Interest rate changes and stock returns: a European multi-country study with wavelets

R. Ferrer, V. J. Bolós, R. Benítez,

   e-mail: roman.ferrer@uv.es

   e-mail: vicente.bolos@uv.es

3 Dpto. Matemáticas, Centro Universitario de Plasencia, Universidad de Extremadura. Avda. Virgen del Puerto 2, 10600 Plasencia (Cáceres), Spain.
   e-mail: rbenitez@unex.es

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Abstract

This paper investigates the linkage between changes in 10-year government bond yields and stock returns for the major European countries in the time-frequency domain by using a number of cross-wavelet tools in the framework of the continuous wavelet transform, mainly the wavelet coherence and phase-difference. The results reveal that the degree of connection between 10-year bond rate movements and stock returns differs considerably among countries and also varies over time and depending on the time horizon considered. In particular, the UK shows the greatest interdependence between long-term interest rates and equity returns across time and frequencies, while the relationship is much weaker for several peripheral European countries such as Portugal, Ireland and Greece. The highest level of connection is observed for most countries since the onset of the recent global financial crisis. In addition, the significant linkage is mainly concentrated at investment horizons from one to two years.

1 Introduction

Understanding interrelations between interest rates and stock prices is important for investors, portfolio managers, corporate managers and policy makers as it has critical implications for different areas of finance such as asset allocation, portfolio management, risk management and monetary policy transmission. The link between changes in interest rates and stock returns is based on financial theory. Indeed, modern financial theory postulates that any firm generates a stream of future cash flows and the stock value of that firm is equal to the present value of all expected future cash flows discounted at the appropriate discount rate. In general, interest rates impact stock prices through two basic channels. Firstly, movements in interest rates have a direct effect on the discount rate used in standard equity valuation models. Secondly, interest rate changes affect firms’ expectations about future cash
flows by altering the cost of borrowing. Accordingly, it is expected that interest rates will be a significant determinant of stock prices.

An extensive literature has investigated the relationship between interest rate fluctuations and stock returns. This body of work is principally focused on the time domain and the time series methods applied range from standard OLS regression to more sophisticated techniques such as cointegration, Granger causality or vector autoregressive (VAR) models. However, little attention has been devoted to the influence of a potentially relevant feature such as the investment horizon on the interest rate-stock market nexus. Financial markets like stock and bond markets are complex systems consisting of thousands of heterogeneous agents operating over different time horizons which range from seconds to years, who collectively determine aggregate market behavior. For instance, agents with very short investment horizons, such as chartists or day traders, are typically linked to speculative activity and their decisions are largely based on ephemeral phenomena such as sporadic events, market sentiment or psychological factors. On the opposite side, agents with long time horizons, such as fundamentalists or big institutional investors, are more involved in investment activity and follow more closely macroeconomic fundamentals. Therefore, it is not unreasonable to think that the degree of connection between interest rates and stock prices may vary across frequencies associated with different investment horizons of market participants. In such a case, the wavelet methodology appears as a very attractive alternative that takes into account both time and frequency domains simultaneously. Wavelet analysis is a comparatively new, at least in finance, and powerful tool for signal processing which offers a unique opportunity to study the interdependence between economic time series in the time-frequency space, providing a deeper understanding of possible dependencies than time domain methods, which aggregate all time horizons together.

The aim of this paper is to examine the interactions between changes in 10-year government bond yields and stock returns for the major European countries over time and across frequencies by using several cross-wavelet tools based on the continuous wavelet transform. The main research question of this study is to determine whether the connection between 10-year bond rate fluctuations and equity returns of a set of European countries changes significantly over time and/or across different investment horizons. A priori we expect that this relationship will be stronger at long investment horizons because stock prices are more likely to better reflect market fundamentals, such as interest rates, on longer time frames. However, at shorter horizons the linkage may be obscured by short-term noise caused by transitory factors.

This work contributes to the existing literature in several ways. First, to the best of our knowledge, this study is the first to apply continuous wavelet tools to analyze the interest rate-stock market at multiple investment horizons in a multi-country setting. Second, this research combines standard cross-wavelet techniques such as the wavelet coherence and phase-difference with the development of novel tools based on the wavelet coherence in an attempt to get a better insight into the connection between these variables. Third, by covering a relatively long time period, this study allows us to determine whether major economic events such as the introduction of the euro in 1999 or the international financial crisis which started in the summer of 2007 have significantly altered the extent of linkage between long-term interest rates and equity markets.

Our results indicate not only that the connection between movements in yields on 10-year sovereign bonds and stock markets is not uniform across countries, but also that it varies significantly over time and across time horizons. In particular, the UK is identified as the country with the strongest interdependence between long-term bond yields and equity returns, followed by Germany, France, the Netherlands and Spain. In contrast, this linkage is much weaker for several peripheral European countries such as Portugal, Ireland and Greece. For most countries the linkage between government bond yields and equity markets increases since the beginning of the recent global financial crisis. The positive sign of this relationship suggests that 10-year bond rates and stock prices have tended to move in the
same direction over the past few years, probably following economic prospects. This positive association may also have been partly driven by flight-to-quality effects from stocks towards long-term government bonds of European countries with stronger economic fundamentals and higher credit rating. In addition, the significant interest rate-equity market link is mainly concentrated at investment horizons from one to two years.

The rest of the article proceeds as follows. Section 2 briefly reviews the relevant related literature. Section 3 introduces the wavelet methodology and the continuous cross-wavelet tools used to characterize the linkage between changes in long-term interest rates and equity markets. Section 4 describes the dataset employed. Section 5 reports and discusses the main empirical findings and Section 6 concludes.

2 Literature review

An important body of research has been developed over the past few decades to investigate the relationship between changes in interest rates and stock returns. The bulk of this literature has concentrated on the banking industry due to the particularly interest rate sensitive nature of the financial intermediation business. In fact, a large proportion of income and expenses of banks is directly dependent on interest rates. Specifically, the typical maturity mismatch or duration gap between banks’ financial assets and liabilities resulting from the maturity transformation function of banking institutions (i.e. the financing of long-term loans with short-term deposits) is the most commonly cited reason for the interest rate sensitivity of these firms [1–3]. This positive duration gap (the average duration of banks’ assets exceeds the average duration of banks’ liabilities) implies that rises in interest rates have a detrimental effect on banks’ value and vice versa. This occurs because when interest rates increase, the present value of banks’ assets falls more than that of banks’ liabilities and also the costs of banks’ liabilities rise faster than the yields on banks’ assets.

Nevertheless, movements in interest rates may also exert a significant influence on the value of non-financial corporations through various channels. Firstly, hikes in interest rates increase debt service payments of firms and can also reduce the demand for products by heavily indebted consumers, which means lower corporate profits and has a negative impact on share prices. Secondly, within the framework of dividend discount models rises in interest rates increase the cost of capital. This causes an increase of the discount rate used by investors and reduces the present value of future cash flows, thereby adversely affecting companies’ equity prices. Thirdly, changes in interest rates alter the market value of financial assets and liabilities held by non-financial firms. Finally, interest rate fluctuations can favour the implementation of portfolio rebalancing strategies. As yields on fixed-income securities decline, investors may shift into equities in search of higher yields, increasing demand for equities and therefore their prices. Regarding non-financial firms, regulated and/or highly indebted industries such as Utilities, Real Estate, Telecommunications and Basic Resources are typically recognized as the most interest rate sensitive [4–6].

All these reasons suggest an inverse connection between interest rate fluctuations and equity returns. A positive link is, however, also possible because interest rates and stock prices can move in the same direction following changes in macroeconomic factors such as inflationary expectations or economic prospects. The flight-to-quality effects from stocks to bonds in an environment of increased financial uncertainty, such as that in force during the recent global financial crisis, may also contribute to the emergence of a positive relationship. Flight-to-quality occurs in times of financial turmoil as investors move capital away from stocks toward safer investments such as government bonds. This process leads to a dramatic decrease in the yield on long-term government bonds because of the big increase in the demand for this type of securities and generates a positive correlation between changes in yields on sovereign bonds and stock returns.

Early studies in this field provided evidence of a significant negative relationship between changes in interest rates and stock returns of both financial and non-financial firms [7–9].
However, some more recent works, such as those of [4,5,10], show that this relationship does not remain constant over time. In fact, the interest rate-equity market link seems to show a downward trend over the last years, mainly due to the increased availability of improved tools for managing interest rate risk. More specifically, the spectacular growth in interest rate derivative markets and the expansion of European corporate bond markets as a result of the euro’s adoption may have played a key role in this respect. In addition, firms’ stock returns tend to be more closely linked with movements in long-term interest rates than to short-term rates [11–14].

So far, most of the empirical research on the interest rate-stock market link has been conducted in the time domain. Specifically, a wide range of time series methods has been utilized, including linear regression [4–6], VAR techniques [15–17], cointegration analysis [18–20], Granger causality tests [21–23], nonlinear models [11,12,24], and GARCH (generalized autoregressive conditional heteroscedasticity) models [1,25,26]. One obvious limitation of these approaches is that they are restricted to one or at most two time scales, i.e. the short run and the long run.

Nonetheless, there are a few recent papers investigating the interest rate-stock market nexus through wavelet methods. For instance, [27], [28] and [29] explore the multi-scale relationship between movements in interest rates and stock returns by using the maximal overlap discrete wavelet transform, a variant of the discrete wavelet transform widely utilized in economic applications of wavelet analysis. These studies focus on aggregate equity markets of different countries and show that the linkage between interest rate fluctuations and stock market differs from country to country and is dependent on the time horizon considered. In turn, [30] is so far the only work that explores the existence of Granger causality between interest rates and share prices across different frequencies using a continuous wavelet approach. He concludes that causal relations between both variables in the Indian economy vary significantly over time and across frequencies.

It is also possible to find a number of studies examining the relationship between interest rate changes and equity returns from an international perspective [4,13,31]. These works detect significant variations in interest rate sensitivity across countries and over time, although they do not take into account the possible effect of the investment horizon. However, no previous research has used continuous cross-wavelet tools to assess the interest rate-stock market nexus in a multi-country framework.

3 Methodology

Wavelet analysis is a powerful mathematical tool for signal processing in the time-frequency domain that overcomes the main limitations of the Fourier transform [32]. Due to its flexibility, wavelet analysis is extensively used in disciplines such as geophysics, medicine, climatology or astronomy, although its application in economics and finance is a relatively new phenomenon [33–35].

A wavelet is a small “wave packet” that grows and decays in a limited time period. It is given by a function $\psi$ in $L^2(\mathbb{R})$ centered at the origin (more or less), with zero average and normalized. A family of daughter wavelets $\psi_{u,s}(t)$ can be obtained by simply scaling and translating $\psi$:

$$\psi_{u,s}(t) := \frac{1}{\sqrt{s}} \psi \left( \frac{t-u}{s} \right),$$

where $s$ is a scaling parameter that controls the length of the wavelet, and $u$ is a location parameter that indicates where the wavelet is centered. Given a signal $x(t)$ in $L^2(\mathbb{R})$, its continuous wavelet transform CWT with respect to the wavelet $\psi$ is a function of two variables

$$W_x(u,s) := \int_{-\infty}^{+\infty} x(t) \psi^*_u(t) \, dt,$$
where \(^*\) denotes complex conjugation. It represents the frequency components (or details) of \(x(t)\) corresponding to the scale \(s\) and time location \(u\), providing a continuous time-frequency decomposition of \(x(t)\), while the \textit{discrete wavelet transform} (DWT) uses a specific subset of discrete scale and location values.

By its very nature, the CWT contains a large amount of redundant information on the original signal that makes it much easier to interpret the empirical results as it provides a more visually intuitive output. As argued by [46], the CWT is better for feature extraction purposes, while the DWT is more useful for multiresolution analysis, particularly for noise reduction and data compression. For a long time, the discrete wavelet analysis has prevailed in economic research [37–41] due to its greater simplicity and more parsimonious nature. However, in recent years the continuous wavelet analysis has also become very popular in the economic-finance literature [42–45]. One of the major benefits of the CWT is its ability to describe localized co-movement between two time series in the time-frequency space through the use of cross-wavelet tools.

Several types of wavelet families with different characteristics are available in the literature. The application presented here utilizes the Morlet wavelet because it is the most commonly used wavelet and implies a very simple inverse relationship between scale and frequency. Moreover, the Morlet wavelet is a complex wavelet that can be decomposed into real and imaginary parts. This feature allows separation of amplitude and phase of the signal under study, providing more information about synchronization and delays between two time series. The Morlet wavelet was introduced by [46] and can be defined as \(\psi(t) = \pi^{-1/4} e^{i\omega_0 t} e^{-t^2/2}\), where \(\omega_0\) denotes the central frequency of the wavelet. We set \(\omega_0 = 6\) since this choice provides a good balance between time and frequency localization and it is very often employed in economic and financial applications [42].

In order to detect and quantify relationships between time series, two cross-wavelet tools, introduced by [47] within the framework of the CWT, can be used, namely the \textit{wavelet coherence} and \textit{wavelet phase-difference}. According to [48], the \textit{wavelet coherence} between two time series \(x(t)\) and \(y(t)\) is defined by

\[
R^2(u,s) = \frac{|S(s^{-1}W_{xy}(u,s))|^2}{S(s^{-1}|W_x(u,s)|^2) S(s^{-1}|W_y(u,s)|^2)}, \tag{3}
\]

where \(W_{xy}(u,s) := W_x(u,s)\overline{W_y(u,s)}\) is the \textit{cross-wavelet spectrum} (\(^*\) indicates the complex conjugate), and \(S\) is a smoothing operator in both time and frequency. The wavelet coherence \((\text{3})\) ranges from 0 (no correlation) to 1 (perfect correlation) and is analogous to the squared correlation coefficient in linear regression. This concept is particularly useful for determining the regions in the time-frequency domain where two time series have a significant co-movement or interdependence.

In spite of its usefulness for measuring the strength of the linkage between any two time series in the time-frequency space, the wavelet coherence is able neither to determine the sign of this link nor to identify lead-lag relations between the two series. This problem can be solved by using the \textit{wavelet phase-difference}, which characterizes possible delays in the oscillations between the two series, providing information on lead-lag effects as well as the sign of the association. Following [48], the phase-difference is defined by

\[
\phi_{xy}(u,s) = \tan^{-1} \left( \frac{\Im \{S(s^{-1}W_{xy}(u,s))\}}{\Re \{S(s^{-1}W_{xy}(u,s))\}} \right), \tag{4}
\]

where \(\Re\) and \(\Im\) represent the real and imaginary parts, respectively.

The phase information is graphically displayed on the same figure that the wavelet coherence by plotting arrows inside the regions characterized by high coherence. A phase-difference of zero indicates that the two time series move together at the specified frequency. Arrows point to the right (left) when the two time series are in phase (anti-phase). When the two series are in phase, they move in the same direction. Anti-phase means that the two series
move in the opposite direction. Arrows pointing up suggest that the first time series leads the second one, while arrows pointing down indicate that the second series leads the first one.

In addition, three novel cross-wavelet tools which complement the graphic information provided by the wavelet coherence and, therefore, allow gaining a more complete insight into the interconnection between time series are proposed in this study. For defining these tools, it is convenient to re-scale the wavelet coherence using base 2 power scales

$$R_{\text{base2}}^2(u, k) := R^2(u, 2^k),$$  \hspace{1cm} (5)

where $k$ is the binary logarithm of the original scale variable $s$, called log-scale. The reason for this change of variable lies in the fact that the family of dyadic wavelets is an orthonormal basis of $L^2(\mathbb{R})$ (see [49]) and so, the “natural” variable for the scale should be $k$ instead of $s$.

Firstly, the percentage of total volume (PTV) of the wavelet coherence summarizes in a simple number the degree of coherence between the time series under study in a given range of times and log-scales. It is, in fact, the average of the wavelet coherence (5) re-scaled from 0 to 100 and is given by

$$\text{PTV} := \frac{100}{(u_1 - u_0)(k_1 - k_0)} \int_{k_0}^{k_1} \int_{u_0}^{u_1} R_{\text{base2}}^2(u, k) \, du \, dk,$$  \hspace{1cm} (6)

where $[u_0, u_1] \times [k_0, k_1]$ determines the range of times and log-scales that we are interested in studying (note that the range of scales is in fact $[2^{k_0}, 2^{k_1}]$).

Secondly, as its name suggests, the percentage of significant area (PSA) of the wavelet coherence measures the proportion of the area in $[u_0, u_1] \times [k_0, k_1]$ which is statistically significant at a given level of significance over the total area, and is given by

$$\text{PSA} := \frac{100}{(u_1 - u_0)(k_1 - k_0)} \int_{k_0}^{k_1} \int_{u_0}^{u_1} \chi_{\text{level}}(u, k) \, du \, dk,$$  \hspace{1cm} (7)

where $\chi_{\text{level}}$ is the characteristic function of the corresponding significance level set.

Thirdly, the percentage of significant volume (PSV) of the wavelet coherence is a mixture of these two concepts, and is given by

$$\text{PSV} := \frac{100}{(u_1 - u_0)(k_1 - k_0)} \int_{k_0}^{k_1} \int_{u_0}^{u_1} R_{\text{base2}}^2(u, k) \chi_{\text{level}}(u, k) \, du \, dk.$$  \hspace{1cm} (8)

The CWT applied to finite length time series inevitably suffers from boundary problems as its computation close to the edge of the signal involves nonexistent values. Although there are a number of methods for dealing with these edge effects, all of them produce artificial wavelet coefficients at the borders [49]. In this context, the cone of influence delimits the region of the wavelet spectrum which is influenced by edge effects. Outside the cone of influence edge effects become important and values should be interpreted with great caution [47].

All these three novel measures can be computed inside the cone of influence by simply multiplying the integrands by the characteristic function of the interior of the cone of influence, $\chi_{\text{Col}}$, and substituting the denominator $(u_1 - u_0)(k_1 - k_0)$ by the area of the interior of the cone of influence. For example, the PTV inside the cone of influence is given by

$$\text{PTV}_{\text{Col}} := \frac{100}{\text{AreaCol}} \int_{k_0}^{k_1} \int_{u_0}^{u_1} R_{\text{base2}}^2(u, k) \chi_{\text{Col}}(u, k) \, du \, dk,$$  \hspace{1cm} (9)

where $\text{AreaCol} := \int_{k_0}^{k_1} \int_{u_0}^{u_1} \chi_{\text{Col}}(u, k) \, du \, dk$. 

6
4 Data description

Our dataset consists of yields on 10-year government bonds and stock market indices of ten European countries (Germany, the UK, France, Italy, Spain, the Netherlands, Finland, Ireland, Portugal and Greece) from January 1993 to December 2012. The starting date of the analysis is January 1993 for two main reasons. First, this choice enables us to avoid possible distortions in the results on the interest rate-stock market nexus caused by turbulences in stock and bond markets within the framework of the crisis of the Exchange Rate Mechanism (ERM) of the European Monetary System (EMS) during the second half of 1992. In essence, the ERM crisis was linked to strong exchange rate pressures which culminated with the exit of the Italian lira and the British pound from the EMS in September 1992. Thus, given that the key role of exchange rate risk during this crisis might lead to a misperception of the real connection between interest rates and stock returns, we have decided to begin the sample period in 1993. Second, the lack of reliable data or even the non-existence of government bond data in the period prior to 1993 for several countries, especially Greece, Portugal and Spain. The stock indices considered are the DAX 30 (Germany), FTSE 100 (UK), CAC 40 (France), FTSE MIB (Italy), IBEX 35 (Spain), AEX (Netherlands), OMXH (Finland), ISEQ (Ireland), PSI 20 (Portugal) and FTSE ATHEX 20 (Greece).

The use of the 10-year government bond yield as a proxy of long-term interest rates has become increasingly popular in the literature on the linkage between interest rates and stock prices [1, 24, 50]. This choice is supported by the following arguments. First, 10-year interest rates incorporate market expectations about future prospects for the economy and determine to a large extent the cost of borrowing funds. Thus, long-term rates are likely to have a critical influence on investment decisions and profitability of firms and, hence, on their stock market performance. Second, long-term government bonds are often viewed as closer maturity substitutes to stocks, which may presumably increase the degree of linkage between both financial assets. All data series are drawn from Thomson Financial Datastream.

In line with, among others, [8], [50] and [14], weekly data series (sampled on Wednesdays) are employed (a total of 1044 observations). Weekly frequency is preferred to daily and monthly frequencies for several reasons. Firstly, daily data are more contaminated by noise and anomalies such as day-of-the-week effects or non-synchronous trading bias than weekly observations. Secondly, compared to monthly data the weekly frequency provides a number of observations large enough to yield more reliable results. Stock returns for each country are calculated as the first log difference of stock price indices. Changes in 10-year sovereign bond yields are obtained as the first difference in the level of bond yields between two consecutive observations.

Table 1 presents some common descriptive statistics for the variables. The average weekly stock return over the whole sample period is positive but very small for all equity markets. The average weekly change in 10-year government bond rates is very close to zero in all cases. Standard deviations reveal, as expected, that movements in yields on 10-year bonds have lower volatility than stock returns for all countries. The sign of skewness varies, although it tends to be negative for equity returns and positive for 10-year bond rate fluctuations. Furthermore, all the series have positive kurtosis coefficients in excess of three, suggesting the existence of heavy tails compared to a normal distribution. The Jarque-Bera statistics confirm this result, rejecting the null hypothesis of normality for stock returns and changes in 10-year bond rates of all countries at the 1% significance level. In order to determine the order of integration of the series, the standard Phillips-Perron (PP) unit root test and the Kwiatkowski-Phillips-Schmidt-Shin (KPSS) stationarity test are conducted. Both tests indicate that all the series of stock returns and movements in yields on 10-year bonds are stationary (integrated of order zero) at the 1% level.
Table 1: Descriptive statistics of stock returns and changes in yields on 10-year government bonds. This table reports descriptive statistics for weekly stock returns and changes in 10-year government bond yields of each country. The sample period is between January 1993 and December 2012. They include mean, median, standard deviation (Std. Dev.), minimum (Min.) and maximum (Max.) values, as well as Skewness and Kurtosis measures. JB refers to the statistic of the Jarque-Bera test for normality. The last three columns present the statistics of the Phillips-Perron (PP) unit root test and the KPSS stationarity test, respectively. *, **, *** indicate statistical significance at the 10%, 5% and 1% level, respectively.
5 Empirical results

Figures 1 and 2 display the graphs of the estimated wavelet coherence and phase-difference between changes in yields on 10-year government bonds and stock returns for each country.

Following standard practice in the literature, the wavelet coherence is presented by using contour plots as it involves three dimensions: frequency, time and wavelet coherence power. Frequency and time are represented on the vertical and horizontal axes, respectively. With the aim of easing interpretation, the frequency is converted into time units (years) and it ranges from the highest frequency of one week (top of the plot) to the lowest frequency of four years (bottom of the plot). The wavelet coherence is depicted by a gray scale and the extent of coherence is interpreted in terms of the intensity of the gray color. Thus, the shades for wavelet coherence range from white (low values) to dark gray (high values). The thin black line represents the cone of influence below which edge effects become important. Hence, values outside the cone of influence should be interpreted very carefully. The thick black line isolates regions where the wavelet coherence is significant at the 5% level.

Since the theoretical distribution of the wavelet coherence is not known in general, the statistical significance is usually assessed by using Monte Carlo simulation methods. For example, [48] generate 10000 pairs of white noise time series with the same length as the original samples. In our case, we use normally distributed time series (concretely 1000 pairs) because the samples resemble more closely to follow a normal distribution. Moreover, the variances of the generated time series affect slightly to the computation of the wavelet power spectra and, consequently, to the wavelet coherency. Although the differences are not relevant, we use time series with the same variances as the original samples because it provides a bit more accurate result and the computational cost is identical.

As mentioned earlier, the phase-difference is a complementary tool to the wavelet coherence. In essence, it enables studying possible lead-lag effects between 10-year bond rate fluctuations and stock returns in the time-frequency domain and also gives us the sign of the link between both variables. Phase information is indicated by arrows on the wavelet coherence plots. Horizontal (or close to horizontal) arrows imply that there is no lead-lag relationships.

The results of the wavelet coherence analysis show that the connection strength between movements in 10-year government bond yields and equity returns varies from country to country and also differs widely over time and across investment horizons. In particular, the highest degree of linkage between 10-year bond rate changes and stock returns is observed in the UK. Two reasons help to explain this finding. First, the British stock exchange is a highly developed equity market with a significant level of maturity, in which a large proportion of market participants have rational expectations and use all information available to them. This results in that stock prices tend to follow closely, with the only exception of shorter investment horizons which are more influenced by noise, fundamentals like long-term interest rates. Second, the fact that the Bank of England has traditionally had a greater real economy orientation, characterized by more aggressive and forceful monetary policy actions aimed at influencing economic growth, than the European Central Bank (ECB) may also play a role in the close linkage between yields on 10-year bonds and equity market. As is well known, the monetary policy of the ECB is conducted on the basis of the entire euro area. This means that the ECB is constrained in its decisions because it must strike a balance among competing interests from different member states with very diverse macroeconomic conditions. Thus, the more rigid and conservative operating framework of the ECB may be behind the lower interest rate-stock market nexus in Eurozone countries. The evidence of a strong interdependence between interest rates and equity prices in the UK presented here is

*All computations in this study have been performed by using a slightly modified version of the wavelet MatLab program written by C. Torrence and G. P. Compo available at http://paos.colorado.edu/research/wavelets/. As described below, the difference with the original program of Torrence and Compo lies in the Monte Carlo simulation employed for the estimation of the statistical significance level of the wavelet coherence.
in line with the results of [51], [31] and [14].

As can be seen in Figure 1, the interest rate-stock market link in the UK is consistent over the entire sample period, although it tends to be stronger in times of market turmoil such as the bond market turbulence of 1994 or, especially, the recent global financial crisis that began in the summer of 2007. It is also found that the significant linkage between movements in 10-year bond yields and equity returns is mainly concentrated at investment horizons from one to two years, while for horizons of less than a month and a half the connection is very weak. This result is in line with the widely accepted notion that investors with long-term horizons are more likely to follow macroeconomic fundamentals such as long-term interest rates than investors with a shorter time frame. The phase information indicates that the relationship between 10-year bond yield fluctuations and stock returns in the UK has undergone a remarkable change during the period of study. This connection is negative until the late-1990s and stock returns lead changes in 10-year bond rates, while the association becomes positive since the early 2000s and stock returns also lead interest rate fluctuations.

A set of core Eurozone countries, including Germany, France, the Netherlands and, to a lesser extent, Finland, also display a significant linkage between 10-year bond yields and stock returns during some specific time periods and frequencies. In particular, the interest rate-stock market nexus in these countries is more pronounced from the beginning of the global financial crisis in 2007. The sign of this relationship is generally positive, indicating that 10-year bond rates and equity prices have moved in the same direction during recent years. This positive association shows that the historically low levels of interest rates over the last few years have not been able to boost European stock markets, highlighting the severity of the global financial crisis. One possible explanation for this finding is that both long-term government bond and stock markets have been primarily driven by the economic outlook. Furthermore, flight-to-quality episodes from stocks into less risky assets such as government bonds of safer European economies, within which these core Eurozone countries occupy a central role, during the recent international financial crisis may also have favoured this positive linkage. Nevertheless, there does not seem to be clear lead-lag effects between changes in yields on 10-year bonds and stock returns in these countries. In addition, most of the significant association between both variables is also observed in the frequency band from one to two years.

Interestingly, Italy and Spain exhibit a similar pattern of connection between yields on 10-year bonds and stock returns, although the level of linkage seems to be a little higher in Spain. The greatest interdependence is detected in both countries in the run-up to the launch of the euro. Specifically, in the pre-euro era the correlation is negative and equity returns seem to lead changes in 10-year bond rates in the two countries. This finding suggests that Italian and Spanish stock markets anticipated the beneficial impact on their respective economies resulting from sharp drops in long-term interest rates during the 1990s within the framework of the European convergence process. Furthermore, the significant interest rate-stock market link is concentrated at time horizons from three months to one year.

Another striking result is the low interdependence between 10-year government bond yields and equity returns for Portugal, Ireland and, to a lesser degree, Greece across most frequencies and time periods. This lack of connection may be attributed to the fact that stock exchanges of these countries are characterized by low liquidity, thin trading and relatively small capitalization, which leads to an idiosyncratic equity market performance in comparison with core Eurozone countries and causes the interest rate-stock market link to be very weak in these countries. Furthermore, from the onset of the global financial crisis in 2007 and especially since the outbreak of the European sovereign debt crisis in late 2009, equity prices in these peripheral countries have primarily reflected very poor economic prospects. Interest rate risk has played, by contrast, a marginal role in explaining the behavior of stock markets of these economies in recent years. As a matter of fact, precisely these three countries were
Figure 1: Wavelet coherence and phase-difference. The thick black contour denotes the 5% significance level of the wavelet coherence estimated from Monte Carlo simulations. The cone of influence is shown with a light black line. The phase-difference between interest rate changes and stock returns is indicated by black arrows.
Figure 2: Wavelet coherence and phase-difference. The thick black contour denotes the 5% significance level of the wavelet coherence estimated from Monte Carlo simulations. The cone of influence is shown with a light black line. The phase-difference between interest rate changes and stock returns is indicated by black arrows.
finally bailed out by the European Union and International Monetary Fund from 2010.

Next, the clear evidence of a time-varying interest rate-stock market link provided by the wavelet coherence is complemented by a sub-period analysis in Tables 2 and 3. These tables report the values of two of the new cross-wavelet tools based on the concept of wavelet coherence introduced in the methodology section. Specifically, Table 2 shows the PTV of the wavelet coherence within the cone of influence for the entire sample period as well as three sub-periods, namely the pre-euro (January 1993-December 1998), post-euro (January 1999-July 2007) and global financial crisis (August 2007-December 2012) periods, for each country. In turn, Table 3 presents the PSA at the 5% level of the wavelet coherence within the cone of influence for the full period and the three sub-periods for the different countries.†‡

Naturally, given that these novel wavelet tools are summary measures of the wavelet coherence, the results in Tables 2 and 3 corroborate the findings of the wavelet coherence analysis with regard to the time evolution of the linkage between changes in yields on 10-year government bonds and stock returns. Therefore, for most countries the greater degree of connection between long-term government bond and stock markets occurs during the period of the recent global financial crisis. However, an important interest rate-stock market link is also identified in the run-up to the euro adoption for some countries, mainly Italy and Spain. In contrast, the lower interdependence between both markets is found, with very few exceptions, in the period immediately after the launch of the euro, probably as a result of the marked reduction in the level and volatility of interest rates caused by the introduction of the euro.†

<table>
<thead>
<tr>
<th>Country</th>
<th>Whole sample period</th>
<th>Pre-euro sub-period</th>
<th>Post-euro sub-period</th>
<th>Global financial crisis sub-period</th>
</tr>
</thead>
<tbody>
<tr>
<td>Germany</td>
<td>44.03%</td>
<td>39.61%</td>
<td>41.84%</td>
<td>53.96%</td>
</tr>
<tr>
<td>UK</td>
<td>45.68%</td>
<td>47.38%</td>
<td>43.05%</td>
<td>49.47%</td>
</tr>
<tr>
<td>France</td>
<td>41.30%</td>
<td>43.93%</td>
<td>38.56%</td>
<td>44.28%</td>
</tr>
<tr>
<td>Italy</td>
<td>38.79%</td>
<td>46.58%</td>
<td>34.42%</td>
<td>39.52%</td>
</tr>
<tr>
<td>Spain</td>
<td>38.24%</td>
<td>47.41%</td>
<td>34.79%</td>
<td>35.29%</td>
</tr>
<tr>
<td>Netherlands</td>
<td>40.79%</td>
<td>42.57%</td>
<td>37.77%</td>
<td>45.40%</td>
</tr>
<tr>
<td>Finland</td>
<td>37.61%</td>
<td>34.31%</td>
<td>37.01%</td>
<td>42.71%</td>
</tr>
<tr>
<td>Ireland</td>
<td>32.22%</td>
<td>35.74%</td>
<td>29.67%</td>
<td>33.79%</td>
</tr>
<tr>
<td>Greece</td>
<td>35.51%</td>
<td>-</td>
<td>36.53%</td>
<td>33.73%</td>
</tr>
<tr>
<td>Portugal</td>
<td>32.61%</td>
<td>34.37%</td>
<td>30.50%</td>
<td>35.41%</td>
</tr>
</tbody>
</table>

Table 2: Percentage of total volume (PTV) of the wavelet coherence for each country. This table presents the values of the PTV of the wavelet coherence between changes in yields on 10-year government bonds and stock returns inside the cone of influence for the full sample period as well as the pre-euro (January 1993-December 1998), post-euro (January 1999-July 2007) and global financial crisis (August 2007-December 2012) sub-periods for each country.

Finally, in order to provide a more detailed picture of the changing nature over time and across frequencies of the association between 10-year bond rate movements and equity returns, Figure 3 shows the rolling window estimation of the PTV of the wavelet coherence for different frequency bands for some of the countries with a more significant connection (the UK, Germany, France and Spain). In particular, a window of fixed size equal to one

†The results for Greece in the pre-euro sub-period are not presented in Tables 2 and 3 as data on yields on Greek 10-year government bonds start from April 1999.
‡The values of the PSV at the 5% level of the wavelet coherence inside the cone of influence are virtually identical to those reported in Table 3. For the sake of brevity, the results of this cross-wavelet tool are not presented here, but they are available upon request from the authors.
<table>
<thead>
<tr>
<th>Country</th>
<th>Whole sample period</th>
<th>Pre-euro sub-period</th>
<th>Post-euro sub-period</th>
<th>Global financial crisis sub-period</th>
</tr>
</thead>
<tbody>
<tr>
<td>Germany</td>
<td>14.54%</td>
<td>11.59%</td>
<td>9.49%</td>
<td>29.11%</td>
</tr>
<tr>
<td>UK</td>
<td>18.73%</td>
<td>23.46%</td>
<td>14.55%</td>
<td>22.48%</td>
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<tr>
<td>France</td>
<td>12.15%</td>
<td>14.67%</td>
<td>8.62%</td>
<td>16.98%</td>
</tr>
<tr>
<td>Italy</td>
<td>11.47%</td>
<td>21.28%</td>
<td>6.36%</td>
<td>11.44%</td>
</tr>
<tr>
<td>Spain</td>
<td>13.07%</td>
<td>26.70%</td>
<td>7.27%</td>
<td>10.17%</td>
</tr>
<tr>
<td>Netherlands</td>
<td>11.39%</td>
<td>13.62%</td>
<td>8.01%</td>
<td>16.26%</td>
</tr>
<tr>
<td>Finland</td>
<td>9.82%</td>
<td>8.06%</td>
<td>7.24%</td>
<td>17.48%</td>
</tr>
<tr>
<td>Ireland</td>
<td>5.25%</td>
<td>8.02%</td>
<td>2.97%</td>
<td>7.09%</td>
</tr>
<tr>
<td>Greece</td>
<td>8.38%</td>
<td>-</td>
<td>9.24%</td>
<td>6.87%</td>
</tr>
<tr>
<td>Portugal</td>
<td>4.79%</td>
<td>5.22%</td>
<td>2.31%</td>
<td>9.74%</td>
</tr>
</tbody>
</table>

Table 3: Percentage of significant area (PSA) of the wavelet coherence for each country. This table reports the values of the PSA at the 5% level of the wavelet coherence between changes in yields on 10-year government bonds and stock returns inside the cone of influence for the full sample period as well as the pre-euro (January 1993-December 1998), post-euro (January 1999-July 2007) and global financial crisis (August 2007-December 2012) sub-periods for each country.

Year is used and three frequency bands are considered to determine the specific time horizons in which the interest rate-stock market linkage is closer: from two weeks to one month and a half, from one month and a half to one year, and from one to two years. The plots in Figure 3 confirm that the strongest relationship between 10-year bond yields and stock returns is found in the frequency band from one to two years, with the only exception of Spain. Furthermore, it is again observed that the connection strength between both markets tends to be higher from the outset of the global financial crisis in 2007, except in the Spanish case. In fact, Spain exhibits a peculiar behavior in terms of the interest rate-stock market link by which the greater connection is confined to the pre-euro era. Instead, the linkage is extremely weak during the recent financial crisis period, reflecting that the key driver of the Spanish stock market over the last few years has been the poor economic outlook and not the behavior of interest rates.

Interestingly, the time interval between the end of 2002 and the first quarter of 2003 is characterized by a highly significant interest rate-stock market nexus at shorter horizons (from two weeks to one month and a half) for all these countries. This period is marked by the confluence of the dramatic decline in stock prices after the bursting of the dotcom bubble in 2000, the terrorist attack on the US on September 11, 2001, and geopolitical tensions in the Middle East, and the sharp fall in interest rates to record lows for the last forty years. Therefore, it is not surprising to find a significant positive association between long-term government bond and stock markets in such a scenario.

## 6 Conclusions

This paper investigates the linkage between changes in yields on 10-year government bonds and stock returns for the largest European countries in the time-frequency space by applying a number of continuous cross-wavelet tools, which include the popular wavelet coherence and phase-difference as well as several novel summary measures based on the wavelet coherence.

The empirical results show that the strength of the relationship between movements in

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1It is worth highlighting that shorter frequency bands (e.g. from two to four years) have not been considered due to the scarcity of data in these shorter bands not subject to edge effects.
Figure 3: Rolling estimates of the percentage of total volume (PTV) of the wavelet coherence for countries and frequency bands. This figure displays the rolling estimates of the PTV of the wavelet coherence between changes in 10-year government bond yields and stock returns inside the cone of influence for different frequency bands. Percentages and time are represented on the vertical and horizontal axes, respectively. A rolling window of fixed length equal to one year is employed. Dotted lines represent the rolling estimates corresponding to the frequency band from two weeks to one month and a half. Dashed lines show the rolling estimates for the frequency band from one month and a half to one year. Finally, solid lines refer to the frequency band from one to two years.
long-term sovereign bond yields and stock returns differs considerably among countries and also varies over time and depending on the investment horizon under consideration. The UK emerges as the country with greater interconnection between 10-year bond yields and equity market across time and frequencies. This finding may be explained for the high level of maturity of the British stock market and the more aggressive and proactive monetary policy stance of the Bank of England in comparison with the European Central Bank. A significant association between long-term bond yields and stock markets is also found for a group of core Eurozone countries such as Germany, France, the Netherlands and Finland, and for Spain. Instead, the linkage is very limited in Portugal, Ireland and Greece.

The highest level of connection between 10-year bond rate fluctuations and stock returns is observed for the UK and core Eurozone countries during the recent global financial crisis period. This finding is consistent with the hypothesis that interactions among financial markets tend to increase in times of financial turbulence due to the existence of significant contagion effects. The positive sign of the interest rate-stock market nexus suggests that yields on 10-year bonds and equity prices have moved together over the past few years, possibly driven by economic prospects and the flight-to-quality wave from stocks into government bonds of countries with more solid economic fundamentals. In addition, it is worth noting that the strongest linkage between changes in 10-year sovereign bond rates and stock returns is generally observed at time horizons from one to two years.

The evidence presented has important practical implications for market participants. For instance, risk-conscious investors and portfolio managers should take into account the time- and investment horizon-dependence of the interest rate-stock market nexus in their investment decisions and diversification and risk management strategies. These results can also help policy makers to gain insight into the transmission mechanism of monetary policy. Finally, this analysis shows the serious shortcomings of prior research focused on standard time series methods which do not consider the time and frequency-varying features of the interest rate-stock market link.

Acknowledgments

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References


