, both variables retrieved from NZ Statistics; Switzerland - Budget Balance souced from Swiss Federal Finance Administration
Government bond yields	Bloomberg	Datastream, and OECD series were used to complement Bloomberg data series.
Inflation	OECD and IMF	
Short-term interest rates	OECD and IMF	Japan 3-month BBA Libor is an exception and is sourced from the ECB
Survey of Professional Forecasters - US	Federal Reserve Bank of Philadelphia	Inter quartile dispersion of forecast 1 and 4 quarters ahead for T-bill interest rates, inflation, real GDP growth rate and real Federal Government Consumption and Gross Investment
Survey of Professional Forecasters - EA	ECB	Inter quartile dispersion and standard deviation of forecast for inflation and real GDP growth rate 4 quarters ahead of last released data
VIX Index	Bloomberg	VIX Index is the Chicago Board Options Exchange's Market Volatility Index, a measure of constant 30-day expected volatility of the U.S. stock market, derived from real-time, mid-quote prices of call and put options on the S&P 500
WEO bi-annual forecasts	IMF	Variables: real GDP growth, inflation rate, budget balance and current account

TABLE A - III – VOLATILITY AND CHANGES IN 10-YEAR YIELDS

Country	Volatility of changes in 10-year yields (in %)				Negative Changes in 10-year yields (in p.p.)					Positive Changes in 10-year yields (in p.p.)				
	Mean	Std.Dev.	Min	Max	Obs	Mean	Std.Dev.	Min	Max	Obs	Mean	Std.Dev.	Min	Max
AUS	0.858	0.292	0.431	1.827	35	-0.295	0.251	-1.191	-0.013	27	0.230	0.196	0.013	0.806
AUT	0.623	0.228	0.345	1.470	40	-0.224	0.150	-0.629	-0.013	22	0.218	0.175	0.014	0.635
BEL	0.641	0.279	0.320	2.189	40	-0.237	0.166	-0.754	-0.001	22	0.249	0.162	0.028	0.621
CAN	0.654	0.158	0.421	1.165	35	-0.227	0.157	-0.624	-0.003	27	0.177	0.157	0.003	0.620
CHE	0.467	0.151	0.249	1.047	42	-0.168	0.138	-0.683	-0.002	20	0.195	0.115	0.020	0.468
CZE	0.592	0.337	0.222	2.525	34	-0.272	0.225	-0.816	-0.005	28	0.226	0.165	0.009	0.590
DEU	0.627	0.212	0.378	1.349	40	-0.224	0.177	-0.846	-0.016	22	0.206	0.142	0.007	0.536
DNK	0.637	0.220	0.346	1.371	40	-0.247	0.194	-0.831	-0.018	22	0.243	0.149	0.006	0.515
ESP	0.862	0.530	0.347	2.806	35	-0.289	0.218	-0.902	-0.010	27	0.245	0.213	0.006	0.996
FIN	0.614	0.191	0.374	1.240	37	-0.242	0.147	-0.711	-0.024	25	0.191	0.147	0.001	0.511
FRA	0.615	0.210	0.330	1.601	41	-0.222	0.151	-0.608	-0.016	21	0.238	0.144	0.021	0.506
GBR	0.736	0.218	0.433	1.624	37	-0.251	0.203	-0.740	-0.004	25	0.216	0.176	0.006	0.694
GRC	3.052	4.543	0.387	28.945	34	-1.065	1.572	-7.228	-0.057	28	1.247	1.894	0.025	9.642
IRL	0.906	0.734	0.333	4.067	40	-0.365	0.400	-2.368	-0.048	22	0.488	0.529	0.017	2.200
ITA	0.877	0.507	0.394	3.048	37	-0.259	0.217	-0.910	0.000	25	0.306	0.241	0.013	0.978
JPN	0.328	0.146	0.098	0.680	41	-0.085	0.062	-0.250	-0.002	21	0.096	0.094	0.002	0.310
KOR	0.669	0.339	0.283	1.977	36	-0.264	0.161	-0.647	-0.005	26	0.238	0.201	0.013	0.748
NLD	0.605	0.182	0.349	1.161	39	-0.228	0.151	-0.726	-0.043	23	0.201	0.152	0.009	0.537
NOR	0.597	0.231	0.310	1.314	37	-0.235	0.188	-0.844	-0.028	25	0.218	0.178	0.021	0.638
NZL	0.657	0.190	0.354	1.374	39	-0.254	0.199	-0.869	-0.015	23	0.244	0.272	0.012	0.997
PRT	1.297	1.275	0.371	7.671	34	-0.521	0.528	-1.811	-0.020	28	0.508	0.505	0.032	2.348
SWE	0.613	0.195	0.278	1.306	37	-0.270	0.201	-0.969	-0.015	25	0.213	0.168	0.020	0.580
USA	0.838	0.294	0.433	1.742	34	-0.259	0.201	-0.785	-0.002	28	0.245	0.207	0.025	0.722

Source: Author own calculations on data from Bloomberg. Volatility is calculated on each quarter of daily changes in 10-years yields and then annualized. Changes in yields is the difference between each two quarters average quarterly yields.

TABLE A - IV - ARDL (1,0) COUNTRY MODELS

Country	Const	AR Coef.	t	P>|t|	F Stat.	P>F	Adj R^2	AIC
AUS	0.19	0.77	11.16	0.000	124.510	0.000	0.581	-28.65
AUT	0.35	0.43	2.41	0.019	5.800	0.019	0.171	-16.93
BEL	0.27	0.57	5.54	0.000	30.700	0.000	0.311	-3.63
CAN	0.23	0.64	5.98	0.000	35.800	0.000	0.402	-82.74
CHE	0.18	0.60	4.17	0.000	17.380	0.000	0.347	-82.96
CZE	0.30	0.49	8.34	0.000	69.630	0.000	0.222	27.48
DEU	0.17	0.72	7.64	0.000	58.350	0.000	0.501	-57.44
DNK	0.25	0.60	5.65	0.000	31.970	0.000	0.344	-36.04
ESP	0.21	0.76	8.8	0.000	77.520	0.000	0.567	47.29
FIN	0.19	0.68	5.87	0.000	34.420	0.000	0.450	-64.37
FRA	0.27	0.56	4.24	0.000	17.950	0.000	0.297	-37.66
GBR	0.18	0.75	8.3	0.000	68.850	0.000	0.540	-58.96
GRC	1.34	0.56	5.13	0.000	26.290	0.000	0.306	342.94
IRL	0.30	0.67	8.4	0.000	70.560	0.000	0.437	103.96
ITA	0.31	0.65	7.93	0.000	62.920	0.000	0.410	60.88
JPN	0.11	0.66	6.71	0.000	44.970	0.000	0.462	-99.33
KOR	0.24	0.62	6.4	0.000	40.980	0.000	0.407	11.30
NLD	0.16	0.73	8.68	0.000	75.280	0.000	0.521	-79.18
NOR	0.21	0.64	7.81	0.000	60.940	0.000	0.399	-35.48
NZL	0.33	0.50	5.37	0.000	28.790	0.000	0.235	-44.49
PRT	0.51	0.61	7.45	0.000	55.570	0.000	0.356	180.71
SWE	0.24	0.61	7.17	0.000	51.400	0.000	0.350	-51.47
USA	0.17	0.79	9.92	0.000	98.350	0.000	0.619	-33.71

Notes: Model: $V_t = \alpha + \beta V_{t-1} + U_t$. OLS regressions with Newey-West standard errors to account for a heteroskedastic error structure possibly autocorrelated up to the fourth lag. The constant is always statistically significant at the 5% significance level; details are not presented for reasons of economy of space. The F-statistic has F (1,60) distribution.

TABLE A - V - DIAGNOSTIC STATISTICS FOR THE ARDL (1,0) COUNTRY MODELS

Country	H_0: no serial correlation				Q(29)		ARCH(1-4)		Heteroskedasticity H_0: const.var					
	LM(1-4)		Durbin Alt(4)		H_0: white noise		H_0: no ARCH effects		White		B-P/C-W test		F-stat	
AUS					26.719				1.27		0.77		0.29	
AUT					15.573				1.33		4.27	**	1.03	
BEL	8.54**	3	3.897***	4	28.021		3.657*	1	6.01	**	42.93	***	5.36	**
CAN					16.343				4.41		4.91	**	3.78	*
CHE					23.935				0.88		1.76		0.78	
CZE					22.253				1.41		5.77	**	0.46	
DEU					20.089		2.948*	1	7.88	**	14.56	***	7.65	***
DNK					42.972	**	8.874***	1	7.68	**	9.4	***	8.41	***
ESP	8.281**	2	2.989*	2	39.187	*			6.23	**	27.14	***	6.61	**
FIN					33.515		9.281***	1	16.86	***	25.82	***	21.09	***
FRA					21.606		8.921***	1	8.65	**	35.9	***	9.45	***
GBR					23.322				6.58	**	17.19	***	6.7	**
GRC					23.962				8.36	**	58.28	***	5.78	**
IRL	4.945**	1	2.599*	2	16.766		9.819***	2	13.89	***	33	***	8.06	***
ITA			2.43*	2	29.905		6.914***	1	3.05		9.16	***	2.13	
JPN					18.568				0.12		0		0	
KOR	4.799*	2			27.427		3.275*	1	14	***	27.6	***	17.43	***
NLD					30.597				4.05		6.85	***	4.15	**
NOR					35.481				0.13		0.01		0	
NZL					21.258				3.34		4.99	**	2.1	
PRT	12.825***	1	2.821*	1	32.185		6.863**	2	8.2	**	36.95	***	4.95	**
SWE					34.877				1.54		0.82		0.34	
USA					30.648		7.616**	2	7.78	**	7.82	***	5.6	**

Notes: Model: $V_t = \alpha + \beta V_{t-1} + U_t$. Serial correlation is tested using two tests. The first performs the Breusch-Godfrey test serial correlation in the residuals at lags 1, 2, 3 and 4, a test that does not require all regressors be strictly exogenous. The test has a $\chi 2$ distribution with p degrees of freedom, p being the lag order. The second test performs Durbin's alternative test for serial correlation in the disturbance using Huber/White/sandwich robust estimator for the variance-covariance matrix. This test also does not require that all the regressors be strictly exogenous. The test has a F (p, N-k-p) distribution, p being the lag order, N the number of observations, k the number of regressors. In both tests when the null is rejected, the lowest statistically significant lag order is reported in a second column. A Portmanteau test for white noise over 29 autocorrelations is also presented but this test is not robust to non-strictly exogenous regressors. Its Q-statistic has a $\chi 2$ distribution with 29 degrees of freedom under the null. Presence of autoregressive conditional heteroskedasticity in the residuals is tested using Engle's Lagrange Multiplier test at lags between 1 and 4. The test has a $\chi 2$ distribution with p degrees of freedom, p being the lag order. When the null is rejected, the lowest statistically significant lag order is reported in a second column. The heteroskedasticity tests include 2 tests. The White (1980) test for homoskedasticity against unrestricted forms of heteroskedasticity, which has a statistic asymptotically $\chi 2$ distributed with 2 degrees of freedom. The Breusch-Pagan (1979) and Cook-Weisberg (1983) tests the null hypothesis that t=0 in $Var(U) = \sigma^2 e^{zt}$ in two versions. The first presented assumes the disturbances to be draws from a normal distribution with variance σ^2 and has a $\chi 2$ distribution with 1 degree of freedom; the second, under F-stat, and due to Wooldridge (2016), drops the normality assumption and has a F (1,60) distribution. Fitted values of the dependent variable are used for z. The asterisks ***, **, * indicate significance at the 1, 5, and 10% level, respectively.

TABLE A - VI - ALTERNATIVE ARDL COUNTRY MODELS

	Lag of AR Coef.	AR Coef.	SE	t	P > t	Sum AR	H_0: no serial correlation							
							LM(1-4)				Durbin Alt(4)			
							1	2	3	4	1	2	3	4
BEL		0.57												
AR(2)	1	0.63	0.13	4.85	0		2.893	6.611	9.674	12.964	1.863	1.655	4.027	3.59
	2	-0.10	0.13	-0.78	0.438	0.53	*0.089*	*0.0367*	*0.0215*	*0.0115*	*0.1776*	*0.2001*	*0.0115*	*0.0113*
AR(3)	1	0.66	0.13	5.15	0		4.214	9.06	9.368	9.797	4.773	4.725	4.443	4.764
	2	-0.26	0.15	-1.71	0.093		*0.0401*	*0.0108*	*0.0248*	*0.044*	*0.033*	*0.0127*	*0.0072*	*0.0023*
	3	0.25	0.13	1.94	0.057	0.65								
AR(4)	1	0.72	0.13	5.66	0		4.856	4.992	5.536	5.681	5.047	3.085	2.785	2.114
	2	-0.33	0.15	-2.2	0.032		*0.0275*	*0.0824*	*0.1365*	*0.2243*	*0.0286*	*0.0537*	*0.0495*	*0.0919*
	3	0.42	0.15	2.84	0.006									
	4	-0.27	0.13	-2.12	0.038	0.54								
AR(5)	1	0.80	0.13	6.25	0		0.059	0.81	1.205	1.252	0.07	1.25	1.335	1.103
	2	-0.45	0.15	-2.93	0.005		*0.8079*	*0.6669*	*0.7518*	*0.8694*	*0.7926*	*0.2946*	*0.2729*	*0.3651*
	3	0.52	0.15	3.47	0.001									
	4	-0.48	0.15	-3.11	0.003									
	5	0.29	0.13	2.27	0.027	0.69								
ESP		0.76												
AR(2)	1	0.66	0.13	5.09	0		6.562	6.592	13.188	13.301	6.031	2.91	4.179	4.033
	3	0.14	0.13	1.07	0.29	0.79	*0.0104*	*0.037*	*0.0042*	*0.0099*	*0.0171*	*0.0626*	*0.0097*	*0.0061*
AR(3)	1	0.61	0.12	4.94	0		5.989	6.451	7.466	7.467	6.121	3.858	2.696	2.113
	2	-0.08	0.15	-0.54	0.592		*0.0144*	*0.0397*	*0.0584*	*0.1132*	*0.0164*	*0.0269*	*0.0547*	*0.0918*
	3	0.34	0.12	2.71	0.009	0.87								
AR(4)	1	0.67	0.10	6.39	0		0.03	2.015	2.032	2.755	0.022	0.664	0.508	0.922
	2	0.00	-	-	-		*0.8619*	*0.3652*	*0.5658*	*0.5996*	*0.882*	*0.5186*	*0.6786*	*0.4579*
	3	0.48	0.12	3.96	0									
	4	-0.32	0.13	-2.56	0.013	0.83								
IRL		0.67												
AR(2)	1	0.48	0.12	3.85	0		2.099	2.1	3.116	3.416	0.543	0.273	0.561	0.434
	2	0.29	0.13	2.28	0.026	0.77	*0.1474*	*0.3499*	*0.3742*	*0.4907*	*0.4642*	*0.7618*	*0.6431*	*0.7833*
PRT		0.61												
AR(2)	1	0.33	0.12	2.86	0.006		0.241	1.14	6.324	6.333	0.23	0.265	0.745	0.687
	2	0.45	0.12	3.91	0	0.79	*0.6236*	*0.5655*	*0.0969*	*0.1756*	*0.6334*	*0.7684*	*0.5299*	*0.604*

Notes: OLS regressions with Newey-West standard errors to account for a heteroskedastic error structure possibly autocorrelated up to the fourth lag. In front of each country, in grey, is reported the AR(1) coefficient previously estimated. Serial correlation is tested using two tests. The first performs the Breusch-Godfrey test serial correlation in the residuals at lags 1, 2, 3 and 4, a test that does not require all regressors be strictly exogenous. The test has a $\chi 2$ distribution with p degrees of freedom, p being the lag order. The second test performs Durbin's alternative test for serial correlation in the disturbance using Huber/White/sandwich robust estimator for the variance-covariance matrix. This test also does not require that all the regressors be strictly exogenous. The test has a F (p, N-K-p) distribution, p being the lag order, N the number of observations, K the number of regressors. The p-values associated with each statistic are reported below it, in italic. when the null is rejected, the lowest statistically significant lag order is reported in a second column.

TABLE A - VII - PERSISTENCE AND TIME-VARYING MEAN VOLATILITY

Country	Const.	Break Coef.	t Stat	P>|t|	Bootstrap SE		AR Coef.	t Stat	P>|t|	Bootstrap SE		F Stat.	P>F	Adj R^2	AIC
					z	P > |z|				z	P > |z|				
AUS	0.25	0.14	1.92	0.059	1.87	0.062	0.66	9.960	0.000	7.58	0.000	85.590	0.000	0.610	-32.20
AUT	0.40	0.17	3.17	0.002	2.94	0.003	0.26	1.76	0.084	1.73	0.083	10.280	0.000	0.258	-22.79
BEL	0.32	0.19	2.47	0.016	2.65	0.008	0.40	4.38	0.000	1.69	0.092	22.860	0.000	0.376	-8.83
CAN	0.33	0.11	3.42	0.001	2.35	0.019	0.44	4.58	0.000	3.68	0.000	20.800	0.000	0.464	-88.61
CHE	0.27	0.20	3.92	0.000	3.39	0.001	0.36	3.86	0.000	3.32	0.001	23.770	0.000	0.490	-97.33
CZE	0.32	0.26	2.12	0.038	2.36	0.018	0.32	4.09	0.000	3.23	0.001	47.960	0.000	0.316	20.47
DEU	0.28	0.17	3.59	0.001	3.14	0.002	0.46	4.54	0.000	2.96	0.003	35.340	0.000	0.578	-66.89
DNK	0.32	0.16	3.04	0.004	2.92	0.003	0.41	4.01	0.000	2.82	0.005	19.750	0.000	0.420	-42.66
ESP	0.37	0.62	3.76	0.000	2.7	0.007	0.42	5.79	0.000	2.33	0.020	44.320	0.000	0.678	29.84
FIN	0.29	0.15	3.03	0.004	3.43	0.001	0.45	3.36	0.001	2.81	0.005	34.420	0.000	0.524	-72.42
FRA	0.33	0.14	2.17	0.034	2.64	0.008	0.38	2.57	0.013	1.83	0.067	17.020	0.000	0.367	-43.28
GBR	0.27	0.14	2.74	0.008	2.38	0.017	0.58	7.04	0.000	4.21	0.000	39.610	0.000	0.588	-64.76
GRC	0.54	3.44	2.95	0.005	2.96	0.003	0.35	3.68	0.001	1.13	0.257	19.220	0.000	0.395	335.44
IRL	0.44	0.95	1.85	0.070	2.61	0.009	0.29	1.44	0.154	1.52	0.127	29.710	0.000	0.570	88.31
ITA	0.38	0.43	2.36	0.022	2.04	0.042	0.47	5.20	0.000	2.62	0.009	34.010	0.000	0.494	52.42
JPN	0.26	-0.11	-3.96	0.000	-3.75	0.000	0.43	4.08	0.000	4.57	0.000	42.230	0.000	0.535	-107.50
KOR	0.46	-0.20	-3.29	0.002	-2.99	0.003	0.46	4.37	0.000	2.66	0.008	26.590	0.000	0.461	6.29
NLD	0.24	0.11	2.76	0.008	2.89	0.004	0.54	6.77	0.000	4.66	0.000	40.830	0.000	0.571	-85.04
NOR	0.25	0.13	2.46	0.017	1.8	0.072	0.50	6.76	0.000	3.78	0.000	40.390	0.000	0.448	-39.85
NZL	0.35	0.06	1.26	0.212	1.21	0.228	0.44	5.78	0.000	3.84	0.000	17.590	0.000	0.243	-44.18
PRT	0.67	1.87	2.92	0.005	2.94	0.003	0.18	1.65	0.105	1.00	0.319	29.000	0.000	0.533	161.71
SWE	0.29	0.13	3.23	0.002	2.07	0.039	0.46	7.33	0.000	4.25	0.000	34.000	0.000	0.410	-56.52
USA	0.32	0.22	3.04	0.004	2.31	0.021	0.54	5.25	0.000	3.95	0.000	35.410	0.000	0.665	-40.74

Notes: OLS regressions with Newey-West standard errors to account for a heteroskedastic error structure possibly autocorrelated up to the fourth lag. Constant details are not presented for reasons of economy of space. Structural break dates are reported in Table A - IX. Bootstrap standard errors based on 1,000 replications. F stat has a F(2,59) distribution.

TABLE A - VIII- STRUCTURAL BREAK T-TESTS

Country	Mean	Break			
		Period		Mean	t Stat.
AUS	0.86	2007q4	2012q1	1.11	3.33 ***
AUT	0.62	2007q3	2012q4	0.77	3.00 ***
BEL	0.64	2007q3	2012q4	0.84	2.56 **
CAN	0.65	2007q4	2012q1	0.80	3.62 ***
CHE	0.47	2007q3	2009q2	0.72	3.74 ***
CZE	0.59	2008q1	2012q3	0.85	2.38 **
DEU	0.63	2007q3	2012q4	0.82	4.32 ***
DNK	0.64	2007q3	2012q4	0.80	3.34 ***
ESP	0.86	2010q3	2012q4	1.72	3.24 ***
FIN	0.61	2007q3	2012q4	0.78	3.83 ***
FRA	0.61	2007q3	2012q4	0.76	2.76 **
GBR	0.74	2007q4	2012q1	0.94	3.75 ***
GRC	3.05	2010q1	2016q2	6.10	2.68 **
IRL	0.91	2010q3	2012q4	2.09	3.66 ***
ITA	0.88	2010q3	2012q4	1.50	2.31 **
JPN	0.33	2009q1	2019q2	0.26	-3.53 ***
KOR	0.67	2011q4	2019q2	0.48	-7.31 ***
NLD	0.61	2007q3	2012q4	0.76	3.98 ***
NOR	0.60	2007q3	2012q4	0.78	2.86 ***
NZL	0.66	2007q4	2012q1	0.75	1.81 *
PRT	1.30	2010q3	2012q4	3.23	3.13 ***
SWE	0.61	2007q4	2012q1	0.77	3.02 ***
USA	0.84	2007q4	2012q1	1.17	4.79 ***

Notes: The asterisks ***, **, * indicate significance at the 1, 5, and 10% level, respectively.

TABLE A - IX - STRUCTURAL BREAK DATES

Begin	End	Countries
2007Q3	2012Q4	AUS, CAN,GBR, NZL, SWE, USA
2007Q4	2012Q1	Core EA, DNK, NOR
2007Q3	2009Q2	CHE
2008Q1	2012Q3	CZE
2010Q2	2013Q2	ESP, IRL, PRT
2011Q3	2012Q2	ITL
2010Q1	2016Q2	GRC
2009Q1	2019Q2	JPN
2011Q4	2019Q2	KOR

TABLE A - X - PERSISTENCE AND TIME-VARYING MEAN VOLATILITY: DIAGNOSTIC STATISTICS

Country	H_0: no serial correlation				Q(29)	ARCH(1-4)		Heteroskedasticity H_0 const.var		
	LM(1-4)		Durbin Alt(4)		H_0: white noise	H_0: no ARCH effects		White	B-P/C-W test	F-stat
AUS					29.476			6.63	2.51	1.35
AUT					15.786			0.37	0.67	0.13
BEL	6.253 **	2	5.119 ***	4	27.527			9.22 *	47.3 ***	5.40 **
CAN					21.293	6.615**	2	12.94 **	10.99 ***	10.99 ***
CHE					31.302			5.37	2.44	1.25
CZE					24.629			3.81	22.35 ***	1.90
DEU					18.867	6.069**	1	12.35 **	24.05 ***	13.89 ***
DNK	9.448 *	4	2.523 *	4	35.744	8.726***	1	8.42 *	8.89 ***	7.64 ***
ESP	8.257 **	3	2.602 **	4	31.013	8.219***	1	24.61 ***	62.56 ***	35.41 **
FIN					32.679	7.598***	1	20.96 ***	28.84 ***	23.29 ***
FRA					20.235	3.375*	1	9.76 **	34.28 ***	8.66 ***
GBR					25.275			9.55 **	21.01 ***	9.83 ***
GRC					25.047			8.83 *	57.44 ***	4.76 **
IRL	6.425 *	3			18.014	4.838*	2	25.66 ***	70.5 ***	25.55 ***
ITA					29.743	9.064*	1	12.31 **	27.15 ***	9.09 ***
JPN					16.266			1.64	2.57	1.05
KOR					28.401	2.764*	1	14.84 ***	27.87 ***	15.32 ***
NLD					29.768	4.034**	1	8.41 *	12.31 ***	7.55 ***
NOR	9.922 **	4			42.167 *			11.14 **	5.38 **	2.03
NZL	8.109 *	4	2.957 **	3	24.778			7.17	5.35 **	2.62
PRT	15.348 ***	4			18.685	4.952*	2	15.39 ***	72.59 ***	11.19 ***
SWE	9.292 *	4	3.035 **	4	38.113			6.65	4.34 **	2.50
USA					30.612	6.838***	1	24.55 ***	19.43 ***	26.41 **

Notes: Serial correlation is tested using two tests. The first performs the Breusch-Godfrey test serial correlation in the residuals at lags 1, 2, 3 and 4, a test that does not require all regressors be strictly exogenous. The test has a $\chi 2$ distribution with p degrees of freedom, p being the lag order. The second test performs Durbin's alternative test for serial correlation in the disturbance using Huber/White/sandwich robust estimator for the variance-covariance matrix. This test also does not require that all the regressors be strictly exogenous. The test has a F (p, N-K-p) distribution, p being the lag order, N the number of observations, K the number of regressors. In both tests when the null is rejected, the lowest statistically significant lag order is reported in a second column. A Portmanteau test for white noise over 29 autocorrelations is also presented but this test is not robust to non-strictly exogenous regressors. Its Q-statistic has a $\chi 2$ distribution with 29 degrees of freedom under the null. Presence of autoregressive conditional heteroskedasticity in the residuals is tested using Engle's Lagrange Multiplier test at lags between 1 and 4. The test has a $\chi 2$ distribution with p degrees of freedom, p being the lag order. When the null is rejected, the lowest statistically significant lag order is reported in a second column. The heteroskedasticity tests include 2 tests. The White (1980) test for homoskedasticity against unrestricted forms of heteroskedasticity, which has a statistic asymptotically $\chi 2$ distributed with 2 degrees of freedom. The Breusch-Pagan (1979) and Cook-Weisberg (1983) tests the null hypothesis that t=0 in $Var(U) = \sigma^2 e^{zt}$ in two versions. The first presented assumes the disturbances to be draws from a normal distribution with variance σ^2 and has a $\chi 2$ distribution with 1 degree of freedom; the second, under F-stat, and due to Wooldridge (2016), drops the normality assumption and has a F (1,60) distribution. Fitted values of the dependent variable are used for z. The asterisks ***, **, * indicate significance at the 1, 5, and 10% level, respectively.

TABLE A - XI - VOLATILITY IN BEAR/BULL MARKETS: DIFFERENCE IN MEANS T-TEST

Country	All Sampe					Ex 2007Q3-2012Q4 (High vol period US block)				
	Bull	Bear	Difference-in-means t-test			Bull	Bear	Difference-in-means t-test		
			H_0: bull = bear	Ha: bull<bear	Ha: bull≠bear			H_0: bull = bear	Ha: bull<bear	Ha: bull≠bear
AUS	0.98	0.70	4.1670		***	0.79	0.70	1.4394		
AUT	0.71	0.51	3.7204		***	0.59	0.51	1.2910		
BEL	0.76	0.49	4.1634		***	0.60	0.49	2.7457		***
CAN	0.72	0.56	4.5281		***	0.64	0.56	2.2492		**
CHE	0.52	0.40	3.5367		***	0.43	0.40	1.0200		
CZE	0.65	0.51	1.6079			0.43	0.51	-1.5886	*	
DEU	0.73	0.49	5.2783		***	0.57	0.49	2.3410		**
DNK	0.73	0.51	4.5756		***	0.61	0.51	2.2185		**
ESP	1.04	0.63	3.3035		***	0.79	0.63	1.7863		*
FIN	0.70	0.50	4.9593		***	0.57	0.50	2.1925		**
FRA	0.71	0.49	4.7842		***	0.61	0.49	3.2943		***
GBR	0.85	0.59	6.0077		***	0.74	0.59	4.1747		***
GRC	4.46	1.23	2.9405		***	3.98	1.23	3.5522		***
IRL	1.18	0.55	3.7402		***	0.64	0.55	1.8190		*
ITA	0.98	0.75	1.7984		*	0.83	0.75	0.8091		
JPN	0.33	0.33	-0.1395			0.26	0.33	-1.4786	*	
KOR	0.65	0.69	-0.4466			0.48	0.69	-2.0185	**	*
NLD	0.69	0.49	4.9832		***	0.57	0.49	2.0427		**
NOR	0.67	0.50	3.1527		***	0.52	0.50	0.4388		
NZL	0.73	0.57	3.5301		***	0.65	0.57	1.7766		*
PRT	1.68	0.80	2.8678		***	1.15	0.80	2.0274		**
SWE	0.70	0.50	4.4954		***	0.59	0.50	2.2556		**
USA	0.96	0.69	3.9819		***	0.70	0.69	0.3650		

Notes: The asterisks ***, **, * indicate significance at the 1, 5, and 10% level, respectively.

TABLE A - XII - VOLATILITY IN BEAR/BULL MARKETS: COUNTRY REGRESSIONS

Country	Const.	NW SE	t Stat.	P>|t|	Bear	NW SE	t Stat.	P>|t|	AR Coef.	NW SE	t Stat.	P>|t|	AR Coef. *Bear	NW SE	t Stat.	P>|t|	F Stat.	P>F
AUS	0.31	0.10	3.18	0.002	-0.13	0.12	-1.05	0.299	0.69	0.09	7.65	0.000	0.02	0.13	0.14	0.89	52.960	0.000
AUT	0.31	0.08	4.09	0.000	0.22	0.10	2.12	0.039	0.57	0.10	5.77	0.000	-0.60	0.12	-5.08	0.00	30.010	0.000
BEL	0.39	0.10	3.89	0.000	0.01	0.12	0.08	0.934	0.49	0.11	4.62	0.000	-0.31	0.17	-1.85	0.07	22.380	0.000
CAN	0.34	0.10	3.37	0.001	-0.03	0.13	-0.26	0.797	0.54	0.15	3.66	0.001	-0.08	0.22	-0.35	0.73	18.030	0.000
CHE	0.23	0.08	2.77	0.008	0.04	0.11	0.34	0.735	0.55	0.17	3.24	0.002	-0.23	0.22	-1.01	0.32	7.380	0.000
CZE	0.34	0.10	3.25	0.002	0.01	0.12	0.06	0.949	0.49	0.09	5.25	0.000	-0.18	0.12	-1.49	0.14	22.000	0.000
DEU	0.26	0.09	2.74	0.008	0.11	0.10	1.10	0.275	0.66	0.12	5.64	0.000	-0.42	0.13	-3.12	0.00	36.020	0.000
DNK	0.34	0.07	4.65	0.000	0.06	0.08	0.76	0.449	0.55	0.10	5.76	0.000	-0.34	0.11	-3.00	0.00	20.660	0.000
ESP	0.22	0.12	1.81	0.075	0.04	0.14	0.27	0.790	0.85	0.12	6.94	0.000	-0.33	0.15	-2.22	0.03	90.670	0.000
FIN	0.23	0.08	2.92	0.005	0.18	0.10	1.81	0.075	0.69	0.11	6.44	0.000	-0.51	0.14	-3.60	0.00	29.950	0.000
FRA	0.41	0.12	3.27	0.002	-0.02	0.14	-0.15	0.879	0.43	0.16	2.72	0.009	-0.22	0.19	-1.21	0.23	16.740	0.000
GBR	0.35	0.10	3.63	0.001	-0.07	0.13	-0.54	0.590	0.60	0.12	5.17	0.000	-0.09	0.18	-0.53	0.60	30.370	0.000
GRC	2.35	0.96	2.44	0.018	-2.13	0.98	-2.18	0.033	0.49	0.11	4.32	0.000	0.24	0.13	1.85	0.07	199.820	0.000
IRL	0.47	0.18	2.67	0.010	-0.09	0.19	-0.45	0.654	0.61	0.10	6.25	0.000	-0.33	0.13	-2.49	0.02	31.610	0.000
ITA	0.35	0.09	3.75	0.000	-0.03	0.15	-0.22	0.829	0.67	0.09	7.71	0.000	-0.14	0.13	-1.06	0.29	35.030	0.000
JPN	0.11	0.05	2.16	0.035	-0.01	0.07	-0.15	0.880	0.65	0.15	4.33	0.000	0.02	0.20	0.12	0.90	14.850	0.000
KOR	0.18	0.05	3.81	0.000	0.11	0.11	1.08	0.285	0.72	0.11	6.55	0.000	-0.19	0.17	-1.11	0.27	25.910	0.000
NLD	0.20	0.07	2.93	0.005	0.14	0.10	1.43	0.157	0.71	0.09	8.10	0.000	-0.42	0.15	-2.74	0.01	47.250	0.000
NOR	0.28	0.09	3.27	0.002	-0.08	0.10	-0.73	0.470	0.58	0.11	5.43	0.000	-0.01	0.15	-0.06	0.95	29.450	0.000
NZL	0.39	0.07	5.48	0.000	0.00	0.13	0.03	0.973	0.47	0.10	4.77	0.000	-0.18	0.23	-0.78	0.44	15.740	0.000
PRT	0.84	0.28	2.98	0.004	-0.69	0.29	-2.37	0.021	0.52	0.09	5.80	0.000	0.21	0.13	1.68	0.10	50.990	0.000
SWE	0.37	0.07	5.17	0.000	-0.11	0.09	-1.26	0.212	0.48	0.10	4.74	0.000	-0.01	0.14	-0.10	0.92	20.030	0.000
USA	0.24	0.10	2.43	0.018	0.00	0.12	0.04	0.968	0.75	0.10	7.33	0.000	-0.11	0.15	-0.75	0.46	40.810	0.000

Notes: OLS regressions with Newey-West standard errors to account for a heteroskedastic error structure possibly autocorrelated up to the fourth lag. F-stat. has a F (3,58) distribution.

TABLE A - XIII - VOLATILITY AND MARKET MOVEMENTS: COUNTRY REGRESSIONS

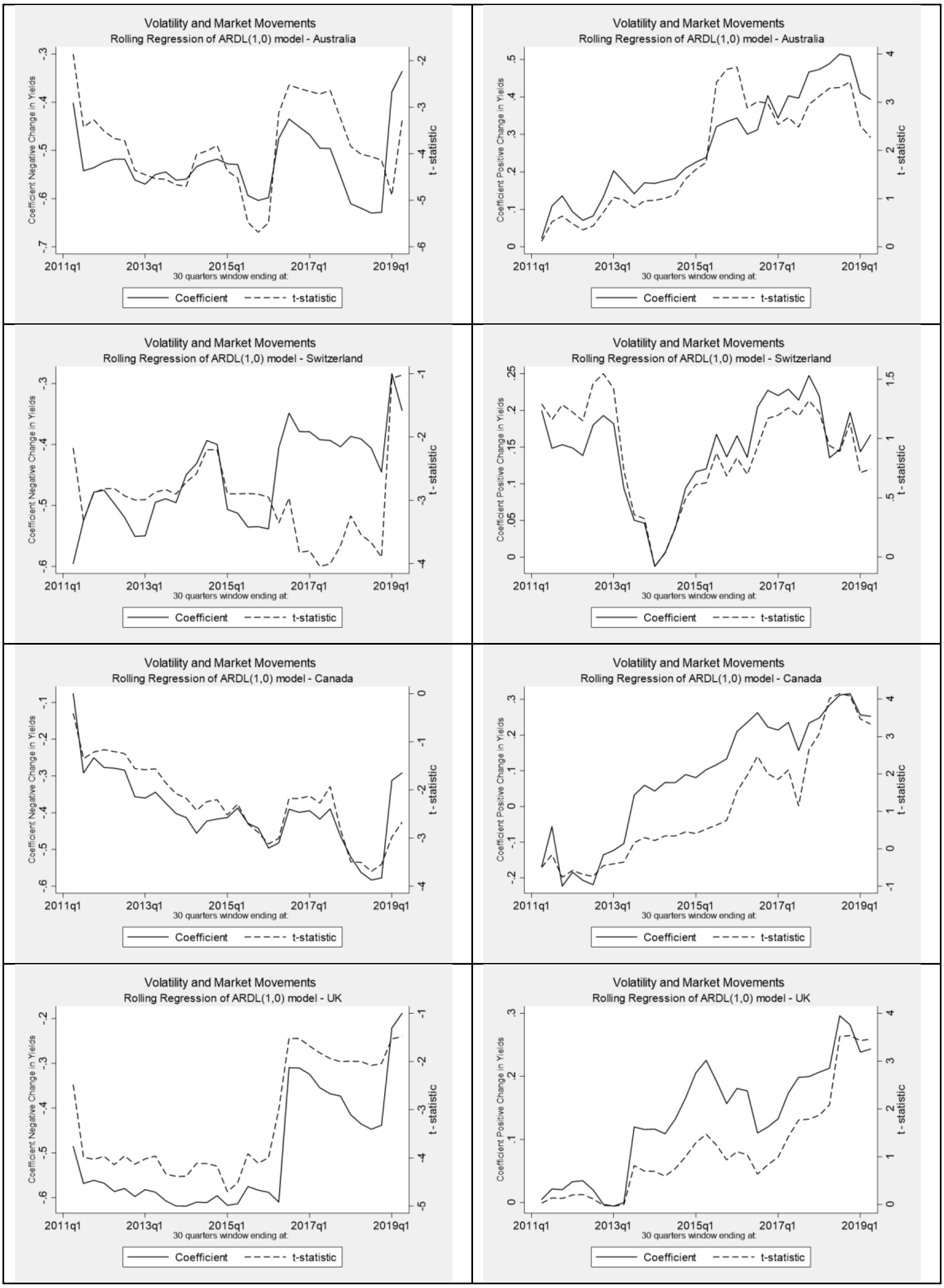
Country	Const. (α)	t Stat	P>|t|	AR (β)	t Stat	P>|t|	γ^-	t Stat	P>|t|	γ^+	t Stat	P>|t|	Wald Tests $\gamma^+ = \gamma^-$	P>F	$\gamma^+ = -\gamma^-$	P>F	F Stat.	P>F	Adj R^2	AIC
AUS	0.17	3.24	0.002	0.68	10.56	0.000	-0.46	-3.52	0.001	0.25	1.91	0.061	9.31	0.003	3.07	0.085	94.97	0.000	0.680	-43.4
AUT	0.25	3.71	0.000	0.43	2.71	0.009	-0.33	-2.11	0.039	0.63	1.69	0.096	3.66	0.061	1.22	0.273	10.58	0.000	0.279	-23.7
BEL	0.25	3.82	0.000	0.59	6.48	0.000	0.10	0.77	0.443	0.31	1.31	0.195	0.83	0.366	1.76	0.190	14.06	0.000	0.334	-3.8
CAN	0.23	3.40	0.001	0.56	4.78	0.000	-0.34	-2.75	0.008	0.17	1.31	0.195	5.12	0.028	2.13	0.150	16.04	0.000	0.477	-89.2
CHE	0.16	2.77	0.007	0.51	4.91	0.000	-0.50	-3.43	0.001	0.21	1.97	0.054	9.61	0.003	6.3	0.015	8.16	0.000	0.487	-96.0
CZE	0.29	4.35	0.000	0.51	8.48	0.000	-0.13	-1.56	0.124	-0.18	-0.89	0.375	0.04	0.849	3.750	0.058	27.220	0.000	0.217	29.8
DEU	0.10	2.15	0.036	0.69	9.53	0.000	-0.48	-3.13	0.003	0.34	3.09	0.000	13.59	0.001	0.87	0.356	50.040	0.000	0.615	-71.6
DNK	0.10	2.21	0.031	0.59	7.62	0.000	-0.65	-6.13	0.000	0.64	4.26	0.000	35.47	0.000	0.01	0.924	49.820	0.000	0.614	-67.0
ESP	0.17	2.61	0.011	0.73	8.65	0.000	0.09	0.34	0.738	0.70	2.59	0.012	2.16	0.147	4.97	0.030	48.230	0.000	0.625	40.3
FIN	0.12	1.69	0.096	0.69	5.85	0.000	-0.34	-2.56	0.013	0.23	2.40	0.020	9.75	0.003	0.57	0.453	15.650	0.000	0.496	-67.9
FRA	0.21	2.61	0.012	0.54	4.13	0.000	-0.30	-2.59	0.012	0.29	2.24	0.029	9.70	0.003	0.01	0.933	10.120	0.000	0.319	-37.8
GBR	0.15	3.20	0.002	0.67	10.36	0.000	-0.46	-3.36	0.001	0.18	1.98	0.053	10.98	0.002	4.69	0.035	42.910	0.000	0.676	-78.8
GRC	1.13	2.27	0.027	0.55	3.68	0.001	0.37	0.68	0.501	0.81	2.28	0.026	0.27	0.606	9.59	0.003	19.000	0.000	0.370	338.9
IRL	0.28	3.03	0.004	0.47	2.60	0.012	-0.29	-1.21	0.230	0.73	3.03	0.004	4.78	0.033	15.57	0.000	82.810	0.000	0.522	95.8
ITA	0.26	3.31	0.002	0.59	4.82	0.000	0.07	0.20	0.845	0.87	2.00	0.051	1.47	0.230	5.12	0.027	22.760	0.000	0.540	47.5
JPN	0.09	2.84	0.006	0.56	6.36	0.000	-0.58	-2.73	0.008	0.62	3.48	0.001	12.99	0.001	0.03	0.853	28.550	0.000	0.530	-105.8
KOR	0.15	1.85	0.07	0.51	5.64	0.000	-0.55	-2.20	0.032	0.85	5.73	0.000	20.12	0.000	1.28	0.263	21.680	0.000	0.531	-1.3
NLD	0.09	1.65	0.104	0.73	9.10	0.000	-0.37	-2.75	0.008	0.27	2.54	0.014	11.11	0.002	0.49	0.488	29.660	0.000	0.591	-87.1
NOR	0.13	3.27	0.002	0.59	9.42	0.000	-0.64	-3.43	0.001	0.28	3.43	0.001	17.00	0.000	3.92	0.053	40.620	0.000	0.604	-59.4
NZL	0.34	6.21	0.000	0.34	3.93	0.000	-0.41	-3.83	0.000	0.33	2.91	0.005	16.95	0.000	0.35	0.558	25.880	0.000	0.391	-56.7
PRT	0.29	3.10	0.003	0.43	5.46	0.000	-0.32	-1.71	0.092	1.56	3.23	0.002	9.70	0.003	8.93	0.004	44.320	0.000	0.552	160.2
SWE	0.18	3.80	0.000	0.53	7.67	0.000	-0.52	-4.09	0.000	0.30	3.23	0.002	18.85	0.000	3.41	0.070	39.430	0.000	0.565	-74.4
USA	0.16	3.14	0.003	0.68	8.72	0.000	-0.58	-4.17	0.000	0.23	1.73	0.089	11.29	0.001	8.14	0.006	64.390	0.000	0.720	-51.1

Notes: OLS regressions with Newey-West standard errors to account for a heteroskedastic error structure possibly autocorrelated up to the fourth lag; Wald test F-statistic has a F(1,21) distribution. The regression F-statistic has a F (3,58) distribution.

TABLE A - XIV- VOLATILITY AND MARKET MOVEMENTS: DIAGNOSTICS

Country	H_0: no serial correlation LM(1-4)		Durbin Alt(4)		H_0: no serial correlation χ^2(4) Stat.	p-value	Q(29) H_0: white noise		ARCH(4) H_0: no ARCH effects		Heteroskedasticity H_0: const.var White	B-P/C-W test	F-stat
AUS					2.013	0.7333	26.6513	0.5905			7.74	0.07	0.05
AUT					2.442	0.6551	26.6835	0.5888			19.88 **	23.78 ***	10.93 ***
BEL	4.768*	2	2.474*	4	5.731	0.2202	31.7996	0.3287	5.065**	1	31.04 ***	49.19 ***	7.90 ***
CAN					0.648	0.9576	19.8926	0.8962			13.20	1.13	0.99
CHE					0.269	0.9917	20.4379	0.8788			12.10	4.78 **	3.61 *
CZE					5.712	0.2217	23.5767	0.7495			4.19	8.30 ***	0.67
DEU	3.626*	1	7.310***	1	2.992	0.5591	29.3758	0.4456			16.12 **	6.87 ***	5.96 **
DNK	5.433**	1	6.164**	1	3.505	0.4771	37.9816	0.1227	4.623**	1	14.00 *	2.05	2.79
ESP	6.755**	2			4.603	0.3305	30.8503	0.3725			6.18	12.24 ***	2.29
FIN					1.399	0.8443	31.4139	0.3462	7.233***	1	23.35 ***	19.69 ***	20.87 ***
FRA					1.568	0.8145	21.9189	0.8235	4.784**	1	13.32	28.30 ***	5.96 **
GBR	5.031**	1	4.991**	1	7.468	0.1131	34.8772	0.2086			21.59 ***	15.22 ***	11.08 ***
GRC	21.193***	1	3.888**	2	4.519	0.3403	34.7926	0.2114			21.12 ***	77.35 ***	7.49 ***
IRL	7.633 **	2			4.576	0.3336	15.9849	0.9757			16.95 **	26.20 ***	3.69 *
ITA					3.770	0.438	32.4156	0.3019			25.64 ***	16.64 ***	8.14 ***
JPN					2.386	0.6651	26.2795	0.6105			6.91	0.04	0.02
KOR	5.629*	2	2.128*	4	7.239	0.1238	18.6763	0.9293	3.063 *	1	21.68 ***	21.96 ***	10.94 ***
NLD					0.625	0.9603	23.2225	0.7663			6.26	3.46 *	2.93 *
NOR					1.535	0.8205	28.9581	0.4673			22.11 ***	6.02 **	5.90 **
NZL					1.069	0.8992	37.7133	0.1288			6.22	4.70 **	2.19
PRT	19.976***	1	7.348 ***	1	5.318	0.2562	34.4447	0.2234			28.46 ***	110.79 ***	18.40 ***
SWE					3.592	0.4641	29.4846	0.4401			8.85	0.36	0.35
USA					5.111	0.2761	38.268	0.1165			10.92	3.19 *	1.45

Notes: Serial correlation is tested using two tests. The first performs the Breusch-Godfrey test serial correlation in the residuals at lags 1, 2, 3 and 4, a test that does not require all regressors be strictly exogenous. The test has a $\chi 2$ distribution with p degrees of freedom, p being the lag order. The second test performs Durbin's alternative test for serial correlation in the disturbance using Huber/White/sandwich robust estimator for the variance-covariance matrix. This test also does not require that all the regressors be strictly exogenous. The test has a F (p, N-K-p) distribution, p being the lag order, N the number of observations, K the number of regressors. In both tests when the null is rejected, the lowest statistically significant lag order is reported in a second column.; the third test is the heteroskedasticity robust Cumby-Huizinga test for autocorrelation up to lag 4. A Portmanteau test for white noise over 29 autocorrelations is also presented but this test is not robust to non-strictly exogenous regressors. Its Q-statistic has a $\chi 2$ distribution with 29 degrees of freedom under the null. Presence of autoregressive conditional heteroskedasticity in the residuals is tested using Engle's Lagrange Multiplier test at lags between 1 and 4. The test has a $\chi 2$ distribution with p degrees of freedom, p being the lag order. When the null is rejected, the lowest statistically significant lag order is reported in a second column. The heteroskedasticity tests include 2 tests. The White (1980) test for homoskedasticity against unrestricted forms of heteroskedasticity, which has a statistic asymptotically $\chi 2$ distributed with 2 degrees of freedom. The Breusch-Pagan (1979) and Cook-Weisberg (1983) tests the null hypothesis that t=0 in Var(U) = $\sigma^2 e^{zt}$ in two versions. The first presented assumes the disturbances to be draws from a normal distribution with variance σ^2 and has a $\chi 2$ distribution with 1 degree of freedom; the second, under F-stat, and due to Wooldridge (2016), drops the normality assumption and has a F (1,60) distribution. Fitted values of the dependent variable are used for z. In the absence of a p-value, the asterisks ***, **, * indicate significance at the 1, 5, and 10% level, respectively.


Volatility and Market Movements
Rolling Regression of ARDL(1,0) model - Australia
Coefficient Negative Change in Yields
t - statistic
30 quarters window ending at:
Coefficient
t-statistic
Volatility and Market Movements
Rolling Regression of ARDL(1,0) model - Australia
Coefficient Positive Change in Yields
t - statistic
30 quarters window ending at:
Coefficient
t-statistic
Volatility and Market Movements
Rolling Regression of ARDL(1,0) model - Switzerland
Coefficient Negative Change in Yields
t - statistic
30 quarters window ending at:
Coefficient
t-statistic
Volatility and Market Movements
Rolling Regression of ARDL(1,0) model - Switzerland
Coefficient Positive Change in Yields
t - statistic
30 quarters window ending at:
Coefficient
t-statistic
Volatility and Market Movements
Rolling Regression of ARDL(1,0) model - Canada
Coefficient Negative Change in Yields
t - statistic
30 quarters window ending at:
Coefficient
t-statistic
Volatility and Market Movements
Rolling Regression of ARDL(1,0) model - Canada
Coefficient Positive Change in Yields
t - statistic
30 quarters window ending at:
Coefficient
t-statistic
Volatility and Market Movements
Rolling Regression of ARDL(1,0) model - UK
Coefficient Negative Change in Yields
t - statistic
30 quarters window ending at:
Coefficient
t-statistic
Volatility and Market Movements
Rolling Regression of ARDL(1,0) model - UK
Coefficient Positive Change in Yields
t - statistic
30 quarters window ending at:
Coefficient
t-statistic

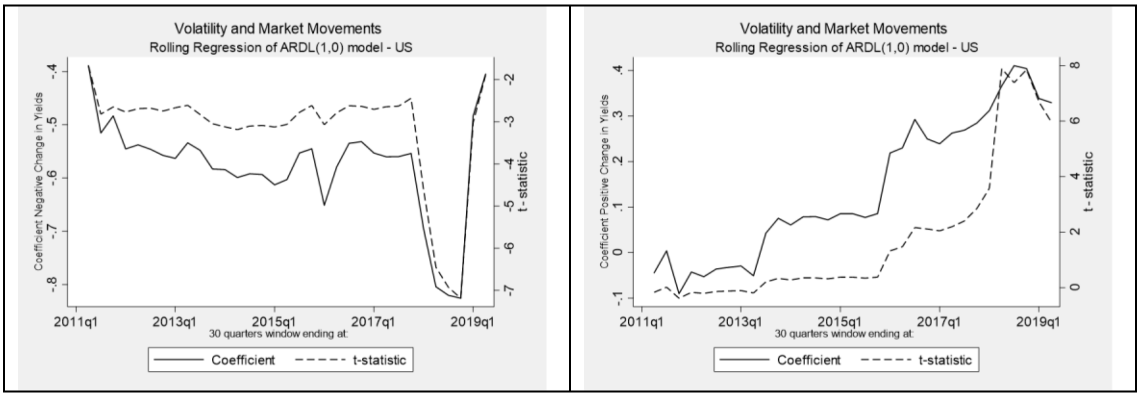


FIGURE A - 1 SELECTED ROLLING REGRESSIONS OF VOLATILITY AND MARKET MOVEMENTS

TABLE A - XV - VOLATILITY, MARKET MOVEMENTS AND REVISIONS OF WEO MACRO FORECASTS

Variables	All Countries (1) Coef.	t Stat	(2) Coef.	t Stat	All Countries ex GRC (3) Coef.	t Stat
Υ^-	0.073	0.27	0.060	0.22	-0.276 **	-2.62
Υ^+	0.789 ***	3.90	0.783 ***	4.04	0.656 ***	4.69
GDP Unc	0.098	1.47	0.079 *	1.82		
Inf Unc	-0.037	-0.66				
Bdg Unc	-0.001	-0.03				
CA Unc	0.008	0.63			0.030 ***	2.93
F Stat	21.45		35.34		40.10	
(p-value)	0.0000		0.0000		0.0000	
R^2	0.403		0.401		0.520	
$\chi^2(4)$ Stat.	5.861		6.050		1.219	
(p-value)	0.2098		0.1954		0.8750	

Variables	Semi-directional Panel (4) Coef.	t Stat	Asymmetrical Panel (5) Coef.	t Stat	Symmetrical Panel (6) Coef.	t Stat	Czechia (7) Coef.	t Stat	Czechia (8) Coef.	t Stat
Υ^-	0.310	0.75	-0.502 ***	-5.08	-0.445 ***	-4.79	-0.257 **	-2.15	-0.251 **	-2.26
Υ^+	0.841 **	2.81	0.238 **	3.43	0.397 ***	4.14	0.162	0.60	0.230	1.12
GDP Unc	0.216	1.17	0.013	0.49	0.028	1.30	-0.133	-0.71		
Inf Unc	-0.182	-1.04	0.008	0.74	0.013	1.15	-0.056	-0.69		
Bdg Unc	0.031	0.58	0.005	0.34	-0.021	-0.98	0.046	1.50	0.064 **	2.23
CA Unc	0.018	0.39	0.016	1.71	0.003	0.36	0.165 **	2.05	0.144 **	2.21
F Stat	17.88		125.01		58.34		11.95		19.75	
(p-value)	0.0029		0.0000		0.0000		0.0000		0.0000	
R^2	0.420		0.653		0.477		0.361		0.376	
$\chi^2(4)$ Stat.	5.114		16.007		4.147					
(p-value)	0.2758		0.0030		0.3865					
Durbin F Stat.										
Lag 1							2.664		1.949	
Lag 2							1.481		1.121	
Lag 3							0.948		0.804	
Lag 4							1.587		1.719	

Notes: Panel fixed effects within regressions with Driscroll-Kraay (1998) standard errors; Czechia OLS regression with Newey-West (1987) implementation of Heteroskedasticity-and-Autocorrelation-Consistent (HAC) standard errors; γ^-/γ^+ = Negative/positive change in yields; ; F Stat. is the statistic of the F-test of overall significance (p-values below); R^2 is the within R^2 in panel regressions and adjusted- R^2 in Czechia regressions; $\chi^2(4)$ is the statistic of the Cumby-Huizinga heteroskedasticity robust test of serial correlation up to lag 4 with a null hypothesis of no serial correlation (p-values below); the test of serial correlation in Czechia's regressions is the Durbin's alternative test that does not require all regressors to be strictly exogenous, its F-statistic has a distribution F(p, T-K-p), where K = number of regressors, T = number of observations, p = lar order. The asterisks ***, **, * indicate significance at the 1, 5, and 10% level, respectively.

TABLE A - XVI - US VOLATILITY, MARKET MOVEMENTS AND DISPERSION OF PROFESSIONAL FORECASTS

Variables	1 Quarter ahead				4 Quarters ahead			
	(1)		(2)		(3)		(4)	
	Coef.	t Stat	Coef.	t Stat	Coef.	t Stat	Coef.	t Stat
γ^-	-0.524 ***	-3.79	-0.522 ***	-4.15	-0.528 ***	-4.03	-0.531 ***	-3.95
γ^+	0.219 *	1.78	0.211	1.60	0.276 **	2.29	0.231 *	1.71
3m T-bill IQD	0.051	0.32			0.109	1.16		
Inflation IQD	0.100	1.26	0.190	1.67	0.221	1.64	0.243 *	1.91
GDP IQD	0.161	1.49			0.123	1.09		
Fed Gov IQD	-0.018	-0.88			-0.026	-0.98		
F Stat	75.71		53.12		37.58		31.46	
(p-value)	0.0000		0.0000		0.0000		0.0000	
Adj. R^2	0.741		0.737		0.737		0.732	
Durbin F Stat.								
Lag 1	2.023		1.861		0.418		0.362	
Lag 2	1.051		0.905		1.114		1.211	
Lag 3	0.753		1.405		1.557		1.860	
Lag 4	0.973		1.490		1.720		1.881	

Notes: OLS regressions with Newey-West standard errors to account for a heteroskedastic error structure possibly autocorrelated up to the fourth lag; γ^- = negative change in yields; γ^+ = positive change in yields; 3mT-bill = 3-month Treasury-bill rate; Inf = inflation rate; GDP = GDP q-o-q growth rate; Fed. Gov. = Federal government consumption and investment; IQD = inter-quartile dispersion; F Stat. is the statistic of the F-test of overall significance (p-values below); R^2 is the adjusted R^2; the test of serial correlation is the Durbin's alternative test that does not require all regressors to be strictly exogenous, its F-statistic has a distribution F(p, T-K-p), where K = number of regressors, T = number of observations, p = lag order. The asterisks ***, **, * indicate significance at the 1, 5, 10% level.

TABLE A - XVII - EA VOLATILITY, MARKET MOVEMENTS AND DISPERSION OF PROFESSIONAL FORECASTS

Variables	Standard Deviation of Individual Forecasts						Interquartile Dispersion of Individual Forecasts					
	All Countries				All Countries ex GRC		All Countries				All Countries ex GRC	
	(1)		(2)		(3)		(4)		(5)		(6)	
	Coef.	t Stat	Coef.	t Stat	Coef.	t Stat	Coef.	t Stat	Coef.	t Stat	Coef.	t Stat
γ^-	0.191	0.54	0.189	0.53	-0.081	-0.68	0.193	0.54	0.196	0.54	-0.075	-0.60
γ^+	0.808 ***	3.17	0.814 ***	3.15	0.826 ***	4.85	0.826 ***	3.16	0.829 ***	3.18	0.824 ***	5.02
Inf Std	1.940 ***	3.15	1.661 *	1.81	0.692 **	2.56						
GDP Std	-0.211	-0.47										
Inf IQD							0.259	0.51	0.774	1.71	0.347 *	2.10
GDP IQD							0.557	0.87				
F Stat	27.32		30.52		47.90		22.48		29.59		44.34	
(p-value)	0.0000		0.0000		0.0000		0.0000		0.0000		0.0000	
R^2	0.420		0.420		0.578		0.418		0.414		0.572	
$\chi^2(4)$ Stat.	5.23		5.195		8.373		5.282		5.169		8.188	
(p-value)	0.2645		0.2678		0.0788		0.2595		0.2704		0.0849	

Notes: GRC = Greece; Panel fixed effects within regressions with Driscroll-Kraay (1998) standard errors; γ^-/γ^+ = Negative/positive change in yields; Std = standard deviation of rolling horizon forecasts one year ahead of the latest available data; IQD = interquartile dispersion of individual forecasts; Inf = EA HICP inflation rate; GDP = EA real GDP growth rate; constant and AR parameter estimates not reported for the sake of conciseness; ; F Stat. is the statistic of the F-test of overall significance (p-values below); R^2 is the within R^2; $\chi^2(4)$ is the statistic of the Cumby-Huizinga heteroskedasticity robust test of serial correlation up to lag 4 with a null hypothesis of no serial correlation (p-values below) . The asterisks ***, **, * indicate significance at the 1, 5, and 10% level, respectively.

TABLE A - XVIII - BOND YIELD VOLATILITY, MARKET MOVEMENTS AND MACRO VOLATILITY

Variables	All Countries				All Countries ex GRC				Semi-directional Panel	
	(1)		(2)		(3)		(4)		(5)	
	Coef.	t Stat	Coef.	t Stat	Coef.	t Stat	Coef.	t Stat	Coef.	t Stat
Υ^-	0.059	0.22	0.060	0.22	-0.272 **	-2.77	-0.275 **	-2.73	0.259	0.65
Υ^+	0.781 ***	4.09	0.778 ***	4.03	0.663 ***	4.77	0.659 ***	4.77	0.840 **	3.06
3m rate Vol.	0.009	0.70			0.029 **	2.67	0.038 ***	2.95	-0.106	-1.37
GDP Vol.	0.052 *	2.02	0.068 **	2.36	0.029	1.38			0.070	1.05
Inflation Vol.	0.040	1.11			0.013	0.82			0.158	1.02
Budget Vol.	-0.004	-0.19			-0.025 *	-1.76			-0.010	-0.21
Cur. Acc. Vol.	0.024	0.97			0.001	0.10			0.109	1.24
F Stat	28.59		28.08		114.77		85.47		26.41	
(p-value)	0.0000		0.0000		0.0000		0.0000		0.0011	
R^2	0.403		0.402		0.528		0.524		0.418	
$\chi^2(4)$ Stat.	6.097		6.060		1.232		1.082		5.274	
(p-value)	0.192		0.1947		0.8729		0.8971		0.2604	

Variables	Asymmetrical Panel				Symmetrical Panel				Czechia			
	(6)		(7)		(8)		(9)		(10)		(11)	
	Coef.	t Stat	Coef.	t Stat	Coef.	t Stat	Coef.	t Stat	Coef.	t Stat	Coef.	t Stat
Υ^-	-0.450 ***	-4.45	-0.454 ***	-4.63	-0.419 ***	-4.52	-0.427 ***	-4.55	-0.252 *	-1.99	-0.055	-0.45
Υ^+	0.229 **	3.59	0.228 **	3.39	0.453 ***	4.46	0.456 ***	4.57	-0.044	-0.33	-0.246	-0.97
3m rate Vol.	0.029 **	2.93	0.027 **	2.70	0.019	1.21	0.030 **	2.78	-0.175	-1.60	-0.109 *	-1.90
GDP Vol.	0.022 *	2.35	0.027 **	2.63	0.025	1.18			0.185	1.11		
Inflation Vol.	0.020	0.88			0.003	0.26			0.067	1.46		
Budget Vol.	-0.011	-0.96			-0.005	-0.45			0.043	1.29		
Cur. Acc. Vol.	-0.005	-0.42			0.004	0.34			-0.001	-0.02		
F Stat	182.42		205.33		85.63		153.69		37.07		43.46	
(p-value)	0.0000		0.0000		0.0000		0.0000		0.0000		0.0000	
R^2	0.667		0.663		0.493		0.487		0.318		0.239	
$\chi^2(4)$ Stat.	21.660		19.837		4.231		4.079					
(p-value)	0.0002		0.0005		0.3756		0.3955					
Durbin F Stat.												
Lag 1									0.896		0.410	
Lag 2									0.422		0.208	
Lag 3									0.714		1.319	
Lag 4									1.465		2.236*	

Notes: GRC = Greece; Panel fixed effects' within regressions with Driscroll-Kraay (1998) standard errors; Czechia OLS regression with Newey-West (1987) implementation of Heteroskedasticity-and-Autocorrelation-Consistent (HAC) standard errors; ; constant and AR parameter estimates not reported for the sake of conciseness; ; F Stat. is the statistic of the F-test of overall significance (p-values below); R^2 is the within R^2 in panel regressions and adjusted- R^2 in Czechia regressions; $\chi^2(4)$ is the statistic of the Cumby-Huizinga heteroskedasticity robust test of serial correlation up to lag 4 with a null hypothesis of no serial correlation (p-values below); the test of serial correlation in Czechia's regressions is the Durbin's alternative test that does not require all regressors to be strictly exogenous, its F-statistic has a distribution F(p, T-K-p), where K = number of regressors ,T = number of observations, p = lag order. The asterisks ***, **, * indicate significance at the 1, 5, and 10% level, respectively, in the Durbin's F-statistics.

APPENDIX B

Supplementary material associated with this article is available upon request: cferreira@iseg.ulisboa.pt.

APPENDIX C

We perform two types of statistical tests, a F-test, and the Breusch-Pagan LM test, following Baltagi (2013). If poolability is confirmed, there are no country-specific effects either in the regressors (fixed effects) or the composite error term (random effects). We carried the F-tests using the strategy proposed by Maddala (1977), which consists in testing four alternative hypothesis: (1) common intercepts and slopes; (2) different intercepts and a common slope; (3) common intercept and different slopes; and (4) common intercepts given common slopes. The results point to different intercepts and a common slope suggesting time constant country heterogeneity.

TABLE C - 1 – POOLABILITY F-TESTS

	F-Statistic		p-value
H_0: common intercepts and slopes	F(44,1380)	1.812	0.001
H_0: different intercepts, common slopes	F(22,1380)	0.131	1.000
H_0: common intercepts, different slopes	F(22,1380)	2.665	0.000
H_0: common intercepts given common slopes	F(22,1402)	3.540	0.000

Source: Author's calculations.

The Breusch-Pagan LM test is used to assess the alternative of a random-effects model, under the null hypothesis that the variance across countries effects (σ^2_α) is nil. The corresponding $\chi^2(1)$ statistic takes the value 0.00 (p-value = 1). Since the null is not rejected, we can conclude that there is not a significant random effect in the data warranting a random effect model to deal with heterogeneity. The results of the two tests point to a fixed effects regression model.

To perform a preliminary identification of the variance-covariance process in the panel we perform a Breusch-Pagan (1979) / Cook-Weisberg (1983) test for heteroskedasticity where its F-stat version drops the assumption that the regression disturbances are independent draws from a normal distribution with variance σ^2. In both cases the null is rejected, confirming residuals' heteroskedasticity. A modified Wald statistic for groupwise heteroskedasticity in the residuals of the fixed effect model was also computed. This test statistic has a $\chi^2(23)$ distribution under the null hypothesis that variance is identical across countries, our cross-sectional unit. The test results confirm the rejection of the null hypothesis of homoskedasticity.

TABLE C - 2 – HETEROSKEDASTICITY TESTS

H_0: residuals' variance constant across countries					
Breusch-Pagan/Cook-Weisberg Test				Modified Wald Test	p-value
χ^2 Stat	p-value	F Stat.	p-value		
34912.66	0.0000	220.14	0.0000	320000	0.0000

Source: Author’s calculations.

A Cumby-Huizinga test for autocorrelation on the residuals using heteroskedastic robust estimates of the variance-covariance matrix suggests possible serial correlation at lag 3, although we cannot reject the null of absence of serial correlation against the alternative hypothesis of its presence between lags 1 and 3.

TABLE C - 3 – CUMBY-HUIZINGA TEST FOR AUTOCORRELATION

H_0: Serially Uncorrelated Ha: Serial correlation at range j					H_0: MA order lag-1 Ha: Serial correlation at lag j			
Lags Range From	To	χ^2 Stat.	df	p-value	Lag	χ^2 Stat.	df	p-value
1	1	0.556	1	0.4557	1	0.556	1	0.4557
1	2	2.612	2	0.2709	2	1.376	1	0.2408
1	3	3.779	3	0.2863	3	6.701	1*	0.0096
1	4	4.461	4	0.3472	4	1.182	1	0.2770
1	5	6.564	5	0.2551	5	2.879	1	0.0897
1	6	7.631	6	0.2664	6	0.969	1	0.3250
1	7	8.085	7	0.3252	7	1.134	1	0.2869
1	8	8.264	8	0.4082	8	2.481	1	0.1152

Source: Author’s calculations. Test robust to heteroskedasticity. MA = moving average; df = degrees of freedom; (*) indicates eigenvalues have been adjusted to make the matrix positive semidefinite.

Cross-sectional dependence in the volatility series was detected in the time-series analysis, with Pesaran (2004) and Pesaran (2015) CD Statistics of 70.55 and 111.39, respectively, both significant at the 1% significance level.

In face of these results, we use Driscoll and Kraay (1998) standard errors for the coefficients of the fixed effects regression model, since they assume an error structure that is heteroskedastic, autocorrelated up to some lag and allow for cross-sectional dependence. We set the maximum lag order correlation at 4[41], considering the previous evidence of possible serial correlation at lag 3.

[41] This value is close to the floor of $4*(T/100)^{(2/9)}$ where T is the number of time periods, that in our case corresponds to a value around 3.6.

TABLE C - 4 – PERSISTENCE IN PANEL FIXED EFFECTS REGRESSION MODEL

Variables		All Countries ARDL (1,0)		
		Coef.		t Stat
Constant	α	0.338	***	3.83
AR Parameter	β	0.574	***	5.77
F Stat. - Overall Significance		33.27		
(p-value)		0.0000		
R^2		0.330		
χ^2(4) Stat. - Serial Correlation		4.489		
(p-value)		0.3439		

Notes: We reject the null of absence of country fixed effects at the 1% significance level: F (22,1402) = 3.54 (p-value = 0.0000); Driscroll-Kraay (1998) standard errors; ; F Stat. is the statistic of the F-test of overall significance (p-values below); R^2 is the within R^2; $\chi^2(4)$ is the statistic of the Cumby-Huizinga heteroskedasticity robust test of serial correlation up to lag 4 with a null hypothesis of no serial correlation (p-values below). The asterisks ***, **, * indicate significance at the 1, 5, and 10% level.

The fixed effects within estimator is unbiased under the assumption of strict exogeneity of the regressors. However, the strict exogeneity assumption never holds in unobserved effects models with lagged dependent variables (Wooldridge, 2002). Under less stringent assumption of sequential exogeneity, and a time-series process appropriately stable and weakly dependent, the fixed effects estimator is biased. The bias is negative and arises because of the demeaning process that creates correlation between regressor and error (Nickell, 1981). The bias is not mitigated by increasing the number of cross-sectional units, nor by smaller values of the autoregressive parameter. However, Nickell (1981) demonstrates that the bias is of order T^{-1} (T = number of time periods). Hence, as $T \rightarrow \infty$ the bias goes to zero. For large values of T, it can be approximated by: - (1+β)/(T-1)[42]. In our case, using the autoregressive parameter estimate of 0.57 and 62 quarters we obtain an estimate of the Nickell's bias of -0.0257 or -4.5% of the parameter estimate. Since the autoregressive parameter estimate is far from 1, we can dismiss Hsiao (1986) concerns of possible large bias even for very large T when the autoregressive parameter estimate is close to 1. An alternative approach would be taking first differences, but in this case, there is still correlation between the differenced lagged dependent variable and the disturbance process, and since the resulting bias does not depend on T, we prefer the fixed effects. Its combination with the use of instrumental variables such as lagged levels in the Anderson and Hsiao estimator have revealed to be poor instruments of first differenced variables, according with Arellano & Bover (1995) and Blundell & Bond (1998). The Arellano & Bond (1991) extension of the eligible instruments in a Generalized Method of Moments (GMM) context, is designed for 'small T, large N' panels which is not the present work's case. Furthermore, GMM using many overidentifying restrictions are also known to have poor finite sample properties. Notwithstanding, for robustness check purposes we make use of the bias corrected least-squares dummy

[42] The exact asymptotic bias is given by $-\frac{1+\beta}{T-1}(1-\frac{(1-\beta^T)}{T(1-\beta)}\left[1-\frac{2\beta}{(1-\beta)(T-1)}(1-\frac{(1-\beta^T)}{T(1-\beta)}\right]^{-1}$

variable estimator[43] that applies the bias approximations of Bruno (2005), who extends the previous work of Bun & Kiviet (2003), Kiviet (1999), and Kiviet (1995). The positive bias correction lies between 3.5% and 5.2%, around our previous estimate of the Nickell's bias.

TABLE C - 5 – BIAS-CORRECTED LEAST SQUARES DUMMY VARIABLE MODEL

	AR Coef.	z Stat	P>|z|
Bias-corrected LSDV ah	0.60	30.69	0.000
Bias-corrected LSDV bb	0.61	32.32	0.000

Notes: All countries; initialization using Anderson and Hsiao estimator (ah) and Blundell and Bond estimator (bb); bias correction up to order O(1/T); bootstrapped standard errors based on 50 repetitions.

Hahn and Kuersteiner (2002) derive an alternative bias-corrected estimator[44] for the case of a simple AR(1) model with fixed effects in the case of large T and large N, such that lim(N/T) is finite. The estimator reduces to adjusting the fixed effect estimator by multiplying it by (T+1)/T and adding (1/T). Applying such adjustment, we obtain an estimate of the AR parameter of 0.60, identical to bias corrected LSDV initialized using the Anderson and Hsiao estimator.

[43] This estimator requires the specification of a consistent estimator to initialize the bias correction, such as the Anderson-Hsiao, the Arellano-Bond or the Blundell-Bond.
[44] This estimator is asymptotically efficient as N, T $\rightarrow\infty$ at the same rate under the assumption of normality of the disturbances.