



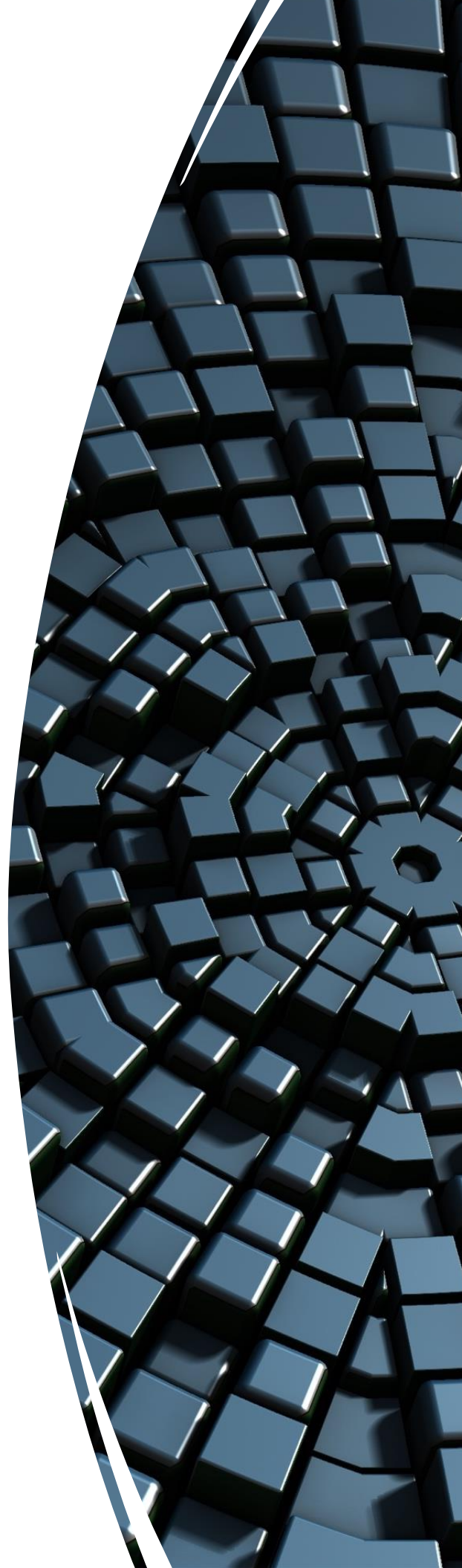
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**Cryptocurrency markets' return,
volatility, and volume relationships
and the connectedness with crude oil
and gold markets:
The effect of COVID-19 Pandemic**

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Cryptocurrency markets' return, volatility, and volume relationships and the connectedness with crude oil and gold markets: The effect of COVID-19 Pandemic

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Understanding the dynamics of cryptocurrency markets during financial crises such as the recent one caused by the COVID-19 pandemic is crucial for policy makers and investors. In this study, the effect of COVID-19 pandemic on the return-volatility and return-volume relationships and the connectedness of the ten most traded cryptocurrencies, namely Tether, Bitcoin, Ethereum, Ripple, Litecoin, Bitcoin Cash, EOS, Chainlink, Cardano, and Monero with crude oil and gold markets is examined. As digital cryptocurrencies are getting more popular among governments, companies, and individuals, there are more traders, investors, and economists who focus on improving their knowledge about characteristics of these markets. COVID-19 outbreak is the most recent global distress which dramatically affected the world economy as many companies were shut down, sales and productions fell, unemployment surged, and most of the global financial markets plunged.

The relationship between asset returns and volatility has been the subject of several studies in the finance literature, [1], [2], [3], and [4]. where evidence of a negative and asymmetric relationship was reported. For instance, a negative stock return is generally related to a large increase in volatility. In contrary, positive stock return is related to a relatively small decrease in volatility. In this paper, the effect of COVID-19 on the relationship between volatility and return of ten most traded cryptocurrencies is investigated. Since cryptocurrency markets are highly volatile in nature, this effect will be compared with the return and volatility of crude oil and gold commodities for the periods prior and during COVID-19 pandemic. In this study, a time frame of one year prior to the COVID-19 pandemic (2019) and one year during this pandemic (2020) is considered to capture both short and relatively long-term effects.

Understanding the relationship between price and volume of financial markets has been an important subject of study among researchers as it provides insights into the structure of markets [5]. The Sequential Arrival of Information model by Copeland, 1976 [6] states that information is spread sequentially, and trading volume is a proxy for the information flow rate, implying a positive correlation between volume and absolute value of price changes.

Although the causal relations between trading volume and stock returns have been widely investigated in the literature [7], [8], and [9], there is limited empirical research to examine these relationships in the cryptocurrency markets. In this paper, we attempt to fill this gap by studying

the unidirectional and bidirectional Granger causality relationships between ten most traded cryptocurrency returns and trading volume changes and further test the effect of COVID-19 pandemic on these relations.

During the COVID-19 pandemic, the extensive shutdown of industrial activities and travel restrictions imposed by the lockdown measures resulted in an unprecedented decline in global crude oil demand, resulting in a significant drop in prices with severe downward fluctuations and a rise in financial market risk. The price of West Texas Intermediate oil dipped below -\$37 due to significant abnormal market pressures, geopolitical tensions, and global concerns about the severity of the COVID-19 pandemic. These changes in economic and financial markets' dynamics are expected to have significant implications for hedge fund managers, cryptocurrency market investors, and policy makers [10]. Therefore, it is essential to examine the interactions between cryptocurrency as investment assets and other financial assets including crude oil and gold markets.

Moreover, some financial researchers believe that the gold market can be a good safe-haven asset against macroeconomic risks during financial crises [11], [12], [13]. In this regard, our study will examine dynamic short-term and long-term relationships and hedging effectiveness of gold and crude oil markets for cryptocurrencies. Specifically, we investigate whether hedging potential of gold or crude oil for cryptocurrency remains the same prior to and during the COVID-19 pandemic.

In this paper, an attempt has been made to study the effect of cryptocurrency volatility on its return, as well as the unidirectional and bidirectional Granger causality relationship between the ten most traded cryptocurrency returns and trading volume changes. Further, the effect of COVID-19 pandemic on these relations is tested. Lastly, the short-term and long-term connectedness between cryptocurrencies and crude oil, and gold markets are examined prior to and during the COVID-19 pandemic. The results of this study will help investors and hedge fund managers to better understand the dynamics of cryptocurrency markets and their behavior during a financial crisis and adjust their investment strategy in a more agile and informed manner.

Data

In this paper, thirteen markets including ten cryptocurrencies, Gold, and West Texas Intermediate (WTI), and Brent Crude Oil markets are studied. Accordingly, daily closing prices of ten most traded cryptocurrencies (in the last three months of 2020), daily prices of Gold, and WTI, and Brent Crude Oil prices are collected for the 2019-2020 period. The cryptocurrencies studied in this paper are Tether (USDT), Bitcoin (BTC), Ethereum (ETH), Ripple (XRP), Litecoin (LTC), Bitcoin Cash (BCH), EOS (EOS), Chainlink (LINK), Cardano (ADA), and Monero (XMR). The full sample of each market is split into two subsamples: prior to COVID-19 pandemic (from January 01, 2019 to December 31, 2019) and during COVID-19 pandemic (from January 01, 2020 to December 31, 2020).

Methodology

Return and volume change series are derived as following:

$$R_t = 100 \times \log\left(\frac{P_{t+1}}{P_t}\right) \quad (1)$$

$$V_t = \log\left(\frac{v_{t+1}}{v_t}\right) \quad (2)$$

Where P_t and v_t are, respectively, the price and trading volume of the asset at time t .

To investigate the effect of the pandemic on the return-volatility relationship, the autoregressive conditional heteroscedasticity in mean (EGARCH-M) [14], [15] is employed. The formulation of the EGARCH(1,1) in mean model used in this study is:

$$r_t = c + \sum_p \varphi_p r_{t-p} + \sum_q \theta_q \varepsilon_{t-q} + \lambda \sigma_t^2 + \varepsilon_t \quad , \quad \varepsilon_t = z_t \sigma_t, \text{ and} \quad (3)$$

$$\ln(\sigma_t^2) = \omega + \alpha_1 (|z_{t-1}| - E(|z_{t-1}|)) + \alpha_2 z_{t-1} + \beta \ln(\sigma_{t-1}^2) \quad (4)$$

In equation (3) c is the constant intercept, ε_t is the error term, σ_t^2 is the conditional variance, and φ_p and θ_q are the parameters of autoregressive and moving average terms, respectively. The structure of ARIMA models for each market in pre-COVID-19 and during-COVID-19 periods are determined by Ljung-Box Q-test for autocorrelations and Akaike Information Criterion (AIC).

In order to find the return-volume change relationships, first a vector autoregression (VAR) model is created and the Granger causality test is performed on the estimated coefficients for the VAR model. This model can be expressed as:

$$R_t = a_r + \sum_{i=1}^l b_{r,i} R_{t-i} + \sum_{i=1}^m c_r V_{t-i} + u_{r,t} \quad (5)$$

$$V_t = a_v + \sum_{i=1}^n b_{v,i} R_{t-i} + \sum_{i=1}^p c_v V_{t-i} + u_{v,t} \quad (6)$$

in which R_t represents returns, V_t denotes volume, $u_{r,t}, u_{v,t}$ are error terms and $l, m, n,$ and p denote the autoregressive lag lengths. The lag structures in Equations (5) and (6) are chosen according to the corresponding AIC.

Further, to examine the co-movement between cryptocurrency markets and Oil and Gold markets, the Johansen and Bounds cointegration tests is performed. The results of these tests will suggest the suitable econometrics model for finding the short-term and long-term relationships between these markets. The Augmented Dickey-Fuller (ADF) [] test should be performed for each series in levels to test whether a series has a unit root. Following the results of ADF test, one of below three cases may apply:

- Series are integrated of order 0 (stationary in level): cointegration test not necessary.
- Series are integrated of order 1 (stationary after first difference): cointegration test is necessary to establish a long-run relationship. Johansen cointegration test [16] should be performed on the level. If any cointegration equation is found, both VAR for short-term relationships and Vector Error Correction Model (VECM) [17] for long-term relationships should be estimated. In case no cointegration equation is found, only VAR (for first difference) model should be estimated.

- Series are integrated of different orders: Bounds test [18] for cointegration should be performed on the level. Estimate the short-term relationships by Autoregressive-Distributed Lag (ARDL) [19] model if there is no cointegration and long-term VECM model if cointegration exists.

Following the cointegration tests, one of below models is applicable.

The equations for $VAR(p)$ model for the first difference of series in this study are:

$$\Delta P_t = a_{0,p} + \sum_{i=1}^p b_{p,i} \Delta P_{t-i} + \sum_{i=1}^p c_p \Delta x_{t-i} + u_{p,t} \quad (7)$$

$$\Delta x_t = a_{0,x} + \sum_{i=1}^p b_{x,i} \Delta P_{t-i} + \sum_{i=1}^p c_x \Delta x_{t-i} + u_{x,t} \quad (8)$$

Where, $a_{0,p}$ and $a_{0,x}$ are constants, P_t is the log of cryptocurrency price, x_{t-j} is the j^{th} lag for the log of Gold, WTI, or Brent price, and $u_{p,t}$ and $u_{x,t}$ are the error terms for the cryptocurrency and crude oil or gold markets, respectively.

The equation for the long-term $VECM(p, q)$ model in this study is expressed as:

$$\Delta P_t = \alpha_0 + \sum_{i=1}^p \varphi_i \Delta P_{t-i} + \sum_{j=1}^q \beta_j \Delta x_{t-j} + \lambda ECT_{t-1} + \varepsilon_{t,vecm} \quad (9-a)$$

$$ECT_{t-1} = c + \gamma P_{t-1} + \theta x_{t-1} \quad (9-b)$$

Where $\varepsilon_{t,vecm}$ is the error term in the VECM model. The long-term effect is captured by the ECT_{t-1} term.

ARDL models are linear time series models in which both the dependent and independent variables are related not only contemporaneously, but across historical (lagged) values as well. A $ARDL(p, q)$ model is shown as below:

$$P_t = \alpha_0 + \sum_{i=1}^p \varphi_i P_{t-i} + \sum_{j=1}^q \beta_j x_{t-j} + \varepsilon_{t,ardl} \quad (10)$$

Where, $\varepsilon_{t,ardl}$ is the error term in the ARDL model. The proper lag structure in ARDL model is selected by Schwarz criterion (SIC) [20].

Summary of Results

Return-Volatility relationships

Understanding the relationship between cryptocurrencies returns and volatilities is crucial for an informed risk management. For this purpose, the EGARCH in mean (EGARCH-M) effects are examined with three assumptions for the error distributions: Normal distribution, Student's t distribution, and Generalized Error distribution. Table 1 shows the effect of return volatility on the return.

Table 1- EGARCH in Mean effects with three different residual distribution assumptions

Market	Pre-COVID-19			During COVID-19		
	Normal	t-student	GED	Normal	t-student	GED
Tether	0.1818 (0.46)	-0.0185 (0.92)	-0.0150 (0.94)	-0.0504 (0.54)	-0.0445* (0.06)	-0.0792 (0.016)
Bitcoin	0.0295 (0.27)	0.0310 (0.25)	0.0102 (0.51)	0.0253 (0.38)	0.0130 (0.45)	-0.0022 (0.88)
Ethereum	0.0115 (0.84)	0.9684 (0.88)	-0.3721 (0.44)	0.0079 (0.75)	-0.1122 (0.54)	0.1160 (0.00)
Ripple	0.0175 (0.56)	-0.0073 (0.49)	0.0162 (0.20)	-0.0036 (0.68)	-0.0050 (0.44)	-0.0136 (0.03)
Litecoin	-0.0140 (0.83)	0.3650 (0.34)	0.0355 (0.23)	-0.0081 (0.37)	0.0100 (0.47)	0.023 (0.11)
Bitcoin Cash	0.0770 (0.47)	0.1809 (0.64)	0.1368* (0.08)	-0.1047 (0.015)	0.0059 (0.61)	0.036 (0.020)
EOS	0.0268 (0.72)	0.0435 (0.69)	0.4931 (0.62)	0.0705 (0.52)	0.0000 (0.96)	0.0272 (0.002)
Chainlink	0.0284 (0.45)	0.0113 (0.45)	0.0094 (0.48)	0.0006 (0.96)	0.0134 (0.46)	-0.7572 (0.24)
Cardano	0.0360 (0.37)	0.0508 (0.13)	0.0538 (0.13)	0.0177 (0.54)	0.3054 (0.11)	0.0920 (0.12)
Monero	-0.0056 (0.81)	-0.0044 (0.85)	0.0075 (0.75)	0.0196 (0.44)	0.0585 (0.53)	0.8008 (0.001)
GOLD	-0.1281 (0.11)	-0.3429 (0.24)	-0.4773 (0.17)	-0.0412 (0.63)	-0.0621 (0.36)	-0.0532 (0.42)
WTI	-0.7605 (0.00)	-4.311 (0.00)	-1.492 (0.12)	0.0000 (0.99)	0.0019 (0.45)	0.0022 (0.14)
BRENT	0.0772 (0.41)	-0.2990 (0.0003)	-0.3002 (0.0002)	-0.0059 (0.14)	0.0072 (0.32)	0.0036 (0.62)

This table presents the value of λ from equation (3). Values in the parentheses are associated p-values. Significant coefficients at 0.05 level are specified in bold. Values with (*) are significant at 0.1 level.

Results from Table 1 do not confirm any significant relationship between volatilities and returns of all the cryptocurrencies with any of the considered error distributions in the pre-COVID-19 period. However, during COVID-19 pandemic in 2020, the return-volatility relationships for Tether, Ethereum, Ripple, Bitcoin Cash, EOS, and Monero are significant when we assume GED distribution. Volatility has a direct impact on the return series of Ethereum, Bitcoin Cash, EOS, and Monero during COVID-19 period which makes investing in these cryptocurrencies more profitable during the pandemic. In contrast, this effect is negative for Tether and Ripple during the COVID-19 pandemic which makes these assets less interesting during this crisis.

Further, the effect of COVID-19 on Gold, WTI, and Brent crude oil is investigated. Our results show that Gold market was a less volatile asset and the effect of volatility on Gold return is not significant in both periods of prior and during the pandemic. Therefore, Gold can be considered a suitable asset for portfolio hedging in the periods studied in this paper. The return-volatility relationship of WTI

and Brent crude oil seems to be significant in the pre- COVID-19 period and the volatilities of these markets have decreased their returns during 2019.

Return-Volume relationships

In this section, bidirectional and unidirectional Granger causality from returns to volume changes, and from volume changes to returns are examined for all cryptocurrencies. Results in Table 2 show that in pre-COVID-19 period, only the returns of Chainlink and Monero Granger cause their own volume changes, while during the COVID-19 pandemic, there is a significant granger causality relationship from return to volume changes for Tether, Ethereum, Ripple, Litecoin, EOS, and Cardano. However, there is no significant causal relationship from return to volume changes in Bitcoin, Bitcoin Cash, Chainlink, and Monero during the COVID-19 pandemic.

Similarly, the Granger causal relationship from volume changes to the return of each cryptocurrency is investigated. The results confirm that only Litecoin’s volume change Granger causes its return prior to the COVID-19 pandemic, while during the pandemic this relationship is only present in Tether and Chainlink. Our analyses could not find any return-volume relationships prior or during the COVID-19 pandemic in either directions for Bitcoin, or Bitcoin cash.

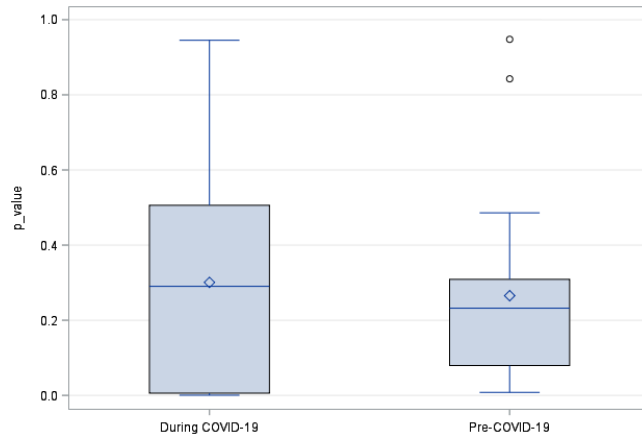
Table 2- Granger Causality test results (p-value)

	H0: Changes in cryptocurrency price (Return) Granger causes changes in the volume		H0: Changes in the cryptocurrency volume Granger cause changes in the price (return)	
	Pre-COVID-19 (2019)	During COVID-19 (2020)	Pre-COVID-19 (2019)	During COVID-19 (2020)
Tether	0.9478	0.0005	0.8425	0.033
Bitcoin	0.1816	0.3675	0.3006	0.6024
Ethereum	0.052*	0.0083	0.3021	0.5428
Ripple	0.1246	0.0272	0.4859	0.3998
Litecoin	0.2531	0.0005	0.0355	0.2865
Bitcoin Cash	0.2561	0.4694	0.1154	0.0574*
EOS	0.3051	0.0033	0.0654*	0.9452
Chainlink	0.008	0.2939	0.2979	0.0142
Cardano	0.0935*	0.0007	0.4047	0.3489
Monero	0.0155	0.6966	0.211	0.9402

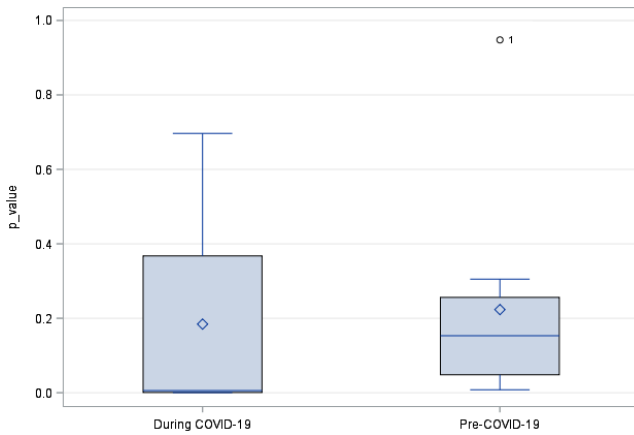
This table represents p-values. Values in bold are significant at 5% level of significance and values with (*) are significant at 10% level of significance.

The distribution of probabilities for the bidirectional and unidirectional Granger causality tests are presented in Figure 1. The box plots show larger ranges for the probability of Granger causality tests in all directions during COVID-19 pandemic compared to the pre-COVID-19 period. It is evident that the median probability of Granger causality test from return to volume changes during COVID-19 pandemic is significant, therefore, it can be inferred that most of the cryptocurrencies studied in this paper show Granger causality relationship from return to volume changes during

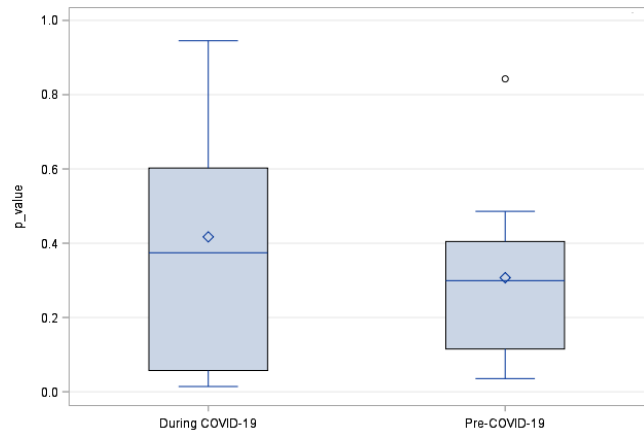
the COVID-19 pandemic. However, the mean and median of probabilities for the Granger causality from volume changes towards returns are not significant at 5% level in both the pre-COVID-19 and during the COVID-19 periods. Therefore, our evidence does not support any causality relation from cryptocurrencies' trading volume changes to their returns.



(a) Bidirectional Granger causality between return and volume changes



(b) return Granger causes volume change



(c) volume change Granger causes return

Figure 1- Distribution of probabilities for the Granger causality tests.

Connectedness between cryptocurrency markets and crude oil and gold markets

Short-term and long-term relationships between cryptocurrency markets and crude oil and gold markets are examined by applying the Johansen and Bounds Cointegration Tests. Table 3 shows the suitable models following the results of cointegration tests for each market.

Table 3- Selected econometrics models to investigate markets co-movement

Markets	Models	
	Pre-COVID-19 (2019)	During COVID-19 (2020)
Tether-Gold	ARDL, VECM	ARDL, VECM
Bitcoin-Gold Ether-Gold Ripple-Gold Litecoin-Gold Bitcoin Cash-Gold EOS-Gold Cardano-Gold Monero-Gold	VAR-first D	VAR-first D
Chainlink-Gold	VAR-first D	VECM
Tether-WTI/ Brent	VAR- level	ARDL, VECM
Bitcoin cash-WTI/Brent	ARDL	VECM
Bitcoin-WTI/Brent Ether-WTI/Brent Ripple-WTI/Brent Litecoin-WTI/Brent EOS-WTI/Brent/Brent Chainlink-WTI/Brent Cardano-WTI/Brent Monero-WTI/Brent	ARDL	VAR-first D

Following the cointegration tests, the potential long-term relationship can be only investigated between Tether-Gold, Tether-Oil, Chainlink-Gold, and Bitcoin cash-Oil by using the VECM model. Moreover, short-term relationships between cryptocurrency markets and oil and gold will be explored by utilizing the ARDL or VAR-in-first-difference models. As it is evident from the results of VECM models in Table 4, during COVID-19 there is a significant long-term negative relationship between Tether and Gold, WTI, and Brent markets at 5% level. Similarly, the significant long-term negative relationships between Bitcoin Cash and WTI, and Brent crude oil markets is found. Our results also show a significant long-term negative relationship between the Chainlink and Gold markets during the COVID-19 pandemic. Comparing the results of VECM model in pre-COVID-19 period shows that the long-term relationship is only available between Tether and Gold markets. Our results suggest that Gold can have a safe haven effect for cryptocurrencies such as Tether, Bitcoin Cash, and Chainlink in both pre-COVID-19 and during the COVID-19 periods. Besides, during the COVID-19 period crude oil markets such as WTI and Brent can play an investment hedging role for Tether and Bitcoin Cash markets.

Table 4- Estimated coefficients in VECM models

	Tether		Bitcoin Cash	Chainlink
	Pre-COVID-19	During COVID-19	During COVID-19	
λ_{Gold}	-0.2623 (-5.365)	-0.8122 (-9.742)		-0.0574 (-2.917)
θ_{Gold}	0.0173 (1.343)	-0.002 (-0.467)		-8.1508 (-9.257)

$\beta_{1,Gold}$	-0.0179 (-0.551)	0.0027 (0.107)	-0.3408 (-0.800)
λ_{WTI}		-0.8187 (-9.923)	-0.0331 (-1.919)
θ_{WTI}		0.0011 (1.108)	-0.693 (-4.716)
$\beta_{1,WTI}$		0.0002 (0.125)	-0.0144 (-0.764)
λ_{Brent}		-0.8241 (-10.046)	-0.0718 (-2.967)
θ_{Brent}		0.0016 (1.470)	-0.465 (-3.265)
$\beta_{1,Brent}$		0.0063 (1.475)	-0.0145 (-0.246)
This table presents the coefficients in equations (9-a) and (9-b). Values in parentheses are t-statistics. Significant coefficients at 0.05 level are in bold.			

The results of the short-term relationships between cryptocurrency markets and crude oil and gold markets are presented in Table 5 and Table 6.

Table 5- Estimated coefficients in ARDL models

	Tether	Bitcoin	Ether	Ripple	Litecoin	Bitcoin Cash	EOS	Chainlink	Cardano	Monero
Pre-COVID-19 (2019)										
Gold	-0.0026 (-0.716)									
WTI		0.0302 (0.722)	0.0481 (0.977)	-0.0073 (-0.169)	0.0003 (0.005)	0.1069 (1.727)	0.0533 (0.839)	-0.0885 (-1.132)	0.0158 (0.272)	0.0003 (0.006)
Brent		0.0529 (1.312)	0.0848 (1.821)	0.0400 (0.970)	0.0737 (1.335)	0.1129 (1.950)	0.1209 (1.918)	-0.0271 (-0.348)	0.0782 (1.332)	0.0380 (0.797)
During COVID-19 (2020)										
Gold	-0.0997 (-4.164)									
Gold (-1)	0.1025 (4.303)									
WTI	-0.0010 (-1.279)									
Brent	-0.0009 (-1.081)									
This table presents the coefficients in ARDL model (equation (10)). Values in the parentheses are associated t-statistic. Significant coefficients at 0.05 level are in bold.										

As shown in Table 5, our findings did not suggest any short-term relationship between cryptocurrency markets and Oil and Gold markets before the COVID-19 pandemic, while during this pandemic there is a significant negative relationship between Tether and Gold market. This indicates that gold market can be a suitable hedging asset for Tether investors during the COVID-19 pandemic.

Table 6- Estimated coefficients in VAR-in-first-difference models

	Bitcoin	Ether	Ripple	Litecoin	Bitcoin Cash	EOS	Chainlink	Cardano	Monero
Pre-COVID-19 (2019)									
DGold (-1)	-0.0182 (-0.048)	-0.2414 (-0.550)	-0.4658 (-1.215)	-0.9277 (-1.862)	-0.7199 (-1.342)	-0.5940 (-1.118)	-0.8389 (-1.215)	-0.6112 (-1.259)	-0.1457 (-0.326)
DGold (-2)	0.2184 (0.579)								-0.3361 (-0.758)
DGold (-3)	-0.4527 (-1.188)								-0.7621 (-1.697)
DGold (-4)	-0.0527 (-0.138)								-0.2142 (-0.475)
Tether in level									
WTI (-1)	0.0007 (0.066)	Brent (-1)	0.0031 (0.273)						
WTI (-2)	0.0026 (0.177)	Brent (-2)	-0.0019 (-0.123)						
WTI (-3)	-0.0073 (-0.670)	Brent (-3)	-0.0029 (-0.261)						
During COVID-19 (2020)									
DGold (-1)*	-0.1958 (-0.822)	0.0694 (0.220)	0.1246 (0.313)	0.0241 (0.078)	-0.2345 (-0.689)	-0.0842 (-0.268)	-0.1067 (-0.298)		0.1217 (0.417)
DGold (-2)	0.2062 (0.864)	0.3666 (1.162)	0.2859 (0.718)	0.2297 (0.756)					0.2833 (0.969)
DGold (-3)	-0.6566 (-2.813)			-0.936 (-3.087)					-0.7307 (-2.552)
DGold (-4)	-0.4908 (-2.078)								-0.5394 (-1.865)
DWTI (-1)	0.0140 (1.005)	-0.0005 (-0.029)	0.0019 (0.086)	0.0112 (0.633)		-0.0004 (-0.024)	0.0005 (0.021)	0.0115 (0.611)	0.0067 (0.402)
DWTI (-2)	0.0048 (0.317)	-0.0045 (-0.256)	-0.005 (-0.222)	0.0067 (0.357)			-0.004 (-0.149)		-0.0003 (-0.016)
DWTI (-3)	0.0142 (0.919)			0.0014 (0.077)			0.005 (0.197)		0.0018 (0.098)
DWTI (-4)	0.0205 (1.356)						0.005 (0.203)		0.0038 (0.230)
DWTI (-5)	0.0272 (1.977)								
DBrent (-1)	0.0084 (0.204)	0.0208 (0.374)	0.0086 (0.122)	0.0169 (0.315)		0.0025 (0.045)	0.0019 (0.025)	-0.0193 (-0.308)	0.0309 (0.620)
DBrent (-2)	0.0039 (0.096)	0.0583 (1.056)	0.0356 (0.509)	0.0278 (0.519)			0.0843 (1.148)		-0.0201 (-0.406)
DBrent (-3)	0.0508 (1.231)	0.0345 (0.621)		0.0488 (0.911)			0.1046 (1.423)		0.0438 (0.880)
DBrent (-4)	0.0289 (0.708)	0.0084 (0.152)					0.0751 (1.023)		0.0122 (0.246)
DBrent (-5)	-0.0845 (-2.077)	-0.1043 (-1.898)							-0.0849 (-1.723)

This table presents the coefficients in VAR model (equation (7)). Values in the parentheses are associated t-statistic. Significant coefficients at 0.05 level are in bold. * First difference of gold at the first lag.

Our results from Table 6 suggest that there is no short-term connectedness between cryptocurrencies and WTI, Brent, and Gold markets in pre-COVID-19 period. However, during the COVID-19 pandemic, lagged Gold returns have a significant negative relationship with Bitcoin, Litecoin, and Monero at 5% level while only the fifth lag of WTI and Brent crude oil returns have a significant relationship with Bitcoin returns. During the pandemic, lagged WTI returns have a significant direct association with Bitcoin while the lagged Brent returns have a significant negative relationship with Bitcoin returns. This study did not find any significant relationship between WTI and Brent crude oils and Ether, Ripple, Litecoin, Bitcoin Cash, EOS, Chainlink, Cardano, and Monero during the COVID-19 pandemic.

The analyses in this study suggest that there is no opportunity to hedge the cryptocurrency markets with crude oil or gold markets in the pre-COVID-19 periods. However, during the COVID-19 crisis, hedge fund managers can reduce the risk of investing in Bitcoin, Litecoin, and Monero by assigning a section of their portfolio to the gold markets. Besides, Bitcoin investors can also reduce their investment risks during the COVID-19 pandemic by investing on the Brent crude oil. However, as the absolute value of the coefficients for the effect of gold on Bitcoin is larger than the effect of Brent crude oil, gold would be a better hedging asset for Bitcoin during the COVID-19 pandemic.

Highlights of Findings

Return-Volatility relationships:

- There is no significant return-volatility relationship in any of cryptocurrencies prior to the COVID-19 pandemic.
- The return-volatility relationship of Tether, Ethereum, Ripple, Bitcoin Cash, EOS, and Monero are significant during COVID-19. However, there is no significant return-volatility relationship for Bitcoin, Litecoin, Chainlink, and Cardano in this period.
- The effect of volatility on return for Tether and Ripple is negative, while this relationship is positive for Ethereum, Bitcoin Cash, EOS, and Monero during COVID-19 pandemic.
- The Gold market is a less volatile asset in both periods and the effect of volatility on Gold return is not significant in both periods of prior and during COVID-19. Gold can be considered a suitable asset for portfolio hedging in the periods studied in this paper.
- The effect of volatility on return for WTI and Brent crude oil is significantly negative prior to the COVID-19 pandemic. However, the return-volatility relationships for these oil markets are not significant during pandemic.

Return-Volume relationships:

- There is significant Granger causal relation from return to trading volume changes for Ethereum, Chainlink and Monero in the pre-COVID-19 period and for Ethereum, Ripple, Litecoin, EOS, and Cardano during the COVID-19 period.

- Except for Litecoin, there is no significant evidence of causal relations from trading volume changes to the return of cryptocurrencies prior to the COVID-19.
 - Trading volume of Tether and Chainlink Granger cause their returns during the COVID-19 period.
 - Considering all ten cryptocurrencies, there is no significant bidirectional return-volume relationship in both periods of prior and during COVID-19.
 - There is a significant relationship from cryptocurrencies returns to trading volume changes during COVID-19 pandemic. However, this relationship cannot be seen prior to the COVID-19.
 - There is a significant causal relationship from the absolute values of cryptocurrencies returns to the changes in their volume in both periods of prior and during COVID-19 pandemic.
- Agenda of Future Studies

Connectedness between cryptocurrency markets and oil and gold markets:

- During COVID-19 there is a significant long-term negative relationship between Tether and Gold, WTI, and Brent markets at 5% level. Similarly, the significant long-term negative relationships between Bitcoin Cash and WTI, and Brent crude oil markets are found.
- A significant long-term negative relationship between the Chainlink and Gold market is available during the COVID-19 pandemic.
- Prior to the COVID-19 pandemic, the long-term relationship is only available between Tether and Gold markets.
- We did not find any short-term connectedness between any of cryptocurrency markets and crude oil and gold markets prior to the COVID-19 pandemic, while during this pandemic there is a significant negative relationship between Tether and Gold market.
- During the COVID-19 pandemic, lagged Gold returns have a significant negative relationship with Bitcoin, Litecoin, and Monero at 5% level.
- During the COVID-19 pandemic, only the fifth lag of WTI and Brent crude oil returns have a significant relationship with Bitcoin returns.
- This study did not find any significant relationship between WTI and Brent crude oil and Ether, Ripple, Litecoin, Bitcoin Cash, EOS, Chainlink, Cardano, and Monero during the COVID-19 pandemic.
- During the COVID-19 crisis, hedge fund managers can reduce the risk of investing in Bitcoin, Litecoin, and Monero by considering gold as the hedging asset.

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