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The Contagion of International Crises: Implications of Inflation and Investor Sentiment on Stock and Treasury bond Returns

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Abstract. *In recent years, the stock market has faced numerous challenges generated by unexpected events that had a major impact on the global economy. Thus, through this paper, which is based on the analysis of the relationships between inflation, stock market yields and treasury bond yields in the context of international crises, it is intended to illustrate the possible effects of inflation on stock market yields and treasury bonds, as well as to compare the performance of stock market indices and treasury bonds in relation to the corresponding inflation. The main objective of this paper was to capture the complex relationships between inflation, stock market index returns and treasury bond yields over a period of ten years by using a series of advanced statistical techniques. Through the advanced techniques and models implemented, it is proposed to evaluate the correlation and causality between these economic variables, the goal being to determine the degree of influence these correlations have on the investor's sentiment in choosing the investment portfolio. The originality of this paper is reflected by the case study carried out on the daily returns of stock indices from America and Central-Eastern Europe, as well as the variable values of the consumer price index and long-maturity treasury bonds, over a period marked by events with a high impact on the global economy. The results obtained show that in the analyzed time series there is a close connection between the contagion of stock markets, inflation and 10-year treasury bonds, and the strong impact tends to be unidirectional, from the changes recorded in the level of inflation to stock index returns and 10-year treasury bond yields, as a result of the evolution of the geopolitical conflict and of the state of the global and regional economies, but not vice versa.*

Keywords: inflation, returns, stock market indices, contagion, investors' sentiment, advanced statistical techniques.

Introduction

Investors' perception of inflation in the stock market, as well as how it affects their sentiment to invest, can differ because, on one hand, inflation can be advantageous for some sectors, such as natural resources or certain industries that have gained from rising prices, while, on the other hand, it can have a negative effect on the values of financial assets because it increases the cost of financing for businesses and reduces the purchasing power of investors.

The effect of inflation on the returns of stock indices and treasury bonds is an important topic and often addressed in specialized studies, especially since investor sentiment and inflation have a major influence on share returns, which constantly causes high volatility in the stock market returns (Sukmadilaga et al., 2023). Depending on how each investor perceives the impact of inflation on the economy and value curves, investor sentiment during periods of inflation can vary, so investors' expectations of future inflation rates disrupt financial markets. According to Cieslak and Pflueger (2023), who, through the implementation of advanced econometric models, observed that, when inflation is in a period that fuels shocks in an economy, both treasury bonds and stock yields decrease at the same time, which increases the need to reduce the risk at the level of both variables so as to determine the attraction of investors. The high degree of contagion shows that the decline or growth of the economy of a highly developed country can be reflected in economies

DOI: 10.2478/picbe-2023-0161
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around the world and, in recent years, the increase in demand has been shown to be exceeded by the decrease in supply on the economic market due to the pandemic and the war in Ukraine, resulting in the production of inflation and international crises, such as that of raw materials, energy and methane gas. In this context, Liu, Umair and Gao (2023) showed that the ever-increasing volatility of prices for raw materials, such as crude oil, has a negative effect on stock returns.

This paper tries to address two main aspects. Firstly, considering that inflation and the returns of stock indices and treasury bonds represent important economic factors in an economy because, through their volatility, they can affect several economic sectors, a detailed analysis between those three variables was needed, from which to reveal the degree of influence they have over each other and what effects they can produce on the level of investor sentiment. Recently, the political and economic events that have affected the global economy have increased the degree of contagion between financial markets around the world. Another main aspect is that the analysis of the degree of influence that inflation has over stock market returns and treasury bonds is of high importance, especially for investors that, knowing this degree of influence, can find much more effective hedging strategies to reduce the risk of loss.

This paper's contribution to the specialized literature is given by the fact that it studies the inflation, yields of long-term government bonds and the performance of stock market indices (especially at the level of Romania), as well as their effects on investor sentiment, subject that is not often researched.

In order to carry out this analysis, we've implemented a multivariate GARCH model, namely DCC-GARCH (1,1). This model is part of the multivariate GARCH family, being a model often used in specialized literature to evaluate different correlations between two or more variables simultaneously (among others, see Benlagha, 2014). The DCC-GARCH model was firstly proposed by Engle (2002) and it's a widely used model due to its approach, that combines univariate GARCH models with simplified parametric models in order to achieve greater flexibility in terms of correlations. Therefore, I've studied, through a multivariate GARCH model, the degree of correlation between inflation, stock index returns and treasury bonds related to the financial markets from USA and Central and Eastern Europe, over a period of 10 years, which captures very well the events of economic uncertainty in recent years.

The results obtained are in accordance with the studies previously carried out regarding the influence that inflation has on the returns of stock indices or on government bonds. The rest of the paper is structured as follows: the following section showcases a study of the specialized literature regarding the relationship between inflation, stock market index returns and treasury bonds seen following the results obtained by applying multivariate GARCH (DCC-GARCH) models, then, in the third section, I've presented, in detail, the methodology based on which I've performed the DCC-GARCH model (as well as the rest of the advanced statistical tests used). The fourth section, which is the most important because it represents the originality of this study, describes the analyzed data, as well as the results obtained after applying the DCC-GARCH model. The fifth section, which is the last one, presents the conclusions of this paper.

Literature review

The DCC-GARCH model is a model that estimates the correlation between several time series, managing to capture the movement trends of active prices. In the specialized literature, by using this multivariate GARCH model, which was also used in this paper, it could be observed, according to Antonakakis, Gupta and Tiwari (2017), that there can be a positive or negative relationship between inflation and stock prices, depending on the analyzed period, which evolves

heterogeneously over time. In order to evaluate the daily returns of shares, in the case of emerging markets, Afzal et al. (2021) used univariate GARCH models, as well as a DCC-GARCH model, and the results obtained showed that the multivariate model offers better performance than other models when it comes to stock markets with a high degree of volatility.

In the specialized literature, inflation, exchange rates and interest rates represent economic factors whose volatility has a significant impact on the volatility of stock market indices. Through empirical evidence, it has been shown that there is a linear relationship between inflation and stock returns such that the inflation's impact on the stock returns influences the decision-making sentiment of the investor, which is based on the information held (Sathyanarayana and Gargesa, 2022).

In other relevant papers, such as those of Eldomiaty, Yasmeen and Hammam (2020) and Alzoubi (2022), it is shown that the inflation and interest rates significantly impact the share prices and stock market indices in a negative way, causing a similar reaction in the case of bonds. There are papers that study, through the use of stock returns, whether a prediction can be made on changes in interest rates and inflation and, contrary to the expectations, namely that changes in inflation produce negative effects on stock price returns, Titman and Warga (1989) showed that there is a positive and significant relationship between stock price returns and changes in the inflation rate, as well as a positive and significant relationship between stock returns and interest rate changes. Covering the risk caused by the volatility of inflation is a major problem among investors that prefer long-term investments, a problem that persists even in the periods when inflation registered relatively low values.

Spierdijk and Umar (2015) focused on analyzing the methods of hedging the inflation risk of stocks, treasury bonds and government securities and the results they've reached were that the short positions of treasury bonds with a maturity greater than 10 years have the potential to provide adequate long-term inflation protection.

According to the study carried out by Muzindutsi et al. (2022), developing countries, in comparison to developed countries, suffered significant consequences because of the pandemic. Contrary to the above, Gunay and Can (2022) provides arguments using a multivariate GARCH model, through which they've shown that, in recent years, shocks have a significantly greater impact over a developed market than over a developing market. Using the DCC-GARCH model, Zinecker et al. (2016) succeeded in evaluating, measuring and forecasting the volatility and the correlation between several capital markets from Europe, from which the high intercorrelation between them emerged.

Methodology

In order to analyze the implications of inflation on stock market returns and treasury bonds yields with a maturity of 10 years, we took into account some of the most significant stock market indices, such as: BET (Bucharest stock exchange index), WIG (Warsaw stock exchange index), NYSE (USA stock exchange index), Shanghai Stock Exchange Index (China stock exchange index), DAX 30 (Germany stock exchange index), CAC 40 (France stock exchange index) and FTSE 100 (Great Britain stock exchange index) and the CPI (consumer price index) and treasury bond yields with a maturity of ten years. The analysis carried out in this paper begins with the determination of descriptive statistics, and the most important statistics are highlighted in the paper, namely: mean, standard deviation, skewness and kurtosis.

Since financial market indices are periodic time series that do not guarantee the normality of the series, we performed the normality of the series in this study, through the test: Jarque Berra (JB). The Jarque Bera (JB) test is a way to test whether the analyzed data series is normally

distributed or not. This test, according to Jarque and Bera (1980), is based on two measures, namely: the asymmetry coefficient ("Skewness") and the curvature coefficient ("Kurtosis coefficient"). The calculation formula is:

$$\text{JB} = \frac{n}{6}\left[s^2 + \frac{(k-3)^2}{4}\right] \quad (1)$$

where: n represents the size of the series, s represents the asymmetry coefficient, and k represents the kurtosis coefficient or the skewness coefficient.

The hypotheses of the test are the null hypothesis whereby the series of residuals comes from a normal distribution, and the probability of the test exceeds the allowed threshold of 0.05, and the hypothesis H_1 in which the series of residuals does not come from a normal distribution with a probability that does not exceed the threshold of 0.05.

One of the most well-known and applied tests on data series to detect the stationarity or non-stationarity of the series is the Augmented Dickey-Fuller test (ADF test). This test is characterized by the formula:

$$\Delta y_t = \alpha + \beta_t + \gamma y_{t-1} + \delta_1 y_{t-1} + \delta_2 y_{t-2} + \cdots + \delta_{p-1}\Delta y_{t-p+1} + \varepsilon_t \quad (2)$$

The hypotheses of the test are the null hypothesis H_0 by which with a probability higher than 0.05 it is accepted that the series is non-stationary, and with a probability lower than 0.05 the null hypothesis is rejected and the hypothesis H_1 is accepted by which the series is stationary. For an analysis to be correct and to generate results as accurate as possible and for it to be in accordance with what is happening in the economy, without being affected by possible syncope, it is very important that it fulfills the criterion of stationarity. If the analyzed data series is not stationary, it is necessary to stabilize the data series by differentiation either of the first or second degree, until the series becomes stationary.

To determine the autocorrelation from the data, one of the most well-known models can be used, namely Durbin Watson test, whose statistic is:

$$d = \frac{\sum_{t=2}^{T} (e_t - e_{t-1})^2}{\sum_{t-1}^{T} e_t^2} \quad (3)$$

where: T represents the number of observations of the analyzed series. If T has a large value, then $d \cong 2 \cdot (1 - \hat{\rho})$, $\hat{\rho}$ represents the autocorrelation of the residuals. If $d = 2$, then it means that there is no autocorrelation.

In order to detect homoscedasticity, the most well-known test is the Breusch Pagan test, developed in 1979 and according to it the calculation formula is:

$$\hat{\varepsilon}_t = b_0 + b_1 xt + \rho_1 \varepsilon_{t-1} + \rho_2 \varepsilon_{t-2} + \mu_t \quad (4)$$

The hypotheses of this test are the null hypothesis whereby $\rho_1 = \rho_2 = 0$ and there is no autocorrelation in the data and the hypothesis H_1 in which $\rho_1 \neq 0$ or $\rho_2 \neq 0$, so there is correlation in the data. In the case of a probability higher than the allowed threshold of 0.05, then we can say that the null hypothesis is accepted, whereby there is no autocorrelation.

The Ljung-Box test is a test that shows if there is autocorrelation at the level of a data series. The Markov condition, as shown by Hausman and Woodward (1999), assumes that there is no

autocorrelation in the series, so zero autocorrelation in a data series is a necessary condition for that series to be modeled with an ARIMA or GARCH model.

The difference between the Ljung-Box test and the Durbin Watson test is quite significant, the Durbin Watson (Durbin and Watson, 1950) test focusing on detecting autocorrelation between consecutive terms of the series and having values between 0 and 4, the value of 2 representing the absence of a correlation while the test Ljung-Box (Box and Pierce, 1970) checks the presence of autocorrelation for a specified number of periods (some of the periods may be even larger than those of the Durbin Watson test). The Ljung-Box test formula is:

$$Q = n(n+2) \cdot \sum_{k=1}^{h} \frac{\hat{\rho}_k^2}{n-k} \qquad 5$$

where: n is the number of observations, $\hat{\rho}_k^2$ is the autocorrelation at lag k and h represents the number of tested lags.The necessary conditions for applying univariate according to Engel (1982) and multivariate ARCH-GARCH models to a data series are: stationarity of the series (the mean and variance should not vary over time), heteroscedasticity of the series (the variance of a series should not be constant over time), the presence of a negative autocorrelation (the past values of the series are negatively correlated with the future values) or that there is no autocorrelation in the data, as well as the testing of the Markov condition (the dependence of the future value of the data series should be conditioned only by the values of the recent past and not the removed).

The heteroscedastic conditional autoregressive multivariate GARCH models are statistical models that can be used to analyze and forecast volatility simultaneously with several economic variables and at the same time allow risk assessment and strategies based on the interaction between several financial assets. The multivariate models have the same theoretical basis as the univariate GARCH autoregressive conditional heteroscedastic models, having as the principle of application the fulfillment of the four conditions listed previously, namely: stationarity, heteroscedasticity, no autocorrelation in the data and the fulfillment of the Markov condition (testing the condition being possible through the Ljung-Box test).

From the existing studies in econometrics Brooks (2014) from the specialized literature, we observe the existence of several types of heteroscedastic conditional autoregressive multivariate GARCH models, among which: GARCH-M (multiplicative GARCH model), VECH Model (Vector Error Correction Model), GARCH-X model (GARCH Model with variables exogenous), the GARCH-S model(Stochastic Correlation GARCH), the GARCH-c model (Conditional Correlation GARCH) and the GARCH-DCC model (Dynamic Conditional Correlation GARCH) that was used in this paper, given the fact that by its properties, it succeeds to model the dependence between several financial variables.

The DCC-GARCH (Dynamic Conditional Correlation GARCH) model is one of the multivariate autoregressive conditional heteroscedastic GARCH models, which analyzes the correlations between several series of financial data, its characteristic being the ability to capture dynamic changes in the correlations between the series, thus providing a description more precise of the relationships between them, and the fact that the model allows the analysis of systematic risk in case investors want to invest in several financial assets, leads to its frequent use.

The DCC-GARCH model is a multivariate model and according to Siddiqui et al. (2022) and Tsay (2005) presupposes the fulfillment of some steps characterized by the formulas:

$$X_t = \alpha + cX_{t-1} + \varepsilon_{it} \quad (6)$$

$$\varepsilon_{it} = {h_{it}}^{-\frac{1}{2}}, \gamma_{it} \quad (7)$$

$$H_t = D_t R_t D_t \quad (8)$$

where: X_{t-1} represents historical performance; ε_{it} represents the error term; ${h_{it}}^{-\frac{1}{2}}$ represents the conditional version; and γ_{it} is a residual vector. In last equation, H_t shows the relationship that changes over time between two or more variables influenced by different market conditions, and it was estimated by Ahmad et al. (2013).

$$D_t = diagonal({h_{it}}^{-\frac{1}{2}}{}_{11t} \cdots\cdots\cdots, {h_{it}}^{-\frac{1}{2}}{}_{sst}) \quad (9)$$

$$R_t = {\varrho_t}^{*-1} \varrho_t \ {\varrho_t}^{*-1} \quad (10)$$

where: ${\varrho_t}^*$ is the diagonal matrix.

$$\varrho_t = diagonal(q^{\frac{1}{2}}{}_{11t,} q^{\frac{1}{2}}{}_{22t} \cdots\cdots q^{\frac{1}{2}}{}_{2lmt}) \quad (11)$$

$$q_{i,j,t} = \underline{\rho}_{i,j} \left(\frac{1-\alpha-\beta}{1-\beta}\right) + \alpha \sum_{f}^{\infty} \quad \beta^f \varepsilon_{it-f} {}^{\varepsilon_{jt-f}} \quad (12)$$

The univariate GARCH (1,1) model is used, so that the conditional correlation can be calculated through the estimates of the GARCH (1,1) model:

$$\varrho_t = (1-\alpha-\beta)\underline{\varrho} + \alpha_{1\varepsilon_{t-1}} \varepsilon'_{t-1} + b_{q_{t-1}} \quad (13)$$

Parameters α and β are positive parameters and as well as the condition of the GARCH model $\alpha + \beta$ must be less than 1. The parameters α and β represent the parameters of the GARCH (1,1) model according to Engle (2002).

The Log-Likelihood function, a function used in statistical and econometric analysis to evaluate how well a model fits the observed data, is characterized by the formula:

$$l_n\big(L(\theta)\big) = -\frac{1}{2} = \sum_{t-1}^{T} \quad \{nln\,(2\pi)\} + ln|D_t^2| + ln|R_t| + \varepsilon'_t D_t^{-2} \varepsilon_t \quad (14)$$

A DCC (p, q) model is characterized by the formula:

$$Q_t = \underline{R} + \sum_{i=}^{p} \quad \alpha_i (\nu_{t-i} \upsilon'_{t-i} - \underline{R}) + \sum_{j=1}^{q} \quad B_j \big(Q_{t-j} - \underline{R}\big) \quad (15)$$

where the orders p, q can be established for example according to the informational criteria.

Results and discussions

In order to be able to observe the correlations between inflation, stock market index returns and 10-year treasury bond yields, we used in this paper data sets with monthly observations, based on the closing prices, of the following stock market indices: BET (Bucharest stock exchange index), WIG (Warsaw stock exchange index), NYSE (USA stock exchange index), Shanghai (China stock exchange index), DAX30 (German stock exchange index), CAC40 (France stock exchange index) and FTSE100 (Great Britain stock exchange index) in the period (01/Feb/2013-31/Dec/2022). The data were collected from the Reuters platform respectively the YCharts platform. The returns of the stock market indices and the consumer price index were calculated with the formula: $\Delta(\%) = ln\frac{P_1}{P_0} \cdot 100$, because the logarithm is considered to have a normal distribution, according to the standard assumptions.

To highlight the interconnected aspects between stock market returns, 10-year treasury bond returns and inflation, I will perform a series of tests, starting from descriptive statistics and up to an extension of the conditional heteroscedastic autoregressive GARCH model, a multivariate model namely DCC-GARCH time series volatility forecasting and analysis tool when volatility varies.

Computing descriptive statistics is a necessary first step because it offers a better understanding of the data used, thus allowing analysts to take useful information and make informed decisions based on it, as the following details would be available: the mean, standard deviation, skewness, kurtosis, which can be used to identify trends related to the evolution of the analyzed variables.

As it can be seen in Table 1, which covers a period of approximately 10 years, when it comes to the closing price returns of the stock market indices, the prices tend to go up, on average, in countries such as Romania, USA, China, France and prices tend to go down in countries such as Germany, Poland and Great Britain. In addition, each annual value of the series tends to deviate from the mean with 5.59% in the case of Romania, 4.23% in the case of the United States of America, 6.52% in the case of China, 5.29% in the case of France, 5.53%, in the case of Germany, 7.23%, in the case of Poland and 4.64% in the case of Great Britain.

The skewness and kurtosis coefficients are showing that the return series of the stock market indices mostly come from platykurtic distributions, meaning that, they present values of kurtosis lower than the normal value of 3 and an asymmetry to the left, less so in the case of France, which has a positive skewness coefficient of 0.46, which shows an asymmetry to the right (positive skewness) and Great Britain which shows a distribution with asymmetry to the left (negative skewness) but with a kurtosis coefficient that exceeds the value of 3, which means that it comes from a leptokurtic distribution (more concentrated around the mean than a normal distribution) and has a longer tail than a normal distribution. These features suggest that the distribution of the UK time series is concentrated around a mean, but there are also outliers that are larger than the normal distribution.

In the case of 10-year treasury bond yields and inflation for the analyzed period, we can say that on average prices and the level of inflation tend to increase, and from the perspective of the dispersion percentage we can state that the annual values of the data series for treasury bond yields and the CPI do not significantly deviates from the average.

From the point of view of the type of distribution in the case of the two data series, in most cases the series register a kurtosis coefficient that exceeds the value of 3, which means that the series come from a leptokurtic distribution. The series of treasury bond yields for Romania, China,

France and Germany have a kurtosis coefficient lower than the value of 3, which means that the series come from a platykurtic series distribution. The asymmetry of the treasury bond yield series is generally to the right with (positive values) except the USA (-0.11), and the consumer price index yields generally have positive values, except Romania (-0.27) and China (-0.32) with an asymmetry to the left with negative values.

Table 1. Descriptive statistics of the analyzed data

Series	Mean	Standard Deviation	Skewness	Kurtosis
Returns				
R_CP_RO	0.34	5.59	-0.54	1.07
R_CP_USA	0.45	4.23	-0.83	2.79
R_CP_CH	0.14	6.52	-0.46	2.32
R_CP_FR	0.30	5.29	0.04	1.76
R_CP_DE	-0.09	5.53	-0.21	0.49
R_CP_PL	-0.06	7.23	-0.06	0.53
R_CP_UK	-0.06	4.64	-0.48	4.78
TBIL10Y				
TBY10Y_RO	4.42	1.30	1.54	2.54
TBY10Y_USA	2.14	0.71	-0.11	3.11
TBY10Y_CH	3.34	0.48	0.66	2.80
TBY10Y_FR	0.82	0.83	0.72	2.71
TBY10Y_DE	0.44	0.75	0.66	2.71
TBY10Y_PL	3.21	1.36	1.23	5.19
TBY10Y_UK	1.47	0.82	0.63	3.16
Inflation				
CPI_RO	0.26	0.55	-0.27	9.57
CPI_USA	0.21	0.30	0.52	5.68
CPI_CH	0.00	0.48	-0.32	3.98
CPI_FR	0.14	0.42	0.17	4.24
CPI_DE	0.18	0.40	2.22	15.10
CPI_PL	0.26	0.50	2.08	9.28
CPI_UK	0.23	0.43	1.37	9.84

Source: Authors' own research.

where: the analyzed data series were named as follows: R_CP represents the returns of the closing prices of the stock market indices in which (RO, USA, CH, FR, DE, PL, UK) are abbreviations of the analyzed countries; TBYL10Y, represents the yields of 10-year treasury bonds and CPI represents the consumer price index (statistical index that measures the level of inflation).

The Jarque-Bera test is an essential test in statistical analysis because, based on the values of skewness and kurtosis, can be used to check whether the data comes from a normal distribution or not. This test is often used in the specialized literature in which the authors performed statistical and mathematical models in order to make predictions and rigorous analyses, the reason why it was also used in this paper.

According to the assumptions of the Jarque-Bera test, if the probability value is lower than the 0.05 threshold, the null hypothesis that the series of residuals comes from a normal distribution ($skewness = 0$ and $kurtosis = 3$) is rejected and the hypothesis is accepted that the series of residuals does not come from a normal distribution. According to Tabel 2, available below, it can be stated that most of the data series present a probability value that does not exceed the threshold of 0.05, which shows that the series are not normally distributed, with the exception of the closing price returns of Germany (0.29) and Poland (0.40) and the US treasury bond yields (0.85), which

remains in the future analysis, because the series data is normally distributed and supports applications of statistical techniques based on the normality of the series.

Table 2. Jarque-Bera test results

Series	Jarque - Bera Test
Returns	
R_CP_RO	X-squared = 12.426, df = 2, p-value = 0.002003
R_CP_USA	X-squared = 55.286, df = 2, p-value = 9.881e-13
R_CP_CH	X-squared = 33.046, df = 2, p-value = 6.669e-08
R_CP_FR	X-squared = 16.82, df = 2, p-value = 0.0002227
R_CP_DE	X-squared = 2.4092, df = 2, p-value = 0.2998
R_CP_PL	X-squared = 1.7977, df = 2, p-value = 0.407
R_CP_UK	X-squared = 20.158, df = 2, p-value = 4.195e-05
TBIL10Y	
TBY10Y_RO	X-squared = 82.669, df = 2, p-value < 2.2e-16
TBY10Y_USA	X-squared = 0.30623, df = 2, p-value = 0.858
TBY10Y_CH	X-squared = 8.9381, df = 2, p-value = 0.01146
TBY10Y_FR	X-squared = 10.634, df = 2, p-value = 0.004906
TBY10Y_DE	X-squared = 8.9449, df = 2, p-value = 0.01142
TBY10Y_PL	X-squared = 53.747, df = 2, p-value = 2.134e-12
TBY10Y_UK	X-squared = 7.9859, df = 2, p-value = 0.01845
Inflation	
CPI_RO	X-squared = 217.48, df = 2, p-value < 2.2e-16
CPI_USA	X-squared = 41.276, df = 2, p-value = 1.089e-09
CPI_CH	X-squared = 6.7941, df = 2, p-value = 0.03347
CPI_FR	X-squared = 8.2066, df = 2, p-value = 0.01652
CPI_DE	X-squared = 830.59, df = 2, p-value < 2.2e-16
CPI_PL	X-squared = 284.26, df = 2, p-value < 2.2e-16
CPI_UK	X-squared = 271.29, df = 2, p-value < 2.2e-16

Source: Authors' own research.

The "Z transformation" method is a well-known procedure for data standardization in a distribution in which the mean is 0 and standard deviation is 1, which can be useful for identifying trends or anomalies in a data set.

For the other time series, which do not come from a normal distribution, I've used the "Z transformation" method by applying the formula:

$$Z = \frac{(X - \mu)}{\sigma} \quad 16$$

where: Z is the value of the Z transformation of the variable X; X is the observed value of the variable; μ is the population mean of variable X; σ is the population standard deviation of the X variable. Usually, the mean and standard deviation of the sample (representative of the population) are used instead of those of the entire population. In this case, the formula would be:

$$Z = \frac{X - \bar{x}}{s} \quad 17$$

where: $\bar{x}$ is the sample mean; s is the sample standard deviation. This process transformed the data series into a standardized data series with a mean 0 and a standard deviation 1.

The ADF test, also known as the Augmented Dickey-Fuller test, is one of the frequently used tests that, through its specifications, shows whether a time series is stationary or not. This test is widely used due to its usefulness in capturing trends and significant changes in time series, as well as due to the precision and validity of the conclusions drawn, which can contribute to better informed decisions in the economic and financial environment.

From the results obtained in Table 3, we can see that the series of returns of the stock market indices are stationary with a probability of 0.01 (a value that does not exceed the threshold of 0.05), but from the CPI perspective, two cases of non-stationarity are recorded for the USA and Poland, and at the level yields of treasury bonds with a maturity of 10 years, all series are non-stationary. As a result, we performed data stationarity with the first difference of the ADF test, for all non-stationary time series.

Table 3. ADF test results

Series	ADF Test	
	Coefficient	p-value
Returns		
R_CP_RO	-5.17	0.01
R_CP_USA	-4.97	0.01
R_CP_CH	-4.52	0.01
R_CP_FR	-4.47	0.01
R_CP_DE	-4.62	0.01
R_CP_PL	-4.50	0.01
R_CP_UK	-5.05	0.01
TBIL10Y		
TBY10Y_RO	-1.23	0.90
TBY10Y_USA	-0.89	0.95
TBY10Y_CH	-2.75	0.27
TBY10Y_FR	0.25	0.99
TBY10Y_DE	0.85	0.99
TBY10Y_PL	-0.14	0.99
R_CP_UK	-5.05	0.01
Inflation		
CPI_RO	-4.43	0.01
CPI_USA	-3.30	0.07
CPI_CH	-5.28	0.01
CPI_FR	-4.77	0.01
CPI_DE	-3.47	0.04
CPI_PL	-3.32	0.07
CPI_UK	-3.62	0.03

Source: Authors' own research.

In order to test the autocorrelation of the errors, we used the Durbin Watson test, one of the most used tests in the detection of autocorrelation.

The Durbin Watson test values (see below Table 4) are around the value of 2 (in which case it can be stated that there is no autocorrelation in the data), and the probability exceeding the 0.05 threshold confirms the absence of autocorrelation.

Table 4. Durbin Watson Test

Series	Durbin Watson Test	
	DW	p-value
Returns		
R_CP_RO	1.91	0.32
R_CP_USA	1.89	0.27
R_CP_CH	2.08	0.66
R_CP_FR	2.10	0.70
R_CP_DE	2.12	0.75
R_CP_PL	2.11	0.73
R_CP_UK	1.97	0.43
TBIL10Y		
TBY10Y_RO	1.80	0.14
TBY10Y_USA	2.20	0.87
TBY10Y_CH	2.00	0.50
TBY10Y_FR	1.93	0.35
TBY10Y_DE	2.02	0.54
TBY10Y_PL	2.08	0.66
R_CP_UK	1.89	0.27
Inflation		
CPI_RO	2.10	0.70
CPI_USA	2.18	0.85
CPI_CH	1.87	0.23
CPI_FR	2.00	0.49
CPI_DE	2.00	0.50
CPI_PL	2.08	0.70
CPI_UK	2.20	0.86

Source: Authors' own research.

In order to detect the presence of heteroscedasticity we've used the Breusch-Pagan test, which determines whether the data series respects the hypothesis of homoscedasticity or not. According to Table 5, the p-value exceeds the value of 0.05, which means that heteroscedasticity is not present in the analyzed data.

Table 5. Breusch Pagan Test

Series	Breusch Pagan Test	
	BP	p-value
Returns		
R_CP_RO	6.5754e-05	0.99
R_CP_USA	1.74	0.18
R_CP_CH	0.09	0.76
R_CP_FR	0.0004	0.98
R_CP_DE	2.26	0.13
R_CP_PL	2.04	0.15
R_CP_UK	0.85	0.36
TBIL10Y		
TBY10Y_RO	0.14	0.71
TBY10Y_USA	0.90	0.34
TBY10Y_CH	0.09	0.76
TBY10Y_FR	0.66	0.42
TBY10Y_DE	1.09	0.29

Series	Breusch Pagan Test	
	BP	p-value
TBY10Y_PL	0.02	0.88
R_CP_UK	3.32	0.07
Inflation		
CPI_RO	1.05	0.30
CPI_USA	1.25	0.26
CPI_CH	0.20	0.66
CPI_FR	0.12	0.73
CPI_DE	0.92	0.34
CPI_PL	0.80	0.37
CPI_UK	3.20	0.07

Source: Authors' own research.

To check whether the Markov condition is fulfilled or not, we've performed the Ljung-Box test. From the results of the Ljung-Box test, we can note that the probability value exceeds the value of 0.05, which shows that the Markov condition has been met.

Table 6. Ljung-Box Test

Series	Ljung-Box Test	
	Ljung-Box	p-value
Returns		
R_CP_RO_	17.47	0.62
R_CP_USA_	16.67	0.67
R_CP_CH_	22.09	0.33
R_CP_FR_	12.96	0.88
R_CP_DE	11.02	0.95
R_CP_PL	26.32	0.15
R_CP_UK_	7.00	0.99
TBIL10Y		
TBY10Y_RO_	22.25	0.32
TBY10Y_USA	8.49	0.98
TBY10Y_CH_	14.14	0.82
TBY10Y_FR_	14.53	0.80
TBY10Y_DE_	14.50	0.80
TBY10Y_PL_	11.30	0.93
R_CP_UK_	16.20	0.70
Inflation		
CPI_RO_	76.31	0.26
CPI_USA_	39.42	0.21
CPI_CH_	0.10	0.89
CPI_FR_	0.37	0.71
CPI_DE_	26.74	0.15
CPI_PL_	60.17	0.15
CPI_UK_	4.72	0.07

Source: Authors' own research.

For the conditional variations and correlations of the returns of the stock market indices based on the variations of the consumer price index and correlations built from the data analyzed in the paper, as well as to model the volatility and dynamic correlation between two or more time series, we used the GARCH-DCC (Generalized Autoregressive Conditional Heteroskedasticity -

Dynamic Conditional Correlation model) because it combines the GARCH model, used to model the conditional volatility of a single time series, with the DCC model, which is used to model the conditional correlation between two or more time series. Because I wanted to show what is the influence of inflation on the returns of the stock market indices, and on the returns of treasury bonds with a maturity of 10 years, I divided the given series, so that I created new time series in the form of vectors, grouped into two series of data: the first series includes the yields of stock market indices and inflation, and the second series includes the yields of government bonds with a maturity of 10 years and inflation.

After fitting the GARCH-DCC model, the most important results are the optimal parameters. Those parameters are important because they include the estimated optimal values of the coefficients for each GARCH model and the correlation coefficients of the DCC models, which are important values that reflect the effects of the explanatory variables and the relationships between the observed variables. The DCC coefficients: $dcc\alpha_1$ and $dccb_1$ reflects the relationship between the series in terms of the conditional correlation, the strength of the connection between series, and how much this connection varies over time, coefficients that through their results lead to the fulfillment of the objectives of this paper. DCC-GARCH is a model often used in the analysis of time series that are related to stock indices and includes several coefficients with the role of forecasting and estimating volatility, but the most important factors that show the correlation between the variables chosen in the paper are: $dcc\alpha_1$, which represents the correlation coefficient between the variations of the first time series and the second series and measures the degree of correlation between the two variations of the time series and, $dccb_1$, which represents the correlation coefficient between the variations of the second time series and the first series and measures the degree of correlation between the variations of the second series and the first.

According to Tabel 7, the analyzed $dcc\alpha_1$ correlation coefficient shows statistically insignificant values, a statement based on the value of the statistical test ($t - stat$) that records values lower than 1.96 (critical value for a significance level of 5%) and the results show that the consumer price index is not influenced by the returns of the stock market indices, for none of the analyzed countries. The $dcc\alpha_1$ parameter records statistically significant values of China's treasury bond yields, TBY10Y_CH (0.22) which shows the influence of conditional volatility, and the conditional volatility of the treasury bond yield series will be influenced by the conditional correlation between the 10-year government bond yield series and the consumer price index series. However, there is an unusual situation, because the parameter $dcc\alpha_1$ for the other yields of treasury bonds and stock market indices (except R_CP_RO, TBY10Y_FR) registers the value 0.00000, which shows how the correlation between two financial series has no influence on their conditioned volatility. The explanation of the value obtained by the $dcc\alpha_1$ parameter is that this parameter is influenced by the economic and political changes that affect the financial market such as economic growth or recession, monetary and fiscal policy as well as geopolitical events. We note these changes from public information from the analyzed period and have taken two examples from the countries that register values of 0.00000 for the $dcc\alpha_1$ parameter as follows: Great Britain went through a significant transformation process, which had a strong impact on the country's economy and politics, and among the events I remember that in 2016, Great Britain voted to leave the European Union through the Brexit referendum. The UK officially left the EU in January 2020 and the transition period ended at the end of 2020.

After the global financial crisis of 2008, the UK economy has grown steadily, but has slowed down in recent years, and the coronavirus pandemic has had a significant impact on the UK economy, causing GDP to fall in 2020. The UK government has implemented a series of fiscal

policies to support the economy, including increasing public spending and cutting taxes to stimulate investment and consumption. The pound sterling has experienced significant fluctuations over the past 10 years, especially after the Brexit vote, and in general, there is a tendency for it to depreciate in recent years. The transformation of Germany also had a strong impact on the country's economy and politics, and among the most important events I remember that in 2015, Germany received a record number of migrants and refugees, mainly from Syria, and political and social tensions were created. Germany has a significant dependence on Russian natural gas, which accounts for approximately 40% of the country's total gas imports, and an escalation of the conflict in Ukraine could lead to an increase in the number of refugees, which could directly affect the country, which has received many refugees in recent years.

In recent years, the German economy has continued to grow despite economic and political problems in other parts of Europe but the coronavirus pandemic has also affected the German economy in 2020, resulting in a drop in GDP.

For the correlation coefficient $dcc\beta_1$, the value of the t-statistic shows that in most cases in the analyzed period, values higher than the 1.96 value were recorded, which concludes that the parameter for most pairs (stock market returns - consumer price index and bond returns - consumer price index) is statistically significant.

For all the analyzed countries the changes recorded in the level of inflation influence the returns of the stock market indices and on the sentiment of investors, but also the yields of the 10-year treasury bonds, but there are also some exceptions at the level of the pair: returns of the stock market indices - the consumer price index, in the case of Poland, where the $t-statistic$ value registers a value of 1.88, a value that does not exceed the value of 1.96, and the case of France, where a $t-statistic$ of 1.33 is observed. These values show that the returns of the stock market indices were not influenced by the changes in the CPI, and the feeling that investors have in investing does not take into account the impact that changes in inflation have on the economy and including the stock market.

In the case of China, for the pair of data (bond yields - CPI) there is a correlation from both directions, namely: the evolution of 10-year government bond yields influences the CPI, but conversely the CPI evolution also influences the 10-year treasury bond yields.

The Log-Likelihood, used as a measure of the fit of a statistical model for a set of data, in which the higher its value, the more appropriate the model is considered and in which the sign of the value must always be negative, because the function of probability is defined in the interval [0,1].Its values on the analyzed data sets are quite high, with the exception being recorded in the case of pairs (treasury bond yields - CPI) where they are low values, for China (-5.87) and the USA (-4.87), which suggest that the models were adjusted, but are relatively consistent with the model.

Table 7. Model GARCH-DCC results

Model : DCC(1,1)			
	R_CP_RO	CPI_RO	
	Parameter	t-stat	Log-Likelihood
$dcc\alpha_1$	0.082005	0.864313	-242.8808
$dccb_1$	0.595157	2.889004	
	TBY10Y_RO	CPI_RO	
	Parameter	t-stat	Log-Likelihood
$dcc\alpha_1$	0.000000	0.001643	-106.4238

Model : DCC(1,1)			
$dccb_1$	0.914504	2.90515	
	R_CP_USA	CPI_USA	
	Parameter	t-stat	Log-Likelihood
$dcc\alpha_1$	0.000000	0.01800	-175.5575
$dccb_1$	0.913562	7.21008	
	TBY10Y_USA	CPI_USA	
	Parameter	t-stat	Log-Likelihood
$dcc\alpha_1$	0.000000	0.004158	-4.870715
$dccb_1$	0.924012	7.395077	
	R_CP_CH	CPI_CH	
	Parameter	t-stat	Log-Likelihood
$dcc\alpha_1$	0.000000	0.000175	-241.0494
$dccb_1$	0.925275	7.865593	
	TBY10Y_CH	CPI_CH	
	Parameter	t-stat	Log-Likelihood
$dcc\alpha_1$	0.221778	3.220831	-5.876108
$dccb_1$	0.450238	2.994481	
	R_CP_FR	CPI_FR	
	Parameter	t-stat	Log-Likelihood
$dcc\alpha_1$	0.000000	0.001337	-228.3461
$dccb_1$	0.883691	1.335376	
	TBY10Y_FR	CPI_FR	
	Parameter	t-stat	Log-Likelihood
$dcc\alpha_1$	0.002821	0.073699	-35.14808
$dccb_1$	0.917163	18.396141	
	R_CP_DE	CPI_DE	
	Parameter	t-stat	Log-Likelihood
$dcc\alpha_1$	0.00000	0.99984	-379.5758
$dccb_1$	0.917141	8.537153	
	TBY10Y_DE	CPI_DE	
	Parameter	t-stat	Log-Likelihood
$dcc\alpha_1$	0.00000	0.002276	23.75769
$dccb_1$	0.917131	6.260790	
	R_CP_PL	CPI_PL	
	Parameter	t-stat	Log-Likelihood
$dcc\alpha_1$	0.000000	0.00003	-423.622
$dccb_1$	0.936716	1.88689	
	TBY10Y_PL	CPI_PL	
	Parameter	t-stat	Log-Likelihood
$dcc\alpha_1$	0.00000	0.032828	-52.35114

Model : DCC(1,1)			
$dccb_1$	0.922720	8.972413	
	R_CP_UK	CPI_UK	
	Parameter	t-stat	Log-Likelihood
$dcc\alpha_1$	0.00000	0.045512	-214.4311
$dccb_1$	0.912281	8.194781	
	TBY10Y_UK	CPI_UK	
	Parameter	t-stat	Log-Likelihood
$dcc\alpha_1$	0.00000	0.088006	-44.40895
$dccb_1$	0.888957	7.711151	

Source: Authors' own research.

The graphs specific to the DCC-GARCH model illustrate the correlation for the pairs of variables studied and show how the relationship between the time series changes over time and the periods in which the relationships between the time series are closer and periods when these relationships are weaker.

Analyzing the graphs from below (see Figure 1 □Figure 7), we can see that in the case of all countries there are correlations in the analyzed period, with a few exceptions, which in certain periods recorded notable increases or decreases because of some economic and political events. The correlation between the returns of the stock market indices and inflation shows during the analyzed period the correlations between the values (-0.1 and 0.2) but there are also other values such as: the positive values recorded in Romania of (0.13) in the period 03/2019, the period 03/2020 with a low value of (-0.2) and the period 10/2022 with a value of (-0.17). Another exception is the US values, which recorded an increase in May 2022, preceded by a decrease in the correlation of (-0.45).

On the other hand, China records the most significant decrease in the correlation in the period 04/2017, followed by increases, of which the most notable is the period 12/2020 with a value of (0.20) and the most notable decrease in the correlation is in the period 02 /2022 with a value of (-0.45) and the period of 10/2022 with a value of (-0.11).

Germany records a decrease in the correlation during 03/2016 of (-0.43), but also significant increases in 05/2022 with a value of (0.09) and in 10/2022 with a value of (0.29). Poland, records a decrease in the correlation during 12/2020, with a value of (-0.08) and one in 10/ 2022 with a value of (-0.05), Great Britain records an increase in 04/2015 with a value of (0.39) then followed by a gradual decrease, notable being the one from 10/2020 of (-0.14), followed by constant increases, the important one being the one from 10/2022 with a correlation value of (0.31) and, in the case of France, it can be observed that no there is a correlation between the return of the stock market index and the CPI, but the t-statistic value is close to 1.96 and the graph shows the very low values recorded in 07/2022 of (-0.001).

The observation of international crises as well as the contagion at the level of financial markets shows as: in countries such as Romania, Poland, the USA and China, negative values of the correlation between yields and inflation were recorded in October of 2022. The fact that at the level of correlations, there are negative values between the yields of the stock market indices ri and the consumer price index, suggest that with an increase in the level of inflation, this would lead to a decrease in the prices of the stock market indices and vice versa, and the inverse relationship can be useful in the decision-making of investors, contributing to the increase of their positive feeling to invest.

The inverse relationship between inflation and stock market index returns, in which negative correlations emerged, is normal, because, usually in periods when inflation registers high values, stock market index returns show low values, and when inflation is low, stock market index returns are high. From the results obtained, there are correlations in most cases between inflation, the returns of the stock market indices and between inflation and the returns of treasury bond's with a maturity of 10 years, a conclusion developed based on the value of the statistical test. It can be seen that there is a correlation from both sides, such as in the case of Romania, between the returns of the closing prices of the stock market index and inflation, and vice versa between inflation and their returns. At the same time, we observed the existence between the yields of 10-year treasury bonds and the inflation of China (-5.87) as well as the USA (-4.87).

There is a close connection between the contagion of the stock markets, inflation and 10-year treasury bonds, since the contagion spreads on the markets and with it the high prices caused by inflation, a fact that is observed through the same periods of time, in which stock markets in the analyzed countries experienced sharp declines.

Inflation also propagates on the stock market, as it leads to a decrease in the value of shares and investors fear that companies' profits will decrease and that their returns will not be sufficient to compensate for the increase in prices, although there are some investments that can be considered a hedge against inflation. In the rest of the cases, it can be observed that inflation has a stronger influence on the yields of 10-year treasury bonds than on the yields of stock market indices and as it appears from the specialized literature, the yield of stock market indices ultimately depends on the risk appetite of investors.

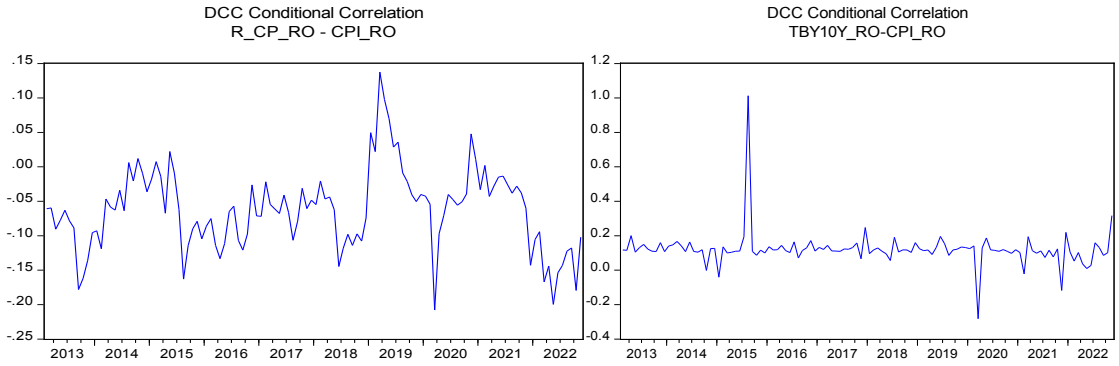


Figure 1. DCC Conditional Correlation Romania

Source: Authors' own research.

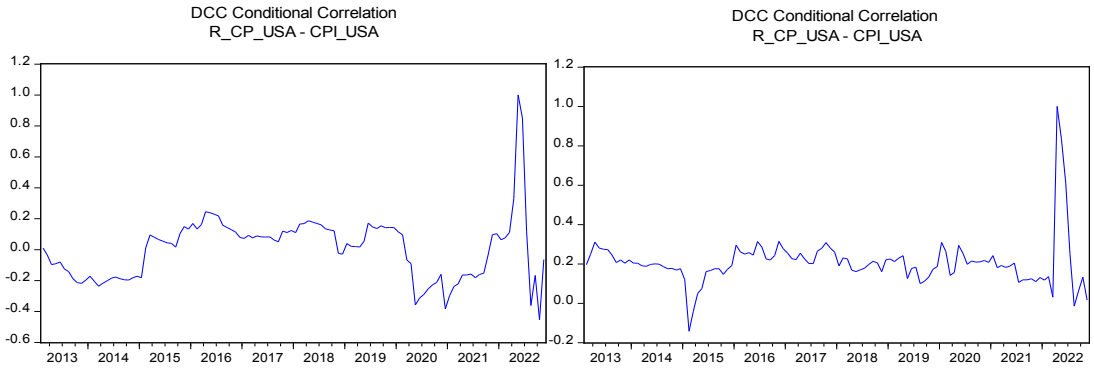


Figure 2. DCC Conditional Correlation USA

Source: Authors' own research.

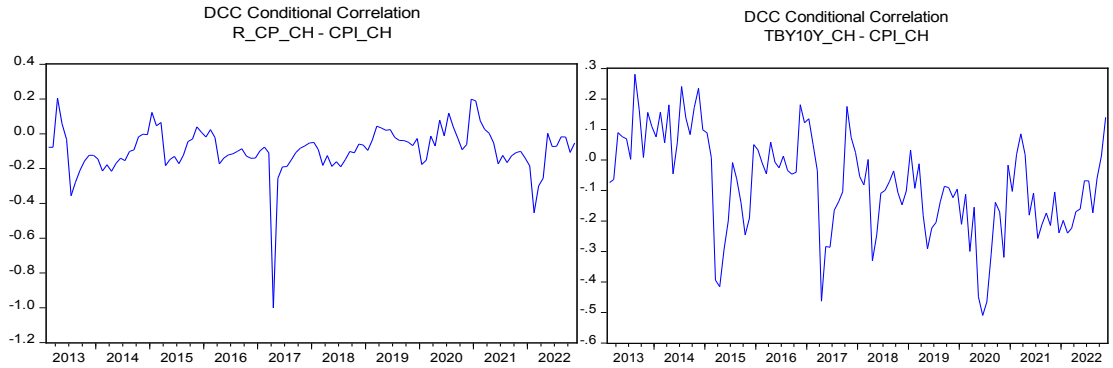


Figure 3. DCC Conditional Correlation China

Source: Authors' own research.

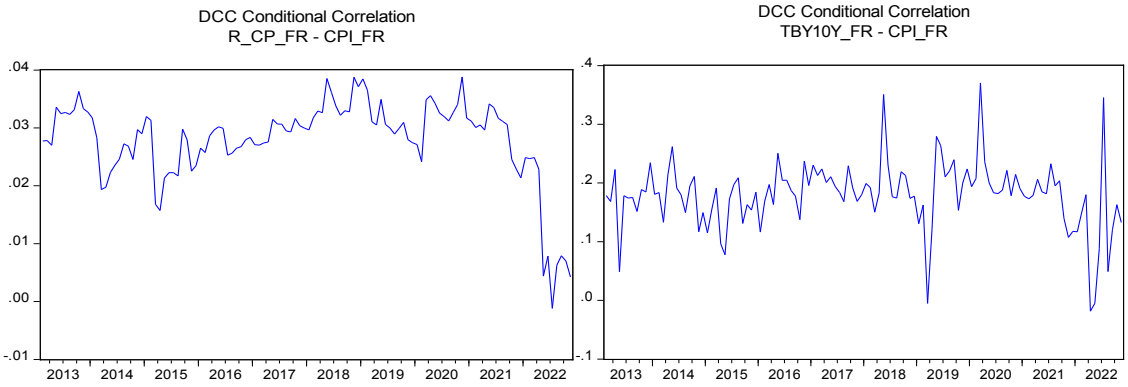


Figure 4. DCC Conditional Correlation France

Source: Authors' own research.

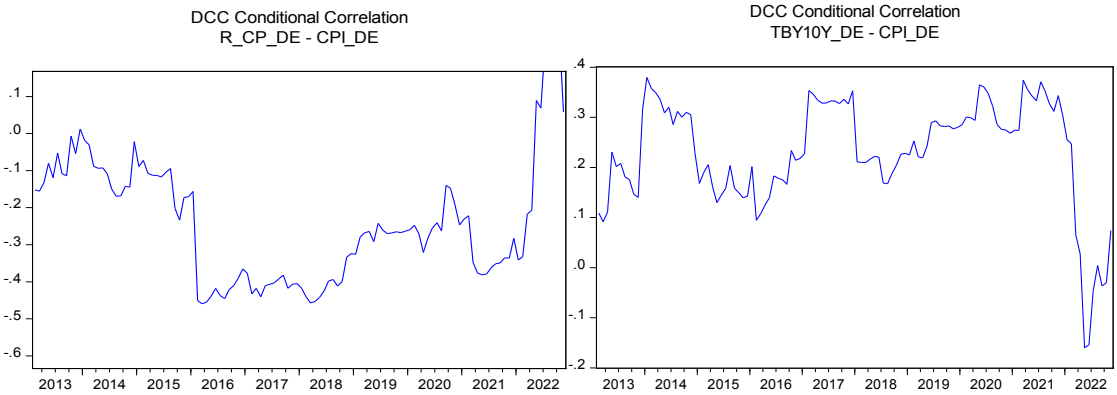


Figure 5. DCC Conditional Correlation Germany

Source: Authors' own research.

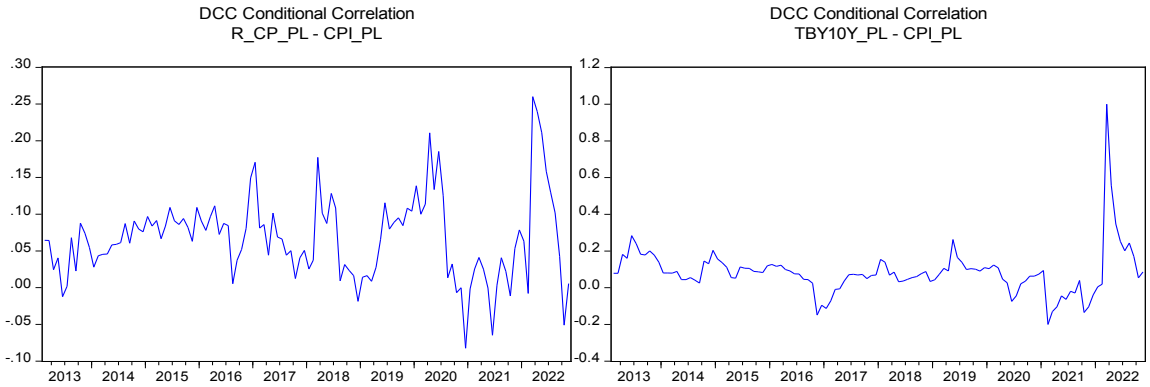


Figure 6. DCC Conditional Correlation Poland

Source: Authors' own research.

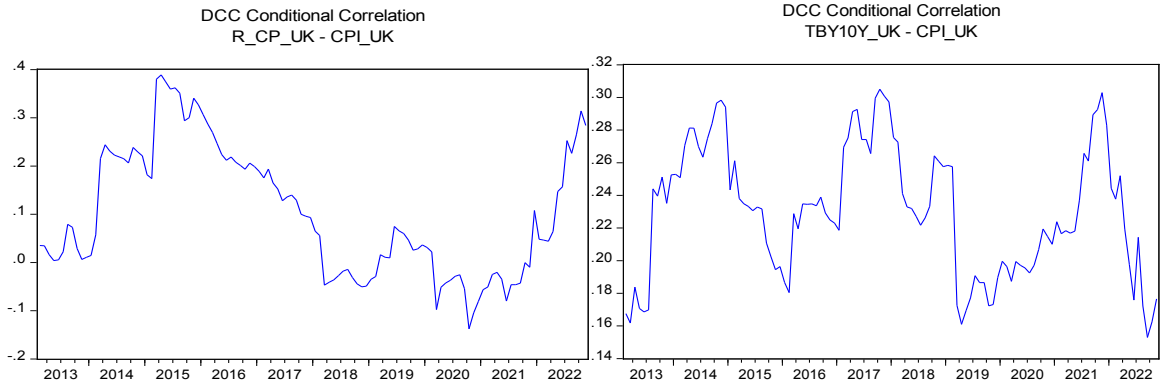


Figure 7. DCC Conditional Correlation UK

Source: Authors' own research.

Conclusion

In this paper we wanted to capture the complex relationships between inflation, stock index returns and treasury bond yields over a ten-year period by using a series of advanced statistical techniques. The results we've reached after the implementation of the multivariate GARCH model (DCC-GARCH) captured what we were looking for since the beginning, namely the fact that the changes recorded in the level of inflation influence both stock market index returns, investor sentiment and treasury bond yields.

There were some exceptions, such as the case of France and Poland, for which there are possible explanations, such as the current economic situation, in which the existence of factors that can influence bond yields and share values should be mentioned, such as: geopolitical conflict developments, the state of global and regional economies.

The results obtained are in accordance with what other researchers have concluded, namely that the changes that occur in the level of inflation significantly and directly affect the returns of stock indices, as well as the returns of treasury bonds with a long maturity, the influence coming from inflation to returns and not vice versa.

The existence of the link between stock markets and 10-year treasury bonds is possible because they are linked to interest rates and yields. The level of inflation affects the yields of 10-year treasury bonds, as we have also seen from the results obtained in the case of China and the USA. In such situations, the investors are expecting to receive a higher interest rate to offset the loss in the value of their money due to inflation.

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