Spillovers between cryptocurrencies, gold and stock markets: implication for hedging strategies and portfolio diversification under the COVID-19 pandemic

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Abstract

Purpose – This study analyzes the static and dynamic risk spillover between US/Chinese stock markets, cryptocurrencies and gold using daily data from August 24, 2018, to January 29, 2021. This study provides practical policy implications for investors and portfolio managers.

Design/methodology/approach – The authors use the Diebold and Yilmaz (2012) spillover indices based on the forecast error variance decomposition from vector autoregression framework. This approach allows the authors to examine both return and volatility spillover before and after the COVID-19 pandemic crisis. First, the authors used a static analysis to calculate the return and volatility spillover indices. Second, the authors make a dynamic analysis based on the 30-day moving window spillover index estimation.

Findings – Generally, results show evidence of significant spillovers between markets, particularly during the COVID-19 pandemic. In addition, cryptocurrencies and gold markets are net receivers of risk. This study provides also practical policy implications for investors and portfolio managers. The reached findings suggest that the mix of Bitcoin (or Ethereum), gold and equities could offer diversification opportunities for US and Chinese investors. Gold, Bitcoin and Ethereum can be considered as safe havens or as hedging instruments during the COVID-19 crisis. In contrast, Stablecoins (Tether and TrueUSD) do not offer hedging opportunities for US and Chinese investors.

Originality/value – The paper's empirical contribution lies in examining both return and volatility spillover between the US and Chinese stock market indices, gold and cryptocurrencies before and after the COVID-19 pandemic crisis. This contribution goes a long way in helping investors to identify optimal diversification and hedging strategies during a crisis.

Keywords Stock markets, Gold, Cryptocurrencies, Stablecoins, Hedging, Diversification, COVID-19 crisis

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1. Introduction

In December 2019, the COVID-19 outbreak, identified in the Chinese city of Wuhan, is quickly spread to other parts of China and around the world. As the virus news moves far beyond China's borders, the COVID-19 pandemic has significantly impacted stock markets around the world (Li, 2021; Mensi *et al.*, 2021; Tan *et al.*, 2021; Ghorbel *et al.*, 2022). The coronavirus pandemic first affected China's stock markets, and then the remaining stock markets around the globe. The COVID-19 recession began in the world in February 2020. The date of March 9, 2020, recorded the triggering of the circuit breakers on the US stock market for the first time since 1997. The 2020 global pandemic caused an unprecedented increase in the risk of global financial markets (Zhang *et al.*, 2020). Tan *et al.* (2021) indicated low risk and high returns in the US market after the crisis. However, China stock markets exhibit high risk and low return. Mensi *et al.* (2021) found that the 2020 global pandemic intensified spillovers from commodity markets to the US and Chinese stock markets.

Risk spillover research is important for market participants in managing assets, hedging risks and enhancing investment efficiencies. Gold is widely considered, in related literature, to be a good asset for hedging risks in financial markets (Shakil *et al.*, 2018). After periods of financial uncertainty witnessed during the last decade, investors tend to search for new investment strategies that can offer diversification and/or hedge advantages. During the global economic and financial crisis of 2008, gold prices rose dramatically, while other assets suffered losses (Beckmann *et al.*, 2015). As was the case for commodities in the early 2000s, and due to its high expected return and low association for large financial assets, Bitcoin may be a useful device for managing portfolios (Bouri *et al.*, 2017, 2020; Guesmi *et al.*, 2019; Fakhfekh and Jeribi, 2020; Charfeddine *et al.*, 2020; Schinckus, 2020; Jeribi and Fakhfekh, 2021; Schinckus *et al.*, 2021; Loukil *et al.*, 2021). It is considered the oldest and the most famous cryptocurrency (Schinckus *et al.*, 2020; Schinckus, 2021).

During the global economic and financial crisis of 2020, financial market risks intensified, causing new challenges for financial risk managers. In order to define their portfolio strategies and hedge their risks, investors need to distinguish between three types of assets: diversifier, hedge and safe haven (Baur and Lucey, 2010). In this context, the most discussed safe-haven assets in the COVID-19 literature include gold (Belhassine and Karamti, 2021; Ghorbel and Jeribi, 2021a, b, c; Jeribi *et al.*, 2021; Lahiani *et al.*, 2021; Rubbaniy *et al.*, 2021) and cryptocurrencies (Conlon and Mcgee, 2020; Mariana *et al.*, 2020; Ghorbel and Jeribi, 2021a, b, c; Jeribi *et al.*, 2021; Jeribi and Snene_Manzli, 2021; Guo *et al.*, 2021; Jeribi *et al.*, 2021). While cryptocurrencies can be considered as diversifier assets, their use as a medium of exchange is limited by their price volatility (Katsiampa, 2017; Fakhfekh and Jeribi, 2020; Jeribi and Masmoudi, 2021; Jeribi *et al.*, 2022). Recently, Stablecoins, which are pegged to less volatile assets or currencies, have received attention from portfolio managers as well as academic researchers beyond the realm of cryptocurrency markets (Wang *et al.*, 2020; Ante *et al.*, 2021a, b; Hoang and Baur, 2021; Giudici *et al.*, 2022; Grobys *et al.*, 2021; Jalan *et al.*, 2021; Kristoufek, 2021).

Based on this crux, we attempt to examine the static and dynamic volatility spillover between US/Chinese stock market cryptocurrencies and gold with the outbreak of the Covid-19 pandemic using Diebold and Yilmaz's (2012) method.

Our study contributes to the existing literature in three ways. First, we examine both return and volatility spillover between the US and Chinese stock market indices, gold and cryptocurrencies before and during the COVID-19 pandemic crisis. Second, we use the digital asset and we distinct between cryptocurrencies (Bitcoin and Ether) and Stablecoins for a more detailed analysis. Third, we calculate the Diebold and Yilmaz (2012) indexes over a period ranging from August 2018 to January 2021 that covers several turbulence events, including the drop in oil prices and the COVID-19 pandemic. This methodology allows us to observe dynamic spillover during recent financial crises, to analyze the spillovers of risks

over time without breaking down the study period into subsamples and to identify the receiver or transmitter of shocks. Our study helps investors to identify optimal diversification and hedging strategies during a crisis. Generally, our results show that gold, Bitcoin and Ether can be considered as safe havens during the COVID-19 crisis.

The layout of this paper is as follows: Section 2 presents an overview of the literature. Section 3 gives an outline of the econometric methodology adopted. Section 4 is devoted to highlighting the relevant data. In Section 5, we report and analyze the empirical findings. Discussions and policy implications are presented in Section 6. Finally, Section 7 concludes.

2. Literature review

Mensi *et al.* (2019) provided evidence of major volatility spillover effects between Bitcoin and precious metals. They show that Bitcoin heavily transmits net-positive spillovers to other commodities. Adebola *et al.* (2019) found indicated that it might be very difficult to determine the changes in the cryptocurrencies' market based on changes in the gold market and vice versa. Kang *et al.* (2019) observed a contagion increase during the European sovereign debt crisis. A relatively high degree of comovement between Bitcoin and gold futures prices for the period between 2012 and 2015 is indicated by wavelet coherence results. Shahzad *et al.* (2019) propose a new definition of a weak and strong safe haven which considers the lowest tails of both the safe-haven asset and the stock index, within a bivariate cross-quantilogram approach. Their main results show that gold, Bitcoin and the commodity index studied can be considered weak safe-haven assets.

Huynh *et al.* (2020) investigated the spillover effects between different types of digital assets and their relationships with gold prices. Their results suggested that Bitcoin is still the most appropriate instrument for hedging, while Tether, as a cryptocurrency that has a strong anchor with the US dollar, is volatile. In the same line of results, Iqbal *et al.* (2021) indicated that digital assets served as an alternative investment tool in times of stress and uncertainty. Bitcoin and other cryptocurrencies performed better in comparison with other currencies. Jeribi and Fakhfekh (2021) applied the FIEGARCH-EVT-Copula and Hedge ratio analysis to assess the capabilities of cryptocurrencies to generate benefits from portfolio diversification as well as hedging strategies. They argue that the investor should hold more conventional financial assets than digital assets. Jeribi *et al.* (2022) studied the volatility dynamics and diversification benefits of Bitcoin under asymmetric and long memory effects. Their results indicated that the digital currency yields significant diversification benefits when being added to a well-diversified benchmark portfolio.

A fast-growing body of research on the Coronavirus effects on traditional as well as digital markets has emerged. Conlon and McGee (2020) found that Bitcoin and Ether are not safe havens for the majority of international equity markets. By using several copula models, Garcia-Jorcano and Benito (2020) suggested that Bitcoin can be considered as a hedge asset against the US, European, Japanese and Chinese stock market index movements under normal market conditions. However, under extreme market conditions, Bitcoin changes to be a diversifier asset. Shahzad *et al.* (2020) investigated the safe haven and hedging characteristics of Bitcoin and gold for the stock markets of the G7 countries. They found that the diversification benefits offered by gold are comparatively more stable and much higher than those of Bitcoin. Jeribi and Ghorbel (2021) used the generalized orthogonal autoregressive conditional heteroskedasticity (GO-GARCH) model to explore the hedging potential of gold and digital assets for investors in developed and BRICS countries. They found that the risks among developed stock markets can be hedged by gold and Bitcoin. This latter can be considered as the new gold for developed economies. Unlike Bitcoin, the authors provide evidence that gold can be considered as a hedge for China. In the same line of results, Ghorbel and Jeribi (2021a, b, c) indicated that Bitcoin and gold were

considered hedges for the US investors before the coronavirus crisis. However, the results show that, unlike gold, digital assets are not a safe haven for US investors during the 2020 global financial crisis.

Ahelegbey *et al.* (2021) used the extreme downside hedge and the extreme downside correlation to study the relationships among digital assets during stressful times. Their results indicated that digital assets can be clustered in two groups: speculative cryptocurrencies, which are mainly "givers" of tail contagion, such as Bitcoin, and technical cryptocurrencies, which are mainly "receivers" of contagion, such as Ether. However, Stablecoins are a world on their own. By employing the same wavelet spectrum approach, Karamti and Belhassine (2022) indicated that fear in the US market spread to all the other financial markets except for gold, SSE and cryptocurrencies, which can be diversifier assets for developing US portfolio strategies. Schinckus *et al.* (2021) considered anonymous cryptocurrencies like Monero, Dash and Verge as good diversifier assets, but their diversifying properties cannot be observed in decreasing markets. They also argued that Dash could be involved in the dynamics of Bitcoin and Ether the two largest pseudo-anonymous cryptocurrencies (Bitcoin/Ether).

Under the shadow of the 2020 pandemic disease, Elgammal *et al.* (2021) found unidirectional mean spillovers from energy markets to the precious metal and equity counterparts, and bidirectional return spillover effects between gold and equity markets. Using the directed acyclic graph, network topology, and spillover index, the empirical results of Guo *et al.* (2021) show that the contagion effect between Bitcoin and developed markets is strengthened during the 2020 crisis. The later cited authors found that Bitcoin always has a contagion effect with gold, while gold, the US dollar and the bond market are the contagion receivers of Bitcoin under the shock of the COVID-19. Their empirical results proved that Bitcoin is considered as a safe haven, hedge and diversifier asset in economic stable times but also found that the sustainability of the safe-haven property is undermined during the market turmoil. Using the methodologies of Diebold and Yilmaz (2012) and Baruník and Křehlík (2018), Nekhili *et al.* (2021) examined the time-frequency return and volatility spillovers between major commodity futures and currency markets. The results show that the intermediate- and long-term return spillovers are dominated by short-term spillovers.

Given the extreme volatility of Bitcoin, investors may rather need a safe haven against Bitcoin (Hoang and Baur, 2021). Grobys *et al.* (2021) concluded that the volatility of Bitcoin is a fundamental factor that drives the Stablecoins' volatilities. Using the generalized vector autoregressive framework and directed spillovers based on the forecast error variance decompositions, Kristoufek (2021) investigated the spillovers within the major cryptocurrencies and Stablecoins. He found no evidence that Stablecoins boost the prices of other cryptocurrencies. Using the DCC-GARCH and time-varying copula models, Wang *et al.* (2020) examined the risk-dispersion abilities of gold-pegged and USD-pegged Stablecoins against traditional digital currencies and also compared their risk-dispersion abilities with their underlying assets. Their empirical results show that Stablecoins can serve as safe havens in specific situations, but the safe-haven property of Stablecoins changes across market conditions. They also indicated that gold-pegged Stablecoins perform worse as safe havens than USD-pegged ones. Hoang and Baur (2021) found that Stablecoins are considered as safe havens against Bitcoin. Jalan *et al.* (2021) studied the performance of five gold-backed Stablecoins during the 2020 global pandemic and compared them to Bitcoin, Tether and gold. They found that gold-backed cryptocurrencies were susceptible to volatility transmitted from gold markets. In addition, the safe-haven potential of gold-backed cryptocurrencies is not comparable to gold. However, Wassiuzzaman and Abdul-Rahman (2021) provided evidence on the safe-haven property of gold-backed cryptocurrencies.

3. Method

To study the spillover between the US and Chinese stock market indices, gold, cryptocurrencies and Stablecoins, we use the econometric model presented by Diebold and Yilmaz (2012). This approach is based on N-variable vector autoregression (VAR) and generalized variance decomposition methods. The starting point for the analysis is the covariance stationary N-variable VAR (p) presented as follows:

$$x_t = \sum_{i=1}^{p} \varphi_i x_{t-i} + \varepsilon_t \tag{1}$$

where x_t is a $N * 1$ vector of endogenous variables φ_i is a $N * N$ matrix of loading coefficients related to lag i, and ε_t is and i.i.d process with mean 0 and covariance matrix Σ.

The above VAR(p) model in Eq. (1) could be reparameterized as an infinite moving average process as follows:

$$x_t = \sum_{i=0}^{\infty} A_i \varepsilon_{t-i} \tag{2}$$

where A_i is an N * N matrix coefficient matrices, which obey the recursion $A_i = \sum_{s=1}^{i} \varphi_{i-s} A_s$ with $A_i = 0$ for $i < 0$. To explain the system dynamics, the key is the moving average coefficients or variance decompositions.

The calculation of variance decomposition often proceeds via precise orthogonalization of VAR shocks. The Cholesky orthogonalization factor produces orthogonalized innovations and derives order-dependent variance decomposition. Likewise, the structural VAR model maintains assumptions from one theory or another. We apply the Generalized Forecast Error Variance Decomposition (GFEVD) approach of Koop *et al.* (1996) and Pesaran and Shin (1998), which accounts for correlated stocks appropriately. The generalized version of H-step variance decomposition matrices can be defined as follows:

$$D^g(H) = \left[d_{ij}^g(H)\right], \text{where}$$

$$d_{ij}^g(H) = \frac{\sigma_{jj}^{-1} \sum_{h=0}^{H-1} \left(e' A_h \sum e_j\right)^2}{\sum_{h=0}^{H-1} e' A_h \sum A_h' e_i} \tag{3}$$

where σ_{jj} is the standard deviation of the error term for the jth equation, and e' is the selection vector, with ith element unity and zeros otherwise. In the generalized VAR, the sum of the elements in each row of the variance decomposition matrix is not equal to one $\sum_{j=1}^{N} d_{ij}^g(H) \neq 1$. Then, each element of the variance decomposition matrix is normalized as follows:

$$\widetilde{d}_{ij}(H) = \frac{d_{ij}^g(H)}{\sum_{j=1}^{N} d_{ij}^g(H)} \tag{4}$$

Note that by construction, $\sum_{j=1}^{N} \widetilde{d}_{ij}(H) = 1$ and $\sum_{i,j=1}^{N} \widetilde{d}_{ij}(H) = N$. The matrix $D^g(H) = [d_{ij}^g(H)]$ permits us to define total spillover index, directional and pairwise spillover indices, net directional and net pairwise spillover indices.

This produces a total spillover index defined as

$$S^{g}(H) = \frac{\sum_{i,j=1}^{N} \widetilde{d}_{ij}(H)}{N} * 100 \quad (5)$$

This index measures the contribution of spillovers of return (volatility) shocks across selected asset classes to the total variance of forecast errors.

The generalized VAR framework allows directional impacts to be inferred. Two basic variants of the measurement of gross directional impacts could be defined. First, spillover received by market i from all other markets j (All to I) by:

$$S_{i.}^{g}(H) = \frac{\sum_{j=1}^{N} \widetilde{d}_{ij}(H)}{N} \times 100 \quad (6)$$

Second, spillover from market i to all other markets (i to All) by:

$$S_{.i}^{g}(H) = \frac{\sum_{j=1}^{N} \widetilde{d}_{ji}(H)}{N} \times 100 \quad (7)$$

Thus, the net directional impact from market I to all other markets can be measured by

$$S_{i}^{g}(H) = S_{.i}^{g}(H) - S_{i.}^{g}(H) \quad (8)$$

The net pairwise spillovers provide information on the net transmission of shocks from market l to market j:

$$S_{ij}^{g}(H) = \left(\frac{\widetilde{d}_{ji}(H) - \widetilde{d}_{ij}(H)}{N} \right) \times 100 \quad (9)$$

The Diebold and Yilmaz (2012) measures are flexible (allow for quantifying both returns and volatility spillovers in markets over time) and they are dynamic. The dynamics of the spillover indices are generated by a moving window, which facilitates the study of shock transmission during and outside crisis periods.

4. Data and preliminary statistics

The empirical study involves 622 daily observations of American and Chinese stock market indices, four popular cryptocurrencies (Bitcoin, Ether, Tether, and TrueUSD), and gold sampled from August 24, 2018, to January 29, 2021. We select here two major pseudo-anonymous cryptocurrencies, Bitcoin and Ether (Schinckus, 2021), and two anonymous USD-pegged Stablecoins namely Tether and True. Daily time series data are collected for traditional assets from DataStream. The S&P500 and SSE indices are assumed to represent traditional diversified financial portfolios for U.S and Chinese investors. Data concerning cryptocurrencies were collected from the Coin Market Cap basis.

Diebold and Yilmaz (2012) indices make it possible to study return and volatility spillovers. For return spillovers, the VAR model is applied directly to the series of daily

returns. The daily stock market indices and cryptocurrencies price returns are computed on a continuous basis as the difference in logarithm between two consecutive observations:

$$r_t = \ln(p_t) - \ln(p_{t-1}) \tag{10}$$

r_t: Return of the asset for daily t;

p_t: Price of the asset for daily t;

p_{t-1}: Price of the asset for daily t−1.

Table 1 presents summary statistics of returns. All assets recorded mean positive returns during this period, whereas Tether presents the lowest risk and Ether presents the highest risk. All asset returns, except for Ether and TrueUSD, have negative skewness. All market returns have kurtosis values higher than three. In addition, the assumption of Gaussian returns is rejected by the Jarque–Bera test for all assets.

During the COVID-19 pandemic period, the returns of all the assets (except for Ether and TrueUSD) showed an increase compared to the returns of the precrisis period. Returns for Tether and TrueUSD, however, fell and even became negative for Tether. In addition, all assets (except for Ether and TrueUSD) have experienced larger standard deviations during the crisis and are therefore becoming riskier. For Tether and TrueUSD, falling yields are

	SP500	SSE	Bitcoin	Ether	Tether	TrueUSD	Gold
Period: August 24, 2018 to January 29, 2021							
Mean	0.000522	0.000468	0.003718	0.004542	7.65E-06	5.87E-06	0.000725
Median	0.000899	0.000440	0.001389	0.000276	0.000000	−9.99E-05	0.001138
Maximum	0.093828	0.063217	0.222361	0.418981	0.021375	0.033774	0.043905
Minimum	−0.119841	−0.076832	−0.391816	−0.440031	−0.025683	−0.022214	−0.057225
Std. dev.	0.015566	0.012259	0.045865	0.062722	0.003185	0.003960	0.009700
Skewness	−0.600665	−0.122950	−0.680647	0.317689	−0.494695	1.279497	−0.534478
Kurtosis	17.04405	8.628538	14.02468	12.09609	23.72030	24.63131	7.926998
Jarque-Bera	5140.807	821.2961	3192.890	2151.314	11134.26	12276.70	657.6901
Period (before Covid-19 crisis): August 24, 2018 to Novembre 29, 2019							
Mean	0.000296	0.000226	0.001432	−0.000151	1.57E-05	8.55E-06	0.000616
Median	0.000509	4.00E-05	0.000297	−0.001732	0.000000	−0.000100	0.000645
Maximum	0.049594	0.056007	0.222361	0.346948	0.021375	0.033774	0.032974
Minimum	−0.032864	−0.052233	−0.144450	−0.200309	−0.025683	−0.022214	−0.021156
Std. dev.	0.009601	0.011694	0.044440	0.058480	0.004292	0.005390	0.007261
Skewness	−0.254844	0.173037	0.421106	0.664608	−0.389235	0.970459	0.517927
Kurtosis	6.654687	6.268712	6.960277	8.087132	13.81378	13.81487	4.816010
Jarque-Bera	183.2557	145.4072	220.6240	372.0654	1581.943	1624.805	58.82483
Period (during Covid-19 crisis): Decembre 01, 2019, to January 29, 2021							
Mean	0.000767	0.000730	0.006195	0.009628	−1.08E-06	2.97E-06	0.000843
Median	0.001857	0.001016	0.002946	0.002772	0.000000	−9.99E-05	0.001776
Maximum	0.093828	0.063217	0.157128	0.418981	0.005076	0.007978	0.043905
Minimum	−0.119841	−0.076832	−0.391816	−0.440031	−0.007525	−0.004904	−0.057225
Std. Dev	0.020143	0.012858	0.047311	0.066744	0.001094	0.001113	0.011799
Skewness	−0.577464	−0.374363	−1.692600	0.012895	−0.351648	0.726792	−0.769852
Kurtosis	12.36359	10.29505	20.42597	14.63133	13.01237	13.84644	6.856260
Jarque-Bera	1105.217	667.7485	3912.789	1679.832	1250.881	1486.996	214.0812

Table 1.
Summary statistics of returns

followed by falling risk. The modern portfolio theory, in which the risk-averse investors will only be willing to take on more risk in exchange for a higher return, holds true for our assets.

Moreover, the volatility series are not directly observable and must be estimated. GARCH models are the most appropriate models that represent volatility in the financial markets. Table 2 summarizes the GARCH models used and Table 3 reports the results of the estimation of the GARCH models.

Table 3 reports the GARCH model estimation of US and Chinese stock market indices, gold, cryptocurrencies (Bitcoin, Ether) and Stable coins (Tether, TrueUSD).

5. Results

First, we present and discuss static spillover indices. Then, we examine the results of the dynamic analysis based on the rolling window spillover index estimation. Tables 4 and 5 show the static total and directional returns and volatility spillover indices for the US and Chinese stock markets, respectively. These indices give an overall average view of return and volatility shocks over the entire study period. The columns represent the US (Chinese) markets indices, Bitcoin, Ether, gold, Tether and TrueUSD. The total spillover indices appear in the first row of the table. Next, the directional spillover indices measure the effects of shocks received by market i from all other markets, the spillovers transmitted by market i to other markets, and finally the difference between these two measures. The last part of the table presents the pairwise indices. All results are based on a vector autoregressive model of order 2 and generalized variance decompositions of 30-day-ahead forecast errors.

Table 2. Summary of the selected models

Assets	Mean specification	Model	Volatility specification	Model
SP500	ARMA (1,2)	$y_t = a_0 + a_1 y_{t-1} + \varepsilon_t + b_1\varepsilon_{t-1} + b_2\varepsilon_{t-2}$	TGARCH(1,1)	$\sigma_t^2 = C_0 + \alpha_1\varepsilon_{t-1}^2 + \gamma_1 S_{t-1}\varepsilon_{t-1}^2 + \beta_1\sigma_{t-1}^2$
SSE	MA(5)	$y_t = a_0 + b_5\varepsilon_{t-5}$	GARCH(1,1)	$\sigma_t^2 = C_0 + \alpha_1\varepsilon_{t-1}^2 + \beta_1\sigma_{t-1}^2$
Bitcoin	MA(7)	$y_t = a_0 + b_7\varepsilon_{t-7}$	GARCH(1,1)	$\sigma_t^2 = C_0 + \alpha_1\varepsilon_{t-1}^2 + \beta_1\sigma_{t-1}^2$
Ether	ARMA((1,1)	$y_t = a_0 + a_1 y_{t-1} + \varepsilon_t + b_1\varepsilon_{t-1}$	GARCH(1,1)	$\sigma_t^2 = C_0 + \alpha_1\varepsilon_{t-1}^2 + \beta_1\sigma_{t-1}^2$
Tether	ARMA(1,1)	$y_t = a_0 + a_1 y_{t-1} + \varepsilon_t + b_1\varepsilon_{t-1}$	GARCH(1,1)	$\sigma_t^2 = C_0 + \alpha_1\varepsilon_{t-1}^2 + \beta_1\sigma_{t-1}^2$
TrueUSD	ARMA(1,1)	$y_t = a_0 + a_1 y_{t-1} + \varepsilon_t + b_1\varepsilon_{t-1}$	GARCH(1,1)	$\sigma_t^2 = C_0 + \alpha_1\varepsilon_{t-1}^2 + \beta_1\sigma_{t-1}^2$
Gold	ARMA(1,1)	$y_t = a_0 + a_1 y_{t-1} + \varepsilon_t + b_1\varepsilon_{t-1}$	TGARCH(1,1)	$\sigma_t^2 = C_0 + \alpha_1\varepsilon_{t-1}^2 + \gamma_1 S_{t-1}\varepsilon_{t-1}^2 + \beta_1\sigma_{t-1}^2$

Table 3. Estimate parameters of GARCH models

	SP500	SSE	Bitcoin	Ether	Tether	TrueUSD	Gold
Mean equation							
a_0	-0.0007^{**}	0.0005	0.0032^{**}	0.0047^{***}	$2.04^{10-6\ ***}$	3.27^{10-7}	0.0007^{***}
a_1	-0.0837^{*}	–	–	-0.9917^{***}	0.7296^{***}	0.6549^{***}	-0.9958^{***}
b_1	–	–	–	0.9950^{***}	-0.9821^{***}	-0.9816^{***}	0.9959***
b_2	0.09***	–	–	–	–	–	–
b_5	–	-0.07634^{**}	–	–	–	–	–
b_7	–	–	0.07596^{*}	–	–	–	–
Conditional variance equation							
C_0	$4.73^{10-6\ ***}$	$7.98^{10-6***}$	0.0003^{***}	0.0004^{***}	9.74^{10-9}	1.48^{10-8}*	$2.18^{10-6***}$
α_1	0.1561***	0.1055***	0.1797***	0.1214***	0.2249***	0.3151***	0.1204***
γ_1	0.2356***	–	–	–	–		-0.1552^{***}
β_1	0.7378***	0.8442***	0.6850***	0.8022***	0.7705***	0.6807***	0.8766***

Note(s): ***, ** and * denote significance at 1, 5 and 10% level, respectively

	SP500	Bitcoin	Ether	Gold	Tether	TrueUSD
Total returns spillover index: 54.89%						
Directional return spillover indices						
I to all	7.46	8.01	5.60	4.60	14.87	14.33
All to I	0.40	23.84	26.69	0.528	1.60	1.82
Net I to Al	7.05	−15.82	−21.08	4.07	13.27	12.51
Pairwise directional return spillover indices						
SP500	9.20	2.76	4.36	0.29	0.02	0.02
Bitcoin	0.13	8.65	7.71	0.09	0.04	0.04
Ether	0.12	5.37	11.06	0.05	0.02	0.03
Gold	0.03	2.39	2.15	12.06	0.01	0.01
Tether	0.06	6.88	6.16	0.04	1.79	1.71
TrueUSD	0.05	6.43	6.29	0.04	1.51	2.32
Total volatility spillover index: 89.27%						
Directional volatility spillover indices						
I to All	15.44	12.30	16.66	15.58	12.60	16.66
All to I	3.99	52.43	0.02	0.04	32.77	0.01
Net I to All	11.45	−40.12	16.64	15.54	−20.17	16.65
Pairwise directional volatility spillover indices						
SP500	1.22	14.23	0.01	0.01	1.20	0.01
Bitcoin	1.87	4.35	0.01	0.01	10.41	0.01
Ether	0.46	11.90	0.01	0.01	4.27	0.01
Gold	0.69	0.72	0.02	1.07	14.15	0.01
Tether	0.48	12.11	0.01	0.01	4.05	0.01
TrueUSD	0.47	13.44	0.01	0.01	2.72	0.01

Table 4.
Total and directional return and volatility spillover indices

Table 4 shows that the total return (volatility) spillover index indicates for the US stock market in combination with other assets is 54.89% (89.27%). The value indicates that more than 54% of the 30-days-ahead forecast error variance comes from spillovers among the markets. As shown in Table 5, 51% (70.22%) are transmitted among the Chinese stock market, gold and cryptocurrencies.

Based on the directional indices, we notice that the return and volatility shocks transmitted by the stock markets to the other markets are more important than the shocks received. The stock markets are the main contributors to the unanticipated volatility of the gold and cryptocurrency markets. The return (volatility) shocks transmitted by US equity markets to other markets are 7.46% (15.44%), while the received shocks are 0.4% (3.99%). The Chinese stock markets also seem to contribute very strongly to other markets. Indeed, the return(volatility) spillover index measuring the shocks transmitted by this market to the others is 4.66% (5.93%). The one measuring shock received was 0.41% (1.03%). The $S_j^g(H)$ index is therefore positive for both return and volatility. Moreover, the shocks received by the Bitcoin market from other markets are quite high. The Bitcoin market can be considered as the main receiver of shocks transmitted from other markets. Bitcoin seems to be a hedge opportunity during the COVID-19 pandemic, which is consistent with Ghorbel and Jeribi (2021a, b, c).

The pairwise spillover indices between the stock markets and gold, Ether and Stablecoins markets show that these markets interact in both directions. For example, the return (volatility) shocks observed on the US stock markets explain 0.4% (5.93%) of the forecast errors on the Stablecoins markets. In the opposite direction, the shocks received by the stock

	SSE	Bitcoin	Ether	Gold	Tether	TrueUSD
Total returns spillover index: 50.99%						
Directional return spillover indices						
I to All	4.66	8.00	5.58	4.23	14.54	13.95
All to I	0.41	21.37	24.63	0.25	2.02	2.29
Net I to All	4.25	−13.36	−19.05	3.98	12.52	11.65
Pairwise directional return spillover indices						
SSE	12.00	1.75	2.41	0.08	0.20	0.20
Bitcoin	0.01	8.66	7.85	0.07	0.03	0.03
Ether	0.02	5.46	11.08	0.04	0.02	0.02
Gold	0.14	2.17	1.91	12.42	0.01	0.01
Tether	0.05	6.23	6.19	0.02	2.11	2.02
TrueUSD	0.17	5.73	6.25	0.02	1.75	2.71
Total volatility spillover index: 70.20%						
Directional volatility spillover indices						
I to All	5.93	2.72	16.66	16.26	11.94	16.66
All to I	1.03	46.46	0.020	0.06	22.57	0.05
Net I to All	4.90	−43.74	16.64	16.19	−10.62	16.61
Pairwise directional volatility spillover indices						
SSE	10.72	4.31	0.01	0.01	1.54	0.04
Bitcoin	0.01	13.94	0.01	0.04	2.67	0.01
Ether	0.13	12.20	0.01	0.01	4.32	0.01
Gold	0.82	4.85	0.01	0.40	10.58	0.01
Tether	0.01	11.94	0.01	0.01	4.71	0.01
TrueUSD	0.05	13.16	0.01	0.01	3.44	0.01

Table 5.
Total and directional return and volatility spillover indices

markets are 0.11%. For the relationship between US (Chinese) stock markets and Bitcoin, the SP 500 (SSE) index volatility explains 14.23% (4.31%) of the 30-day-ahead forecast error variance of Bitcoin. Inversely, the value is equal to 1.87% (0.01%). Bitcoin is the main receiver of return shocks from the US and Chinese stock markets. In this context, Bitcoin can be seen as a safe haven for the US and Chinese investors to hedge during the COVID-19 pandemic.

The results presented above reported the average of interconnections that exist between the different markets. However, these results have revealed only a few important relationships between markets. Therefore, a dynamic study over the whole period will allow us to better deepen our analysis. We then estimate the spillover indices over 30-day moving windows. In this way, we understand the dynamic and continuous interconnections that exist between the different markets.

Based on 30-day rolling windows, we measured the dynamic returns and volatility total and directional spillover indices. We note that the fluctuations of the total and net pairwise directional volatility spillover indices are generally larger than total and net pairwise directional return spillover indices. We begin with the evolution of the total spillover indices (Figure 1). These indices display large values (80% on average), showing the strong interdependence that exists between the selected markets. In addition, those indices are characterized by peaks in values observed mid-2018, in the last quarter of 2019, mid-2020 and the beginning of 2021. The first and second peaks are attributed to the falls in commodity prices. The three last increases can be associated with the COVID-19 crisis. This confirms previous studies stating that the interconnection between financial markets is more important in the crisis period (Hung, 2019; Ji *et al.*, 2019; Kang *et al.*, 2019; Lahiani *et al.*, 2021; Yousaf *et al.*, 2021; Mishra *et al.*, 2022).

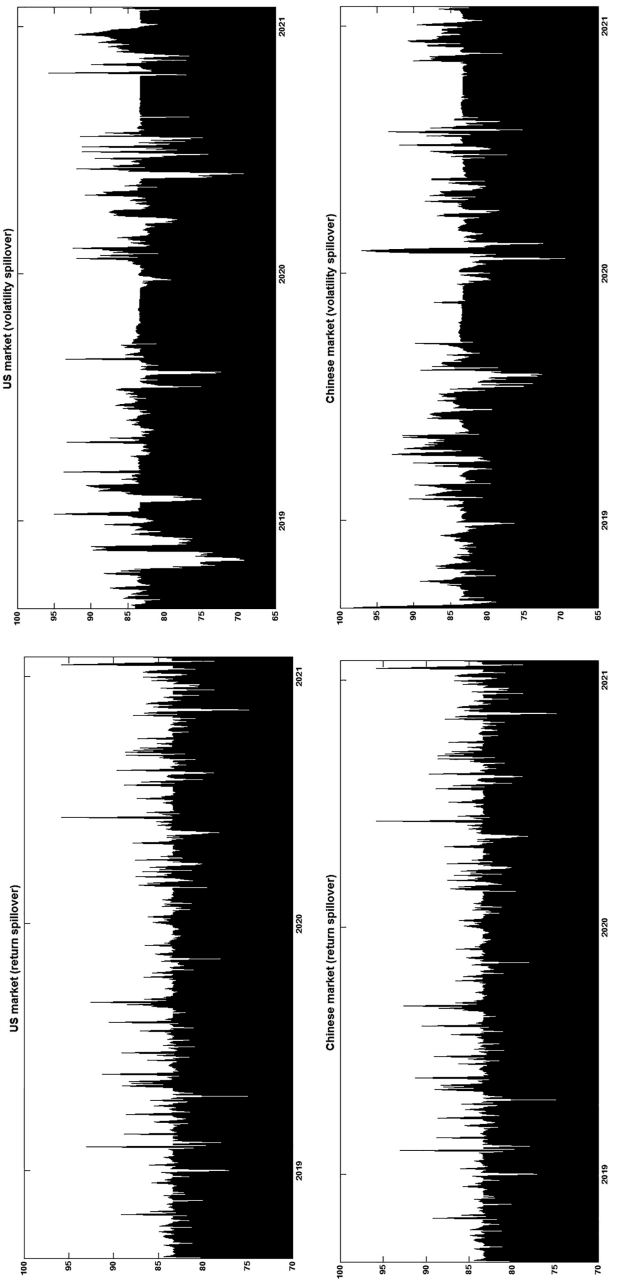

Figure 1.
Evolution of the total spillover index

In this paper, more attention was paid to the dynamic net pairwise directional spillover indices in order to identify net transmitters and receivers of shocks and investigate implications in terms of portfolio hedging and diversification strategies. The net pairwise directional spillover indices ($S_{ij}^{g}(H)$) of Diebold and Yilmaz (2012) measures the difference between shocks transmitted and received by a market i from market j. Positive values of this index mean that the market is a net transmitter of shocks. Otherwise, the market is a net receiver of shocks. We find that the pairwise net directional return and spillover volatility indexes do not differ significantly in pacing and in identifying shock-transmitting and shock-receiving markets. Therefore, we will join together in the interpretation of the results.

The shocks transmitted by the American and Chinese stock markets to the Bitcoin and Ether markets are more important than the shocks they receive from these markets (Figure 2). Bitcoin and Ether appear to be products that American and Chinese investors can add to their portfolios for hedging and risk reduction purposes. This finding is similar to Corbet *et al.* (2018), Corbet *et al.* (2019), Aslanidis *et al.* (2019), Tiwari *et al.* (2019), Charfeddine *et al.* (2020), Huynh *et al.* (2020) and Ghorbel and Jeribi (2021a, b, c) but inconsistent with that of Conlon and McGee (2020).

Similarly, the gold market receives more shocks than it transmits during 2020 and the first month of 2021 (Figure 3). American and Chinese stock markets are net transmitters of return (volatility) shocks to the gold market. These relationships intensified during the COVID-19 pandemic crisis. Indeed, during these periods, American and Chinese investors turn to the gold market to reduce their risk exposure and minimize the impact of the crisis on their portfolios. This precious metal is thus a safe haven for all participants in the selected markets. The introduction of gold, Bitcoin and Ether into traditional diversified financial portfolios offers hedging and diversification benefits for American and Chinese investors.

In addition, the shocks transmitted by the gold market to the Bitcoin and Ether markets are larger than the shocks it receives from these markets (Figure 4). For the American and Chinese investors, Bitcoin and Ether can be a good hedge, offering risk-averse, more performing portfolio investments than gold during the COVID-19 pandemic crisis.

On the other hand, Tether is a net transmitter of shocks to the US and Chinese stock markets (Figure 5). The influence of these digital assets on the American and Chinese stock markets reached its maximum during the corona crisis. Similar results were found for the relations between the TrueUSD and American/Chinese stock markets (Figure 5). For US and Chinese investors, Stablecoins (Tether and TrueUSD) are not safe havens and are not used as hedging strategies. In addition, these products will not be included in the diversification portfolios of the US and Chinese investors.

6. Discussions

6.1 Theoretical implications

In this paper, we sought to study the dynamic interdependence relationships between stock markets, cryptocurrencies and gold for the period before and during the COVID-19 crisis. We used the spillover index based on the forecast error variance decomposition from a VAR as proposed by Diebold and Yilmaz (2012). Based on this study, we unveil the hedging and diversification opportunities available to the US and Chinese investors in the cryptocurrency and gold markets, especially during the health crisis. The empirical results show that prior to the COVID-19 pandemic, the interdependence relationships between cryptocurrency markets and stock markets were weak in both directions. Cryptocurrencies can be considered, like gold, as an alternative investment class. The addition of cryptocurrencies and gold reduces the risk in investors' portfolios and generates diversification gains in times of economic stability. This result is consistent with Shahzad *et al.* (2019), Wang *et al.* (2020), Schinckus *et al.* (2021), Hoang and Baur (2021) and Guo *et al.* (2021).

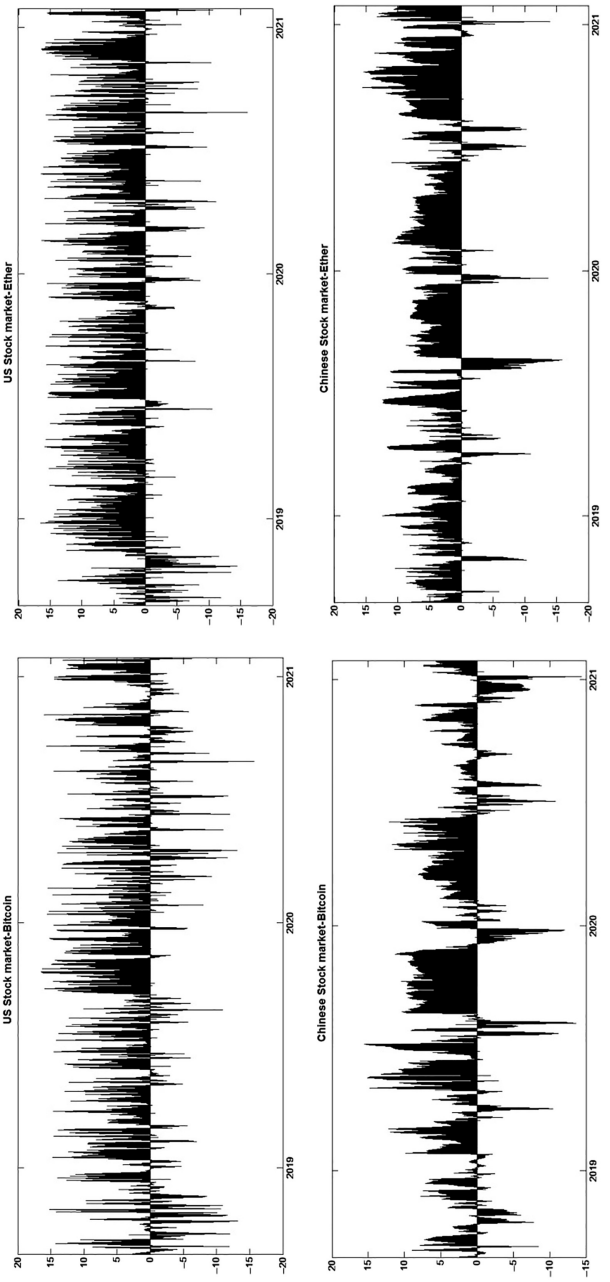

Figure 2.
Dynamic spillover between US/Chinese stock markets and Bitcoin/Ether

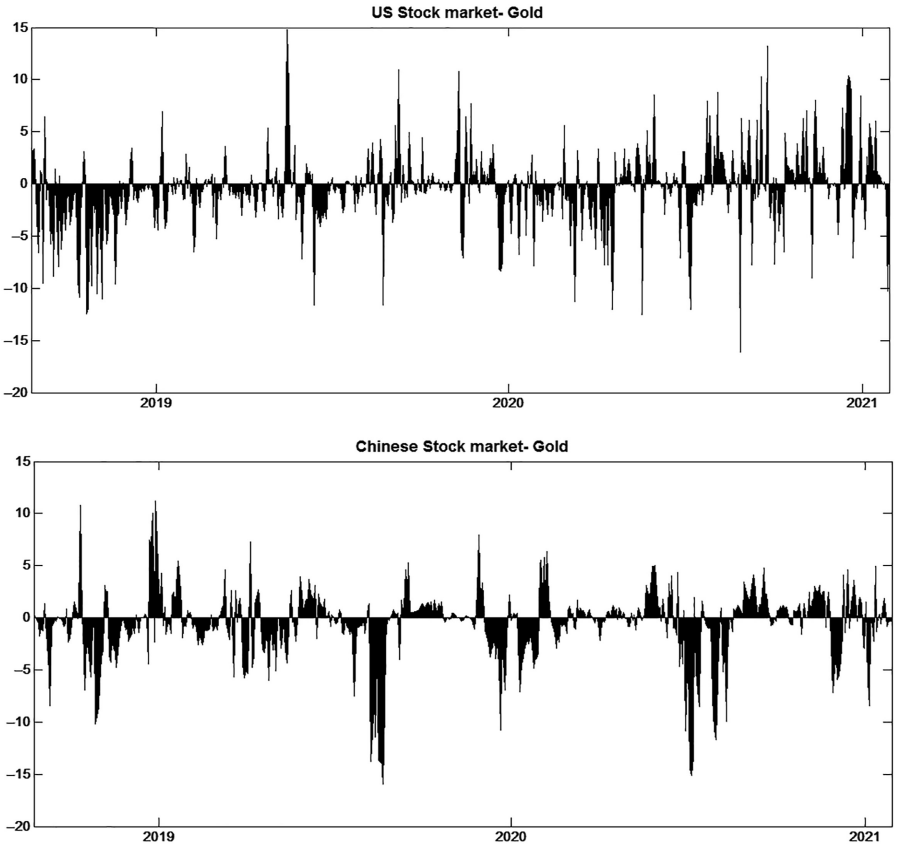

Figure 3.
Dynamic spillover between US/Chinese stock markets and gold

During the COVID-19 health crisis, the interdependence between markets intensified (Ji *et al.*, 2019; Kang *et al.*, 2019; Lahiani *et al.*, 2021). Gold, Bitcoin and Ether become net receivers of shocks. Moreover, gold and cryptocurrencies are strongly linked in both directions. On the one hand, gold is a shock transmitter for the Bitcoin and Ether markets. However, the US and Chinese stock markets are strong contributors to the unexpected volatility of the cryptocurrency and gold markets. In other words, new information that arrives in the stock markets has a very large impact on the other markets. Our results, therefore, show that the addition of pseudo-anonymous cryptocurrencies (Bitcoin, Ether) and gold could provide diversification and hedging opportunities for the US and Chinese investors during the COVID-19 crisis. The results are consistent with Ghorbel and Jeribi (2021a, b, c), Karamti and Belhassine (2022), Hoang and Baur (2021), Jalan *et al.* (2021), Wassiuzzaman and Abdul-Rahman (2021), Ji *et al.* (2019), Corbet *et al.* (2019, 2018), Conlon and McGee (2020) and Aslanidis *et al.* (2019). However, it is contradictory to the results of Guo *et al.* (2021).

In contrast, Stablecoins (Tether and TrueUSD) are thus net transmitters of shocks to the US and Chinese stock markets. These assets are very sensitive to shocks and depend mainly on the general economic environment. The effectiveness of Stablecoins as a safe haven or diversification asset is questioned during market turbulence. The results seem

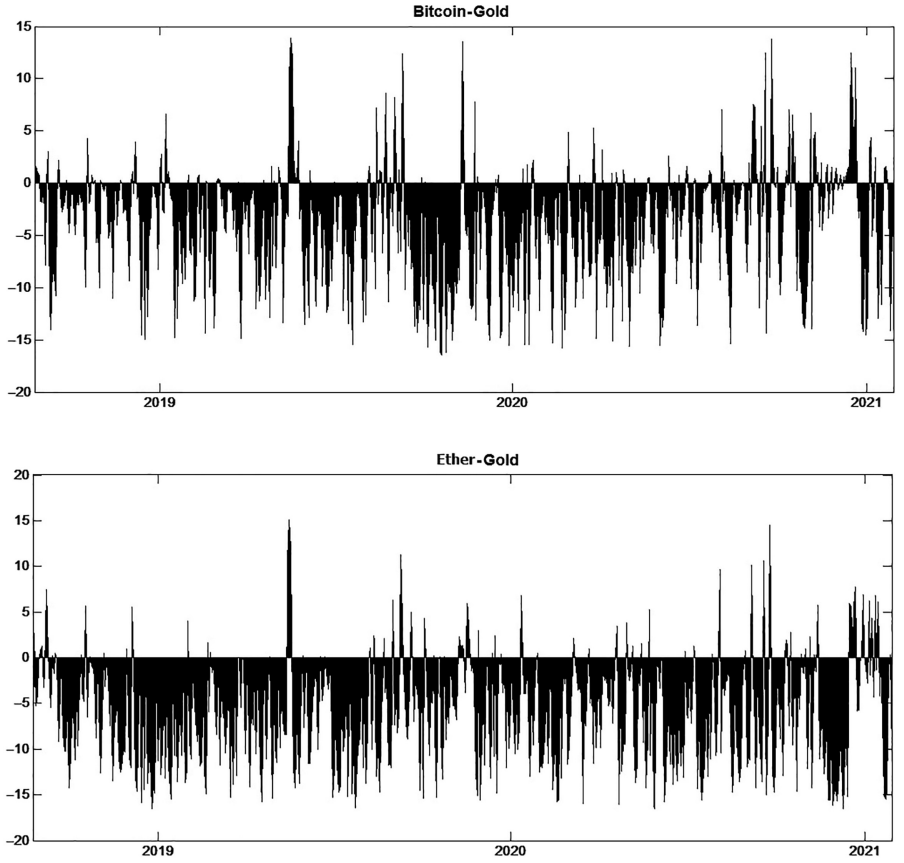

Figure 4.
Dynamic spillover between Bitcoin/Ether and gold

consistent with Wang *et al.* (2020) and Schinckus *et al.* (2021). We suggest that investors use Stablecoins with caution to avoid an extremely negative effect on their portfolios. Stablecoins appear to be different investment products than pseudo-anonymous cryptocurrencies (Bitcoin, Ether).

6.2 Policy/managerial implications

The empirical findings of this study provide insightful information for portfolio managers and investors. For instance, portfolio managers can use suitable tools to account for the risk spillover between digital and traditional asset returns in order to adapt their hedging strategy to the shock risk size and maturity. Also, US and Chinese investors may consider gold and cryptocurrencies (Bitcoin, Ether) as alternative assets from a portfolio management perspective. Such assets offer hedging and diversification benefits for the US and Chinese investors. Stablecoins appear to be different from traditional cryptocurrencies. Tether and TrueUSD are far from being safe havens during the COVID-19 crisis and do not offer diversification benefits for American and Chinese investors. In addition, speculators may opt for a spread strategy to improve their portfolio returns in both traditional and digital markets.

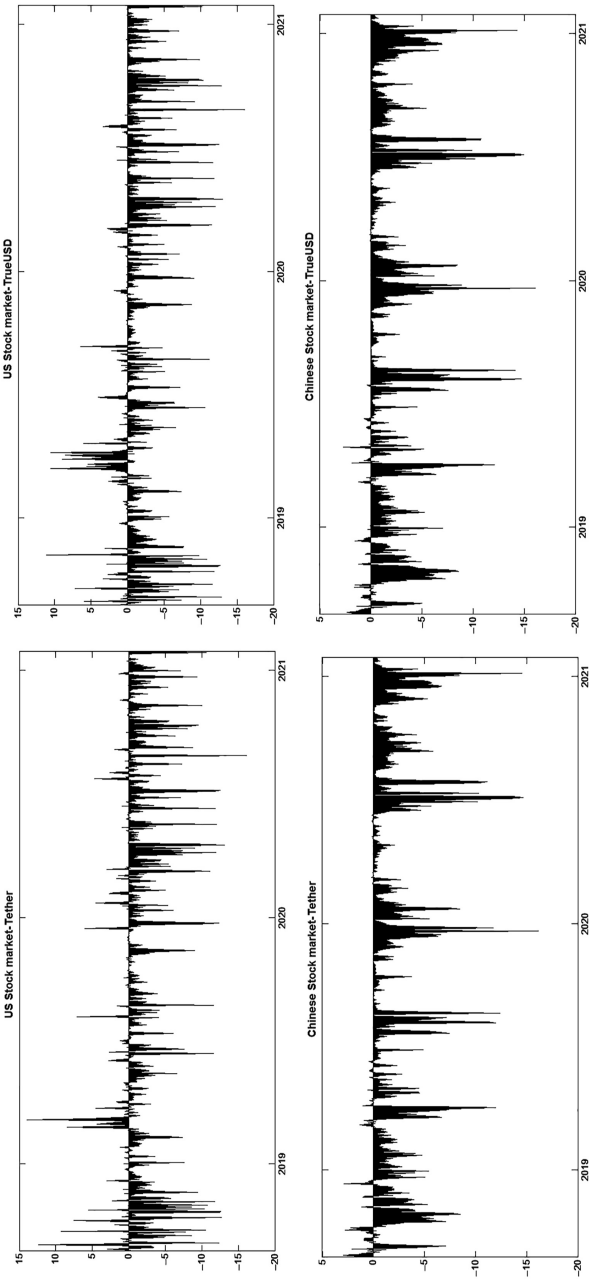

Figure 5.
Dynamic spillover between US/Chinese stock markets and Stablecoins

6.3 Future research agenda

Future research can use other methodologies such as the quantile connectedness approach as well as bivariate VAR for each pair or multivariate VAR for both traditional and digital markets to study the effect of the 2022 Russian invasion of Ukraine on the behavior of traditional and digital markets. As well, given that NFTs and DeFi have received growing attention, strategic asset allocation in NFT and DeFi markets can be studied and the role of traditional and digital safe havens and hedges during war crisis times. In addition, Latin America has seen impressive levels of cryptocurrency adoption over the last few years. We can study linkages between digital assets, especially Stablecoins and Latin American equity markets. These linkages help American Latin investors to determine whether cryptocurrencies can reduce the equity risk during crisis periods.

7. Conclusion

This paper investigates the dynamic linkages between stock markets, cryptocurrencies and gold. It attempts to provide suggestions for portfolio risk management. We analyze volatility return and risk spillover effects between these markets using the Diebold and Yilmaz (2012) spillover index. Our empirical results show statistically significant risk spillovers among financial markets, which intensified during the recent COVID-19 crisis. The Diebold and Yilmaz (2012) indices show that Bitcoin, Ether and gold are net receivers of return and volatility shocks. In the context of portfolio management analysis, the results show that a mix of cryptocurrencies (Bitcoin, Ether), gold and equities could offer diversification opportunities for the Americans and Chinese during the COVID-19 pandemic crisis. Moreover, we show that, in periods of turbulence, both American and Chinese investors turn to the Bitcoin, Ether and gold markets to minimize the impact of the crisis on their portfolios and therefore their wealth. Indeed, we find that the introduction of gold and cryptocurrencies (Bitcoin, Ether) can improve the performance of the US and Chinese traditional diversified financial portfolios. These assets, therefore, offer hedging and diversification benefits for the US and Chinese investors. Nevertheless, Stablecoins cannot be a good hedge portfolio investment and cannot offer any diversification benefits during the COVID-19 pandemic crisis.

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