RELATIONSHIPS BETWEEN INTEREST RATE CHANGES AND STOCK RETURNS: INTERNATIONAL EVIDENCE USING A QUANTILE-ON-QUANTILE APPROACH

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Relationships between interest rate changes and stock returns: International evidence using a quantile-on-quantile approach

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Abstract

This paper empirically examines the linkage between changes in 10-year government bond yields and stock returns for fourteen developed countries over the period 1999-2015 using the quantile-on-quantile (QQ) approach. This methodology, recently introduced by Sim and Zhou (2015), analyzes the effect that the quantiles of interest rates have on the quantiles of stock market returns and, therefore, provides a suitable framework for capturing the overall dependence structure between interest rate fluctuations and stock returns.

The empirical results show a notable heterogeneity across countries in terms of the stock market-interest rate link. In particular, the weakest relationship between 10-year sovereign bond yield changes and equity returns is found for Australia, Germany, Netherlands, the UK and the US. In contrast, the most pronounced interest rate-stock market link is observed for the euro area peripheral countries most severely affected by the European sovereign debt crisis, i.e. Greece, Ireland, Italy, Portugal and Spain. Furthermore, the aforementioned relationship tends to be stronger during periods of major financial turmoil such as the recent global financial crisis period. On the other hand, the relationship between interest rate changes and stock market returns also differs across quantiles. In this context, for most countries, interest rates exert a higher exposition mainly during periods of extreme bearish conditions in the stock markets. Likewise, negative interest rate shocks exert a larger influence on stock markets than the positive ones, suggesting that the relationship between interest rates and equity markets is asymmetric

Keywords: *changes in interest rates, 10-year government bond yields, stock returns, quantile-on-quantile approach (QQ), quantile regression*

Contents

1. INTRODUCTION 3

2. LITERATURE REVIEW 5

3. METHODOLOGY 7

4. DATA DESCRIPTION 10

5. EMPIRICAL RESULTS 12

 5.1. Estimates of the QQ approach for full sample 12

 5.2. Estimates of the QQ approach during the global financial crisis sub-period 15

 5.3. Checking the QQ methodology 16

6. CONCLUDING REMARKS 18

7. REFERENCES 19

APPENDIX: 23

1. INTRODUCTION

The relationship between changes in interest rates and stock returns is a topic of unquestionable relevance in the financial literature given its critical role in several key areas of finance, such as asset allocation, risk management, risk diversification and transmission of monetary policy. According to financial theory, interest rates influence stock prices through several channels. First, movements in interest rates have a direct effect on the discount rate used in standard equity valuation models, with the subsequent impact on share prices. Second, interest rate fluctuations affect the cost of financing of firms, especially those with a heavy debt burden, thus impacting expected future corporate cash flows and, therefore, stock prices. Third, interest rate variations can also influence stock prices through portfolio rebalancing strategies. For example, as yields on fixed-income securities decline, stocks become more attractive compared to bonds and investors may shift their money from bonds to equities in search of higher yields, increasing demand for stocks and hence driving up their prices. In this regard, according to survey evidence by Graham and Harvey (2001), interest rate risk is ranked by U.S. firm managers as the second most relevant financial risk factor, only behind credit risk. Furthermore, the stock market performance can also exert a significant influence on interest rates. For instance, given the forward-looking nature of the stock market, a sharp fall in stock prices can be interpreted as a signal of pessimism about future economic prospects, which may eventually lead to a reduction in interest rates in an effort to stimulate the economy.

The linkage between changes in interest rates and the value of firms and, hence, their stock prices, has received a great deal of attention in the literature. Much of this empirical research has focused on the banking industry due to the peculiar nature of the financial intermediation business, as a large proportion of banks' income and costs depends directly on interest rates (Staikouras, 2003). Nevertheless, interest rate fluctuations may also exert a notable influence on the value of nonfinancial corporations, primarily because of their effect on the costs of financing and the market value of financial assets and liabilities held by these companies.

The classical ordinary least squares (OLS hereafter) regression has been the most commonly used approach to estimate interest rate exposure as the sensitivity of the value of a firm, proxied by its stock return, to variations in interest rates. This standard regression model describes the effect of the explanatory variables on the conditional mean of the response variable. OLS is a very effective method to understand the central tendency of the variable of interest. However, it loses much of its value when the analysis tries to go beyond the mean value or toward the extremes of a data set. In contrast, the quantile regression methodology developed by Koenker and Bassett (1978) is an extension of the traditional OLS estimation of the conditional mean to a compilation of models for different conditional quantile functions. This approach analyzes the effect of the explanatory variables not only at the center but also at the tails of the distribution of the variable of interest.

Nonetheless, there are some complexities in the relationship between interest rates and stock returns that are difficult to analyze using OLS and quantile regression techniques. For example, the effect of interest rate shocks on stock returns may be substantially different when the stock market is bearish or bullish. The impact of large movements in interest rates could be also different from the impact caused by small interest rate movements. In addition, stock returns may also react asymmetrically to positive and negative fluctuations in interest rates. Therefore, the effect of changes in interest rates on stock returns may be heterogeneous, depending on the market conditions and the nature and sign of interest rate shocks. The quantile-on-quantile (QQ hereafter) methodology introduced by Sim and Zhou (2015) emerges as a particularly suitable framework in this context as it estimates the overall dependence structure between interest rate fluctuations and stock returns taking into account the conditions in the stock market as well as the size and sign of interest rate changes.

The primary aim of this paper is to examine the linkage between changes in interest rates and stock market returns for fourteen developed economies (Australia, Belgium, France, Germany, Greece, Ireland, Italy, Japan, Netherlands, Norway, Portugal, Spain, the United Kingdom and the United States of America) using the QQ approach. The QQ framework combines quantile regression and nonparametric estimation techniques and allows estimating the effects that the quantiles of interest rate changes have on the quantiles of stock returns, thus providing a comprehensive characterization of the overall dependence between both variables. The QQ analysis makes it possible to uncover complex linkages between interest rates and stock markets that would be difficult to detect using standard econometric techniques. In this sense, the QQ approach is a very suitable method as nonlinear econometric techniques are becoming increasingly important in the study of the relationship between interest rates and stock prices.

This research contributes to the current literature in the following aspects. First, to the best of our knowledge, this is the first study that explores the linkage between changes in interest rates and stock returns through the application of the QQ methodology. The relationship between interest rates and stock markets can be contingent on the stock market cycle (bullish or bearish market) and the size and sign of interest rate shocks. Therefore, this method is able to detect such asymmetries and may provide more meaningful information to investors, portfolio managers and corporate managers. Second, no previous study has been found examining the interest rate exposure on equity markets in such a wide sample of countries.

This paper yields several noteworthy results. Firstly, the connection between interest rate changes and stock returns varies considerably across quantiles and countries. In particular, the relationship between interest rate variations and stock returns is weaker in case of Australia, Germany, Netherlands, the UK and the US, which suggests a low influence of interest rates on their respective stock markets. However, this relation between interest rate changes and stock returns become stronger for Greece, Ireland, Italy, Portugal and Spain, countries with a predominantly negative connection between both variables. Secondly, the interest rate-stock market connection is not stable, as the effect of interest rate changes on stock returns is consistently more prominent under periods of strong turbulences in financial markets and, more concretely, during extreme bearish conditions. In this regard, an asymmetric behavior in the interest rate-equity market nexus is observed in this study, as decreases in interest rates have a major impact on the stock market than hikes in interest rates.

The remainder of this paper is structured as follows. Section 2 provides a brief literature review on the relationship between movements in interest rates and stock returns. Section 3 introduces the key features of the QQ methodology. Section 4 describes the data used in the empirical analysis. The main empirical results are reported and discussed in Section 5. Finally, Section 6 offers some concluding remarks.

2. LITERATURE REVIEW

The relationship between changes in interest rates and stock returns has given rise to an extensive body of research over the past few decades. 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 firms (i.e. the financing of long-term loans with short-term deposits) is the most commonly suggested reason for the high interest rate sensitivity of banks (Ballester et al., 2011; Elyasiani and Mansur, 1998; Staikouras, 2003 and 2006). This positive duration gap (i.e. the average duration of banks' assets typically exceeds the average duration of banks' liabilities) implies that increases in interest rates have a detrimental effect on the value of banks and vice versa. This is because when interest rates rise, the market value of banks' assets declines more than that of banks' liabilities and also the costs of banks' liabilities go up faster than the yields of banks' assets. In this regard, Flannery and James (1984) conclude that the interest rate sensitivity of bank stocks presents a systematic relationship with the maturity structure of bank's assets and liabilities; therefore, higher interest rate risk is linked to financial institutions with greater duration gaps. Therefore, the relationship between movements in interest rates and bank stock returns is expected to be negative.

However, movements in interest rates may also have a significant effect on the value of nonfinancial companies through several channels. First, 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. Second, within the framework of dividend discount models rises in interest rates increase the cost of capital for firms. This causes an increase of the discount rate used by investors and reduces the present value of future cash flows, thereby adversely affecting firms' equity prices. Third, changes in interest rates alter the market value of financial assets and liabilities held by nonfinancial corporations. Finally, interest rate fluctuations can favor 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.

All these channels suggest an inverse connection between interest rate changes and stock returns. Nevertheless, there are also some reasons that justify a positive connection between these variables. First, interest rates and equity markets may move in the same direction following changes in macroeconomic factors such as economic prospects. Second, the existence of flight-to-quality effects from stocks to bonds in an environment of increased financial market uncertainty, such as that in force during the recent global financial crisis, may also have contributed to the emergence of a positive relation between changes in bond yields and equity returns. Flight-to-quality occurs in times of financial turmoil as investors move capital away from risky assets such as 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 nonfinancial companies (Flannery and James, 1984; Dinenis and Staikouras, 1998; Lynge and Zumwalt, 1980; Prasad and Rajan, 1995; Sweeney and Warga, 1986). However, some more recent studies, such as those of Czaja et al. (2009), Korkeamäki (2011) and Reilly et al. (2007), have shown that this relationship does not remain constant over time. In particular, the interest rate-stock market link seems to exhibit 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 to movements in long-term interest rates than to movements in short-term rates (Bartram, 2002; Czaja et al., 2009; Ferrer et al., 2010; Olugbode et al., 2014).

So far, the empirical literature on the linkage between interest rates and stock returns has developed primarily in the time domain by using a broad range of time series methods, including linear regression (Korkeamäki, 2011; Reilly et al., 2007; Sweeney and Warga, 1986), VAR models (Campbell and Ammer, 1993; Laopodis, 2010), cointegration analysis (Chan et al., 1997; Hatemi-J and Roca, 2008), Granger causality tests (Alaganar and Bhar, 2003; Shah et al., 2012), GARCH (generalized autoregressive conditional heteroscedasticity) models (Elyasiani and Mansur, 1998; Verma and Jackson, 2008) and nonlinear models (Ballester et al., 2011; Bartram, 2002). In addition, two recent studies of Ferrando et al. (2016) and Jareño et al. (2016) have examined the interest rate sensitivity of the Spanish and US stock market, respectively, at the industry level applying the quantile regression methodology. These contributions pay special attention to the effect of interest rate changes on stock returns under different stock market conditions, i.e. in bullish, bearish or relatively stable stock markets. However, no previous study has investigated the relationship between quantiles of interest rate changes and quantiles of stock returns.

3. METHODOLOGY

In this section, the key features of the QQ approach developed by Sim and Zhou (2015) as well as the model specification used in this study to examine the relationship between changes in interest rates and stock returns are described.

From a methodological perspective, the OLS regression is indisputably the most commonly used statistical technique in economic research to quantify relationships among variables. This method describes how the conditional mean of a dependent variable varies with the vector of covariates of independent variables under the assumption of independent and identically distributed error terms. In essence, OLS regression constitutes a very suitable method to understand the central tendency of the variable of interest, although it is not efficient when the distribution of the dependent variable is non-normal, with characteristics such as skewness, kurtosis or heteroskedasticity.

The quantile regression approach, introduced by Koenker and Bassett (1978), goes one step further from classical OLS estimation. The quantile regression enables analyzing the effect of the explanatory variables not only at the center, but also at the different quantiles (e.g., median and tails) of the distribution of the dependent variable. Thus, the quantile regression framework allows a more comprehensive characterization of the relationship between variables.

The QQ methodology can be seen as a generalization of the standard quantile regression approach that allows the estimation of the effect of the quantiles of a variable on the quantiles of another variable. The QQ approach is based on the combination of quantile regression and nonparametric estimation. First, conventional quantile regression is implemented to measure the effect of an explanatory variable on the different quantiles of the dependent variable. Second, local linear regression is utilized to estimate the local effect of a specific quantile of the explanatory variable on the dependent variable. The local linear regression introduced by Stone (1977) and Cleveland (1979) avoids the "curse of dimensionality" problem associated with purely nonparametric models, which appears when the convergence of any estimator to the true value of a smooth function is very slow if this function is defined in a high-dimensional space. The basic idea behind this dimension reduction technique is to fit a linear regression locally around a neighborhood of each data point in the sample, giving greater weight to closer neighbors through a kernel to construct a weighted objective function. Thus, by combining these two approaches it is possible to model the relationship between quantiles of the explanatory variable and quantiles of the dependent variable, providing a greater amount of information than alternative estimation techniques such as OLS or standard quantile regression.

In the context of the present study, the QQ approach proposed to investigate the effect of the quantiles of changes in interest rates on the quantiles of stock market returns of a country has its starting point in the following nonparametric quantile regression model:

$$R_t = \beta^{\theta}(\Delta I_t) + u_t^{\theta} \tag{1}$$

where R_t denotes the stock market return of a given country in period t, ΔI_t is the change in the interest rate in that country in period t, θ is the θth quantile of the conditional distribution of the stock return and u_t^{θ} is a quantile error term whose conditional θth quantile is equal to zero. $\beta^{\theta}(\cdot)$ is an unknown function since we have no prior information on how interest rate changes and stock returns are linked.

This quantile regression model measures the impact of movements in interest rates on the distribution of stock market returns of a country whilst allowing the effect of interest rate fluctuations to vary across different quantiles of stock returns. The main advantage of this specification is its flexibility as no hypothesis is made about the functional form of the relationship between bonds and indices. However, a shortcoming of the quantile regression approach is its inability to capture dependence in its entirety. In this sense, the quantile regression model does not take into account the possibility that the nature of interest rate shocks may also influence the way in which interest rates and stock returns are related. For instance, the effect of large, negative interest rate shocks can be different from the effect of small, negative interest rate shocks. In addition, stock returns can also react asymmetrically to negative and positive interest rate shocks.

Therefore, with the aim of analyzing the linkage between the θth quantile of stock returns and the τth quantile of interest rate changes, denoted by ΔI^{τ}, Eq. (1) is examined in the neighborhood of ΔI^{τ} employing local linear regression. As $\beta^{\theta}(\cdot)$ is unknown, this function can be approximated through a first order Taylor expansion around a quantile ΔI^{τ}, such that:

$$\beta^{\theta}(\Delta I_t) \approx \beta^{\theta}(\Delta I^{\tau}) + \beta^{\theta'}(\Delta I^{\tau})(\Delta I_t - \Delta I^{\tau}) \tag{2}$$

where $\beta^{\theta'}$ is the partial derivative of $\beta^{\theta}(\Delta I_t)$ with respect to ΔI, also called marginal effect or response and is similar in interpretation to the coefficient (slope) in a linear regression model.

A prominent feature of Eq. (2) is that the parameters $\beta^{\theta}(\Delta I^{\tau})$ and $\beta^{\theta'}(\Delta I^{\tau})$ are doubly indexed in θ and τ. Given that $\beta^{\theta}(\Delta I^{\tau})$ and $\beta^{\theta'}(\Delta I^{\tau})$ are functions of θ and ΔI^{τ}, and ΔI^{τ} is a function of τ, it is evident that $\beta^{\theta}(\Delta I^{\tau})$ and $\beta^{\theta'}(\Delta I^{\tau})$ are both functions of θ

and τ. Moreover, $\beta^{\theta}(\Delta I^{\tau})$ and $\beta^{\theta'}(\Delta I^{\tau})$ can be renamed as $\beta_0(\theta,\tau)$ and $\beta_1(\theta,\tau)$, respectively. Consequently, Eq. (2) can be rewritten as:

$$\beta^{\theta}(\Delta I_t) \approx \beta_0(\theta,\tau) + \beta_1(\theta,\tau)(\Delta I_t - \Delta I^{\tau}) \tag{3}$$

By replacing Eq. (3) in Eq. (1), the following equation is achieved:

$$R_t = \underbrace{\beta_0(\theta,\tau) + \beta_1(\theta,\tau)(\Delta I_t - \Delta I^{\tau})}_{(*)} + u_t^{\theta} \tag{4}$$

As can be seen, the part (*) of Eq. (4) is the θth conditional quantile of the stock return. However, unlike the standard conditional quantile function, this expression shows the relationship between the θth quantile of the stock return and the τth quantile of interest rate changes since the parameters β_0 and β_1 are doubly indexed in θ and τ. These parameters may vary across different θth quantiles of stock returns and τth quantiles of interest rate changes. Furthermore, at no time a linear relationship is assumed between the quantiles of the variables under study. Therefore, Eq. (4) estimates the overall dependence structure between equity returns and movements in interest rates through the dependence between their respective distributions.

To estimate Eq. (4), it is required to substitute ΔI_t and ΔI^{τ} by its estimated counterparts $\widehat{\Delta I}_t$ and $\widehat{\Delta I}^{\tau}$, respectively. The local linear regression estimates of the parameters b_0 and b_1, which are the estimates of β_0 and β_1, are obtained by solving the following minimization problem:

$$\min_{b_0,b_1} \sum_{i=1}^{n} \rho_{\theta}[R_t - b_0 - b_1(\widehat{\Delta I}_t - \widehat{\Delta I}^{\tau})] K(\frac{F_n(\widehat{\Delta I}_t) - \tau}{h}) \tag{5}$$

where $\rho_{\theta}(u)$ is the quantile loss function, defined as $\rho_{\theta}(u) = u(\theta - I(u < 0))$ being I the usual indicator function. $K(\cdot)$ denotes the kernel function and h is the bandwidth parameter of the kernel.

The Gaussian kernel, which is one of the most popular kernel functions in economic and financial applications because of its computational simplicity and efficiency, is used in this study to weight the observations in the neighborhood of ΔI^{τ}. The Gaussian kernel is symmetric around zero and assigns low weights to observations further away. Specifically, in our analysis these weights are inversely related to the distance between the empirical distribution function of $\widehat{\Delta I}_t$, denoted by $F_n(\widehat{\Delta I}_t) = \frac{1}{n}\sum_{k=1}^{n} I(\widehat{\Delta I}_k < \widehat{\Delta I}_t)$ and the value of the distribution function that corresponds with the quantile ΔI^{τ}, denoted by τ.

The choice of the bandwidth is critical when using nonparametric estimation techniques. The bandwidth determines the size of the neighborhood around the target point and, therefore, it controls the smoothness of the resulting estimate. The larger the bandwidth, the bigger the potential for bias in estimates, while a smaller bandwidth can lead to estimates with higher variance. Thus, a bandwidth that strikes a balance between bias and variance must be chosen. Following Sim and Zhou (2015), a bandwidth parameter $h = 0.05$ is employed in this study [1].

4. DATA DESCRIPTION

The dataset in this study consists of yields on 10-year government bonds and stock market indices of fourteen developed countries, which can be classified into four different groups: (1) Countries in the periphery of the euro area (Greece, Ireland, Italy, Portugal and Spain); (2) A set of countries belonging to the core of the euro area (Belgium, France, Germany and the Netherlands); (3) Two non-eurozone members (Norway and the UK); (4) A number of non-European countries which includes some of the major economies in the world (Australia, Japan and the US). The sample period extends from January 1999 to December 2015.

In order to assess whether the interest rate-stock market link has remarkably changed during some major economic events such as the global financial crisis started in 2008 or the subsequent European sovereign debt crisis, we also examine the relationship between changes in interest rates and stock returns during the financial crisis sub-period (see Section 5.2). In particular, the global financial crisis sub-period covers from September 2008 to September 2012. The beginning of this period coincides with the Lehman Brothers collapse in September 2008[2] and the date of the end coincides with the statement of Mario Draghi, President of the European Central Bank (ECB hereafter), in September 2012, announcing the intention of the ECB to make any effort to support the euro[3]. The stock indices considered are the ASX 200 (Australia), BEL 20 (Belgium), CAC 40 (France), DAX 30 (Germany), FTSE ATHEX 20 (Greece), ISEQ (Ireland), FTSE MIB (Italy), NIKKEI (Japan), AEX (the Netherlands), OSEBX (Norway), PSI 20 (Portugal), IBEX 35 (Spain), FTSE 100 (the UK) and S&P 500 (the US).

[1] Different values of the bandwidth have been also considered and the results of the estimation remain qualitatively the same.

[2] The bankruptcy of Lehman Brothers on 15 September 2008 was an alarm signal of the transmission of the financial crisis from the US to all over the world and caused a wave of global panic across financial markets. In fact, Bartram and Bodnar (2009) and Bessler and Kurmann (2014), among others, also consider this date as a key milestone event in the recent global financial crisis.

[3] ECB president Mario Draghi's declaration in July 2012 that the ECB was ready to do whatever it takes to preserve the euro marked a key turning point in the European sovereign debt crisis. In September 2012 the OMT program was officially launched, under which the ECB committed to purchasing unlimited amounts of government bonds of distressed Eurozone countries, provided they agreed to undertake fiscal and economic reforms. In fact, the mere announcement of the OMT program caused a considerable reduction in Spanish and Italian yields across the entire yield curve and particularly at the short end.

The interest rates used in this study are the yields on 10-year government bonds. This choice has become increasingly popular in the literature on stock-bond nexus (Ballester et al., 2011; Elyasiani and Mansur, 1998; Faff et al., 2005; Oertmann et al., 2000) and is supported by the following arguments. First, 10-year interest rates contain market expectations about future prospects for the economy and largely determine 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 sometimes considered as closer maturity substitutes to stocks, which may presumably increase the extent of linkage between the two financial assets. Both stock returns and interest rate changes for each country are calculated as the first logarithmic difference of two consecutive observations. All data series have been collected from Thomson Financial Datastream.

Along the lines of, among others, Flannery and James (1984), Hirtle (1997), Olugbode et al. (2014) and Shamsuddin (2014), weekly data series (Wednesday to Wednesday) are employed (a total of 887 weekly observations)[4]. Wednesday's data are used in order to avoid the weekend effect. Weekly frequency is preferred over daily and monthly frequencies for several reasons. Firstly, daily data are more contaminated by noise associated with higher frequency data and anomalies such as day-of-the-week effects or non-synchronous trading bias for less actively traded stocks than weekly observations (Arouri, 2012). Secondly, compared to monthly data, the weekly frequency provides a number of observations large enough to yield more reliable results.

[INSERT TABLE 1 HERE]

Summary descriptive statistics for the variables used in the analysis are reported in Table 1. The averages of both weekly stock market returns and 10-year government bond yield changes are close to zero in the great majority of cases and small relative to their standard deviations, which implies relatively high volatility in both markets. Stock returns tend to have negative skewness, while 10-year bond rate fluctuations tend to have positive skewness, indicating that the respective distributions are non-symmetric. Furthermore, all the series have positive kurtosis coefficients in excess of three, suggesting the existence of heavy tails compared to a normal distribution. This leptokurtic behavior confirms a typical result from empirical literature according to which financial return distributions exhibit fatter tails than the normal distribution. The Jarque-Bera statistics confirm this result, rejecting the null hypothesis of normality for stock market returns and changes in 10-year bond interest rates of all countries at the 1% significance level. In order to determine the order of integration of the variables, the conventional Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) unit root tests and the Kwiatkowski-Phillips-Schmidt-Shin (KPSS) stationarity test are conducted. All

[4] It is worth noting that data on Greek 10-year government bond yields are available from April 1999. Therefore, in the special case of Greece, a total of 872 weekly observations are utilized.

tests indicate that the series of stock returns as well as those of changes in 10-year government bond yields are stationary (integrated of order zero) at the 1% level.

In order to facilitate the interpretation of the quantiles of interest rate changes and stock returns, Figure 1 in Appendix plots the simple quantile associated to each quantile of changes in interest rates and stock returns for all countries considered. It can be seen that stock returns below the 40th percentile are negative for the vast majority of countries. Hence, the lower quantiles of stock returns are indicative of a bearish stock market and vice versa. Similarly, changes in interest rates below the 50th percent represent interest rate falls for most countries.

[INSERT FIGURE 1 HERE]

5. EMPIRICAL RESULTS

5.1. Estimates of the QQ approach for full sample

This section presents the main results of the QQ analysis between changes in 10-year sovereign bond yields and stock returns for the fourteen countries under consideration over the whole sample period. Figure 2 (a-n) displays the estimates of the slope coefficient, $\beta_1(\theta,\tau)$, which captures the impact of the τth quantile of interest rate changes on the θth quantile of stock returns, at different values of τ and θ, for each country.

[INSERT FIGURE 2 HERE]

Several interesting results emerge from graphs in Figure 2. First, there is a considerable heterogeneity across countries in terms of the stock market-interest rate nexus. This finding is probably due to differences among countries concerning the level of indebtedness of the economy, the relative weight of the sectors most interest rate sensitive (i.e. Utilities and Banking) within the stock market of each country, the degree of development of financial derivative markets and the level of interest rates. Second, within each country, notable variations in the slope coefficient are observed across different quantiles of movements in interest rates and stock returns. This finding suggests that the linkage between interest rate fluctuations and stock returns is not uniform across quantiles, but this relationship depends on both the sign and size of interest rate changes, as well as on the specific cycle of the stock market.

There is a large set of countries, including Australia, France, Germany, Netherlands, Japan, Norway, the UK and the US, where the connection between movements in 10-

year government bond yields and stock returns is quite weak. For all these countries, it is shown that the coefficients measuring the linkage between changes in interest rates and stock returns take very low values for the vast majority of combinations of quantiles of both variables. In the Australian case, a relatively pronounced positive relationship appears only in the area which combines the lowest quantiles of interest rate fluctuations (0.05-0.10) with the lowest quantiles of equity returns (0.05-0.10). This result suggests that strong falls in 10-year government bond yields have a significant detrimental effect on Australian stock returns under extreme bearish conditions in the Australian equity market. A possible explanation for this finding is that sharp decreases in interest rates in a bearish market environment are interpreted by the market as a signal of economic slowdown, which exacerbates the decline in the stock market. For Netherlands, the only exception to the generally poor interest rate-equity market link is found in the area combining low quantiles of interest rate changes (0.25-0.30) with the lowest quantiles of stock returns (0.05-0.15). In particular, a negative relationship is observed in this region, indicating that moderate decreases in interest rates have a beneficial impact on the Dutch stock market during strongly bearish conditions. This finding may be interpreted in the sense that moderate falls in interest rates are well received by the stock market as they imply a reduction in the cost of financing for firms. Concerning Germany, the relationship between movements in interest rates and stock returns is also generally quite weak, although the sign of the connection varies significantly across quantiles.

It can be seen that France, Japan, Norway, the UK and the US exhibit a similar pattern of connection between changes in 10-year government bond yields and stock returns, which is characterized by the low interest rate-stock market link and a predominantly positive sign for the aforementioned relationship across most quantiles. In the French case, the strongest positive linkage manifests in the area that combines the intermediate quantiles of changes in interest rates (0.55-0.60) with the highest quantiles of stock returns (0.90-0.95). This means that small increases in interest rates during periods of extreme bullish conditions are interpreted as a sign of economic strength and further bolster the French equity market. For Japan the connection between interest rates and stock market is mainly positive, although the most pronounced relationship is negative and located in the area combining the lowest quantiles of interest rate variations (0.05-0.10) with the lowest quantiles of stock returns (0.05-0.10). This result indicates that strong falls in interest rates have a beneficial effect on the Japanese equity market during periods of extreme bearish conditions. A possible explanation is that extreme reductions in interest rates are favorably received by the stock market insofar as they imply a notable decrease in the financing cost for companies. In the case of Norway, the more pronounced positive relationship is observed in the area that combines lower to intermediate quantiles of changes in 10-year government bond yields (0.25-0.50) with the lowest quantile of stock returns (0.05). This result means that moderate falls in interest rates exert a negative influence on the Norwegian stock market under extreme bearish conditions, suggesting that declines in interest rates in periods of significantly falling stock markets may be viewed by the stock market as a symptom of deterioration of the economy, with the subsequent negative effect on the equity market. In addition, for the UK the more pronounced linkage is found in the area combining the highest quantiles of interest rate changes (0.80-0.90) and the highest quantile of stock returns (0.95). This positive relationship implies that extreme increases in interest rates have a positive influence on the stock market during extreme bullish conditions. This result may be explained by the fact that sharp rises in interest rates are considered by the stock market as signal of economic expansion, which accentuates the stock market boom. Regarding the US case, two remarkable areas of relatively important connection between 10-year government bond yield fluctuations and stock returns are found. First, a pronounced positive relationship appears in areas which combine the lowest quantiles of interest rate changes (0.05-0.15) with the lowest quantiles of stock returns (0.10-0.30). This finding indicates that large negative interest rate changes have a detrimental effect on the US stock market in extreme bearish periods. This implies that extreme drops in interest rates are conceived by the market as an anticipation of the upcoming decline of the economy, which strengthens the pessimistic expectations of the equity market. Second, despite the linkage between interest rate variations and stock returns is mainly positive for the US, a significant negative connection is also found in the area combining the lowest quantiles of 10-year interest rate variations (0.05-0.15) with the highest quantiles of stock returns (0.90-0.95). This means that strong falls in interest rates involving a drastic reduction in the financing cost for firms further boost the stock market in extreme bullish conditions.

For Belgium, the interest rate-stock market linkage is slightly stronger compared to previous countries and the sign of this connection varies substantially across quantiles. However, the most pronounced relationship has negative sign and is observed in the area that combines higher quantiles of interest rate changes (0.80) with higher quantiles of stock returns (0.65-0.85). This result indicates that strong increases in interest rates have a detrimental effect on the Belgian stock market under strong bullish conditions. A possible explanation for this finding is related to the fact that sharp rises in interest rates imply an increase in the cost of financing for companies. This is interpreted as a bad news in a bullish environment, affecting negatively the stock market performance.

On the contrary, a wide range of countries, made up of Portugal, Greece, Ireland, Italy and Spain, show a stronger connection between changes in 10-year government bond yields and stock returns compared to that of the previous countries. Moreover, for almost all these countries the most pronounced interest rate-stock market link has positive sign, is observed during strong bearish conditions in the equity market and can be related to the prospects of slowdown or improvement in the economy. For Portugal, the most significant linkage between 10-year interest rate fluctuations and stock returns has negative sign and is located in the area combining the highest quantiles of interest rate variations (0.90-0.95) with the lowest quantiles of stock returns (0.10-0.20), suggesting that strong rises in interest rates cause a negative impact on the Portuguese stock market in extreme bearish conditions. A possible explanation may be that sharp increases in interest rates imply a rise in the costs of financing for corporations, which consequently exerts a negative impact on the stock market during periods of strong falls in the stock market. For Greece, the most remarkable connection between interest rate variations and stock returns is positive and takes place in the area that combines the highest quantiles of interest rate changes (0.90-0.95) with the lowest quantiles of stock returns (0.05-0.20), which implies that strong increases in interest rates exert a beneficial impact on the stock market during extreme bearish conditions. This finding may be explained by the fact that sharp rises in interest rates are viewed by the market as a clear sign of economic recovery, which enhances the performance of the equity market. In the Irish case, the most pronounced positive linkage between yield changes and stock returns appears in the area that combines a high quantile of interest rate changes (0.75) with lower quantiles of stock returns (0.15-0.35), indicating that notable rises in interest rates exert a favorable effect on the Irish stock market in periods of significant decline in the stock market. This means that strong increases in interest rates are perceived as a sign of economic recovery when the stock market is declining. For Italy, the most meaningful positive relation between both variables is found in the area that combines the lowest quantiles of interest rate changes (0.05-0.15) with the lowest quantiles of stock returns (0.05-0.20), noting that strong falls in interest rates have a detrimental effect on the Italian stock market under extreme bearish conditions. This finding may be explained by the fact that sharp decreases in interest rates are considered by the market as an accentuation of the economic deterioration, which aggravates the decline of the stock market. Finally, the most significant positive connection between interest rate variations and stock returns in Spain is found in the area that combines the lowest quantile of interest rate changes (0.05) with the highest quantiles of stock returns (0.85-0.95), implying that strong falls in interest rates exert an adverse impact on the Spanish stock market under extreme bullish conditions. This suggests that sharp decreases in interest rates are conceived by the market as a potential deterioration of the economy, thus, affecting negatively the equity market. Another remarkable positive linkage between both variables is observed in the area that combines the lowest quantile of interest rate fluctuations (0.05) with low quantiles of stock returns (0.20-0.35). This result indicates that strong falls in interest rates have a detrimental effect on the Spanish stock market when it is falling. A possible explanation is that sharp decreases in interest rates anticipate the deterioration of the economy and potentiate the decline of the equity market.

5.2. Estimates of the QQ approach during the global financial crisis sub-period

This section reports the estimation results of the QQ approach for the period of the global financial crisis (September 2008 to September 2012) in order to assess whether the most significant linkage between changes in 10-year government bond yields and stock returns may be associated to this sub-period, which is characterized by major turbulences in international financial markets. Figure 3 plots the estimates of the slope coefficient, $\beta_1(\theta, \tau)$, at different values of τ and θ, corresponding to this sub-period.

[INSERT FIGURE 3 HERE]

Several interesting results emerge from graphs in Figure 3. Firstly, the relationship between movements in 10-year sovereign bond yields and stock returns tends to be more pronounced for almost all countries during the financial crisis period than during the overall sample. In particular, the magnitude of coefficient estimates is higher (in absolute value) across most quantiles of both variables for the vast majority of countries when considering the global financial crisis sub-period. This finding suggests that the interdependence between interest rates and stock markets is greater during times of significant financial turmoil than during relatively stable periods. However, it is worth noting that the results for the financial crisis period are largely consistent with those of the full sample period regarding the heterogeneity among countries and the countries with higher and lower connection between changes in 10-year interest rates and equity returns. Secondly, the most significant interest rate-stock market link during the financial crisis period takes positive values for most countries. In fact, Greece, Ireland and Portugal, that is, the three countries most affected by the European debt crisis since the end of 2009, are the only exceptions to this result. Interestingly, for these three countries the strongest linkage takes place in the highest quantiles of interest rate changes (0.90-0.95) and has negative sign, indicating that strong increases in interest rates of sovereign debt of these countries in the context of the euro area sovereign debt crisis had a very harmful effect on their stock markets. In addition, for most countries the more pronounced relationship during this sub-period is found for the lowest quantiles of interest rate changes and the lowest quantiles of stock returns. This finding implies that the more intense interest rate-equity market link tends to be associated with strong falls in interest rates and extreme bearish conditions in the stock market.

5.3. Checking the QQ methodology

The QQ approach can be seen as a technique that "descomposes" the estimates of the standard quantile regression model, allowing to obtain specific estimates for the different quantiles of the explanatory variable. In the framework of the present study, the quantile regression model is based on regressing the θth quantile of stock returns on 10-year sovereign bond yield changes and, hence, the quantile regression parameters are only indexed by θ. Nonetheless, as pointed out earlier, the QQ method regresses the θth quantile of stock returns on the τth quantile of interest rate changes and, therefore, the QQ parameters will be indexed by both θ and τ. Thus, the QQ framework contains more disaggregated information about the stock market-interest rate nexus than the quantile regression model as this linkage is viewed by the QQ approach as potentially heterogeneous across different quantiles of interest rates.

Given this property of decomposition inherent to the QQ approach, it is possible to use the QQ estimates to recover the estimates of the standard quantile regression. Specifically, the quantile regression parameters, which are only indexed by θ, can be replicated by averaging the estimated QQ parameters along τ. For example, the slope coefficient of the quantile regression model, which measures the effect of changes in 10-year sovereign bond yields on the distribution of stock returns and is denoted by $\gamma_1(\theta)$, can be obtained as follows:

$$\hat{\gamma}_1(\theta) \equiv \bar{\hat{\beta}}_1(\theta) = \frac{1}{S}\sum_{\tau} \hat{\beta}_1(\theta, \tau) \tag{6}$$

where $S = 19$ is the number of quantiles $\tau = [0.05, 0.10, \dots, 0.95]$ considered.

In this context, a simple way of checking the validity of the QQ approach is to compare the estimated quantile regression parameters with the τ-averaged QQ parameters. Figure 4 plots the quantile regression and averaged QQ estimates of the slope coefficient that measures the effect of changes in yields on 10-year sovereign bonds on stock returns for all the countries under scrutiny over the entire sample period.

[INSERT FIGURE 4 HERE]

The graphs in Figure 4 (a-n) reveal that the averaged QQ estimates of the slope coefficient are very similar to the quantile regression estimates regardless of the quantile considered for the different countries. Thus, this graphical evidence provides a simple validation of the QQ method by showing that the main results of the quantile regression estimation can be recovered by summarizing the more thorough information contained in the QQ estimates. Moreover, Figure 4 largely confirms the findings of the QQ analysis stated earlier. First, the effect of movements in 10-year sovereign bond yields on stock returns is consistently positive across quantiles for Australia, France, Germany, Japan, Netherlands, Norway, the UK and the USA. In contrast, the impact of 10-year government bond yields interest rate variations on stock returns is predominantly negative for Belgium, Greece, Ireland, Italy, Portugal and Spain. Second, a substantial heterogeneity across countries and across quantiles within each country in terms of the impact of changes in 10-year sovereign bond yields on stock returns is noticed. More precisely, the highest effect (in absolute value) of changes interest rates on the equity market is found at the extreme quantiles of the distribution of stock returns for most countries. This finding indicates that the interdependence between changes in interest rates and stock markets tends to be stronger under extreme market conditions, either bearish or bullish, suggesting that interest rates become an important explanatory factor of the stock market performance in times of significant turmoil in the equity markets.

6. CONCLUDING REMARKS

This paper investigates the linkage between changes in 10-year government bond yields and stock returns for fourteen developed countries over the period 1999-2015 using the QQ (quantile-on-quantile) approach recently developed by Sim and Zhou (2015). The QQ analysis enables estimating the way in which the quantiles of interest rate fluctuations influence the quantiles of stock returns and thus, it provides a more precise description of the overall dependence structure between both variables than alternative standard techniques such as OLS or quantile regression.

This paper yields a number of interesting empirical results. First, the relationship between 10-year sovereign bond yield fluctuations and stock returns is heterogeneous across countries, possibly because of differences in the degree of indebtedness among countries, the level of interest rates in each country, the relative weight of most interest rate sensitive sectors in the stock market of each country and the level of development of financial derivative markets. In particular, the weakest interest rate-stock market nexus is observed for Australia, Germany, Netherlands, the UK and the US. On the contrary, the strongest linkage has negative sign and is found for the euro area peripheral countries most severely affected by the European sovereign debt crisis, i.e. Ireland, Spain, Greece, Italy and Portugal. Second, the interest rate-equity market link also varies substantially across quantiles of interest rate changes and stock returns, indicating that the connection is not stable, but it depends on both the sign and size of interest rates fluctuations and the cycle of the stock market. It is also shown that the relationship between changes in 10-year bond yields and equity returns tends to be stronger during periods of major financial turmoil such as the recent global financial crisis period. In particular, for the vast majority of countries analyzed, interest rate variations are a significant driver of the equity market performance during periods of extreme market conditions and mainly under strong bearish conditions in the stock market. In addition, falls in interest rates exert generally a larger influence on the equity market than rises in interest rates, revealing an asymmetric effect of interest rate changes on equity markets. These results confirm that the linkage is nonlinear and asymmetric.

The evidence presented in this study is particularly relevant for policy makers who should consider that the effect of interest rates depends on both equity and bond market conditions. These findings are also crucial for investors and portfolio managers in order to design effective strategies against interest rate risk.

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7. REFERENCES

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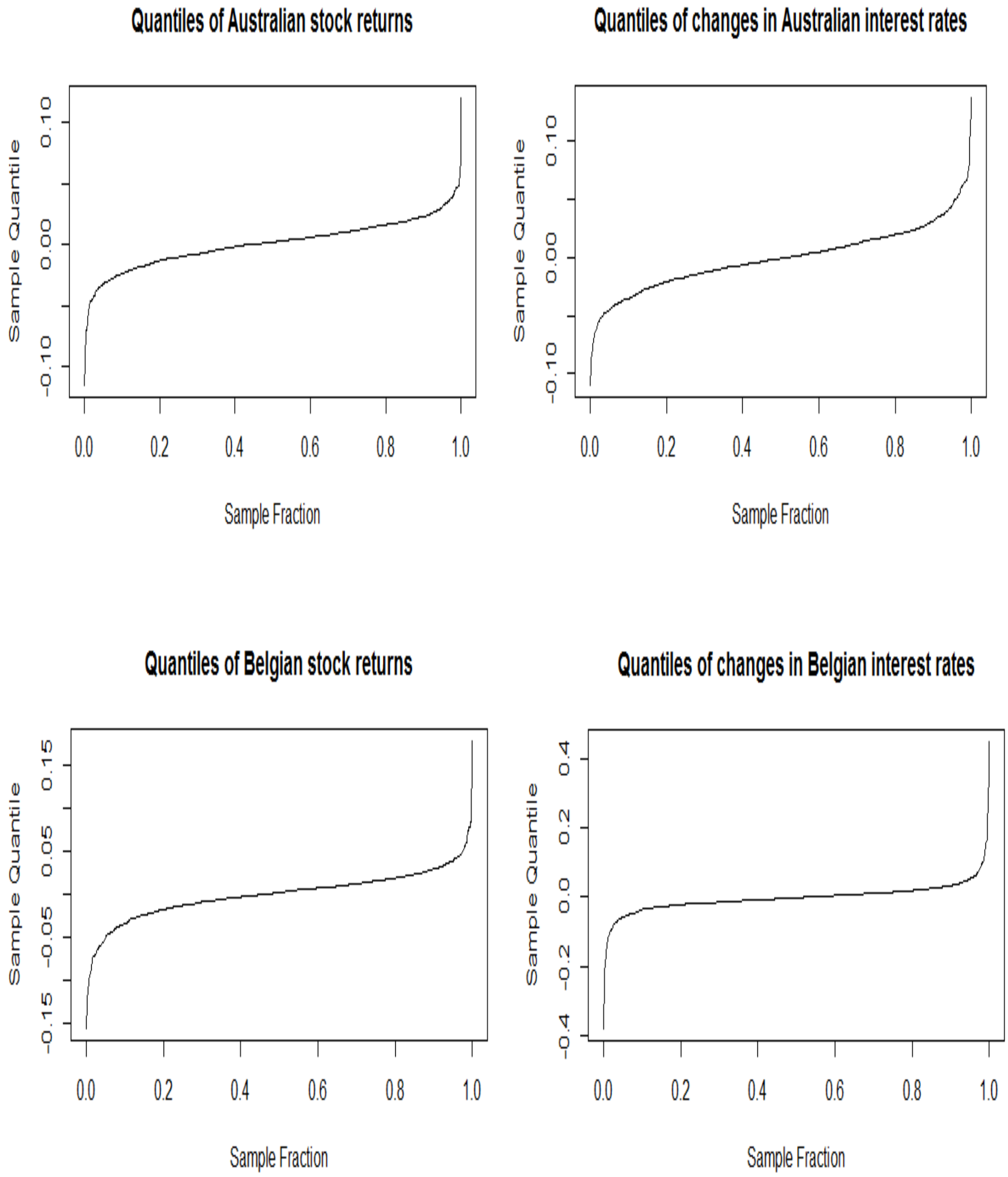
APPENDIX:

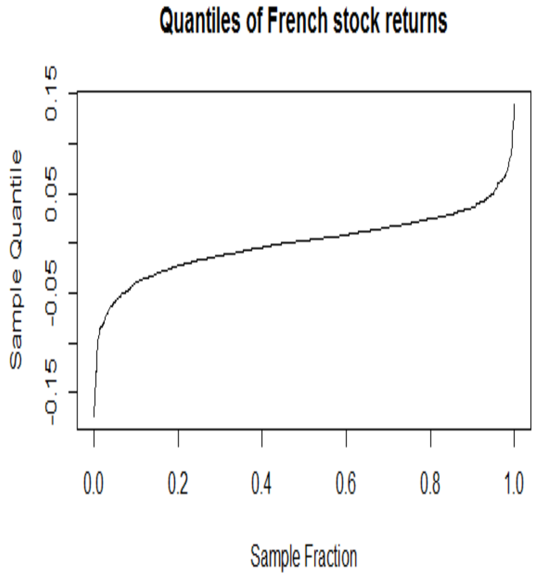
Table 1. Descriptive statistics of stock returns and changes in yields on 10-year government bonds of each country.

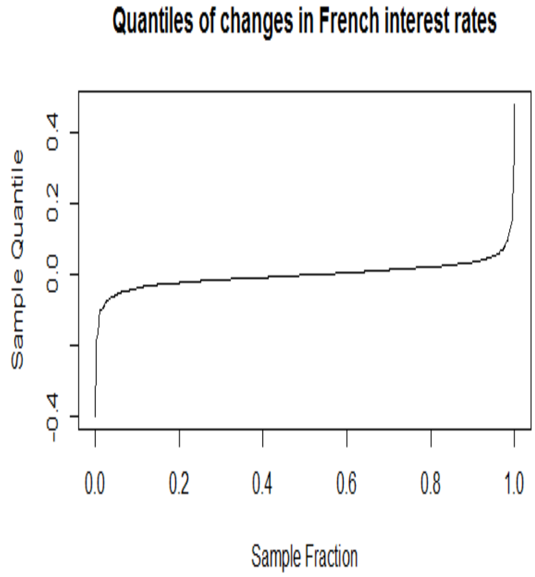
Variables	Mean	Median	Min.	Max.	Std. Dev.	Skewness	Kurtosis	JB statistic	ADF statistic	PP statistic	KPSS statistic
Australian stock returns (ASX 200)	0.00077	0.00201	-0.11530	0.12016	0.02049	-0.47	6.63	519.77***	-9.32***	-30.82***	0.10
Belgian stock returns (BEL 20)	0.00007	0.00276	-0.15607	0.17912	0.02914	-0.41	7.58	800.36***	-8.98***	-32.34***	0.17
French stock returns (CAC 40)	0.00011	0.00229	-0.17375	0.13952	0.03449	-0.48	5.75	314.07***	-9.62***	-34.20***	0.06
German stock returns (DAX 30)	0.00086	0.00433	-0.16804	0.17155	0.03350	-0.66	6.57	535.37***	-9.01***	-32.89***	0.12
Greek stock returns (FTSE ATHEX 20)	-0.00207	0.00152	-0.21500	0.18830	0.04439	-0.21	4.76	118.44***	-9.00***	-30.07***	0.15
Irish stock returns (ISEQ)	0.00036	0.00282	-0.17576	0.14881	0.03135	-0.62	7.22	714.88***	-8.20***	-31.98***	0.23
Italian stock returns (FTSE MIB)	-0.00057	0.00180	-0.14735	0.11659	0.03278	-0.37	4.94	158.65***	-10.07***	-31.90***	0.07
Japanese stock returns (NIKKEI)	0.00036	0.00307	-0.21126	0.14794	0.03124	-0.56	6.56	514.17***	-9.01***	-30.01***	0.18
Dutch stock returns (AEX)	-0.00021	0.00263	-0.17538	0.20377	0.03243	-0.52	8.43	1130.50***	-9.33***	-33.55***	0.12
Norwegian stock returns (OSEBX)	0.00120	0.00448	-0.22650	0.22040	0.03388	-0.92	9.74	1800.50***	-8.50***	-31.94***	0.07
Portuguese stock returns (PSI 20)	-0.00082	0.00119	-0.18923	0.09713	0.02911	-0.59	6.10	407.18***	-8.88***	-31.53***	0.07
Spanish stock returns (IBEX 35)	-0.00002	0.00206	-0.13330	0.12390	0.03208	-0.34	4.63	115.56***	-9.77***	-32.96***	0.06
UK stock returns (FTSE 100)	0.00007	0.00218	-0.12730	0.13590	0.02459	-0.35	6.49	466.64***	-10.28***	-32.97***	0.08
US stock returns (S&P 500)	0.00058	0.00189	-0.16451	0.10186	0.02413	-0.60	7.61	837.89***	-9.76***	-32.27***	0.18
Australian 10-year bond yield changes	-0.00063	-0.00097	-0.10957	0.13696	0.02787	0.29	4.92	148.89***	-8.93***	-30.97***	0.15
Belgian 10-year bond yield changes	-0.00162	-0.00198	-0.37954	0.44823	0.04600	1.12	27.06	21573***	-9.38***	-31.64***	0.21
French 10-year bond yield changes	-0.00156	-0.00215	-0.39887	0.47765	0.04539	1.26	30.81	28824***	-10.11***	-29.24***	0.17
German 10-year bond yield changes	-0.00204	-0.00161	-0.62996	0.74073	0.06656	1.34	42.43	57738***	-10.83***	-28.07***	0.12
Greek 10-year bond yield changes	0.00147	-0.00051	-0.43230	0.35960	0.04782	-0.30	19.63	10064***	-7.76***	-29.44***	0.23
Irish 10-year bond yield changes	-0.00156	-0.00281	-0.24766	0.43718	0.04050	1.51	23.04	15172***	-10.19***	-27.89***	0.42*
Italian 10-year bond yield changes	-0.00104	-0.00161	-0.19856	0.25963	0.03342	0.45	12.54	3390.50***	-10.17***	-32.23***	0.33
Japanese 10-year bond yield changes	-0.00226	-0.00514	-0.19729	0.41030	0.05433	1.69	12.97	4096.60***	-9.80***	-29.42***	0.17
Dutch 10-year bond yield changes	-0.00182	-0.00167	-0.57237	0.57916	0.05255	0.35	40.73	52620***	-9.35***	-29.41***	0.16
Norwegian 10-year bond yield changes	-0.00144	-0.00157	-0.23300	0.17150	0.03326	-0.19	9.07	1367.90***	-9.55***	-30.43***	0.14
Portuguese 10-year bond yield changes	-0.00053	-0.00086	-0.22154	0.22927	0.03929	0.20	8.49	1121.30***	-9.50***	-27.35***	0.22
Spanish 10-year bond yield changes	-0.00091	-0.00050	-0.21040	0.27940	0.03501	0.14	11.78	2849.50***	-10.12***	-31.14***	0.26
UK 10-year bond yield changes	-0.00088	-0.00083	-0.16211	0.18087	0.03525	0.18	5.79	292.10***	-9.06***	-31.70***	0.10
US 10-year bond yield changes	-0.00080	0.00000	-0.19966	0.15670	0.03997	-0.03	5.30	195.02***	-10.22***	-31.13***	0.04

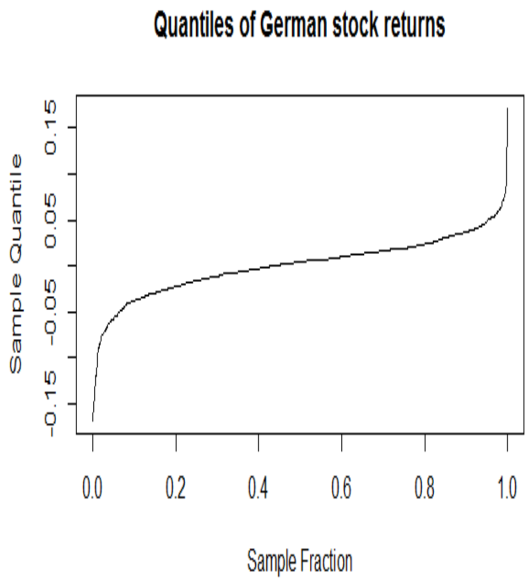
Notes:
This table presents the main descriptive statistics of weekly stock market returns and changes in 10-year government bond yields over the period from January 1999 to December 2015. They include mean, median, minimum (Min.) and maximum (Max.) values, standard deviation (Std. Dev.) and Skewness and Kurtosis measures. JB denotes the statistic of the Jarque-Bera test for normality. The results of the augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) unit root tests and the Kwiatkowski et al. (KPSS) stationarity test are also reported in the last three columns. As usual, *, **, *** indicate statistical significance at the 10%, 5% and 1% levels, respectively.

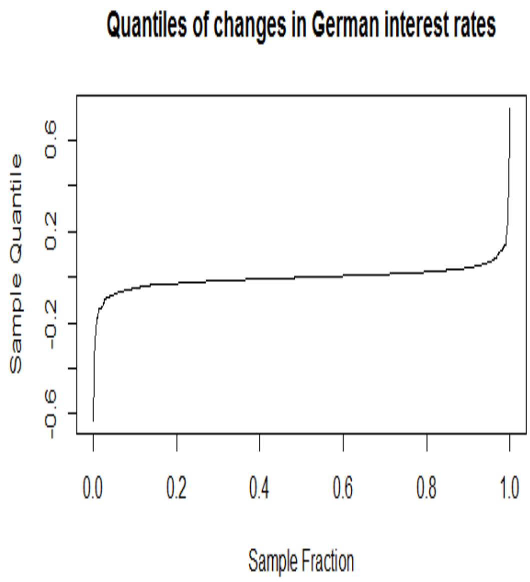
Figure 1. Quantile plots of stock returns and interest rate changes for each country.

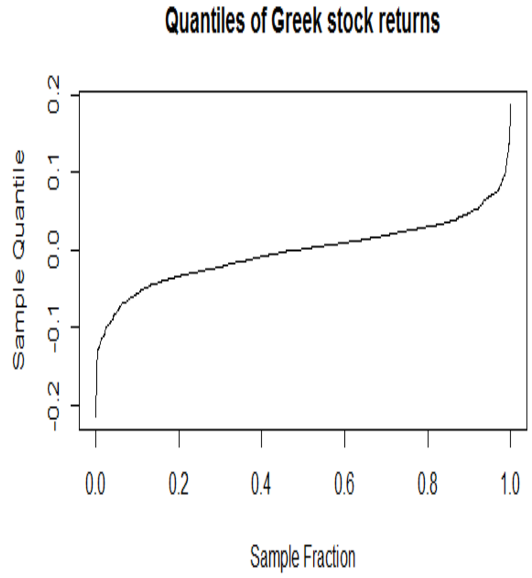


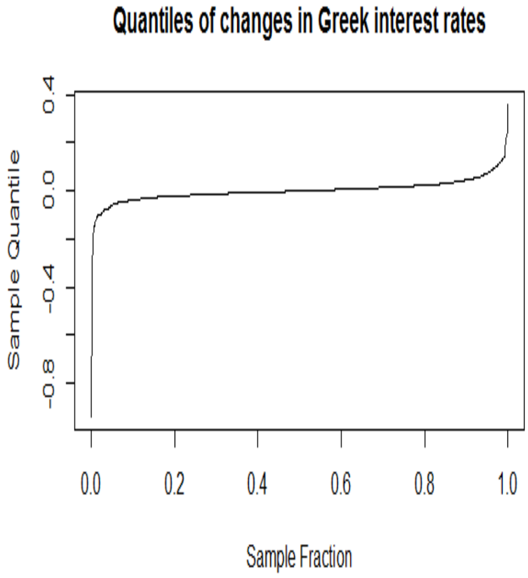

Quantiles of French stock returns
Sample Quantile
-0.15
-0.05
0.05
0.15
0.0
0.2
0.4
0.6
0.8
1.0
Sample Fraction

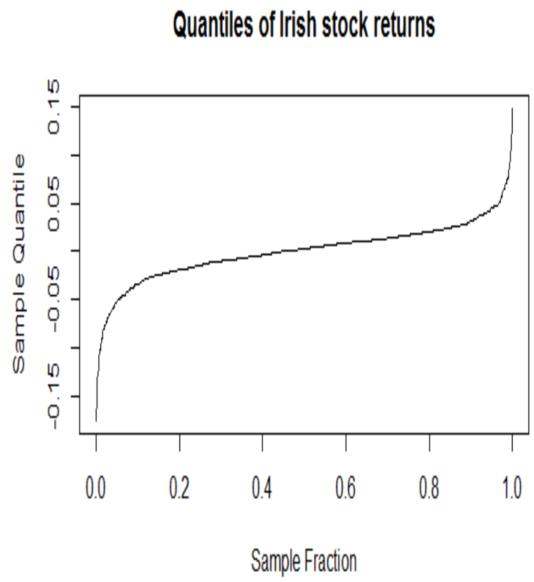

Quantiles of changes in French interest rates
Sample Quantile
-0.4
0.0
0.2
0.4
0.0
0.2
0.4
0.6
0.8
1.0
Sample Fraction

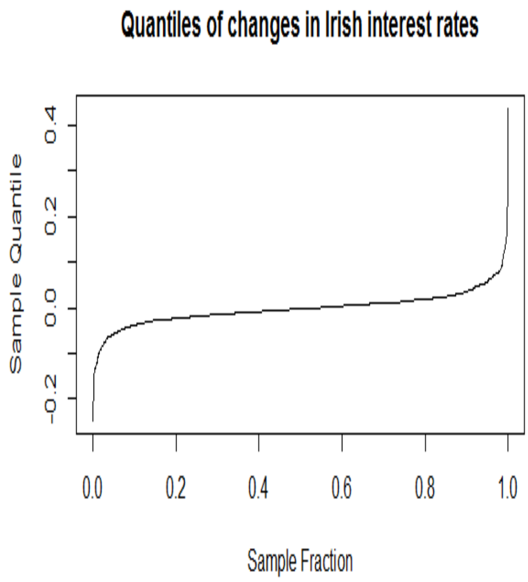

Quantiles of German stock returns
Sample Quantile
-0.15
-0.05
0.05
0.15
0.0
0.2
0.4
0.6
0.8
1.0
Sample Fraction

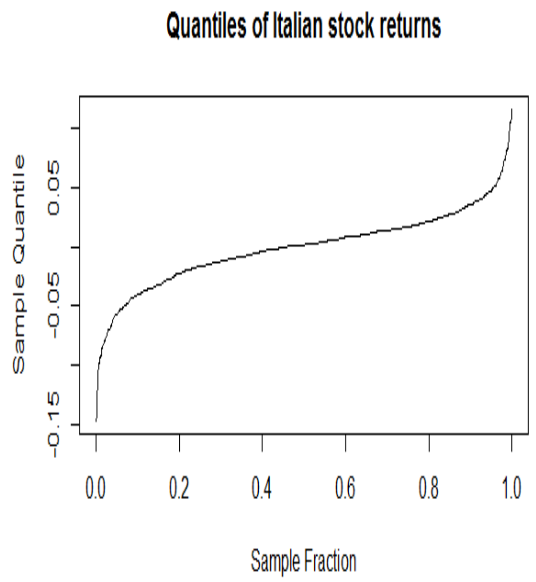

Quantiles of changes in German interest rates
Sample Quantile
-0.6
-0.2
0.2
0.6
0.0
0.2
0.4
0.6
0.8
1.0
Sample Fraction

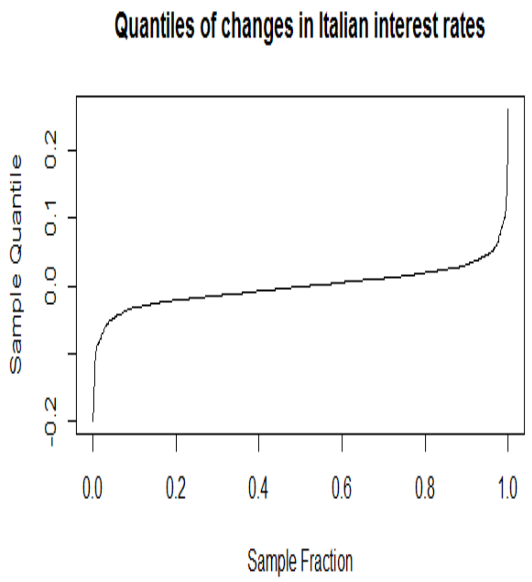

Quantiles of Greek stock returns
Sample Quantile
Sample Fraction
-0.2
-0.1
0.0
0.1
0.2
0.0
0.2
0.4
0.6
0.8
1.0

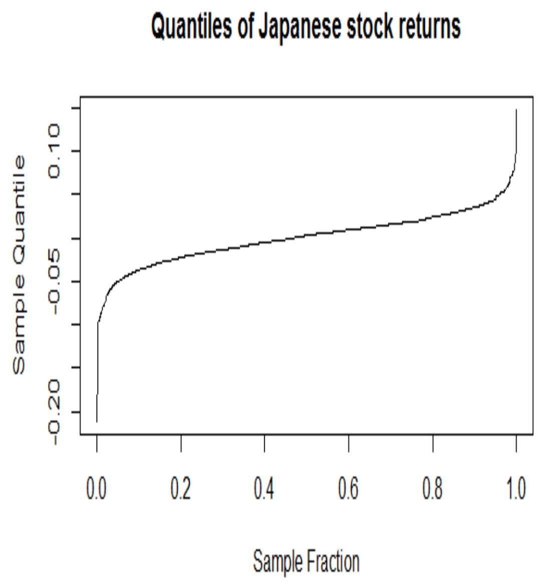

Quantiles of changes in Greek interest rates
Sample Quantile
Sample Fraction
-0.8
-0.4
0.0
0.4
0.0
0.2
0.4
0.6
0.8
1.0

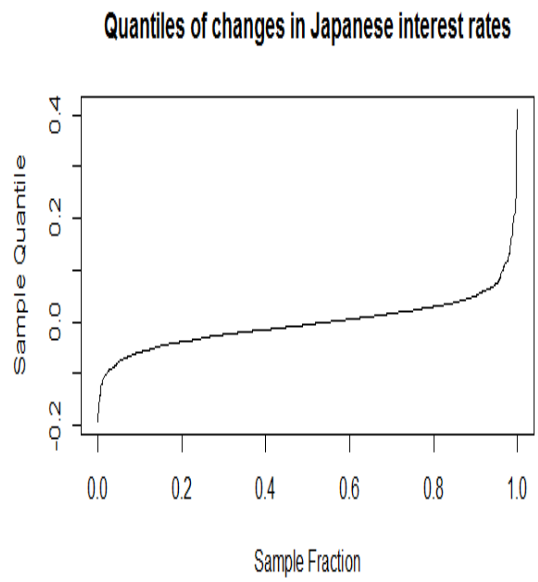

Quantiles of Irish stock returns
Sample Quantile
Sample Fraction
-0.15
-0.05
0.05
0.15
0.0
0.2
0.4
0.6
0.8
1.0

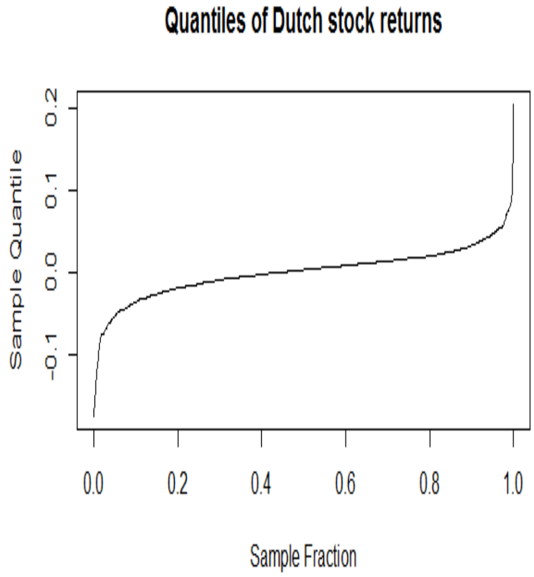

Quantiles of changes in Irish interest rates
Sample Quantile
Sample Fraction
-0.2
0.0
0.2
0.4
0.0
0.2
0.4
0.6
0.8
1.0

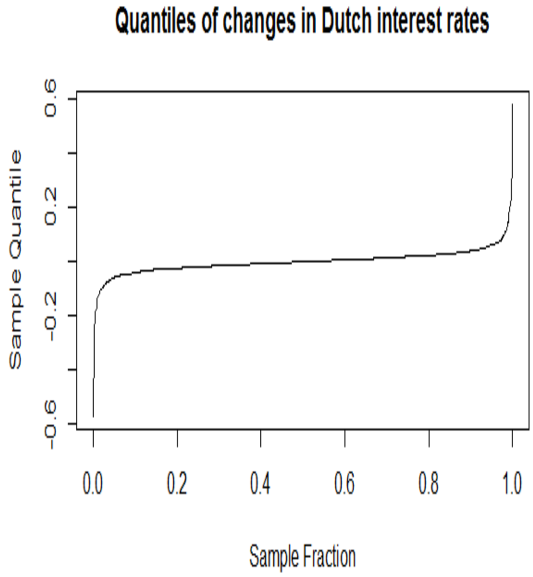

Quantiles of Italian stock returns
Sample Quantile
-0.15
-0.05
0.05
0.0
0.2
0.4
0.6
0.8
1.0
Sample Fraction

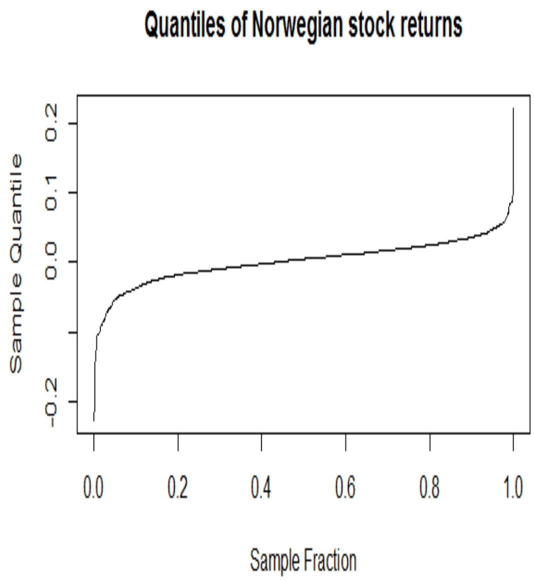

Quantiles of changes in Italian interest rates
Sample Quantile
-0.2
0.0
0.1
0.2
0.0
0.2
0.4
0.6
0.8
1.0
Sample Fraction

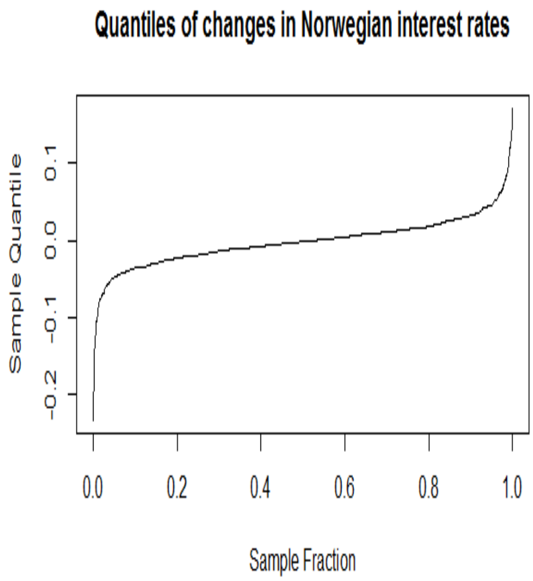

Quantiles of Japanese stock returns
Sample Quantile
-0.20
-0.05
0.10
0.0
0.2
0.4
0.6
0.8
1.0
Sample Fraction

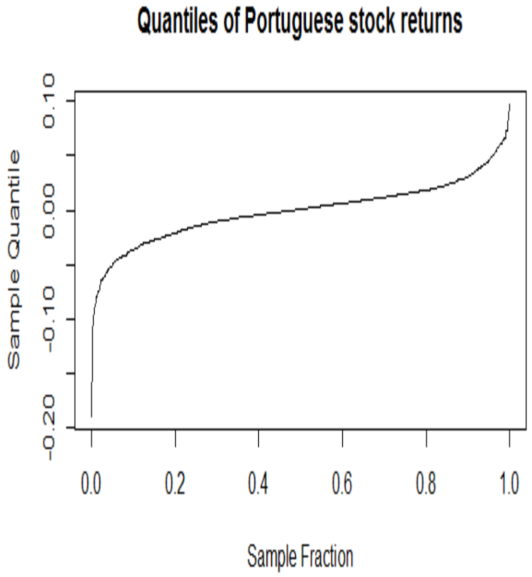

Quantiles of changes in Japanese interest rates
Sample Quantile
-0.2
0.0
0.2
0.4
0.0
0.2
0.4
0.6
0.8
1.0
Sample Fraction

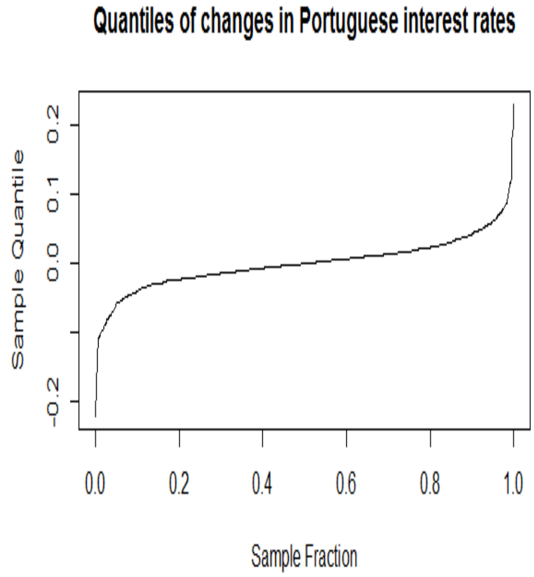

Quantiles of Dutch stock returns
Sample Quantile
-0.1
0.0
0.1
0.2
0.0
0.2
0.4
0.6
0.8
1.0
Sample Fraction

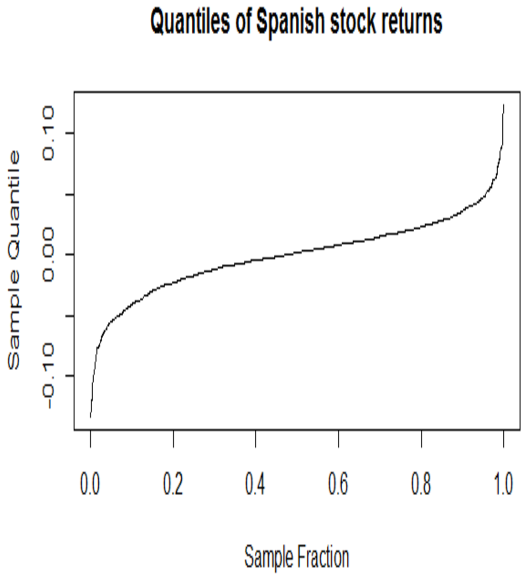

Quantiles of changes in Dutch interest rates
Sample Quantile
-0.6
-0.2
0.2
0.6
0.0
0.2
0.4
0.6
0.8
1.0
Sample Fraction

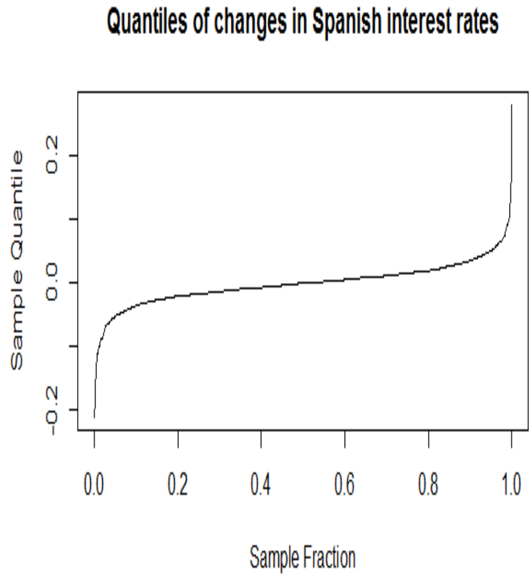

Quantiles of Norwegian stock returns
Sample Quantile
-0.2
0.0
0.1
0.2
0.0
0.2
0.4
0.6
0.8
1.0
Sample Fraction

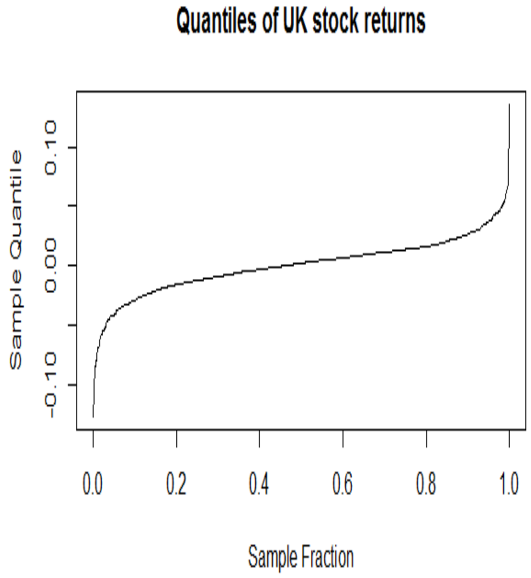

Quantiles of changes in Norwegian interest rates
Sample Quantile
-0.2
-0.1
0.0
0.1
0.0
0.2
0.4
0.6
0.8
1.0
Sample Fraction

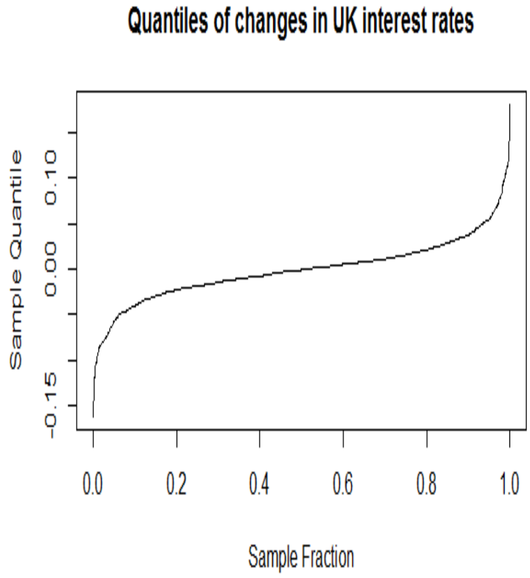

Quantiles of Portuguese stock returns
Sample Quantile
-0.20
-0.10
0.00
0.10
0.0
0.2
0.4
0.6
0.8
1.0
Sample Fraction

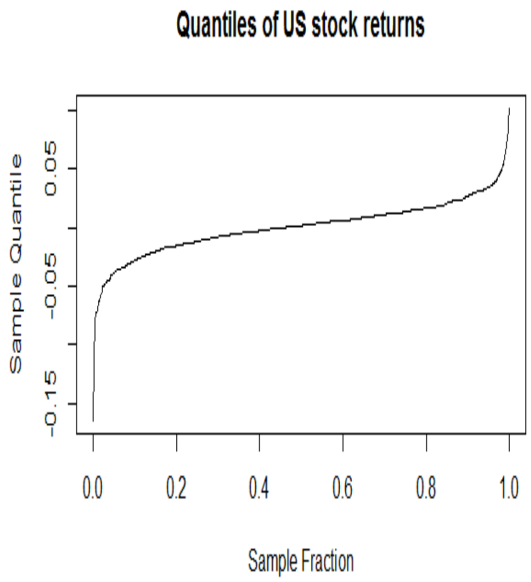

Quantiles of changes in Portuguese interest rates
Sample Quantile
-0.2
0.0
0.1
0.2
0.0
0.2
0.4
0.6
0.8
1.0
Sample Fraction


Quantiles of Spanish stock returns
Sample Quantile
-0.10
0.00
0.10
0.0
0.2
0.4
0.6
0.8
1.0
Sample Fraction


Quantiles of changes in Spanish interest rates
Sample Quantile
-0.2
0.0
0.2
0.0
0.2
0.4
0.6
0.8
1.0
Sample Fraction


Quantiles of UK stock returns
Sample Quantile
-0.10
0.00
0.10
0.0
0.2
0.4
0.6
0.8
1.0
Sample Fraction


Quantiles of changes in UK interest rates
Sample Quantile
-0.15
0.00
0.10
0.0
0.2
0.4
0.6
0.8
1.0
Sample Fraction


Quantiles of US stock returns
Sample Quantile
-0.15
-0.05
0.05
0.0
0.2
0.4
0.6
0.8
1.0
Sample Fraction

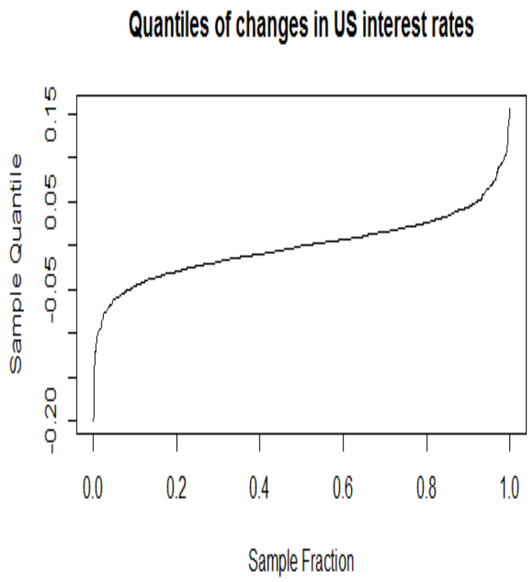
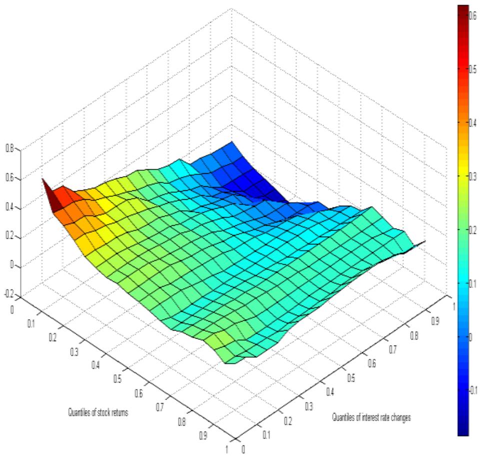
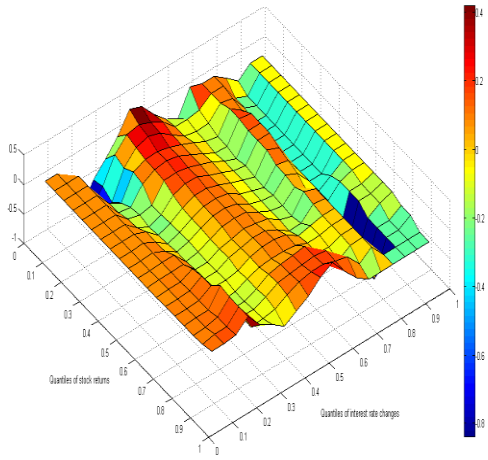

Quantiles of changes in US interest rates
Sample Quantile
-0.20
-0.05
0.05
0.15
0.0
0.2
0.4
0.6
0.8
1.0
Sample Fraction

Figure 2: Quantile-on-Quantile (QQ) estimates of the slope coefficient, $\hat{\beta}_1(\theta, \tau)$, for full sample.

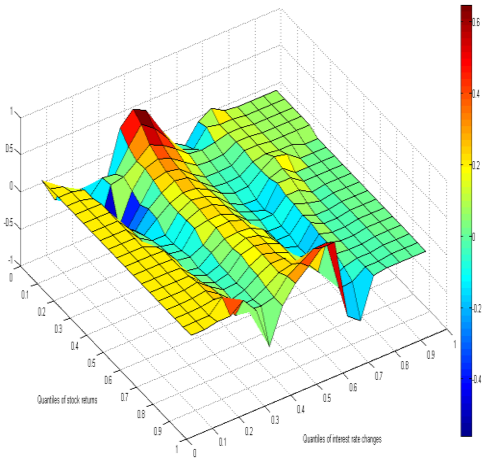
a) Australia



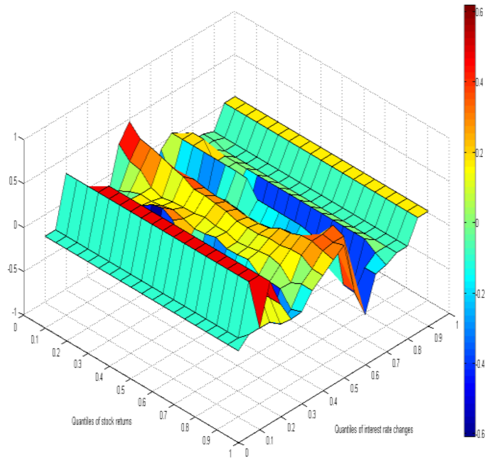
b) Belgium



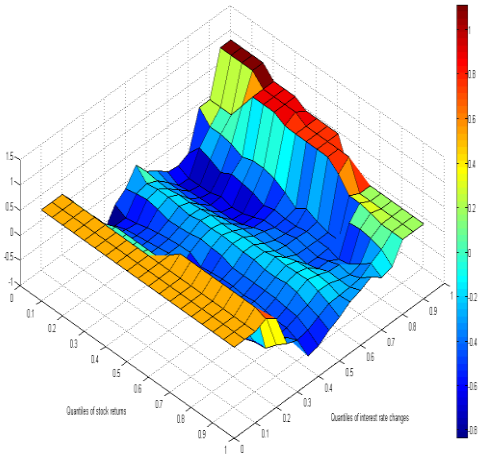
c) France



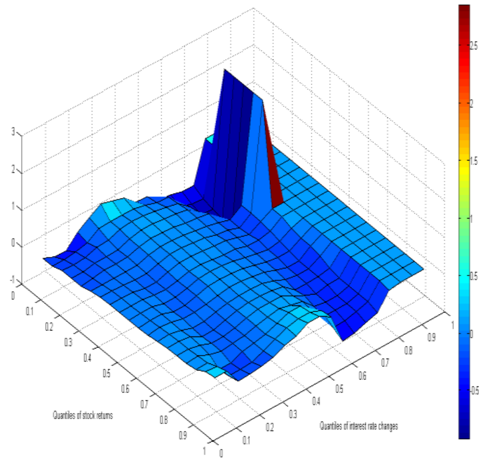
d) Germany



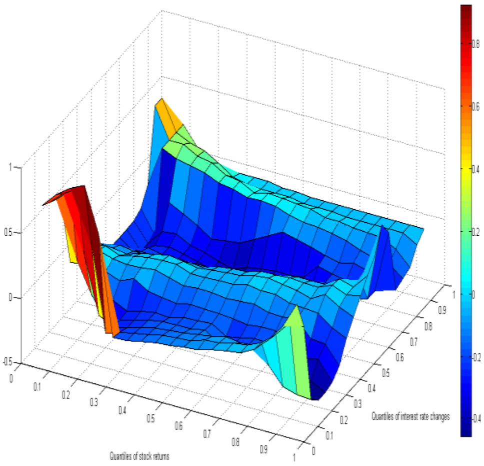
e) Greece



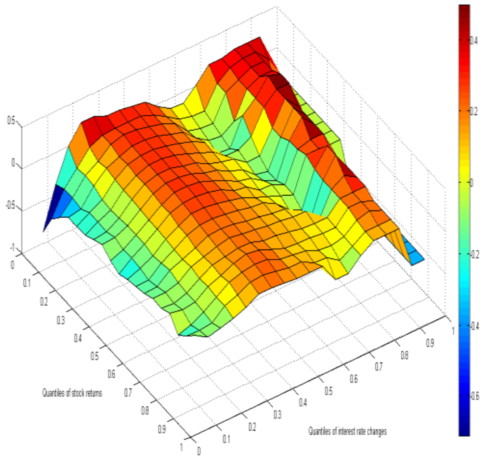
f) Ireland



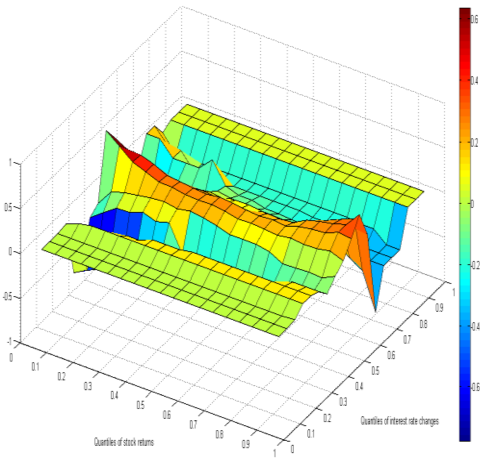
g) Italy



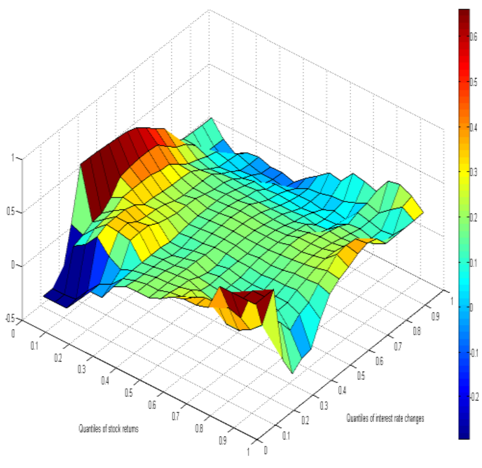
h) Japan



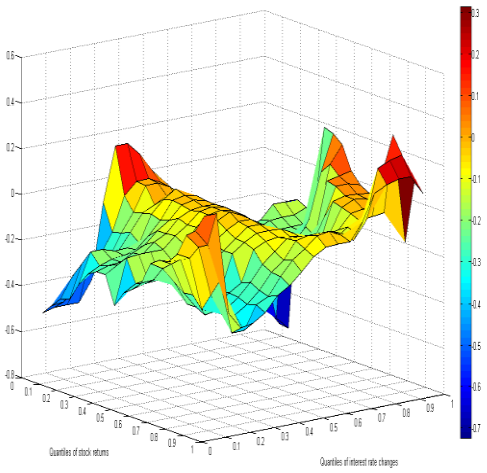
i) Netherlands



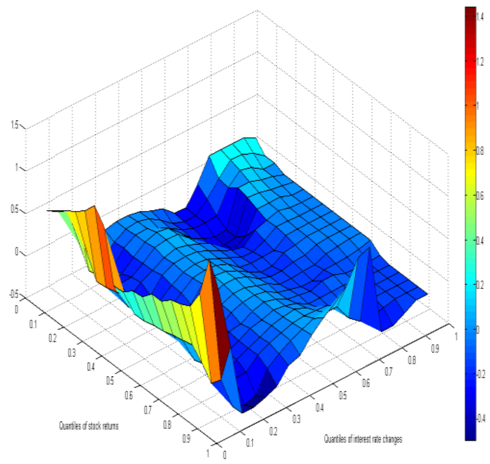
j) Norway



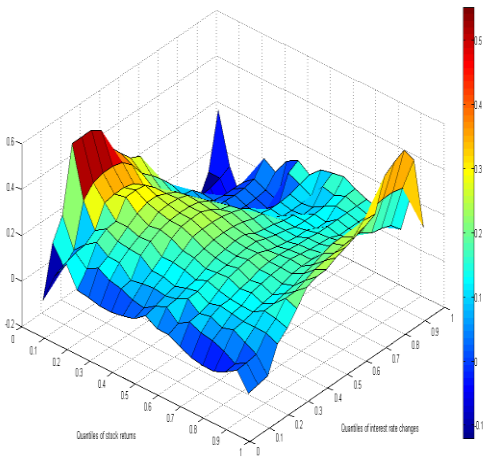
k) Portugal



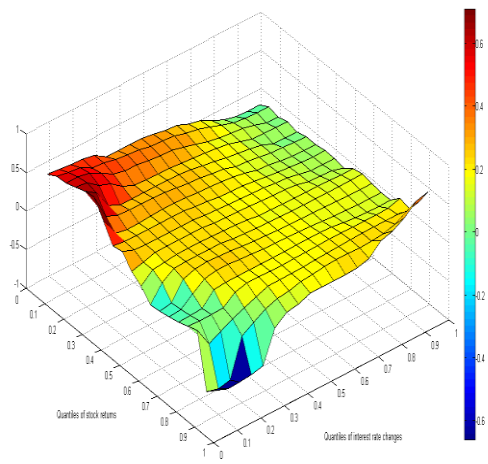
l) Spain



m) UK



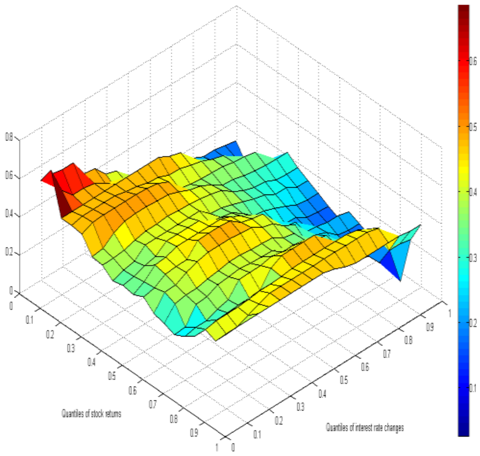
n) USA



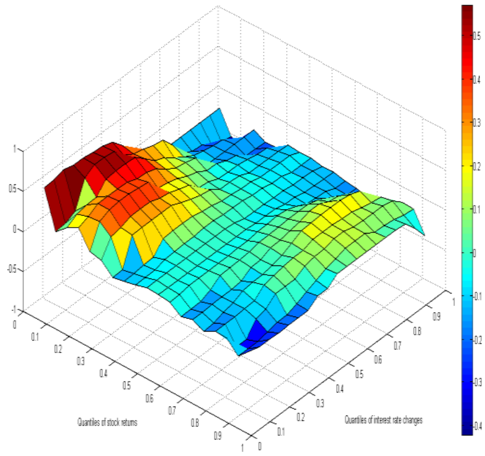
Note: The graphs show the estimates of the slope coefficient, $\hat{\beta}_1(\theta, \tau)$, in the *z*-axis against the quantiles of stock market returns (θ) in the *x*-axis and the quantiles of changes in interest rates (τ) in the *y*-axis, for full sample.

Figure 3: Quantile-on-Quantile (QQ) estimates of the slope coefficient, $\hat{\beta}_1(\theta, \tau)$, for the global financial crisis sub-period.

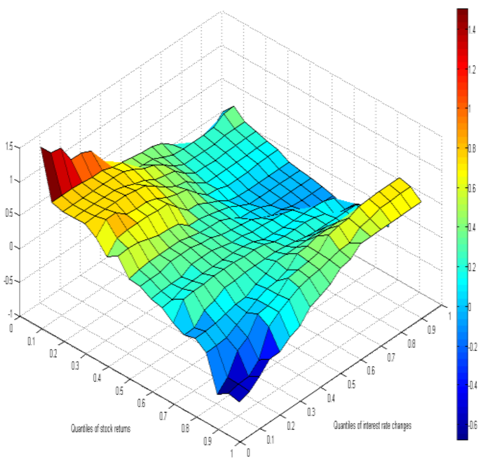
a) Australia



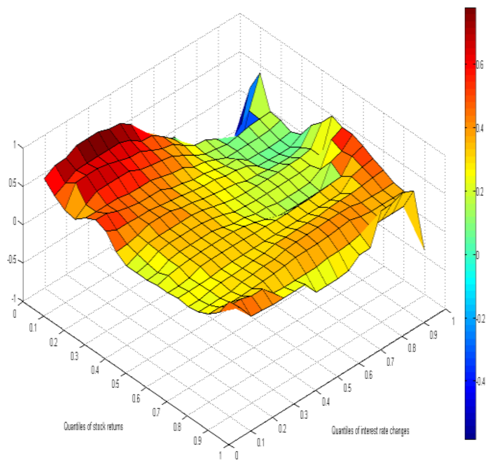
b) Belgium



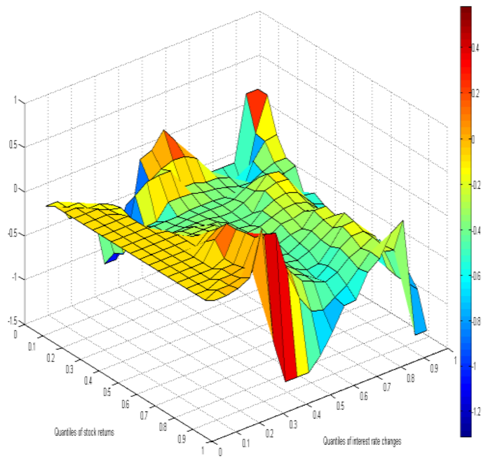
c) France



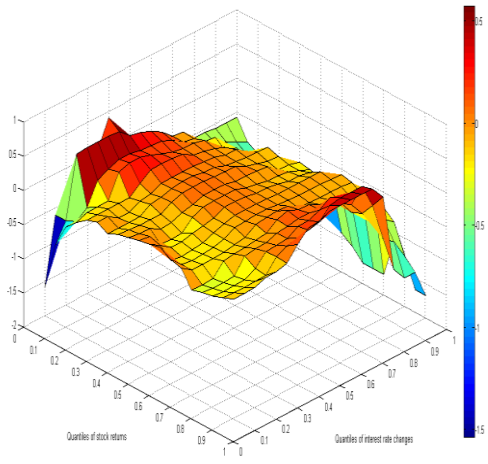
d) Germany



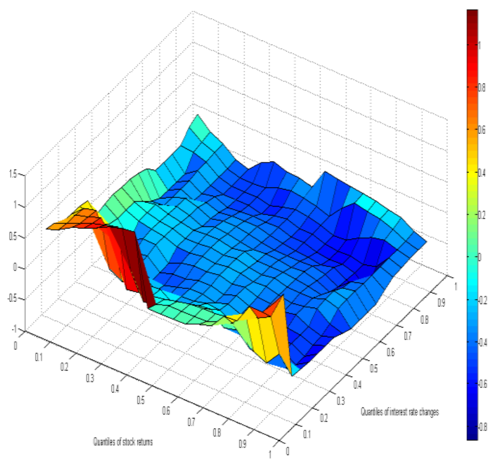
e) Greece



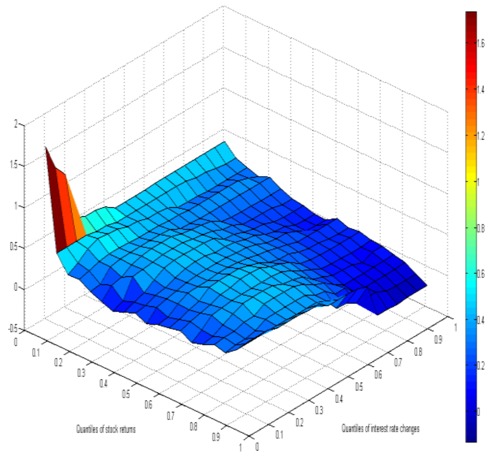
f) Ireland



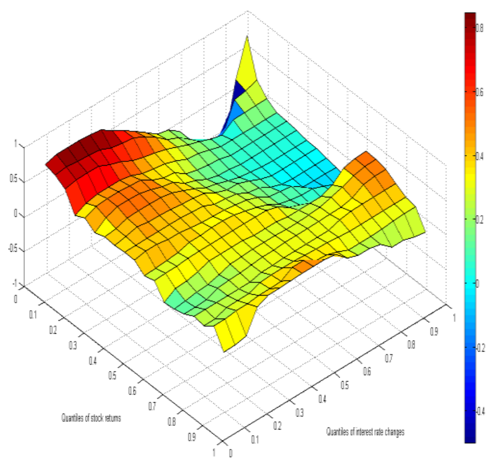
g) Italy



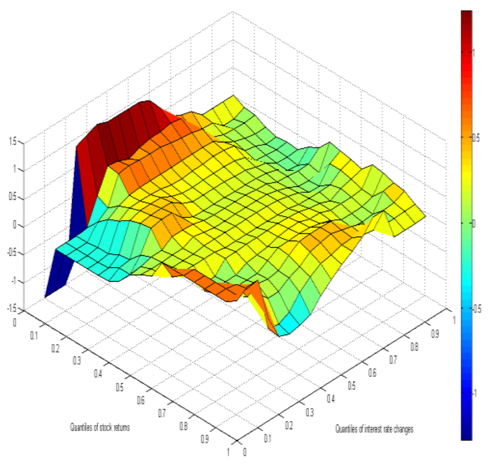
h) Japan



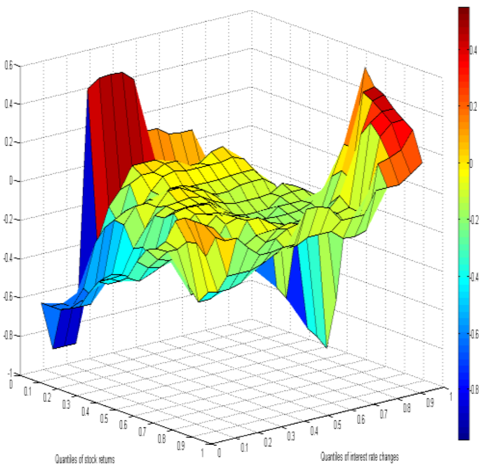
i) Netherlands



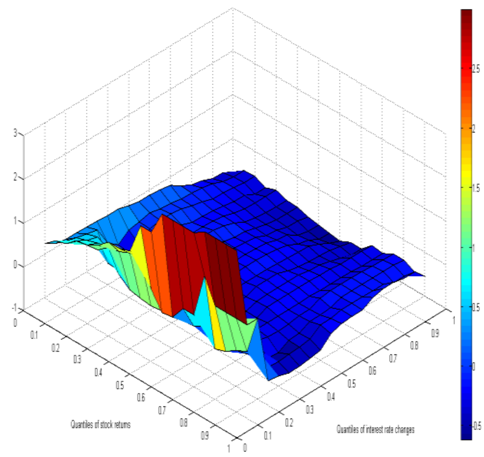
j) Norway:



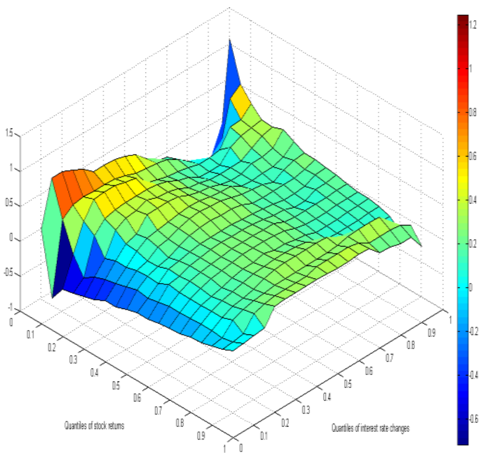
k) Portugal



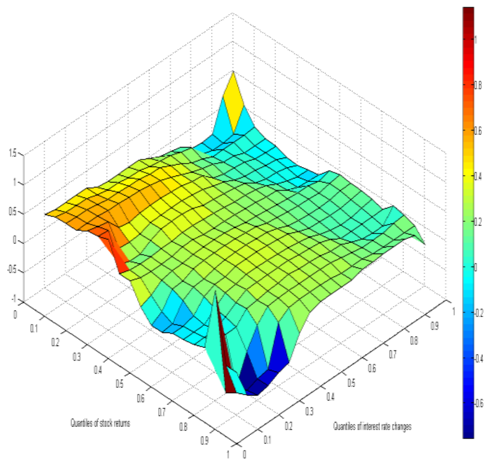
l) Spain



m) UK

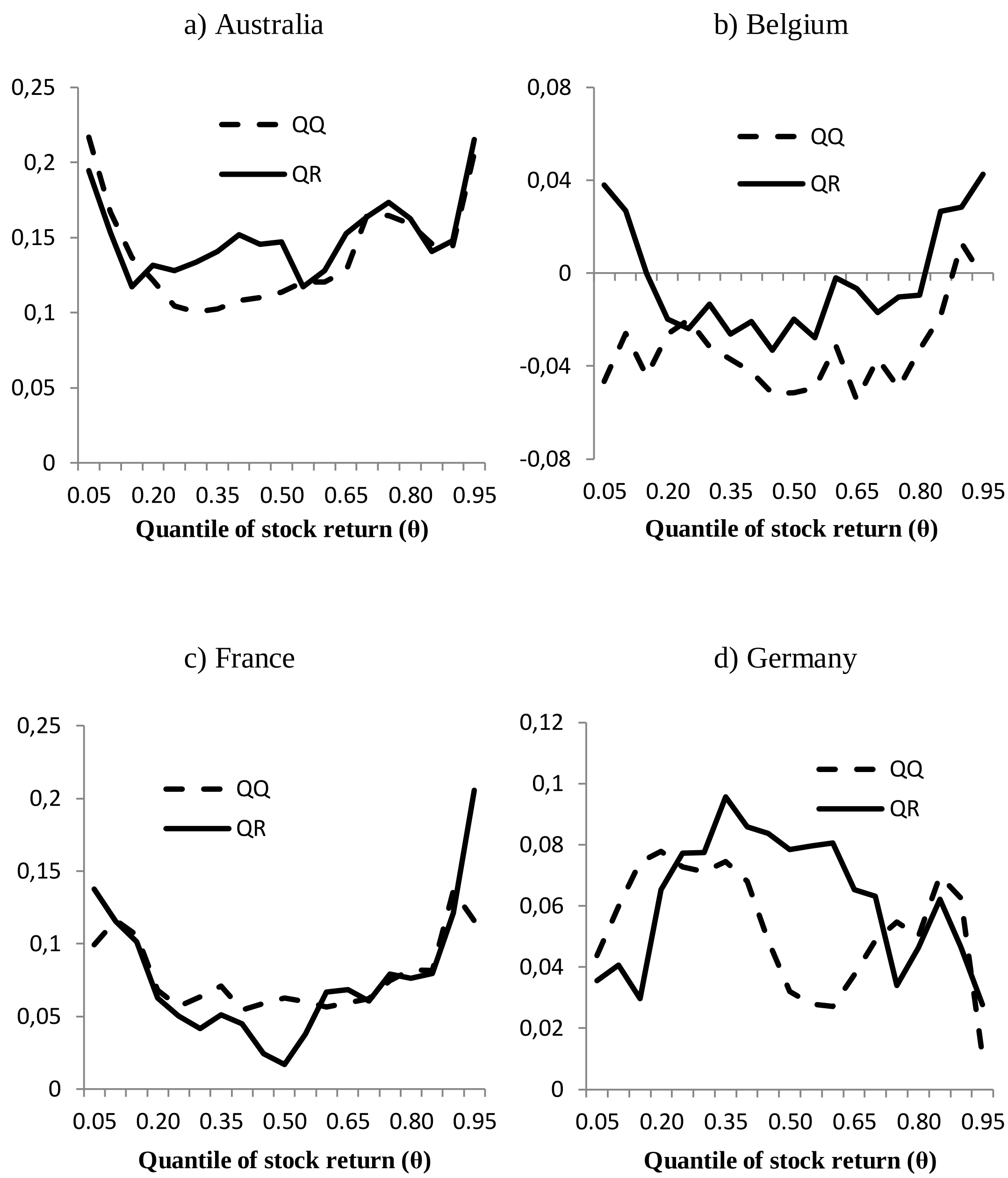


n) USA

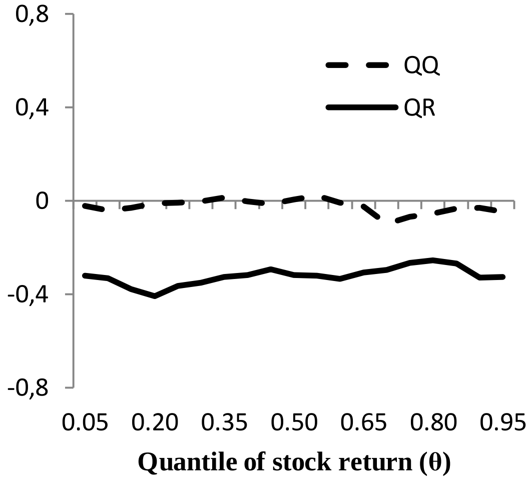


Note: The graphs show the estimates of the slope coefficient, $\hat{\beta}_1(\theta,\tau)$, in the *z*-axis against the quantiles of stock market returns (θ) in the *x*-axis and the quantiles of changes in interest rates (τ) in the *y*-axis, for crisis sub-period.

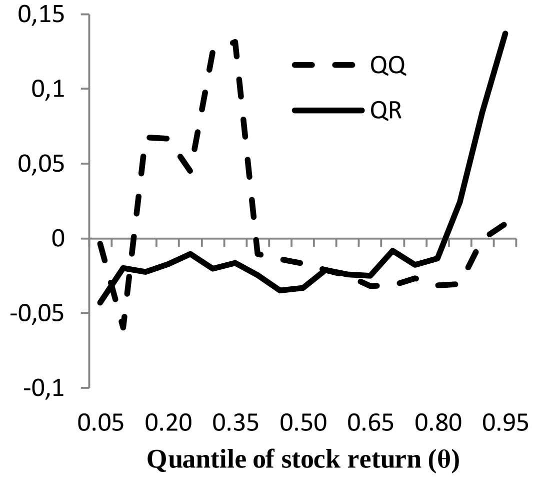
Figure 4: Comparison of the QR and the averaged QQ estimates.



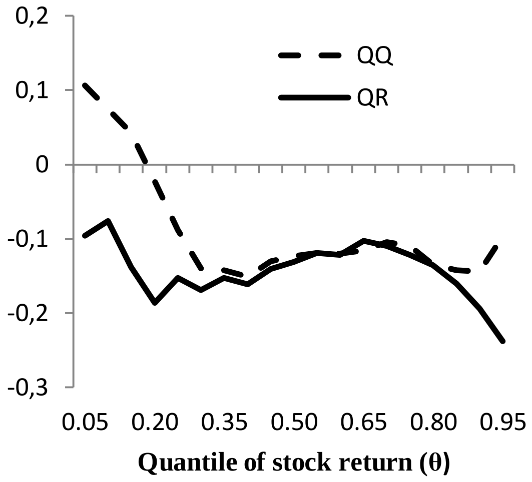
e) Greece



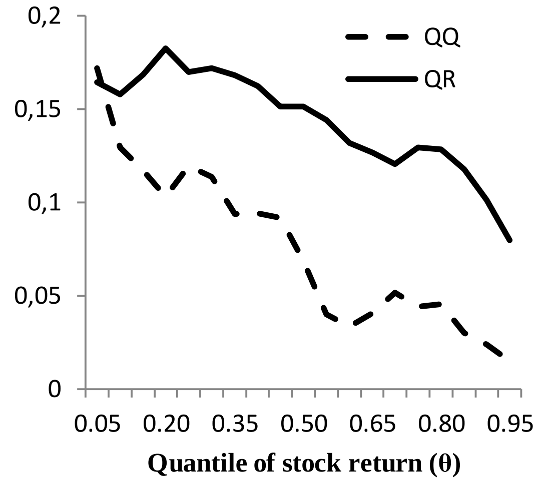
f) Ireland



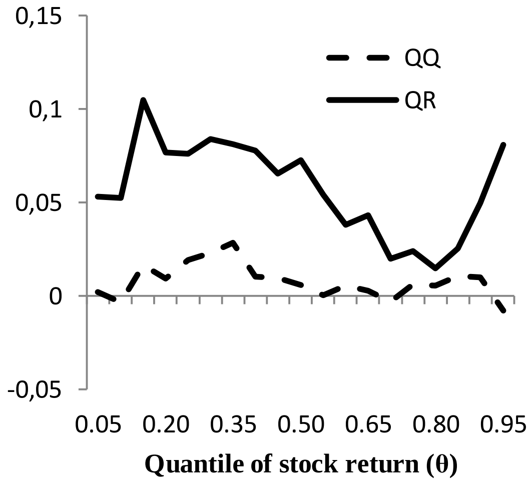
g) Italy



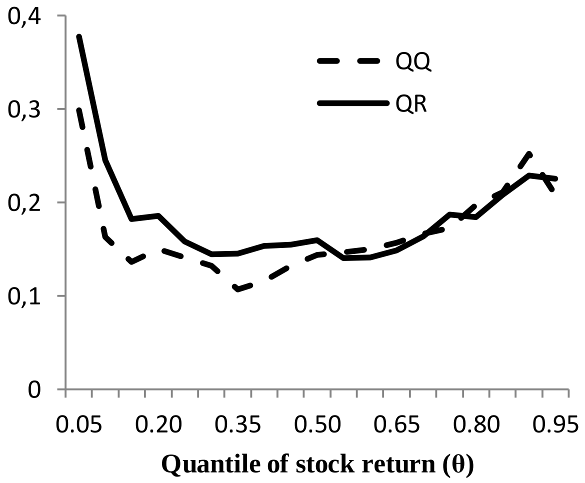
h) Japan



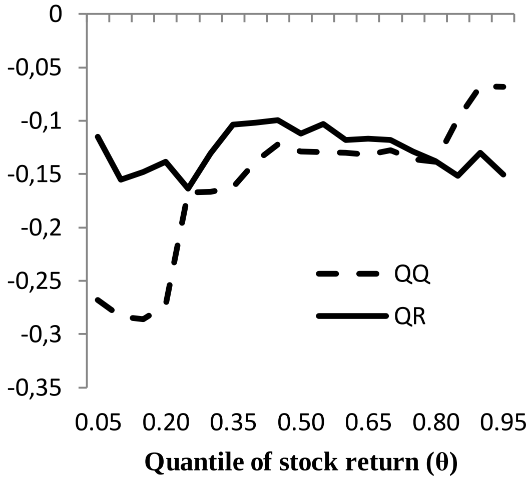
i) Netherlands



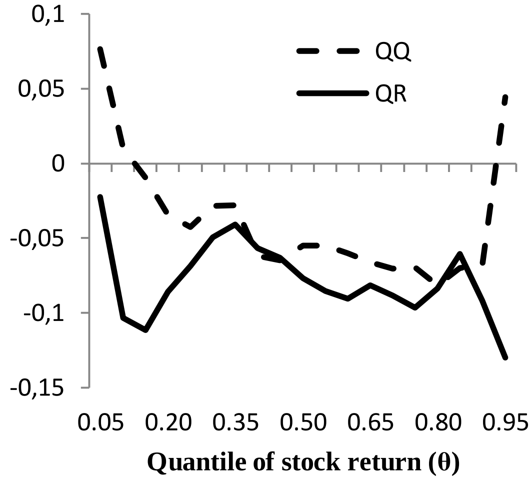
j) Norway



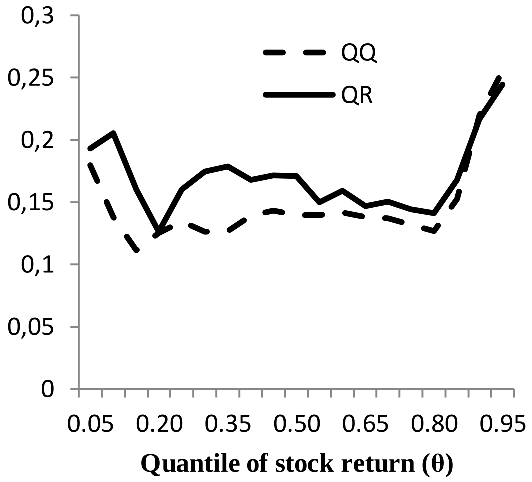
k) Portugal



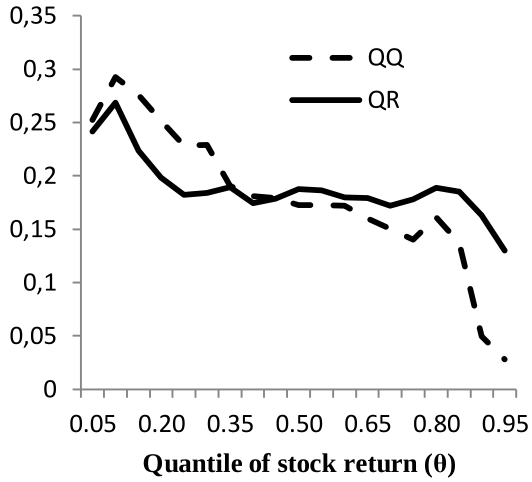
l) Spain



m) UK



n) USA



Note: The graphs display the estimates of the standard quantile regression parameters, denoted by QR (continuous black line), and the averaged QQ parameters, denoted by QQ (dashed black line), at different quantiles of stock market return for all countries analyzed.