On the safe-haven and hedging properties of Bitcoin: new evidence from COVID-19 pandemic

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Abstract

Purpose – This study aims to investigate the safe-haven and hedging properties of Bitcoin against a wide variety of conventional assets before and during the coronavirus disease 2019 (COVID-19) pandemic.

Design/methodology/approach – This paper uses a smooth transition regression (STR) to jointly test the hedging properties of Bitcoin in normal conditions and Bitcoin's safe-haven properties in extreme stock market conditions.

Findings – Highlighting the results, the authors show that Bitcoin is able to provide safe-haven feature during the COVID-19 pandemic period while Bitcoin serves as a hedge tool in the pre-COVID-19 pandemic period. The findings also show that the prowess of the safe-haven/hedge nature is sensitive to the type of the asset market and the time horizon when switching from daily to weekly frequency data.

Originality/value – This is one of the first studies that conduct a combined analysis of the safe-haven and hedging capabilities of Bitcoin against several asset classes using an STR method. This study uses the longest sample period to yet, allowing researchers to examine Bitcoin's safe-haven and hedging features both before and after the COVID-19 pandemic.

Keywords Bitcoin, Safe-haven, Hedge, COVID-19, Smooth transition regression

Paper type Research paper

1. Introduction

The coronavirus disease 2019 (COVID-19) pandemic is an unprecedented global phenomenon that has disrupted lives across all countries and communities and negatively affected financial markets. The sudden increase in the level of uncertainty and risk averseness caused by the emergence of COVID-19 resulted in a decline of traditional assets' prices. For instance, the Standard & Poor's 500 (S&P500) index has decreased by 19% since the last peak observed on February 19, 2020 and crude oil prices have collapsed by more than 30%, with West Texas Intermediate (WTI) plunging as low as $30 per barrel. Ultimately, all the traditional and new financial assets have experienced downturns in their performance (Shehzad *et al.*, 2020). In contrast, cryptocurrencies gained value during the period of COVID-19 pandemic, as their prices displayed on average an increasing trend over this period. For instance, the price of Bitcoin increased from $8367 on 25 January 2020 to about $10,000 on June 1, 2020, which further increased to $11,410 on August 11, 2020 [1].

The astonishing high performance of Bitcoin, the world leading digital currency, in comparison with conventional assets during the current crisis, has attracted the attention of researchers to investigate the safe-haven properties of Bitcoin during turbulent times (Huang *et al.*, 2021; Conlon *et al.*, 2020; Kristoufek, 2020; Mariana *et al.*, 2021). Yet, the existing studies on the safe-haven abilities of Bitcoin are inconclusive, ambiguous and generally provide early evidence on COVID-19 period. Then, is Bitcoin really a safe-haven tool during the COVID-19 pandemic? This study attempts to answer this question and to contribute to the literature by exploring the effect of the COVID-19 epidemic on the safe-haven and hedging properties of Bitcoin against several financial assets using a smooth transition regression (STR) method.

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This study focuses on whether Bitcoin can be considered as a potential safe-haven asset during a period of market turmoil, particularly during the COVID-19 pandemic.

The study of the safe-haven concept is motivated by investor loss aversion (Tversky and Kahneman, 1991), where investors are often more concerned about avoiding losses than with any associated prospective gains (Hwang and Satchell, 2010). This loss aversion may motivate investors to seek out safe-haven assets. Within the literature, Baur and Lucey (2010) were the first to propose clear definitions that make possible the exploration and identification of the capability of an asset to be a safe-haven and/or a hedge against movements in the returns of another asset. Baur and McDermott (2010) extended these initial definitions significantly by differentiating between weak and strong hedge and safe-haven properties of an asset. An asset which is uncorrelated (negatively correlated) with another asset, on average, can be categorized as a weak (strong) hedge. Similarly, an asset that is uncorrelated (negatively correlated) with another asset, on average, in times of market stress or turmoil, is then considered a weak (strong) safe-haven. According to Conlon and Richard McGee (2020) and Shahzad *et al.* (2019), Bitcoin can possess safe-haven ability, mainly due to its limited correlation with traditional financial assets, its role as a store of value and its independence from monetary policies.

While some researchers contend that the Bitcoin safe-haven claim was not evident during the recent pandemic period (see, for example, Kristoufek, 2020; Conlon *et al.*, 2020), others support the hypothesis that Bitcoin serves as a safe-haven during extreme stock market volatility, such as that caused by the COVID-19 pandemic (Mariana *et al.*, 2021; Huang *et al.*, 2021).

However, these studies do not examine both the hedging properties under regular market conditions and the safe-haven properties under extreme market conditions. We address this deficiency by analyzing the safe-haven and hedging properties of Bitcoin using an STR method with a logistic transition function, allowing the regression model to be divided into two distinct regimes. The first regime, normal conditions, is used to determine if Bitcoin works as a hedge for the assets under investigation. The second, characterized by extreme stock market conditions, is used to evaluate Bitcoin's safe-haven capability.

Most research have restricted the study of safe-haven and hedging properties only to the pandemic period. Meanwhile, this study considers two periods, the first covers the period during the COVID-19 pandemic while the second describes the pre-pandemic period.

The paper contributes innovatively to the analysis of the properties of Bitcoin in several ways. First, whereas prior works utilize a small number of asset classes other than Bitcoin, this paper employs a richer dataset comprised of several equity indexes and a variety of other asset classes, including sovereign bond markets, international market indexes and commodities indices. In addition, compared to earlier studies such as Melki and Nefzi (2022), whose sample ends in September 2020, the sample for the current research extends to March 2021.

Second, the majority of empirical researches analyze only a single property of bitcoin, namely safe-haven or hedging, but this article undertakes a combined analysis of the two qualities, making our methodology unique in that it permits investigating both properties simultaneously. Moreover, the majority of previous studies do not concurrently focus on both of these properties in the context of the COVID-19 pandemic; nevertheless, this research focuses on the novel examination of the two properties under COVID-19.

Third, unlike other studies on the safe-haven property of Bitcoin that rely on the copula or regression approach (Long *et al.*, 2021; Syuhada *et al.*, 2022), we employ the STR method, a non-linear method developed by Teräsvirta *et al.* (2004) that reveals the changes in the safe-haven property during the COVID-19 pandemic. In reality, the STR model enables the return on the asset under consideration to switch gradually between two distinct regimes rather than abruptly. The first state can be referred to as "normal times" that permits testing the hedging hypothesis of Bitcoin. The second state can be referred to as "extreme times" (market stress or turmoil) that permits testing the safe-haven hypothesis of Bitcoin.

Lastly, our analysis is useful for investors and financial advisors seeking safe-haven assets in times of crisis, particularly in the cryptocurrency market as it can improve their portfolio risk management decisions.

Using an STR model for data comprising various asset classes from November 14, 2018 to March 24, 2021, our findings indicate that Bitcoin can act as a safe-haven during the COVID-19 pandemic era and as a hedge during the pre-pandemic phase. In addition, results indicate that the time horizon influences Bitcoin's ability to act as a safe-haven and/or a hedge against a variety of financial assets.

The remainder of this paper is organized as follows: Section 2 presents the literature review and the hypotheses development. Then, Section 3 presents the data used and the preliminary analyses. Section 4 describes the econometric framework, and Section 5 presents and analyses the empirical results. Finally, Section 6 concludes the study with policy implications.

2. Literature review

The safe-haven and hedging capabilities of assets have been extensively investigated in the existing literature. Most of the prior empirical investigations on this topic focused on testing the capabilities of gold to serve as a safe-haven and/or hedge against other assets (see, for instance, Baur and Lucey, 2010; Baur and McDermott, 2010; Reboredo, 2013; Hood and Malik, 2013; Bredin *et al.*, 2015; Bouri *et al.*, 2019).

However, the growing curiosity of investors and policymakers with regard to apprehending the nature of Bitcoin as the leading cryptocurrency has revived devotion to the investigation of the safe-haven and hedging properties of assets by considering this new arrival in the financial market as being at the center of the debate. Dyhrberg (2016a) was the first to investigate the hedging capability of Bitcoin using asymmetric Generalized AutoRegressive Conditional Heteroskedasticity (GARCH) modeling. The results indicate that Bitcoin can serve as a hedge, and they place the hedging capability of Bitcoin between the gold and the US dollar.

In addition, Dyhrberg (2016b) reviews the hedging capability of Bitcoin by considering other financial assets. The findings of this second study reveal that Bitcoin acts as a hedge against stocks on the Financial Times Stock Exchange Index and against the US dollar in the short term. Bouri *et al.* (2017) address the literature gap concerning the properties of Bitcoin by exploring the safe-haven capability of this cryptocurrency. Their results show that Bitcoin acts as a safe-haven against extreme downward movements but only in Asian stock markets.

Along with these seminal works, several empirical studies have been conducted to assess the safe-haven and hedging capabilities of Bitcoin against different conventional assets. These studies can be separated into two major strands.

The first strand of literature provides evidence of the role of Bitcoin as a safe-haven and/or a hedge against movements in the returns of financial assets. Pal and Mitra (2019) use a battery of GARCH models to compute optimal hedge ratios between Bitcoin and other financial assets. The results provide evidence that Bitcoin acts as a hedge against the S&P 500 composite price index, gold and wheat. Shahzad *et al.* (2019) employ a cross-quantilogram approach to assess whether Bitcoin serves as a safe-haven during extreme market conditions. Their findings indicate that Bitcoin, similarly to gold and the commodity index, serves as a weak safe-haven against several stock market indices. Chan *et al.*, (2019) employ a number of GARCH specifications to investigate the hedging capability of Bitcoin against major local stock indices. They mainly find that Bitcoin can serve as a hedge against the indices considered for monthly data but not for daily and weekly data.

The second strand of literature shows that the evidence pointing to the safe-haven and hedging capabilities of Bitcoin is not accurate. For instance, Klein *et al.* (2018) use multivariate

GARCH modeling to explore some of the financial properties of Bitcoin. Their results show that there is no evidence for the hedging capabilities of Bitcoin. In the same vein, Smales (2019) suggests that even if it were to meet the existing criteria related to return correlations, Bitcoin should not be considered as a safe-haven for other assets. Urquhart and Zhang (2019) investigate whether Bitcoin can act as a safe-haven for a number of world currencies. Conducting an intraday analysis, they find that Bitcoin is a safe-haven during periods of extreme market turmoil for a very limited number of currencies.

Overall, opinions on the capabilities of Bitcoin to serve as a safe-haven and/or a hedge are not conclusive and depend mostly on the assets under investigation, the data frequency, the periods studied and the econometric frameworks employed.

The COVID-19 pandemic is the first global health crisis to transform into an economic shock, resulting in the first such event since the global financial crisis of 2008. This event provides the background to investigating whether Bitcoin acts as a safe-haven for assets. Corbet *et al.* (2020) argue that large cryptocurrencies present safe-haven assets during the COVID-19 pandemic. Ji *et al.* (2020) profess that Bitcoin and Forex currencies are weak safe-haven tools during the COVID-19 pandemic. Mariana *et al.* (2021) contend that Bitcoin and Ethereum are suitable as short-term safe-havens. Huang *et al.* (2021) show that Bitcoin can be considered a safe-haven within financial markets during severe downturns, such as that related to the current COVID-19 pandemic. In contrast, Kristoufek (2020) and Cobert *et al.* (2020) show that Bitcoin does not serve as a safe-haven for the majority of the assets under investigation. Recently, Melki and Nefzi (2022) find that while Bitcoin shows neither a safe-haven nor a hedge for the stock, commodity and foreign exchange markets, it provides, respectively, safe-haven functions for the commodity and foreign exchange markets during the pandemic period.

3. Econometric methodology

3.1 Smooth transition model (STR)

Following the definitions on hedge and safe-haven proprieties of a security developed in (Baur and Lucey, 2010) and the econometric proposed by Teräsvirta *et al.* (2004), we estimate the STR model presented as follows:

$$r_{BTC,t} = \phi' z_t + \theta' z_t\, G(\gamma, c, s_t) + \varepsilon_t,\ \varepsilon_t \sim iid\left(0, \sigma^2\right) \tag{1}$$

where $r_{BTC,t}$ are the Bitcoin returns and $z_t = (r'_{BTC,t}, r'_{a,t})'$ is an $((m+1)\times 1)$ with $r'_{a,t} = (r_{a_{1t}}, \ldots, r_{a_{kt}})'$ vector of explanatory variables and $r'_{BTC,t} = (1,\ r_{BTC,t-1,\ldots,} r_{BTC,t-p})'$. In equation (1), ϕ and θ are the parameter vectors of the linear and non-linear parts, respectively.

The function $G(\gamma, c, s_t)$ is commonly known as a transition function. The transition function is a bounded function of the continuous variable s_t that insures the speed of transaction between several extreme regimes. In this empirical study, we consider only two regimes. The first can be viewed as regular times allowing testing the hedging hypothesis of Bitcoin. The second can be regarded as abnormal or extreme times due to the financial market stress or turmoil. The second state is considered to test the safe-haven hypothesis of Bitcoin. The choice of the transition function depends also on the slope parameter γ and the vector of location parameters $c = (c_1,\ \ldots, c_k)'$ (see for instance, Teräsvirta *et al.*, 2004). The vector of location parameters c can be interpreted as vector of threshold values. The number of thresholds (K) chosen is mostly $K = 1$ or $K = 2$.

When considering a number of thresholds $K = 1$, the parameters $\phi + \theta G(\gamma, c, s_t)$ change monotonically as a function of s_t from ϕ to $\phi + \theta$. In addition, to account for the asymmetric patterns of financial series, a general logistic function as transition function for the STR with $K = 1$ seems to be the most appropriate (Teräsvirta *et al.*, 2004).

Accordingly, we use the general logistic function as transition function that is presented as follows:

$$G(\gamma, c, s_t) = \left(1 + exp\left\{-\gamma \prod_{k=1}^{K}(s_t - c_t)\right\}\right)^{-1}, \gamma > 0 \tag{2}$$

where, $\gamma > 0$ is an identifying restriction. The transition function $G(.) \equiv 1/2$ when $\gamma = 0$ and thus the STR model presented in equation (1) nests the linear model. At the other end, when $\gamma \to \infty$, the LSTR1 model approaches the switching regression model with two regimes that have equal variances. When $\gamma \to \infty$ in the LSTR2 model, the result is another switching regression model with three regimes such that the outer regimes are identical and mid regime is different from other two.

The transition function $G(.)$ determines the speed of transition between two extreme regimes. In our case, a state that can be referred to as "normal times" that permits testing the hedging hypothesis of Bitcoin and a state that can be referred to as "extreme times" (market stress or turmoil) that permits testing the safe-haven hypothesis of Bitcoin.

Following we present the model to be estimated when considering Bitcoin returns vs a single selected asset returns.

$$r_{BTC,t} = \alpha_1 + \psi_1 r_{a,t} + (\alpha_2 + \psi_2 r_{a,t})G(\gamma, c, s_t) + \varepsilon_t,\ \varepsilon_t \sim iid\left(0, \sigma^2\right) \tag{3}$$

The parameters of the STR are estimated by means of conditional maximum likelihood which is possible by implementing the iterative Broyden, Fletcher, Goldfarb, and Shanno (BFGS) numerical optimization algorithm (see for instance; Shanno, 1970 and Fletcher, 2013).

To test our hypothesis regarding the hedging and safe-haven capabilities of Bitcoin, a logical choice for the transition variable s_t would be the lagged asset return $r_{a,t-j}$ since the asymmetry of the model depends on the state of the asset returns. Indeed, when the conventional financial assets display extreme volatile returns, investors in financial markets urge to invest in the cryptocurrency market by purchasing Bitcoins. However, under normal market condition investors neither sell nor purchase Bitcoin to a noticeable level.

In equation (3), α_1 and ψ_1 are the parameters of the linear part reflecting the lower regime where the transition function $G(\gamma, c, s_t)$ equals zero. Accordingly, the estimated values of ψ_1 and $\psi_1 + \psi_2$,, for a selected transition variable, can be employed to test for the hedging and the safe-haven hypotheses of Bitcoin.

3.2 Testable hypotheses

Based on the literature review and the methodology discussed above, the following three hypotheses are examined.

H1. Bitcoin serves as a safe-haven against extreme movements in the returns of several assets during the COVID-19 pandemic.

H2. Bitcoin serves as a hedge against movements in the returns of several assets, mainly in the pre-COVID-19 period.

H3. The safe-haven and hedging capabilities of Bitcoin are the same regardless of whether daily or weekly data are used.

According to Beckmann *et al.* (2015), hedging and safe-haven properties can be tested by examining ψ_1 and $\psi_1 + \psi_2$, respectively.

Indeed, when the estimated parameter ψ_1 is significantly negative, there is strong evidence that Bitcoin serves as an effective hedge for the considered asset or market, because conventional financial assets are, on average, negatively or uncorrelated with each other. Then Hypothesis 1 holds.

Otherwise, if $\psi_1 + \psi_2$ is found to be significantly negative, this indicates that bitcoin serves as a powerful safe-haven for the financial asset, as the assets are negatively connected during extreme market conditions. Then Hypothesis 2 holds.

Overall, if Hypothesis 1 (2) holds, and then the Bitcoin safe-haven (hedge) capabilities are supported, highlighting the role of Bitcoin as a safe-haven and/or a hedge. Therefore, Bitcoin can be used by analysts to hedge market-specific risk.

In the existing literature, researchers hold differing opinions regarding Bitcoin's function as a safe-haven and/or a hedge, depending on variables such as data frequency. Given the rise in high-frequency trading among investors and the huge variation in price of Bitcoin at the daily level, the interaction between Bitcoin and other financial assets at the daily level may be quite different from the weekly or monthly interaction between the assets (see for instance, Lucey and Li, 2014 and Urquhart and Zhang, 2019). Accordingly, to examine the effect of Bitcoin's time horizon on its safe-haven and hedging capabilities, we test the Hypothesis 3. If this holds true, then the data frequency has no effect on Bitcoin's safe-haven and hedging capabilities.

4. Data and preliminary analyses

4.1 Data

To perform this empirical investigation, we use a recent dataset containing closing price series of Bitcoin and 20 conventional financial assets that are subdivided into 4 groups (local stock markets, local bond markets, international indices and commodity prices and indices). We use daily and weekly data from November, 14 2018 to March 24, 2021, with a focus on those from the COVID-19 pandemic, from January 20, 2020 to March 24, 2021. The choice of start date and analysis period is justified by our research objective, which is to determine whether the COVID-19 economic crash has an impact on Bitcoin's hedging and safe-haven functions. Following Wan *et al.* (2021), we consider January 20, 2020 as the start date of the pandemic period [2] (during COVID-19). We also define a pre-COVID-19 pandemic period from November 14, 2018 to January 19, 2020, which is specifically chosen to evaluate Bitcoin's hedging capability prior to the occurrence of the health pandemic.

Bitcoin prices are collected from Coin Desk (www.coindesk.com), whereas all the financial asset data are extracted from the Bloomberg database. All the returns series are computed on a continuous compound basis using the formula as follows:

$$r_t = 100 * log(P_t/P_{t-1})$$

Figure 1 depicts the daily evolution of Bitcoin prices and returns during the COVID-19 pandemic, spanning the period from January 20, 2020 to March 24, 2021. Figure 1 shows that, in contrast with most of the conventional assets, Bitcoin, as a leading coin in the cryptocurrency market, performed well during the COVID-19 pandemic period. For instance, Figure 1 shows an important increase in the price of Bitcoin. The surge in Bitcoin prices in that period is estimated to be about 12%, exceeding \$23,421 and taking its year gains to more than 200% [3]. Figure 1 also indicates an upward trend in the prices of Bitcoin starting at the end of April 2021. More precisely, on March 12, 2021, the price of Bitcoin beat the historical benchmark of \$60,000 per Bitcoin, closing in on a total value of \$1 trillion. This exceptional performance of Bitcoin presents a strong motivation to reassess the properties of Bitcoin during this particular period.

4.2 Preliminary analyses

This section presents the summary statistics of Bitcoin's returns and those of conventional assets under study during the COVID-19 epidemic. The primary computed statistics are shown in Table 1.

Table 1 indicates that during the pandemic period considered, Bitcoin has a positive mean return and a higher level of daily volatility. It experiences excess kurtosis, indicating a leptokurtic distribution, and has positive skewness.

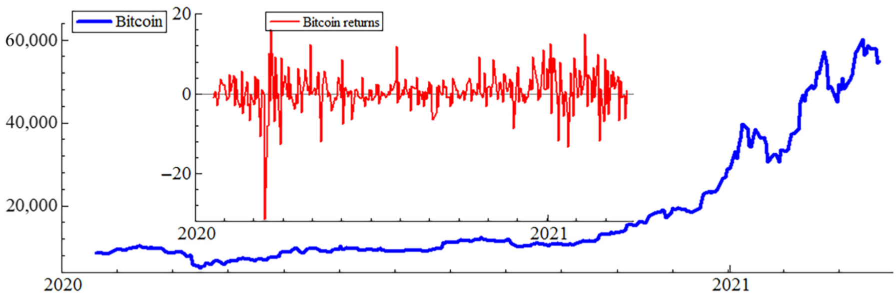

Figure 1. Bitcoin price evolution during the COVID-19 pandemic period

	Mean	Max	Min	Std. dev	Skewness	Kurtosis	Jarque–Bera
Bitcoin	0.849	16.104	−13.428	4.141	0.214	4.786	40.600***
Panel A. Stocks							
US	−0.010	8.968	−12.765	1.899	−1.651	14.806	1809.702***
UK	−0.079	8.667	−11.512	1.715	−0.988	12.768	1196.042***
GERMANY	0.002	10.414	−13.055	1.932	−0.977	13.631	1407.001***
JAPAN	0.085	7.731	−5.198	1.441	0.407	8.051	315.159***
CHINA	0.032	5.554	−8.034	1.278	−0.935	9.709	584.164***
Panel B. Bonds							
US	−0.065	40.593	−34.146	6.683	0.283	15.230	1805.063***
UK	−0.225	53.701	−40.095	13.500	0.344	4.395	29.140***
GERMANY	0.230	49.863	−60.158	8.623	−0.804	14.884	1731.757***
JAPAN	1.679	256.49	−204.76	53.386	0.123	7.915	291.619***
CHINA	0.010	1.239	−0.914	0.224	0.589	9.072	460.741***
Panel C. Indexes							
MSCIW[a]	−0.002	8.406	−10.442	1.641	−1.808	16.216	2260.520***
MSCIEU[b]	−0.036	8.180	−12.314	1.648	−1.635	16.669	2378.651***
MSCIAP[c]	0.050	5.432	−5.753	1.235	−0.531	6.951	201.570***
USDX	−0.016	1.588	−1.107	0.408	0.664	5.005	69.603***
Panel D. Commodities							
Gold	0.032	4.967	−5.863	1.173	−0.680	7.209	235.591***
Oil	0.078	24.887	−28.221	5.039	−0.322	15.228	1805.478***
S&P commodity	0.080	7.117	−12.269	1.837	−1.460	12.525	1195.264***
Industrial metal	0.079	2.715	−3.719	1.039	−0.590	3.702	22.721***
Agriculture	0.076	3.459	−3.698	1.027	−0.073	4.039	13.256***
Non-energy	0.083	2.309	−3.017	0.726	−0.744	5.303	90.529***

Note(s): Std. dev. stands for standard deviation. *** denotes significance levels at 1%
[a]MSCIW denotes the MSCI World Index captures large and mid-cap representation across 23 developed markets (DM) countries
[b]MSCIEU denotes the MSCI Europe Index captures large and mid-cap representation across 15 developed markets (DM) countries in Europe
[c]MSCIAP denotes The MSCI AC Asia Pacific Index captures large and midcap representation across 5developed markets countries and 8 emerging markets countries in the Asia Pacific region

Table 1. Summary statistics

For stock indices, it appears that during the pandemic period, on average, the daily returns of both the S&P 500 (USA) and FTSE100 (UK) stocks are negative. In contrast, on average, the daily returns of the DAX 30 (Germany), Nikkei 225 (Japan) and SHASHR (China) stocks are positive for the same period.

The DAX 30 (Germany) has the biggest standard deviation whereas the SHASHR (China) has the lowest, as shown in Table 1. Except for the Nikkei 225, all stock return series are found to be leptokurtic and have negative skewness.

During the COVID-19 epidemic, the average daily return on both US and UK bonds is negative. However, relative to Germany, Japan and China, average bond returns are positive. Table 1 also reveals that Japan's bond market has the highest standard deviation, while China's bond market has the lowest. Except for German bonds, all bond return series are found to be leptokurtic and positively skewed, just like stock returns.

Regarding foreign stock market indices, the MSCIW, MSCIEU and USDX have negative average daily returns. In contrast, the MSCIAP daily returns are proven to be positive on average. The MSCIEU has the greatest standard deviation, whilst the USDX has the least. In addition, Table 1 reveals that, with the exception of the USDX, all international stock index return series are leptokurtic and exhibit negative skewness.

In terms of commodities, the average returns on oil and gold remain positive during the pandemic period. The volatility indicated by standard deviation is significantly greater than that of gold and all other investigated commodities indexes. In comparison, the Standard and Poor's Goldman Sachs Commodity (S&P GSCI) Non-Energy Index has the least amount of variance. In addition, the commodity return indices are found to be leptokurtic with a negative skewness, as illustrated for the other assets. As shown in Table 1, the Jarque–Bera test indicates that the hypothesis of normality is rejected at the 1% significance level for all series.

In conclusion, the series under consideration are not normally distributed; hence, regressions assuming normality are inappropriate for analyzing potential correlations between these time series.

In addition to the measures of variability, the skewness, the kurtosis and the Jarque–Bera test that are used to investigate the normality of the time series under investigation, a quantile-quantile (QQ) depiction helps to identify cases of non-normality. Figures 2 and 3 depict the quantiles of Bitcoin and the other considered asset returns. The figures show that there are significant differences between the lower and higher quantiles of the most represented return series. Therefore, the distributions of Bitcoin and the assets under study differ for extreme market conditions.

4.3 Correlation analysis

The unconditional correlations between the daily returns of Bitcoin and other financial assets are described in Figures 4 and 5.

Figure 4 illustrates the correlations between Bitcoin returns and stock market index and bond returns during the COVID-19 pandemic. First, Figure 4 shows that Bitcoin has a slightly positive correlation with all stock indices, except for the S&P 500 index. In particular, the Nikkei 225 and SHASHR stock indices have the highest correlations with Bitcoin (between 0.17 and 0.25). The FTSE 100 stock index has the lowest correlation of 0.037 with Bitcoin. In contrast, Bitcoin has a slightly negative correlation of −0.105 with the S&P 500. Second, Figure 4 exhibits that Bitcoin has a slightly positive correlation with German and Chinese bonds, but a slightly negative correlation with US, UK and Japanese bonds. In particular, German bonds have the highest positive correlation of 0.093 with Bitcoin, while UK bonds have the lowest negative correlation of −0.107 with Bitcoin.

Figure 5 illustrates the correlations between Bitcoin returns and stock market index and commodity returns during the COVID-19 pandemic. First, Figure 5 shows that Bitcoin has a slightly positive correlation with the MSCI Europe (MSCIEU) and MSCI All Country Asia Pacific (MSCIAP) stock market indices, but a slightly negative correlation with those of the

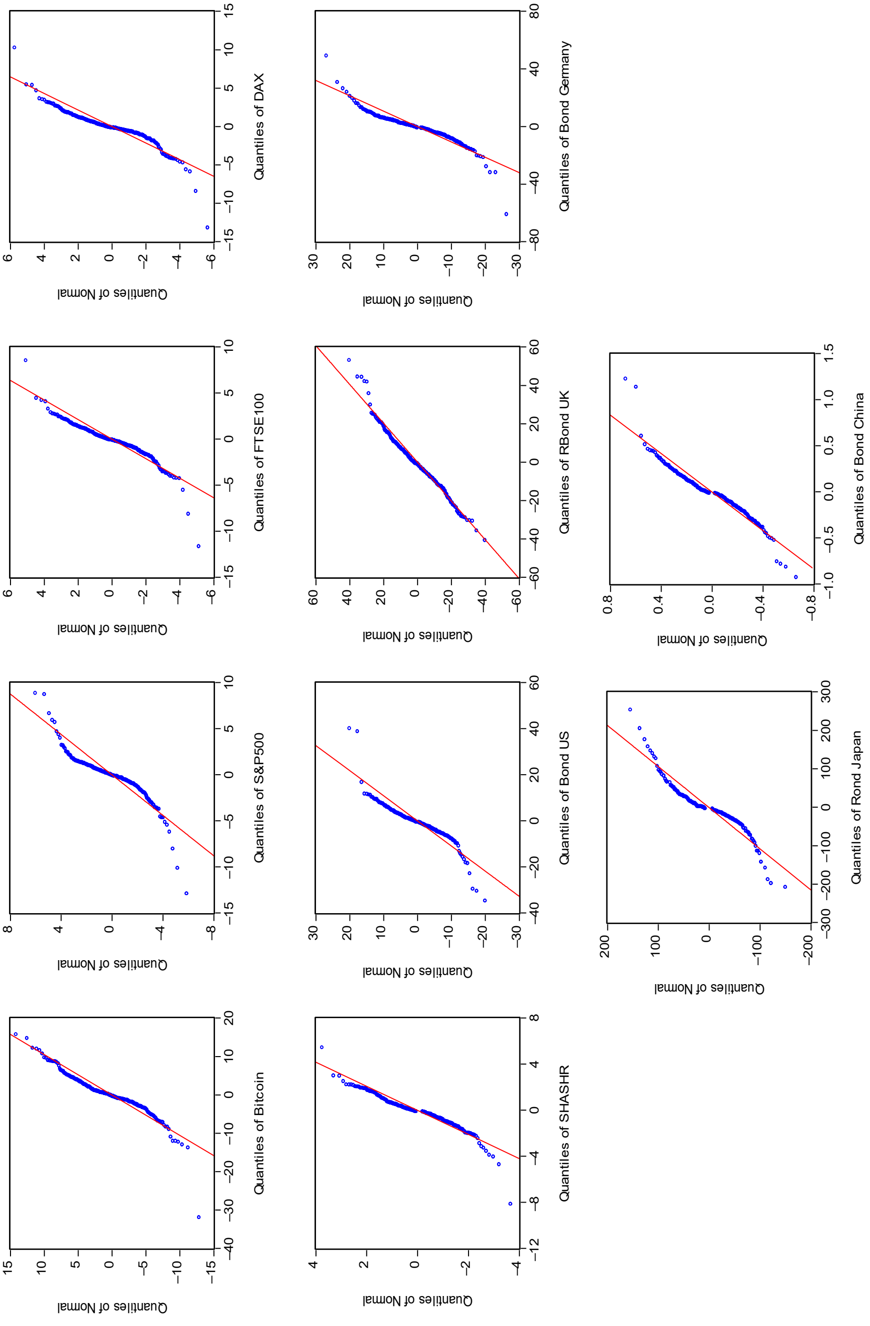

Figure 2.
QQ plots for Bitcoin and stock and bond markets during the COVID-19 pandemic

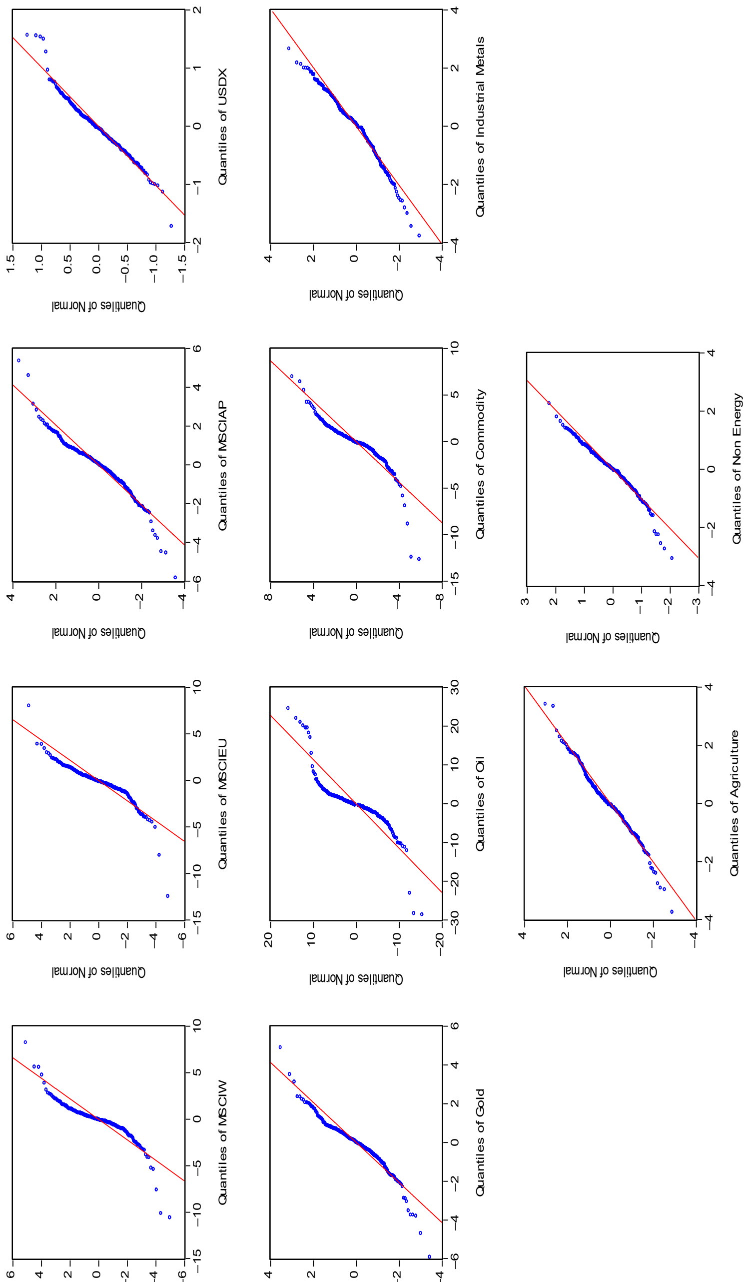

Figure 3.
QQ plots for selected commodity and non-commodity indices during the COVID-19 pandemic

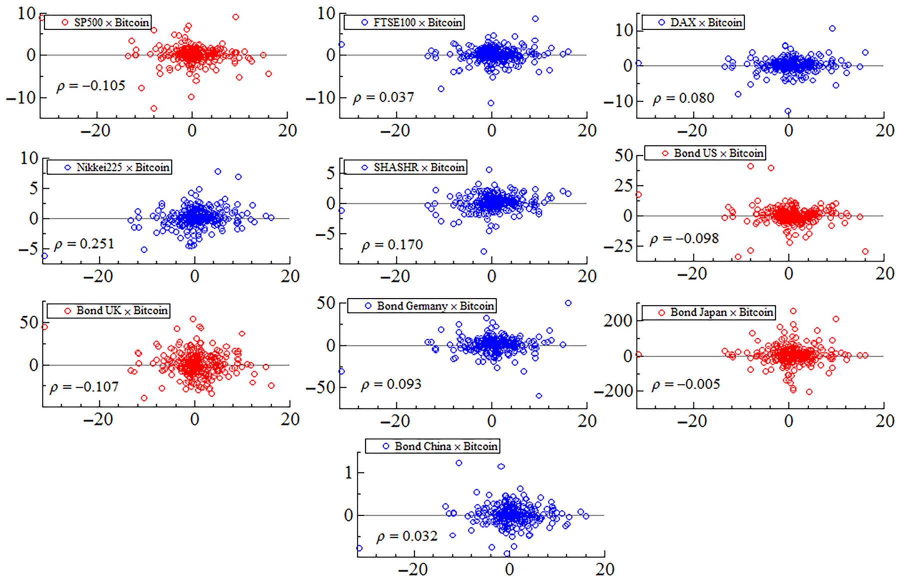

Figure 4.
Scatter plots of Bitcoin versus stock and bond returns during the COVID-19 pandemic

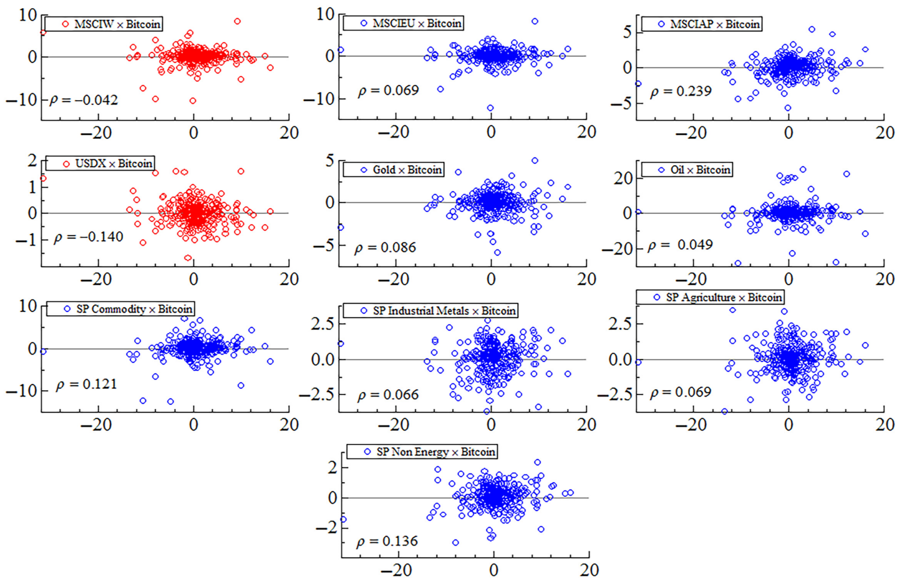

Figure 5.
Scatter plots of Bitcoin versus international stocks, US Dollar index and commodity returns during the COVID-19 pandemic

MSCI World index (MSCIW) and the US Dollar index (USDX). In particular, the MSCIAP stock market index has the highest positive correlation of 0.239 with Bitcoin, while the USDX stock market index has the lowest negative correlation of −0.14 with Bitcoin. Second, Bitcoin has a slightly positive correlation with all the commodities. The highest correlation is noted between Bitcoin and the S&P GSCI Non-Energy commodity, with a value equal to 0.136. In contrast, the lowest correlation is noted between Bitcoin and the crude oil commodity, with a value equal to 0.049.

In conclusion, the correlation analysis shows that the relationship between Bitcoin and other financial variables is non-linear. Furthermore, the correlation analysis only provides an indication of whether Bitcoin is a hedge or a diversifier for stocks or bonds or commodities, but does not reveal whether it is a safe-haven asset. In fact, a positive correlation is observed between Bitcoin and Financial Times Stock Exchange 100 (FTSE 100), Deutscher AktienindeX (DAX 30), Nikkei 225 and Shanghai A Share (SHASHR) stocks; German and Chinese bonds; the MSCIEU and MSCIAP stock market indices and all the commodities, implying that Bitcoin can be a diversifier for these assets. In contrast, it is indicated that there is a negative correlation between Bitcoin and the S&P 500 index; the USA, the UK and Japanese bonds and the MSCIW and USDX stock market indices, implying that Bitcoin can be a hedge for these assets. We cannot pronounce on whether Bitcoin can be a prospective safe-haven for these assets. Therefore, more detailed analysis is necessary to provide a more robust estimation of the non-linear relationship between Bitcoin and other variables and to examine if Bitcoin is a potential safe-haven for these assets.

4.4 Testing linearity against smooth transition regression

Testing the linearity against STR is a prerequisite for modeling non-linear relationship between variables. Furthermore, the test of non-linearity allows identifying the appropriate transition variable and the lag order for the considered asset return as well. In this study we use the Lagrange multiplier (LM) test developed and discussed by Luukkonen *et al.* (1988). The test approximates the transition function presented in equation (2) using a Taylor expansion around the null hypothesis $\gamma = 0$. Luukkonen *et al.* (1988) suggests using a number of thresholds $K = 1$ and the third order Taylor approximation. Accordingly, assuming the transition variable s_t is an element in z_t the approximation yields the following equation.

$$r_{BTC,t} = \beta_0 + \beta_1 r_{a,t} + \beta_2 r_{a,t} z_t + \beta_3 r_{a,t} z_t^2 + \beta_4 r_{a,t} z_t^3 + \varepsilon_t^*,\ t = 1, \ldots, T. \tag{4}$$

where $\varepsilon_t^* = \varepsilon_t + R_3(\gamma, c, s_t)$ and the $R_3(\gamma, c, s_t)$ is qualified as a remainder.

The null hypothesis is H_0: $\beta_2 = \beta_3 = \beta_4 = 0$ and the alternative is H_1: *At least one* $\beta_i \neq 0$ for $i = 2, 3, 4$ which implies that the higher order terms are statistically significant. The appropriate test statistic is a χ^2 with three degree of freedom. Once linearity assumption is rejected, the second step would be the selection of the appropriate transition variables by computing the test statistic for several transition functions that are considered with different lag order.

5. Estimation results

5.1 Non-linearity test results

In this empirical study, we considered delays from one to twelve lags. Table 2 reports the p-values of the LM tests corresponding to equation (4). The results show that the hypothesis of linearity is rejected for most of the asset returns considered. The linearity hypothesis is rejected for at least one lag. Accordingly, a non-linear approach to modeling the relationship between Bitcoin and the other asset returns seems to be the most appropriate. The non-linear test also allows the identification of the appropriate transition function. The results in Table 2 show that the optimal transition function differs among the asset returns considered. For instance, the appropriate transition function to model the non-linear relationship between Bitcoin and USA stocks is the lagged USA stock return at the sixth level (L_6).

The transition variable with the highest test statistic is highlighted in bold and denoted by an asterisk (see Table 2). The denoted transition variable is then used to estimate the model describing the relationship between Bitcoin and the asset returns under study.

Table 2. Results of the linearity test for daily data during COVID-19 period

	Lag 1	Lag 2	Lag 3	Lag 4	Lag 5	Lag 6	Lag 7	Lag 8	Lag 9	Lag 10	Lag 11	Lag 12
Panel A. Stocks												
USA	$1.6e^{-03}$	$4.70e^{-05}$	$2.90e^{-03}$	0.620	0.015	*$8.30e^{-07}$**	$2.30e^{-03}$	$1.2e^{-04}$	$4.6e^{-06}$	$9.1e^{-03}$	$4.6e^{-03}$	0.011
UK	$1.4e^{-04}$	0.120	0.270	*$1.01e^{-05}$**	$2.40e^{-03}$	$5.00e^{-04}$	0.82	0.045	$5.01e^{-03}$	$8.3e^{-04}$	0.03	0.13
GERMANY	*$4.70e^{-05}$**	0.290	0.016	$9.00e^{-05}$	$4.40e^{-03}$	$5.50e^{-03}$	0.49	0.035	0.014	0.012	0.055	0.23
JAPAN	$6.60e^{-05}$	$1.10e^{-04}$	0.041	*$7.70e^{-09}$**	$3.70e^{-04}$	$8.60e^{-03}$	$1.1e^{-03}$	0.010	0.1	$1.4e^{-06}$	0.03	$1.5e^{-04}$
CHINA	0.11	$3.30e^{-03}$	$1.50e^{-03}$	*$1.00e^{-05}$**	0.020	$2.50e^{-04}$	0.740	$3.50e^{-03}$	$2.2e^{-04}$	0.011	0.18	0.073
Panel B. Bonds												
USA	0.004	$1.90e^{-03}$	$6.9e^{-05}$	*$2.80e^{-06}$**	$1.60e^{-04}$	$8.70e^{-05}$	0.031	$1.5e^{-03}$	0.12	$9.3e^{-03}$	0.02	0.019
UK	0.006	$3.00e^{-05}$	*$4.20e^{-06}$**	$9.60e^{-05}$	$1.30e^{-04}$	0.077	0.14	0.03	$4.0e^{-03}$	0.053	0.025	0.24
GERMANY	1.5e–03	0.013	0.019	*$9.90e^{-05}$**	0.067	$5.60e^{-03}$	0.017	0.21	0.17	0.098	$1.1e^{-03}$	0.55
JAPAN	0.940	0.860	0.130	0.320	0.710	0.980	0.99	0.82	0.66	*$9.48e^{-03}$**	0.68	0.097
CHINA	0.250	0.100	*$3.09e^{-05}$**	$4.60e^{-04}$	$3.90e^{-03}$	0.065	0.36	0.26	0.073	$3.9e^{-04}$	0.11	0.046
Panel C. International stocks and USD												
MSCIW	0.3	$1.00e^{-04}$	$7.00e^{-03}$	0.870	$8.30e^{-03}$	$1.2e^{-06}$	$8.3e^{-03}$	$1.6e^{-03}$	$3.0e^{-05}$	*$2.30e^{-04}$**	0.27	0.31
MSCIEU	0.049	0.13	0.019	0.070	0.011	0.023	0.026	0.15	0.067	$1.41e^{-03}$	*0.033**	0.03
MSCIAP	$4.80e^{-04}$	$1.5e^{-05}$	0.013	$4.80e^{-05}$	$6.50e^{-03}$	0.013	0.084	0.031	0.202	$4.00e^{-06}$	0.14	*$4.4e^{-06}$**
USDX	$4.60e^{-05}$	$1.3e^{-06}$	3.10e–05	$4.80e^{-03}$	$3.30e^{-07}$	$4.2e^{-04}$	0.044	$4.9e-^{03}$	*$2.50e^{-04}$**	1.10e–04	$5.3e^{-03}$	0.1
Panel D. Commodities												
Gold	0.042	$7.6e^{-06}$	$2.00e^{-04}$	0.047	0.504	*$1.60e^{-07}$**	0.65	$1.5e^{-03}$	$3.4e^{-04}$	8.6e–03	0.11	0.23
Oil	$9.70e^{-06}$	*$4.80e^{-05}$**	$6.60e^{-04}$	$1.70e^{-03}$	$3.30e^{-06}$	$3.30e^{-04}$	0.32	0.38	$9.e^{-04}$	2.4e–03	0.18	0.014
Commodity	0.001	$4.7e^{-03}$	$8.8e^{-04}$	$1.40e^{-03}$	$2.20e^{-04}$	*$2.00e^{-04}$**	0.10	0.23	$6.6e^{-04}$	0.011	0.17	$5.7e^{-04}$
Ind. metal	0.011	$3.0e-^{05}$*	0.087	0.015	0.250	0.580	0.850	0.034	0.021	0.250	0.35	0.051
Agriculture	*$4.80e-^{05}$**	$1.10e-^{04}$	0.012	$8.70e^{-03}$	0.13	0.010	0.069	0.31	$6.3e-^{03}$	$2.8e^{-03}$	$2.4e^{-04}$	0.13
Non-energy	$7.40e^{-06}$	$8.50e^{-09}$	0.148	$1.40e^{-04}$	$6.e^{-04}$	$2.40e^{-04}$	0.51	0.35	$1.6e^{-06}$	0.38	*$1.5e-^{03}$**	$9.5e^{-03}$

Note(s): The table shows the p-values for the linearity test proposed by Luukkonen *et al.* (1988) for different lag orders. The asterisk represents the lag length corresponding to the highest test statistic

In addition, the non-linear test results for the pre-COVID-19 period [4] for the daily data also indicate that the linearity hypothesis is rejected for the majority of the assets under study. However, in contrast with the daily data, there are some cases where the linearity hypothesis is not rejected when considering the weekly data before and during the COVID-19 pandemic. Thus, the appropriate specification for these few cases would be the linear model.

5.2 Regression analysis results for the during COVID-19 pandemic period

In this section, we present the estimation results of the regression model as specified in Equation (3) during COVID-19 pandemic period.

Notably, the estimated coefficients reveal substantial differences between asset classes with regard to Bitcoin's ability to serve as a hedge or safe-haven.

Panel A of Table 3 shows that the coefficient ψ_1 is significantly positive for the United States of America and the United Kingdom, whereas the coefficient $\psi_1 + \psi_2$ appears to be negative and statistically significant for the United Kingdom, Germany, Japan and China. This indicates that Bitcoin is a safe-haven for these stock markets during the COVID-19 period.

Results reported in Panel B of Table 3 indicate that the coefficient ψ_1 is significantly positive for the United Kingdom and Japan, whereas the coefficient $\psi_1 + \psi_2$ appears to be negative and statistically significant for Germany. This indicates that Bitcoin is a safe-haven for this bond market during the COVID-19 period.

Results reported in Panel C of Table 3 exhibit that the coefficient ψ_1 is statistically non-significant for all the considered international indexes. However, the coefficient $\psi_1 + \psi_2$ appears to be negative and statistically significant for the MSCIAP index and the US Dollar index, indicating that Bitcoin serves as a safe-haven for these international stock markets during the COVID-19 period.

In Panel D of Table 3, the estimated results indicate that the coefficient ψ_1 is significantly negative for the Gold and Non-Energy Index indicating that Bitcoin serves as a hedge for these commodities. On the other side, the coefficient $\psi_1 + \psi_2$ appears to be negative and statistically significant for Industrial metal, indicating that Bitcoin serves as a safe-haven for this commodity during the COVID-19 period.

Ultimately, Bitcoin serves as a hedge only for the Gold and Non-Energy Index during the COVID-19 period. However, Bitcoin serves as a safe-haven for several asset classes, namely the United Kingdom, German, Japanese and Chinese stock markets, the German bond markets, the international MSCIAP index, the US Dollar index and the industrial metal during the COVID-19 period.

5.3 Comparison of pre-to during COVID-19 eras

To assess whether the COVID-19 pandemic is affecting the hedging and safe-haven capabilities, we compare the results on the safe-haven and hedging abilities of Bitcoin during the COVID-19 pandemic to the pre-pandemic period. Table 4 reports the detailed results of the STR estimates in the pre-COVID-19 period.

Panel A of Table 4 reveals that the coefficient ψ_1 is negative and statistically significant for Germany and Japan, indicating that Bitcoin is an effective hedge against the stock market returns of these two countries. However, the coefficient $\psi_1 + \psi_2$ is positive and statistically significant for the United States of America, the United Kingdom and Japan, indicating that Bitcoin is not a safe-haven against the stock markets of all the countries under consideration during the pre-COVID-19 period.

The coefficient ψ_1 is negative and statistically significant for three of the five bond markets analyzed, namely the United States of America, German and Chinese bond markets as presented in Panel B of Table 4. This study indicates that Bitcoin can also serve as an effective hedge against bond market returns during pandemics. In addition, the data show

Table 3. Smooth transition regression estimation results during COVID-19

	α_1	ψ_1	α_2	ψ_2	γ	c	$\psi_1+\psi_2$	Lag
				Panel A. Stocks				
USA *s.e*	0.105 (0.361)	0.361*** (0.132)	1.120*** (0.426)	−0.925*** (0.469)	13.39 (22.7)	4.63*** (2.45)	−0.564 (0.447)	9
UK *s.e*	−0.187 (0.126)	0.294*** (0.126)	2.250** (1.203)	−2.207** (1.179)	4.168*** (1.910)	9.772*** (2.472)	−1.912** (1.08)	4
GERMANY *s.e*	0.121 (0.150)	0.119 (0.134)	2.450* (1.410)	−2.355** (1.195)	0.577* (0.320)	8.485*** (2.466)	−2.235** (1.40)	3
JAPAN *s.e*	0.181 (0.126)	0.050 (0.102)	2.924** (0.988)	−1.049* (0.610)	19.60 (29.80)	9.389*** (0.048)	−0.998* (0.610)	3
CHINA *s.e*	−0.118 (0.166)	0.053 (0.095)	1.206*** (0.379)	−0.376** (0.189)	2.136 (2.065)	1.570*** (0.505)	−0.323** (0.153)	1
				Panel B. Bonds				
USA *s.e*	0.175 (0.128)	−0.055 (0.051)	2.130** (1.022)	0.669* (0.387)	9.368 (21.42)	8.487*** (0.204)	0.613** (0.387)	3
UK *s.e*	0.184 (0.126)	0.059*** (0.022)	2.282** (1.097)	0.017 (0.464)	62.10 (143.04)	9.303*** (0.057)	0.076 (0.469)	3
GERMANY *s.e*	−0.147 (0.176)	0.002 (0.003)	1.264 (0.421)	−0.0128 (0.011)	1.818 (1.729)	1.744*** (0.664)	−0.010*** (0.009)	1
JAPAN *s.e*	0.151 (0.129)	0.004* (0.002)	1.124* (0.589)	0.022 (0.021)	4.244 (14.36)	5.496*** (0.858)	0.027 (0.021)	6
CHINA *s.e*	−0.167 (0.331)	−0.278 (1.364)	3.181* (1.786)	1.314 (2.742)	0.448 (0.436)	8.251*** (3.255)	1.035 (2.147)	1
				Panel C. International stocks and USD				
MSCIW *s.e*	0.181 (0.128)	0.058 (0.167)	1.319* (0.718)	2.160 (1.306)	3.082 (5.707)	7.262*** (0.800)	2.219* (1.290)	6
MSCIEU *s.e*	−0.113 (0.169)	0.108 (0.239)	1.236*** (0.410)	−0.134 (0.391)	1.976 (2.020)	1.798*** (0.643)	−0.025 (0.225)	4
MSCIAP *s.e*	0.125 (0.197)	0.051 (0.326)	11.24*** (3.581)	−20.69** (10.05)	0.213** (0.101)	23.10*** (5.587)	−20.65** (9.79)	3
USDX *s.e*	−0.150 (0.161)	0.538 (0.404)	1.133*** (0.310)	−1.243** (0.648)	3.466 (3.848)	1.110*** (0.319)	−0.705* (0.522)	1
				Panel D. Commodities				
Gold *s.e*	1.729** (0.616)	−3.944*** (0.892)	−1.534*** (0.630)	3.894*** (0.903)	150.9 (921.3)	−7.611*** (0.040)	−0.050 (0.156)	1
Oil *s.e*	0.182 (0.126)	0.023 (0.044)	2.212** (1.130)	−0.433 (0.475)	70.18 (171.2)	9.295 (0.135)	−0.409 (0.470)	3
Commodity *s.e*	−0.115 (0.171)	0.054 (0.106)	1.236 (0.413)	−0.083 (0.242)	1.890 (1.919)	1.781*** (0.666)	−0.028 (0.201)	2
Industrial metal *s.e*	0.182 (0.126)	−0.032 (0.103)	2.519** (1.168)	−1.210** (0.734)	55.95 (372.7)	9.399*** (0.028)	−1.242** (0.738)	3
Agriculture *s.e*	0.556 (0.493)	1.614*** (0.526)	−0.298 (0.522)	−1.539*** (0.552)	10.39 (26.85)	−4.837*** (0.230)	0.074 (0.131)	2
Non-energy *s.e*	2.958*** (1.252)	−6.327*** (1.583)	−2.763** (1.254)	6.168*** (1.609)	8.743 (12.67)	−11.849 (0.263)	−1.158 (0.217)	1

Note(s): *s.e* is the standard error of the estimates and the asterisk ***, **, * denote the significance levels at 1%, 5% and 10%, respectively

Table 4.
Smooth transition regression estimation results from pre-COVID period

	α_1	ψ_1	α_2	ψ_2	γ	c	$\psi_1+\psi_2$	Lag
Panel A. Stocks								
USA *s.e*	0.643** (0.271)	0.751*** (0.131)	−1.643** (1.203)	3.168*** (0.162)	1.742 (2.497)	9.575*** (0.565)	6.359** (3.913)	6
UK *s.e*	0.086 (1.211)	2.394*** (0.314)	0.688 (1.233)	−1.917*** (0.313)	11.34 (23.22)	−4.908*** (0.074)	0.476*** (0.121)	4
GERMANY *s.e*	0.237 (1.360)	−1.874*** (0.353)	0.308 (1.384)	1.869*** (0.440)	6.591 (51.80)	−7.168 (2.553)	−0.004 (0.175)	1
JAPAN *s.e*	1.974** (2.05)	−3.640*** (0.941)	−1.459 (1.283)	4.036*** (1.00)	4.665 (7.266)	−7.080 (0.374)	0.396** (0.276)	3
CHINA *s.e*	0.685** (0.295)	0.547** (0.252)	−106.9 (135.5)	57.31 (73.37)	0.746** (0.293)	15.83 (3.397)	57.86 (73.26)	4
Panel B. Bonds								
USA *s.e*	2.857 (1.919)	−0.120*** (0.027)	−2.350 (2.000)	0.052*** (0.060)	16.25 (77.22)	−6.714*** (0.291)	−0.068* (0.058)	4
UK *s.e*	0.558** (0.284)	0.018 (0.018)	2.055*** (0.829)	0.212*** (0.058)	4.069 (8.557)	9.275*** (0.621)	0.230*** (0.053)	3
GERMANY *s.e*	−4.229 (3.504)	−5.531** (0.271)	4.229 (3.479)	0.526** (0.283)	4.769 (17.13)	−7.095*** (0.974)	−0.005 (0.034)	4
JAPAN *s.e*	0.431 (0.455)	0.030** (0.013)	0.221 (0.546)	−0.041*** (0.015)	8.957 (14.59)	−2.043*** (0.194)	−0.010*** (0.004)	10
CHINA *s.e*	0.641 (0.702)	−13.90** (5.668)	−0.001 (0.728)	14.90*** (5.858)	0.024 (0.980)	−3.350** (1.449)	0.997 (1.101)	3
Panel C. International stocks and USD								
MSCIW *s.e*	0.716** (0.291)	−0.750*** (0.199)	−0.136 (0.462)	1.053 (0.665)	29.51 (143.9)	−0.351** (0.209)	0.303 (0.667)	10
MSCIEU *s.e*	−0.543 (1.113)	2.292*** (0.229)	1.303 (1.133)	−1.776*** (0.226)	38.68 (67.02)	−4.911*** (0.020)	0.515 (0.134)	4
MSCIAP *s.e*	0.756*** (0.294)	1.138** (0.578)	−0.802 (0.592)	−1.298** (0.693)	113.2 (1003)	3.976 (0.118)	−0.159 (0.338)	1
USDX *s.e*	1.962 (1.305)	6.336*** (1.603)	−1.435 (1.342)	−8.433*** (1.646)	1.654** (0.914)	−7.363*** (0.503)	−2.096 (0.735)	9
Panel D. Commodities								
Gold *s.e*	0.750** (0.315)	1.248*** (0.356)	−0.789 (0.585)	−0.967** (0.432)	42.22 (90.28)	3.106*** (0.032)	0.281 (0.442)	6
Oil *s.e*	0.431 (0.649)	−0.159** (0.081)	0.128 (0.712)	0.392*** (0.116)	12.78 (12.91)	−0.578*** (0.125)	0.232*** (0.065)	2
Commodity *s.e*	0.412 (0.328)	0.459** (0.200)	0.810 (0.860)	−1.081** (0.462)	2.459 (4.629)	3.971 (0.737)	−0.621 (0.371)	6
Industrial metal *s.e*	0.724** (0.296)	−0.397** (0.197)	0.877** (0.350)	57.27*** (0.685)	4.00*** (1.483)	12.85*** (0.117)	56.87*** (0.597)	2
Agriculture *s.e*	1.647 (2.303)	10.726** (4.591)	−1.015 (2.352)	−10.190** (4.547)	2.136 (3.812)	−8.340** (0.849)	0.536** (0.240)	1
Non-energy *s.e*	0.692** (0.317)	−0.090 (0.551)	−1.743** (0.865)	1.853** (1.020)	6.099 (25.42)	6.492*** (0.433)	1.762 (1.101)	2

Note(s): *s.e* is the standard error of the estimates and the asterisk ***, **, * denote the significance levels at 1, 5 and 10%, respectively that the coefficient $\psi_1 + \psi_2$ is negative and statistically significant for the United States of America and Japan bond markets, showing that Bitcoin served as a safe-haven for these bond markets prior to COVID-19.

Panel C of Table 4 shows that the coefficient ψ_1 is only negative and significant for the MSCIW index, indicating that Bitcoin is only used as a hedge for this international index. Furthermore, the coefficient $\psi_1 + \psi_2$ appears to be statistically non-significant for all of the international indexes considered, indicating that Bitcoin was not a safe-haven against all international stock markets prior to COVID-19.

As seen in Panel D of Table 4, the coefficient ψ_1 is significantly negative for oil and industrial metal, indicating that Bitcoin serves as a hedge for these commodities. However, the coefficient $\psi_1 + \psi_2$ appears to be positive and significant for oil, industrial metal and agriculture indicating that during the pre-COVID-19 period Bitcoin cannot serve as a safe-haven for these commodities.

Ultimately, Bitcoin serves as a hedge for several asset classes, namely the German and Japanese stocks, for the United States of America, German and Chinese bond markets, for the MSCIW index, for oil and industrial metal during the pre-COVID-19 period. However, Bitcoin serves as a safe-haven only for the United States of America and Japanese bond markets during the pre-COVID-19 period.

The comparison between the results, before and during the COVID-19 pandemic, shows that the pandemic has an impact on the hedging and safe-haven properties of Bitcoin for some assets. In fact, Bitcoin gains the safe-haven property for several assets, namely the United Kingdom, German, Japanese and Chinese stock markets, the German bond markets, the international MSCIAP index, the US Dollar index and the industrial metal, during the pandemic as compared to the pre-COVID-19 period. In contrast, Bitcoin loses its safe-haven property for the United States of America and Japanese bond markets during the COVID-19 period.

Moreover, Bitcoin gains the hedging property for the Gold and Non-Energy, but it loses its hedging property for the German and Japanese stocks, for the United States of America, German and Chinese bond markets, for the MSCIW index, for oil and industrial metal during the COVID-19 period. It is important to notice that the hedging property of Bitcoin for the German and Japanese stocks before the pandemic is converted to the safe-haven property during the pandemic.

Overall, we can conclude that Bitcoin plays the role of a safe-haven against some conventional assets during the COVID-19 pandemic. This important result supports the findings of Corbet *et al.* (2020), Ji *et al.* (2020), Mariana *et al.* (2021) and Huang *et al.* (2021), but it contradicts the findings of Kristoufek (2020) and Conlon *et al.* (2020). The safe-haven behavior of cryptocurrencies, particularly Bitcoin, can be attributed to their specific properties including independence from monetary policy, their role as a store value and the non-correlation with traditional assets, which strengthen their resilience during crisis periods (Baur *et al.*, 2018).

Regarding the hedging capability of Bitcoin, in the pre-COVID-19 period, our findings are consistent with those of Wen *et al.* (2022) who argue that Bitcoin can be considered as good hedging tool before the COVID-19 pandemic.

5.4 Time horizon effects

To consider the time horizon effects, we estimate the relationship between Bitcoin and the considered asset returns on a weekly basis. Table 5 reports the conclusions on the safe-haven and hedging capabilities of Bitcoin based on the weekly results for the pre- and during COVID-19 periods [5].

Table 5 shows that during the COVID-19 pandemic, Bitcoin only serves as a safe-haven for three out of twenty assets, namely Bitcoins serves as a safe-haven against extreme movements in UK and Chinese bonds and the MSCIAP. Considering the pre-COVID-19

	Pre COVID-19			During		
	Selected model	Safe-haven	Hedging	Selected model	Safe-haven	Hedging
Panel A. Stocks						
US	STR1(L_4)	√	×	STR2(L_4)	×	×
UK	STR1(L_8)	√	×	Linear	×	×
GERMANY	STR1(L_{10})	×	√	Linear	×	×
JAPAN	STR1(L_6)	√	×	STR2(L_1)	×	×
CHINA	STR1(L_4)	×	√	STR1(L_4)	×	×
Panel B. Bonds						
US	Linear	×	×	Linear	×	×
UK	Linear	×	×	STR1(L_4)	√	×
GERMANY	Linear	×	×	Linear	×	×
JAPAN	Linear	×	×	Linear	×	×
CHINA	STR1(L_1)	×	×	STR1(L_4)	√	×
Panel C. International stocks and USD						
MSCIW	STR1(L_8)	×	×	Linear	×	×
MSCIEU	STR1(L_3)	√	×	Linear	×	×
MSCIAP	STR1(L_8)	×	√	STR1(L_2)	√	×
USDX	STR1(L_4)	×	√	Linear	×	×
Panel D. Commodities						
Gold	STR1(L_3)	×	×	STR1(L_1)	×	×
Oil	STR1(L_8)	×	×	Linear	×	×
Commodity	STR1(L_8)	√	×	Linear	×	×
Industrial Metal	STR1(L_2)	√	√	STR1(L_1)	×	×
Agriculture	STR1(L_7)	√	√	STR1(L_3)	×	×
Non Energy	STR1(L_1)	×	×	STR1(L_4)	×	×

Note(s): STR1 and STR2 denote the logistic smoothing regressions for K = 1 and K = 2 respectively. The symbols √ and × indicate whether the safe-havenand Hedging capability exists or not

Table 5. Smooth transition regression estimation results before and during COVID-19 pandemic based on weekly data

period, the results show that Bitcoin serves as a safe-haven for three out of five stocks, namely the USA, UK and Japanese stocks. Besides, the results indicate that Bitcoin is not a safe-haven for all the bonds studied. Moreover, the reported results indicate that Bitcoin only acts as a safe-haven for the MSCIEU index and for three commodities, which are the S&P GSCI and the industrial metal and the agriculture commodity indices.

Regarding the hedging capabilities of Bitcoin, the results reported in Table 5 show that, during the COVID-19 pandemic, Bitcoin is not a hedge for any of the assets under study. However, in the pre-COVID-19 period, there is some evidence of the hedging capabilities of Bitcoin against movements in asset returns. Explicitly, for investors, the results indicate that the hedging capabilities are very successful for the German and Chinese stock markets, for the MSCIAP index, for the USDX and for the industrial metal and agriculture commodity indices during the pre-COVID-19 period. Our results on the hedging capabilities of Bitcoin support evidence from previous studies using weekly returns. For instance, the findings on the hedging capabilities of Bitcoin against movements in the Chinese stock market support those obtained in Bouri *et al.* (2017).

A systematic comparison between the daily and weekly findings reveals that the time horizon plays a major part in Bitcoin investors'decisions. Indeed, the safe-haven and hedging capabilities of Bitcoin significantly differ between time horizons.

For instance, in the pre-COVID-19 period, the hedging property of Bitcoin against the Japanese stock markets, the United States of America, German and Chinese bond markets, the MSCIW index and the oil as observed in the daily data, vanishes with regard to the weekly data. In contrast, Bitcoin gains the hedging property for the Chinese stock markets, for the MSCIAP index, for the USDX and the agriculture commodity indices, which are not present in the daily data. Nevertheless, Bitcoin preserves the same hedging property for the German stock markets and the industrial metal by switching from the daily data to the weekly data.

During the COVID-19 period, the hedging role of Bitcoin against movements in Gold and Non-Energy Index in the daily data disappears when considering the weekly data. Thus, the hedging property is not valid for the weekly data during the COVID-19 pandemic.

Regarding the safe-haven role of Bitcoin in the pre-COVID-19 period, it is observed that this role fades for the United States and Japanese bond markets by switching from the daily data to the weekly data. In contrast, Bitcoin gains the safe-haven property for the US, UK and Japanese stock markets, for the MSCIEU index, for the S&P GSCI, for the industrial metal and for the agriculture commodity indices with the weekly data.

The results also show that Bitcoin's safe-haven status during the COVID-19 pandemic disappears for the UK and German stock markets, the Japanese and Chinese stock markets, the German bond markets, the US Dollar index and industrial metal. When compared to bonds issued by the United Kingdom and China, Bitcoin becomes a safer haven investment when weekly data are used. However, when looking at the MSCIAP index, going from the daily data to the weekly data shows that Bitcoin has the same safe-haven property.

Overall, in the pre-COVID-19 period, the hedging property of Bitcoin only remains the same for German stock markets and the industrial metal for both the daily and the weekly data. Conversely, during the COVID-19 period, the hedging property of Bitcoin disappears for all the assets when switching from the daily data to the weekly data. Bouri *et al.* (2017) suggest that Bitcoin acts as a hedge in the short run since it reacts positively to large (low and up) financial movements. On the other hand, Bitcoin preserves the same safe-haven property only for the MSCIAP index for both the daily and weekly data during the COVID-19 period.

6. Conclusion and policy implications

The COVID-19 pandemic is a global health crisis that has invoked a great amount of uncertainty for investors in local and international financial markets. In this period of increasing uncertainty, followed by extreme losses incurred with regard to most conventional assets, Bitcoin, the world's leading digital currency, is showing astonishing performance, offering new opportunities for investors to generate profit through their portfolios. In light of these events, this paper examines the hedge and safe-haven properties of Bitcoin against stocks and bonds markets covering five major countries/regions, the major world stock indices and commodity market, before and during the COVID-19 pandemic.

Using an STR model, our results highlight the ability of Bitcoin to act as a safe-haven asset during the pandemic crisis for several asset markets, namely the United Kingdom, German, Japanese and Chinese stock markets, the German bond markets, the international MSCIAP index, the US Dollar index and the industrial metal. These findings are consistent with those of Corbet *et al.* (2020), Ji *et al.* (2020), Mariana *et al.* (2021) and Huang *et al.* (2021) arguing that cryptocurrencies can be safe-haven tools during the COVID-19 pandemic. However, Bitcoin serves as a hedge only for a limited number of assets, namely the Gold and Non-Energy Index, during the pandemic crisis. In the other side, while Bitcoin shows a safe-haven role only for the United States of America and Japanese bond markets during the pre-COVID-19 period, it provides a hedge role for several asset classes, namely the German and Japanese stocks, the United States of America, German and Chinese bond markets, the MSCIW index, oil and industrial metal. Our results support the findings of Wen *et al.* (2022) who argue that Bitcoin can be considered as good hedging tool before the COVID-19 pandemic.

Hence, we can conclude that the hedge property of Bitcoin is more suitable in times of calm and tranquility of financial market, while the safe-haven property of Bitcoin is more relevant during crisis period. Moreover, we also find that the prowess of the safe-haven/hedge nature is sensitive to the type of the asset market and the time horizon when switching from daily to weekly frequency data.

Overall, our findings are significant and potentially useful to researchers, practitioners and participants in the Bitcoin market who are looking to make better investment and risk management decisions. Our findings have implications for investors who seek protection in periods of extreme uncertainty. As such, investors with exposure to several conventional assets could benefit from buying Bitcoin in times of extreme uncertainty. The COVID-19 bear market provides the background for investigating the safe-haven role of Bitcoin against other financial assets. Bitcoin serves as a safe-haven during the COVID-19 pandemic period; thus, investors and fund managers should invest money into this leading cryptocurrency to adjust and diversify their portfolios. In addition, in periods of normal movements in returns, they can trust Bitcoin and use it to hedge against several conventional assets.

Furthermore, our findings could be of interest to regulators and governments, who may be wondering whether to make cryptocurrencies a monetary policy device or a kind of complementary currency. Regulatory authorities, financial institutions, central banks and other key policymakers should trust more in Bitcoin and make more efforts to benefit from the advantages of the cryptocurrency market. They are invited to consider this alternative financial market as an opportunity rather than as a threat.

Moreover, the outcomes on the safe-haven capabilities of Bitcoin are supported by the continued guidance and acceptance of cryptocurrencies as a viable and stable asset class by a number of researchers and policymakers. During a market panic, such policy-makers reassurance could serve as both a catalyst and a supporting structure for the perception of investment safety. Regulatory and policy-making authorities will be alarmed by the use of cryptocurrencies as a safe-haven during episodes of extreme market volatility. The pervasive absence of continuity, regulation and international law, as well as the significantly pronounced risks associated with relatively unsophisticated fraud, present formidable challenges to policymakers.

Our interesting findings add more detail to prior studies that show some hedging and safe-haven capabilities of Bitcoin against conventional assets. However, our findings are limited to the COVID-19 era and Bitcoin market. Future research could use uncertainty measures to analyze their effects on cryptocurrency markets, including other cryptocurrencies, and to explore COVID-19-related uncertainty measures in the post-COVID-19 period.

Notes

1. https://coinmarketcap.com/
2. On January 20, 2020, the leading expert of the National Health Commission of the People's Republic of China, Nanshan Zhong, confirmed the human-to-human transmission of COVID-19; hence, we treat this as the date when the outbreak of COVID-19 occurred.
3. Coin metrics.
4. The detailed non-linearity tests for the pre-COVID-19 period based on the daily data are reported in the supplementary document and can be provided upon request.
5. To save space, we included all the detailed non-linear tests and estimation results of the weekly data in the supplementary documents. The detailed results are reported in tables similar to Tables 2 and 3.

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Supplementary documents

Table S1. Results of the linearity test for the pre-COVID-19 period based on daily data

	Lag 1	Lag 2	Lag 3	Lag 4	Lag 5	Lag 6	Lag 7	Lag 8	Lag 9	Lag 10	Lag 11	Lag 12
Panel A. Stocks												
USA	1.5e−03	4.1e−03	0.35	0.013	0.36	0.68	0.21	0.66	0.29	0.22	0.40	0.45
UK	0.012*	0.28	0.099	0.54	0.76	0.52	0.06	0.93	0.46	0.33	0.81	0.55
GERMANY	0.019	0.89	0.13	0.56	0.42	0.36	0.76	0.93	0.046	1.4e−03*	0.027	0.648
JAPAN	0.29	0.032	0.098	7.4e−04	0.09	0.012	0.18	0.13	0.044*	0.37	0.96	0.55
CHINA	0.55	0.12	0.11	0.99	0.01*	0.28	0.37	0.99	0.9	0.19	0.99	0.61
Panel B. Bonds												
USA	1.6e−03	0.67	0.12	0.62	0.40	0.089	0.03	0.016*	0.4	0.72	0.2	0.57
UK	0.9	0.54	0.99	0.84*	0.93	0.96	0.95	0.94	0.99	0.66	0.16	0.37
GERMANY	0.99	0.95	0.99	0.99	0.96	0.97	0.97	0.99	0.99	0.98	0.99	0.99
JAPAN	0.99	0.87	0.99	0.99	0.78	0.9	0.99	0.99	0.99	0.99	0.99	0.99
CHINA	8.3e−03*	3.8e−04	0.47	0.055	0.23	0.05	5.6e−03	2.1e−05	0.56	1.3e−03	6.6e−03	0.039
Panel C. International stocks and USD												
MSCIW	2.8e−03	0.015	0.11	0.27	0.51	0.27	0.37	0.94	0.042*	0.063	0.56	0.15
MSCIEU	0.0.7	0.2	0.29	0.13	0.7	0.2	0.22	0.96	0.14	0.078	0.035*	0.54
MSCIAP	0.26	0.012*	0.64	0.35	0.35	0.65	0.24	0.97	0.1	0.13	0.72	0.11
USDX	0.013	0.37	0.02	0.83	0.039	0.13	0.077	0.95	0.027*	0.45	0.6	0.14
Panel D. Commodities												
Gold	0.028*	0.05	6.6e−04	6.9e−03	6.e−07	4.3e−04	7.e−03	6.7e−04*	0.47	0.1	0.039	4.e−03
Oil	0.17	0.04	0.73	0.71	0.27	0.14	0.4	0.6	0.91	0.95	0.99	0.97
Commodity	0.034	0.042*	0.54	0.32	0.14	0.19	0.39	0.82	0.91	0.81	0.97	0.86
Ind. metal	0.27	0.56*	0.11	0.34	0.99	0.15	0.78	0.21	0.11	0.9	0.97	0.6
Agriculture	0.0.2	0.14	0.098	0.91	0.9	0.43	0.97	0.78	0.24	0.016*	0.488	0.06
Non-energy	0.034	0.92	0.085	0.15	0.97	0.016*	0.932	0.52	6.e−05	0.22	0.601	0.021

Note(s): The table shows the p-values for the linearity test proposed by Luukkonen *et al.*, (1988) for different lag orders. The asterisk represents the lag length corresponding to the highest test statistic

Table S2.
Smooth transition regression estimation results for the pre-COVID-19 period based on daily data

	α_1	ψ_1	α_2	ψ_2	γ	c	Lag
Panel A. Stocks							
USA *s.e*	-1.206^{*} (1.05)	-0.157^{***} (0.079)	1.705 (1.297)	1.019^{**}(0.539)	2.882^{**} (1.337)	-0.477^{**} (0.223)	4
UK *s.e*	0.154 (0.127)	-0.378^{***} (0.159)	-5.682^{***} (2.136)	2.904^{***} (1.201)	46.689 (38.52)	1.173^{***} (0.023)	1
GERMANY *s.e*	0.803^{***} (0.252)	0.342 (0.223)	-1.501^{**} (0.691)	0.587^{**} (0.279)	6.730^{***} (2.694)	0.387^{***} (0.104)	10
JAPAN *s.e*	0.193 (0.123)	0.199^{**} (0.116)	1.116 (2.192)	-0.733^{*} (0.439)	$1.1e^{04}$ ($3.4\ e^{11}$)	2.096 1.0 $e-^{04}$	9
CHINA *s.e*	−9.294 (13.106)	−1.208 (1.496)	11.409 (15.795)	0.430 (0.399)	0.679^{**} (0.385)	-3.406^{**} (1.905)	5
Panel B. Bonds							
USA *s.e*	0.167 (0.168)	0.008 (0.091)	$1.1\ e^{6}$ ($2.7\ e^{7}$)	$1.4\ e^{5}$ ($3.2\ e^{6}$)	1.776^{**} (0.581)	17.349 (26.429)	8
UK *s.e*	−0.262 (0.422)	-0.105^{*} (0.062)	–	–	–	–	Linear
GERMANY *s.e*	0.009 (0.157)	-0.015^{**} (0.008)	–	–	–	–	Linear
JAPAN *s.e*	0.009 (0.157)	0.073^{***} (0.028)	–	–	–	–	Linear
CHINA *s.e*	0.102 (0.212)	−0.611 (1.329)	-6.421^{*} (4.60)	-1.351^{***} (0.464)	43.594^{*} (30.3)	0.292^{***} (0.007)	12
Panel C. International stocks and USD							
MSCIW *s.e*	1.282 (1.550)	-0.981^{**} (0.556)	−1.161 (1.568)	-1.205^{**} (0.608)	9.097 (5.913)	-0.951^{***} (0.072)	9
MSCIEU *s.e*	0.377 (0.559)	0.043 (0.388)	−0.245 (0.580)	0.530^{**} (0.303)	$1.15\ e^{04}$ ($2.4\ e^{04}$)	-0.587^{***} (0.006)	11
MSCIAP *s.e*	0.148 (0.124)	-0.300^{*} (0.179)	−0.783 (2.805)	-0.719^{***} (0.202)	111.12 (112.1)	1.298^{***} (0.007)	2
USDX *s.e*	0.227^{*} (0.128)	-0.940^{***} (0.314)	0.603 (1.700)	-2.533^{**} (1.145)	511.7 ($2.5\ e^{04}$)	0.562^{***} (0.008)	9
Panel D. Commodities							
Gold *s.e*	0.283 (1.480)	-1.279^{**} (0.504)	−0.206 (1.494)	1.093^{**} (0.532)	19.872 (16.167)	−0.945 (0.058)	4
Oil *s.e*	0.304 (0.155)	-0.115^{**} (0.064)	–	–	–	–	Linear
Commodity *s.e*	2.007 (1.716)	0.724^{**} (0.432)	−1.844 (1.730)	−0.762 (0.668)	10.401^{**} (6.164)	-1.669^{***} (0.106)	2
Industrial metal *s.e*	2.007 (1.716)	0.724^{*} (0.432)	−1.844 (1.730)	−0.762 (0.668)	10.401^{*} (6.164)	-1.669^{***} (0.106)	2
Agriculture *s.e*	0.190 (0.127)	-0.226^{*} (0.132)	−0.242 (3.980)	−0.233 (1.715)	24.85 (32.78)	1.676^{***} (0.100)	10
Non-energy *s.e*	0.333 (0.235)	-0.536^{**} (0.269)	−0.733 (0.698)	0.961^{*} (0.514)	5.739^{**} (2.729)	0.226^{**} (0.079)	6

Note(s): *s.e* is the standard error of the estimates and the asterisk *, ** and *** are the significance levels at 1, 5 and 10%, respectively

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