Finance Research Letters 44 (2022) 102049

Contents lists available at ScienceDirect

Finance Research Letters

journal homepage: www.elsevier.com/locate/frl

COVID-19 pandemic improves market signals of cryptocurrencies–evidence from Bitcoin, Bitcoin Cash, Ethereum, and Litecoin

Samuel Asumadu Sarkodie *, Maruf Yakubu Ahmed, Phebe Asantewaa Owusu

Nord University Business School (HHN). Post Box 1490, 8049 Bodø, Norway

ARTICLE INFO

Keywords:
Bitcoin
Bitcoin Cash
Ethereum
Litecoin
Cryptocurrency
COVID-19 Pandemic
Romano-Wolf multiple hypotheses
Economic uncertainty
Market signals
Commodity market

ABSTRACT

The COVID-19 global pandemic has disrupted business-as-usual, hence, affecting sustained economic development across countries. However, it appears economic uncertainty following COVID-19 containment measures favor market signals of cryptocurrencies. Here, this study empirically and structurally investigates the implication of COVID-19 health outcomes on market prices of Bitcoin, Bitcoin Cash, Ethereum, and Litecoin. Evidence from the novel Romano-Wolf multiple hypotheses reveal COVID-19 shocks spur Litecoin by 3.20-3.84%, Bitcoin by 2.71-3.27%, Ethereum by 1.43-1.75%, and Bitcoin Cash by 1.34-1.62%.

1. Introduction

The COVID-19 outbreak solely triggered the pandemic recession since 1870, with alarming speed of shock to global economy (IMF, 2020). This initiated a severe global economic crisis—affecting the global economy, financial, and commodity market (Ahmed and Sarkodie, 2021). The COVID-19 outbreak initially occurred in China — Wuhan province and later spread throughout the world. On December 30, 2020, the world recorded more than ~83,953,903 confirmed cases, ~1,836,909 death cases, and ~60,400,789 recovery and discharge cases (Worldometer, 2020). During the global pandemic, countries instituted containment measures to mitigate the spread of COVID-19 virus including— travel restrictions, social distancing, and lockdown policies (Sarkodie *et al.*, 2020). The containment measures instituted significantly affected the already fragile global economy, which has already surpassed the 2008 financial crisis estimated to reach the deepest recession since World War II (WorldBank, 2020a; Yakubu *et al.*, 2021). When the global pandemic is kept under control, financial stress is likely to trigger defaults that may be more severe on emerging and developing markets than developed markets (IMF, 2020). The COVID-19 pandemic is expected to leave a lasting scar on the world economy—in global value chain systems, investor and consumer confidence, and human capital. The global economic activities are unlikely to immediately return to its glorious state even if the pandemic is curtailed (Yakubu *et al.*, 2021). Thus, effective strategies for containing COVID-19 pandemic remain critical—unless access to vaccines is globally available for population to reach herd immunity.

Bitcoin is the most popular cryptocurrency with innovative characteristics, viz. simplicity, and transparency—outlined in the peer-to-peer electronic cash system (Nakamoto, 2008). Existing literature on cryptocurrency particularly bitcoin focuses on security,

* Corresponding author.
E-mail address: asumadusarkodiesamuel@yahoo.com (S.A. Sarkodie).

https://doi.org/10.1016/j.frl.2021.102049
Received 29 January 2021; Received in revised form 25 March 2021; Accepted 2 April 2021
Available online 6 April 2021

legality, and technical aspects (Barber *et al.*, 2012;Reid *et al.*, 2013). During the COVID-19 pandemic, bitcoin surged by 300% in 2020 amid speculations in the financial market that investors were piling the digital currency—due to low interest rate in the market (Bloomberg, 2021). The upward gains were partly influenced by financial market investors who saw the potential of using bitcoin to hedge against recent inflation due to the global pandemic—although inflation in countries like the U.S. was fairly stable. It has long been argued that central bank printing of money will lead to inflation or decrease the value of money over the period of time. On the contrary, cryptocurrency such as bitcoin has fixed supply of 21 million coins that resist inflation. The ideal conditions to test this argument were presented by COVID-19 pandemic once many countries injected trillions of dollars as stimulus package to stabilize the economy (Handagama, 2021).

The European central bank president Christine Lagarde described cryptocurrency as high speculative asset (Bloomberg, 2021). It is argued that Bitcoin should be considered as a speculative commodity compared to currency (Baek *et al.*, 2015). However, existing studies propose the consideration of Bitcoin as asset—following efficient market hypothesis (Jakub, 2015). The COVID-19 outbreak is reported to have affected the efficiency of cryptocurrencies particularly Bitcoin and Ethereum, but recovered faster at the end of March 2020 (Naeem *et al.*, 2021). The average monthly Bitcoin volatility was higher than gold volatility and the lowest monthly volatility of Bitcoin was less than gold's monthly volatility (Dwyer, 2015). Evidence from GARCH and EGARCH models indicate that Bitcoin volatility is highly unstable in speculative periods whereas in stable periods, S&P500 and fear index (VIX) is reported to influence its volatility (López-Cabarcos et al., 2019). The bullish volatility is triggered by safe-haven effect of cryptocurrencies in time of pandemic uncertainty (Bouoiyour *et al.*, 2020). Thus, cryptocurrencies can be used in diversification of portfolio assets by investors (Briere *et al.*, 2015).

In contrast to the existing literature, our study evaluates the effect of COVID-19 health outcomes on market price volatility of cryptocurrencies. We demonstrate the role of COVID-19 as proxy for economic uncertainty indicator affecting market signals. We employ novel Romano-Wolf multiple-hypotheses testing that simultaneously assess the effect of COVID-19 confirmed cases, and deaths on Bitcoin, Bitcoin Cash, Ethereum, and Litecoin. To test multiple-hypotheses and control false rejection of the null hypotheses, we use bootstrapping-based resampling technique that absorbs the dependence structure of baseline test to develop robust and consistent Romano-Wolf corrected p-values. We explore the structural effects of the global pandemic on cryptocurrencies and examine its predictive power. To control for endogeneity, omitted-variable bias, and measurement errors, we incorporate COVID-19 recoveries, reproduction rate of COVID-19, and vaccination as instrumental variables. We contribute to the extant literature and global debate on uncertainties and cryptocurrencies by providing insights to traditional investors and portfolio managers who use cryptocurrencies for hedging potential risks or diversification during pandemic uncertainties.

The subsequent sections of this study include methods utilized for the model estimation (Section 2), results and discussion of the estimated models presented in Section 3, and conclusion and policy implications presented in Section 4.

2. Methods

To examine the nexus between cryptocurrencies and COVID-19 pandemic, our study retrieved global daily-frequency data from January 22, 2020-December 31, 2020. January 22, 2020 corresponds with the date the first global pandemic was reported by WHO. Data on COVID-19 confirmed cases (number), recovery cases (number), and deaths (number) were employed from John Hopkins' database on COVID-19 (Lauren, 2020). COVID-19 health outcomes are used herein as a proxy for global pandemic uncertainty, an indicator for market signals. Data on reproduction rate of COVID-19 (%) and total vaccinations (number) were collected from Our World in Data (OWID, 2020). These variables in addition to COVID-19 recovery cases were used in this study as instrumental variables to control for potential endogenous effect of independent variables, omitted-variable bias, and dimension errors. Data on cryptocurrencies including Bitcoin cash (US$), Ethereum (US$), Bitcoin (US$), and Litecoin (US$) were collected from Coinbase, retrieved from FRED economic database (FRED, 2020).

2.1. Empirical model

Our empirical analysis begins with the specification of a baseline model that estimates the impact of COVID-19 on using a polynomial regression expressed as:

$$Cryptocurrency_t = \delta_0 + \beta_1 COVID-19_t + \beta_2 COVID-19_t^2 + \beta_3 COVID-19_t^3 + \varepsilon_t \quad (1)$$

Where, *Cryptocurrency* represents the target variables namely Bitcoin Cash, Ethereum, Bitcoin, and Litecoin, $COVID-19_t$ denotes both confirmed cases and deaths reported, δ_0 and β_1, …, β_3 are constant and coefficients to be estimated, ε_t denotes the white noise in time t = January22, 2020, …, December31, 2020. The specified baseline model is used to examine the structural relationship between cryptocurrencies and COVID-19 outcomes. Next, we test the stationarity properties of the data series using unit root tests including

Phillips-Perron (Phillips *et al.*, 1988) and Augmented-Dickey Fuller (Dickey *et al.*, 1979). We employ the two-stage least squares estimator with instrumental variable function in multiple-hypotheses testing procedure by Romano-Wolf (Clarke *et al.*, 2020). The standard two-stage least squares estimator can be expressed as:

$$Cryptocurrency_t = \delta_0 + \beta_1 Endog_t + \beta_2 COVID-19\ Confirmed\ Cases_t + u_t \quad (2)$$

$$Cryptocurrency_t = \delta_0 + \beta_1 Endog_t + \beta_2 COVID-19\ Deaths_t + u_t \quad (3)$$

$$Endog_t = \lambda_1 Vaccine_t + \lambda_2 Recoveries_t + \lambda_3 Reproduction_t + v_t \quad (4)$$

Where, $Cryptocurrency_t$ is the target variables specified in Eq. (1) for t-th period, $Endog_t$ represents the endogenous regressors, $COVID-19ConfirmedCases_t$ and $COVID-19Deaths_t$ are the exogenous regressors, $Vaccine_t$, $Recoveries_t$, and $Reproduction_t$ are the instrumental variables, u_t and v_t are the error terms with zero mean.

Contrary to existing traditional estimation techniques, Romano-Wolf algorithm allows simultaneous hypothesis testing of several target variables with existing standard estimators used as baseline model for the uncorrected probability values of corresponding null hypothesis. Significantly, the approach eliminates the challenges associated with *p*-hacking and incorrectly rejecting null hypothesis. With the resampling via bootstrapping technique incorporated in the approach, the dependence structure of estimated test statistics from standard estimators is controlled. For brevity, the Romano-Wolf multiple-hypotheses testing can be expressed as (Clarke *et al.*, 2020):

$$Cryptocurrency_t^k = \delta_0^k + \beta_t^k\ COVID-19\ Confirmed\ Cases_t + \varepsilon_t^k \quad (5)$$

$$Cryptocurrency_t^k = \delta_0^k + \beta_t^k\ COVID-19\ Deaths_t + \varepsilon_t^k \quad (6)$$

Where, $Cryptocurrency_t^k$ denotes the four outcome variables $k = 1, \ldots, 4$ outlined in Eq. (1), ε_t^k denotes the stochastic white noise from a multi-variate normal distribution.

3. Results & discussion

The characteristics of sampled data series using descriptive statistics are presented in Table 1. The average market price in 345 days for Bitcoin, Bitcoin Cash, Ethereum, and Litecoin are approximately US$ 11,301, US$ 270, US$ 317, and US$ 57, respectively. The first reported vaccinations were initiated on December 12, 2020 totaling 297. As of December 31, 2020, a total of 9,944,820 vaccination doses were administered. The mean confirmed cases and deaths of COVID-19 in 345 days were 22,137,757 and 647,234 people. The Jarque-Bera test statistics show all sampled data series reject the null hypothesis of normal distribution. Thus, the study applied logarithmic transformation to achieve a constant variance and control potential heteroskedasticity.

The trend analyses of market price dynamics of cryptocurrencies are presented in Figs. 1, 2. A visual inspection of the trends reveal prominent peaks and depression with economic implications. The March 12, 2020 depression (Black Thursday)—suffered a global market crash attributable to COVID-19 pandemic and its related economic depression (Figs. 1, 2). The stock market crash is the most prominent single day market price recession that caused Bitcoin Cash, Ethereum, Bitcoin, and Litecoin to plummet by 43.95%, 43.09%, 37.41%, and 35.53% change in price, respectively. Notwithstanding, cryptocurrencies observed a rebound-effect of market price, causing the price of Bitcoin Cash, Ethereum, Bitcoin, and Litecoin to increase by 19.98%, 15.34%, 12.54%, and 12.27%, respectively. Surprisingly, while 4.57% change in global daily confirmed cases, and 6.64% change in global daily deaths led to a global market crash on March 12, 2020—12.32% change in global daily confirmed cases, and 12.54% change in global daily deaths led to a global market rebound. Similarly, 12.45% change in global daily confirmed cases, and 18.85% change in global daily deaths on March 23, 2020—improved the market price of Bitcoin, Ethereum, Litecoin, and Bitcoin cash by 13.67%, 12.66%, 11.52%, and 11.40%. In contrast, a seeming decline of global daily confirmed cases and deaths to 1.08% and 0.66% on September 03, 2020—plunged Bitcoin Cash, Litecoin, Ethereum, and Bitcoin by 14.14%, 13.57%, 12.79%, and 10.22%, respectively. This perhaps set-out our *a priori* expectation to assume that increasing level of COVID-19 health outcomes improves market price of cryptocurrencies. To test this hypothesis, we first assessed the structural dynamics of the nexus between COVID-19 and cryptocurrencies presented in Figs. 3, 4. The trends coincide with our *a priori*, confirming changes in COVID-19 confirmed cases predict Bitcoin, Bitcoin Cash, Ethereum, Litecoin, and by 83%, 46%, 88%, and 63%, respectively. Similarly, variations in COVID-19 reported deaths predict market prices of Bitcoin, Bitcoin Cash, Ethereum, Litecoin, and by 83%, 52%, 90%, and 65%. This implies that dynamics of COVID-19 deaths have more predictive power of cryptocurrencies compared to confirmed cases.

Table 1
Descriptive statistical analysis.

Statistics	Bitcoin	Bitcoin Cash	Confirmed Cases	Deaths	Ethereum	Litecoin	Vaccines
Mean	11301.32	269.7743	22137757	647234	317.1826	56.60803	185688.3
Median	9854.5	252.98	12921600	565846	262.13	48.9	0.000
Maximum	29026.97	494.61	83519171	1818336	754.45	130.2	9944820
Minimum	4980	149.8	557	17	111.04	31.39	0.000
Std. Dev.	4375.824	56.931	23690228	530458	143.381	18.654	952499.4
Skewness	1.731	1.516	1.003	0.431	0.861	1.841	6.341638
Kurtosis	6.062	5.451	2.878	2.071	3.062	6.783	49.29908
Jarque-Bera	307.061	218.511	58.112	23.088	42.717	400.704	33126.76
Probability	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***
Observations	345	345	345	345	345	345	345
Correlation							
Bitcoin	1						
Bitcoin Cash	0.285	1					
Confirmed Cases	0.924	0.021	1				
Deaths	0.868	-0.086	0.976	1			
Ethereum	0.943	0.209	0.947	0.932	1		
Litecoin	0.870	0.656	0.670	0.555	0.771	1	
Vaccines	0.652	0.212	0.479	0.409	0.495	0.667	1

Notes:
*** represents the rejection of the null hypothesis of normal distribution at *p-value* < *0.01*.

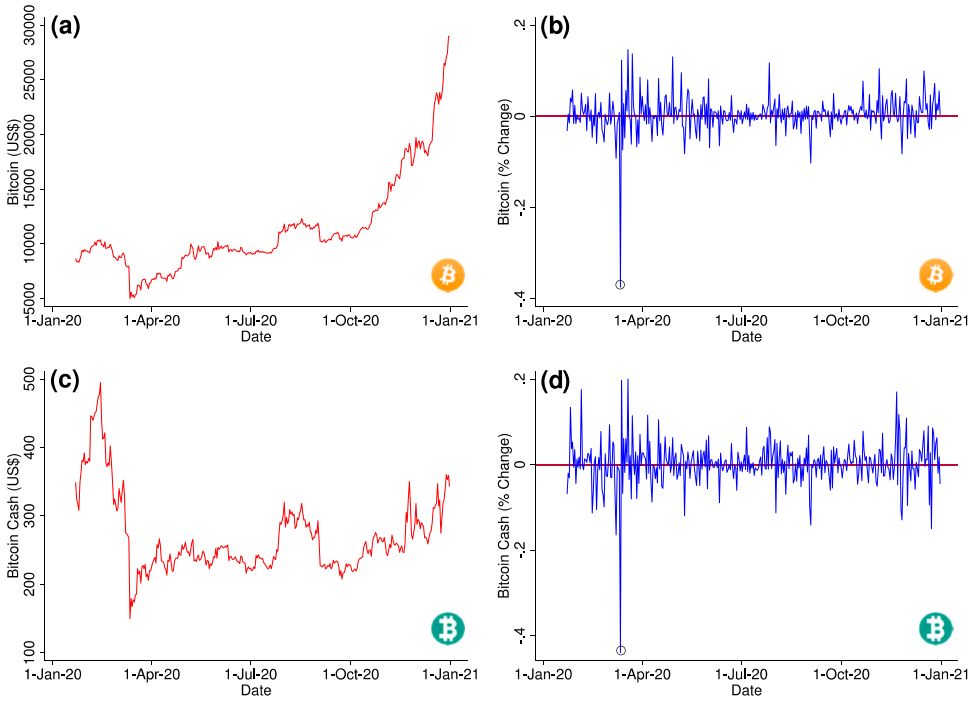

Fig. 1. Pattern analysis (a) Daily trend of Bitcoin price (US$) (b) Historical daily change of Bitcoin price (% change) (c) Daily trend of Bitcoin Cash price (US$) (d) Historical daily change of Bitcoin Cash price (% change). **Legend:** The black circle denotes COVID-19 pandemic economic recession (March 12, 2020).

Evidence from the empirical analysis reported in Figs. 5, 6 and Table 2 shows 1% increase in COVID-19 confirmed cases spur Litecoin, Bitcoin, Ethereum, and Bitcoin cash market price by 3.20%, 2.71%, 1.43%, and 1.34%, respectively. Likewise, 1% growth in COVID-19 deaths spurs Litecoin, Bitcoin, Ethereum, and Bitcoin cash market price by 3.84%, 3.27%, 1.75%, and 1.62%. Synonymous to the March 12, 2020 COVID-19 recession-driven stock market crash, pandemics act as economic uncertainty indicators of market signals—directing investments and transactions. With growing lockdowns and social distancing measures disrupting traditional in-person goods and services, investors increase demand for digital goods that act as safe-haven over uncertainties with traditional regularized-systems, hence, increasing circulation of cryptocurrencies—due to spike in investments and market capitalization. Besides, investor sentiments and herd behavior including recession fears, denial, despair, greediness, eagerness, contagion of opinion, and

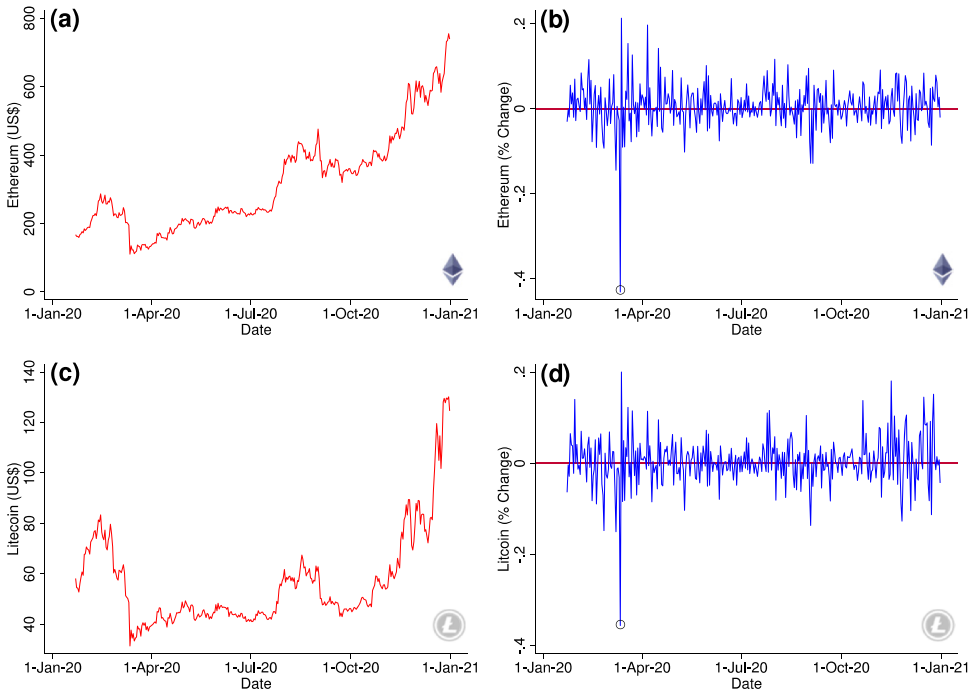

Fig. 2. Pattern analysis (a) Daily trend of Ethereum price (US$) (b) Historical daily change of Ethereum price (% change) (c) Daily trend of Litecoin price (US$) (d) Historical daily change of Litecoin price (% change). **Legend:** The black circle denotes COVID-19 pandemic economic recession (March 12, 2020).

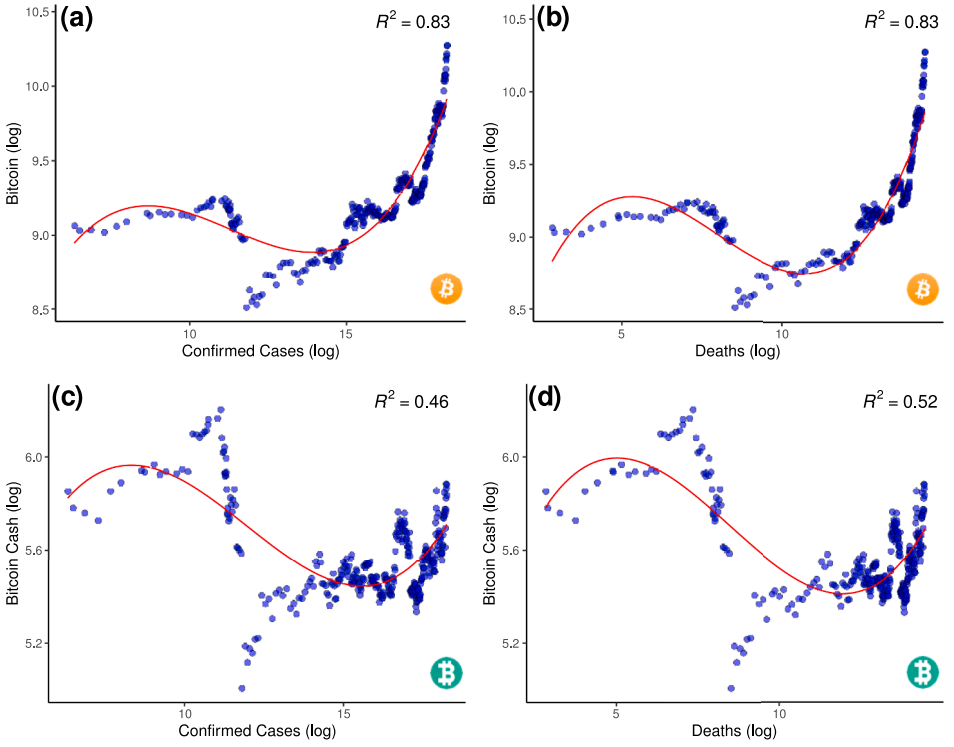

Fig. 3. Relationship between (a) Bitcoin price and confirmed COVID-19 cases (b) Bitcoin price and COVID-19 deaths (c) Bitcoin Cash price and confirmed COVID-19 cases (d) Bitcoin Cash price and COVID-19 deaths

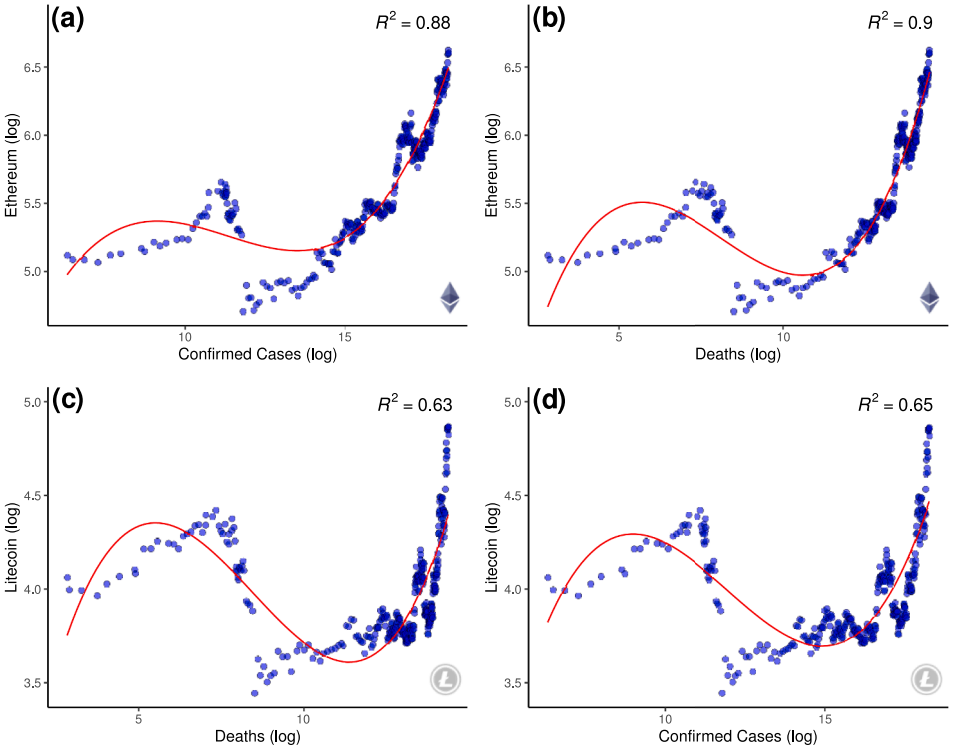

Fig. 4. Relationship between (a) Ethereum price and confirmed COVID-19 cases (b) Ethereum price and COVID-19 deaths (c) Litecoin price and confirmed COVID-19 cases (d) Litecoin price and COVID-19 deaths

media consideration are reported to affect the price volatility of cryptocurrencies through market bubble or market crash (López-Cabarcos *et al.*, 2019; Lux, 1995). This perhaps explain why COVID-19 attributed sentiments determine investment, trading, total circulation, and market price of cryptocurrencies.

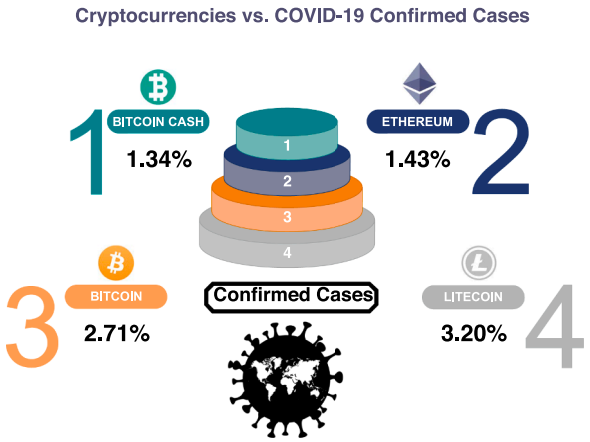

Fig. 5. Nexus between decentralized cryptocurrencies and COVID-19 confirmed cases

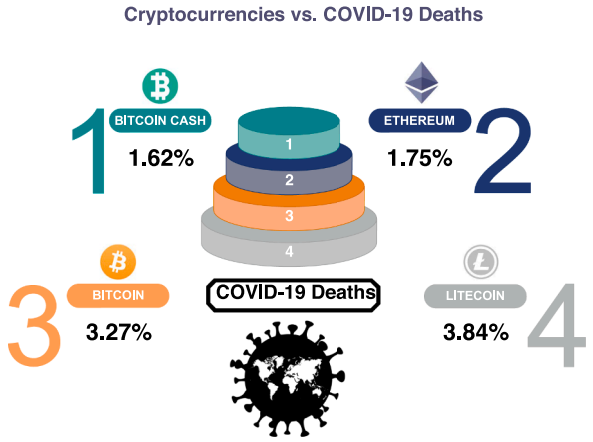

Fig. 6. Nexus between decentralized cryptocurrencies and COVID-19 deaths

Table 2
Estimated parameters of decentralized cryptocurrencies vs. COVID-19 health outcomes

Parameters	Bitcoin	Litecoin	Ethereum	Bitcoin Cash
Confirmed	**2.711*****	**3.199*****	**1.434*****	**1.336*****
Std. Err.	0.208	0.427	0.323	0.345
95% CI	2.303; 3.119	2.362; 4.036	0.800; 2.067	0.660; 2.012
Constant	**-39.181*****	**-53.422*****	**-19.578*****	**-18.516*****
Std. Err.	3.786	7.762	5.877	6.265
95% CI	-46.601; -31.761	-68.635; -38.210	-31.10; -8.060	-30.795; -6.236
Wald chi^2 (1)	169.38	56.110	19.660	15.02
Prob > chi^2	0.000***	0.000***	0.000***	0.000***
R-squared	0.904	0.757	0.518	0.448
Root MSE	0.035	0.073	0.055	0.059
Resample p-value	0.010***	0.010***	0.010***	0.010***
Romano-Wolf p-value	0.010***	0.010***	0.010***	0.010***
Deaths	**3.273*****	**3.836*****	**1.750*****	**1.621*****
Std. Err.	0.250	0.525	0.387	0.417
95% CI	2.783; 3.762	2.808; 4.863	0.992; 2.508	0.803; 2.438
Constant	**-36.898*****	**-50.357*****	**-18.649*****	**-17.502*****
Std. Err.	3.586	7.532	5.551	5.990
95% CI	-43.927; -29.869	-65.120; -35.595	-29.530; -7.768	-29.242; -5.761
Wald chi^2 (1)	171.680	53.470	20.490	15.090
Prob > chi^2	0.000***	0.000***	0.000***	0.000***
R-squared	0.905	0.747	0.525	0.443
Root MSE	0.035	0.074	0.055	0.059
Resample p-value	0.010***	0.010***	0.010***	0.010***
Romano-Wolf p-value	0.010***	0.010***	0.010***	0.010***

Notes:
*** denotes statistical significance at 1% level. Parameters are estimated using Instrumental Variables (2SLS) regression and validated with Multiple-Hypotheses testing algorithm.

3.1. Model verification

To validate the estimated models and confirm our *a priori* expectation based on the baseline model, we further employed Instrumental Variables (2SLS) regression and confirmed similar signs on estimated parameters. The error metric, viz. R-squared reveals COVID-19 confirmed cases explain changes in market price of Bitcoin, Litecoin, Ethereum, and Bitcoin cash by 90.40%, 75.70%, 51.80%, and 44.80%, respectively. Correspondingly, COVID-19 attributed deaths explain fluctuations in market price of Bitcoin, Litecoin, Ethereum, and Bitcoin cash by 90.50%, 74.70%, 52.50%, and 44.30%. Besides, we used both Resampled and Romano-Wolf adjusted p-values to validate the estimated uncorrected (2SLS model) probability values. Resampled and Romano-Wolf adjusted *p-values* reject 4 null hypotheses at 95% Confidence Interval (CI) presented in Table 2 and Figs. 7, 8. Both robustly estimated *p-values* from Resampled and Romano-Wolf estimator reject the null hypotheses (i.e., at $p\text{-value} < 0.01$) that: COVID-19 confirmed cases has no effect on Bitcoin, Litecoin, Ethereum, and Bitcoin cash (see Fig. 7) and COVID-19 deaths have no effect on Bitcoin, Litecoin, Ethereum, and Bitcoin cash (see Fig. 8). Finally, we examined the parameter stability of the estimated data series using recursive residuals based on cumulative sum test. The estimated coefficients show all data series are within the 95% confidence plot, confirming the stability of estimated parameters over time (see Fig. 9).

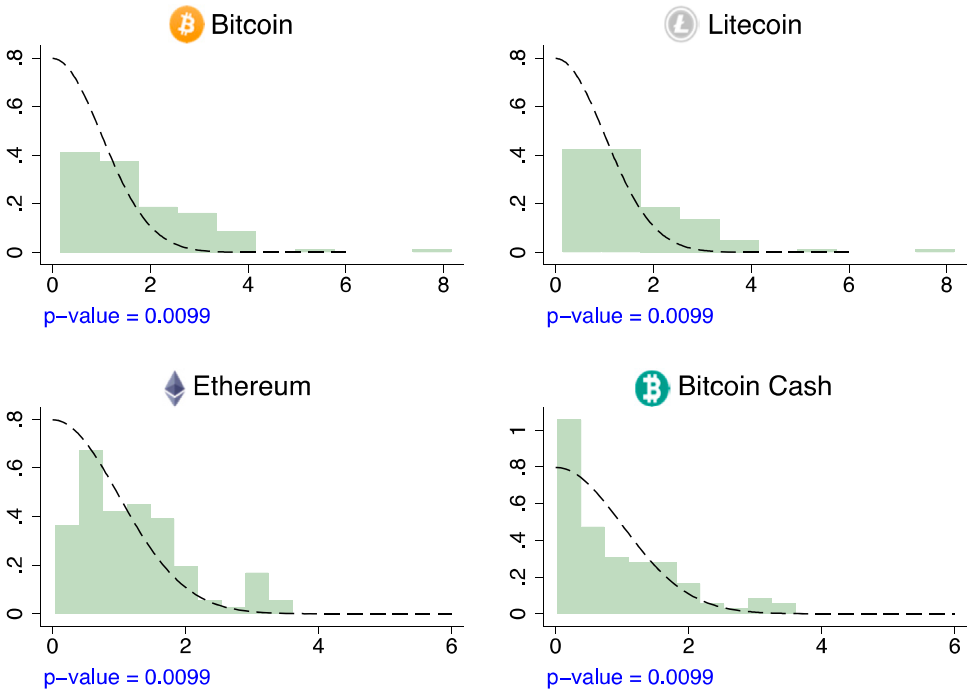

Fig. 7. Multiple-Hypotheses validation using Romano-Wolf (a) Bitcoin (b) Litecoin (c) Ethereum (d) Bitcoin Cash. Regressor: COVID-19 confirmed cases. Instruments: Reproduction, Vaccines, Recovery cases.

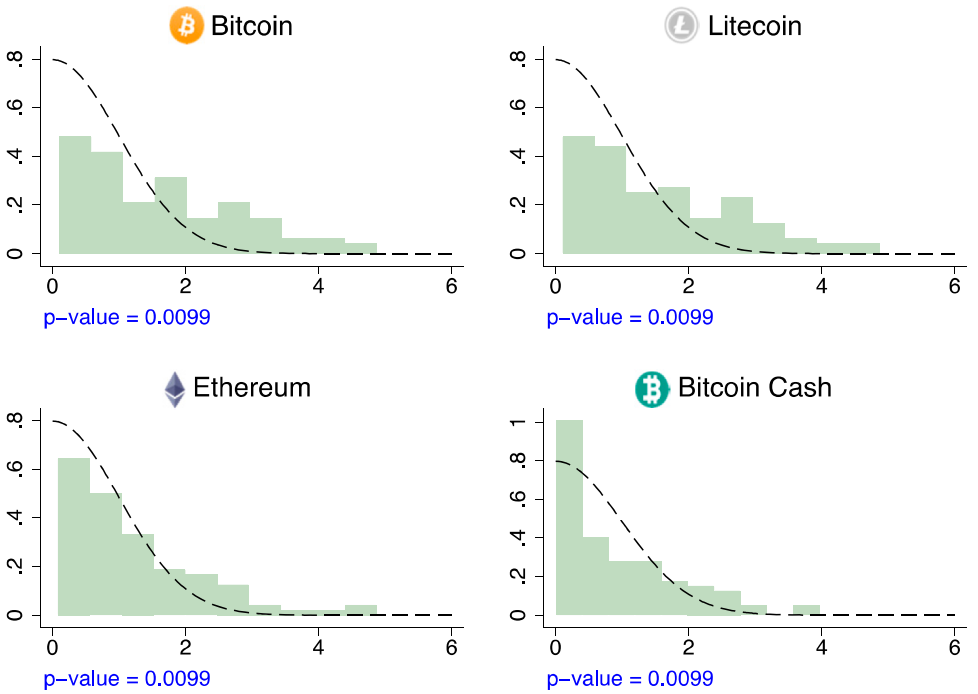

Fig. 8. Multiple-Hypotheses validation using Romano-Wolf (a) Bitcoin (b) Litecoin (c) Ethereum (d) Bitcoin Cash. Regressor: COVID-19 Deaths. Instruments: Reproduction, Vaccines, Recovery cases.

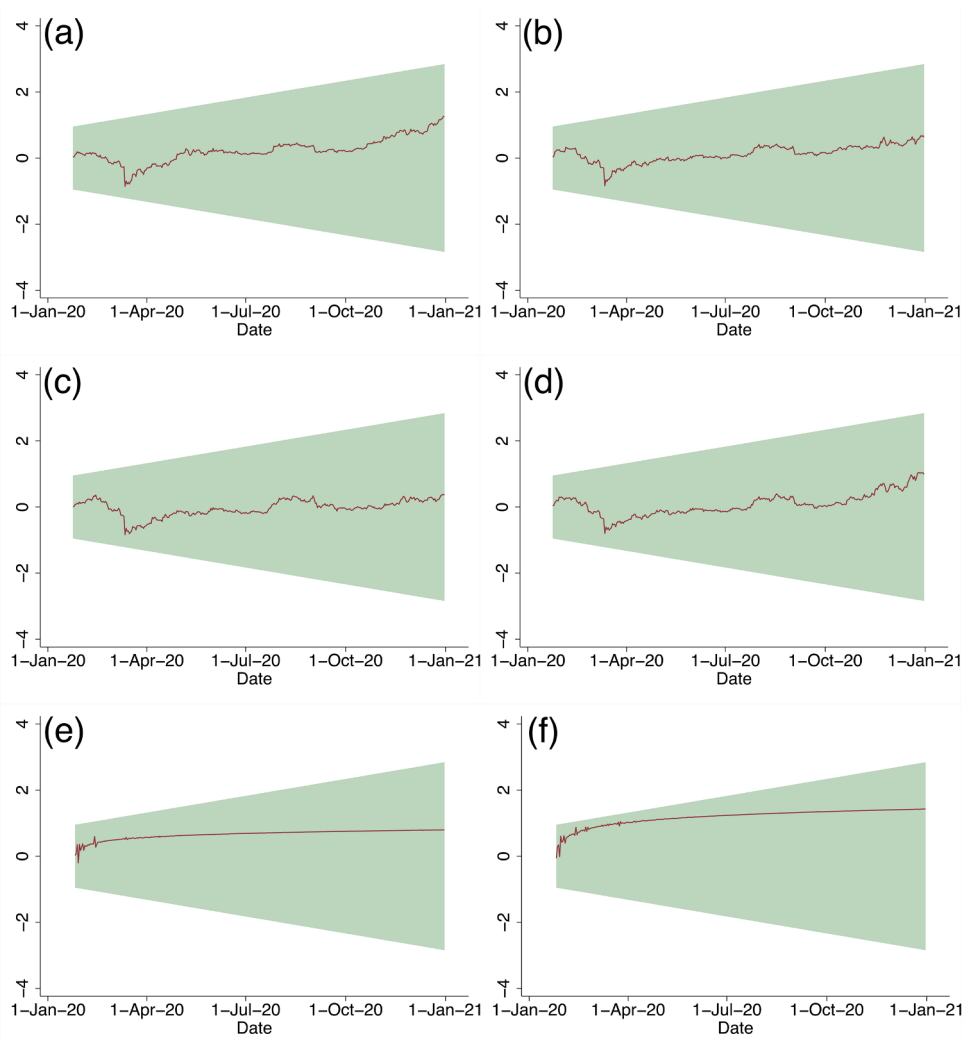

Fig. 9. CUSUM Parameter Stability (a) Bitcoin (b) Bitcoin Cash (c) Ethereum (d) Litecoin (e) Confirmed COVID-19 Cases (f) COVID-19 attributed Deaths

4. Conclusion

The over-decadal entry of Bitcoin as the first decentralized cryptocurrency, among other altcoins including Bitcoin Cash, Ethereum, and Litecoin have gained momentum in the public space albeit mining, investment, trading, total circulation, market price, market capitalization, and exchange trade volume. This study assessed the role of COVID-19 pandemic, as proxy for global economic uncertainty and market signal shock affecting cryptocurrency market value, realized value, network value, and transaction signals. Our empirical analysis revealed that cryptocurrencies namely Bitcoin and alternative coins follow nonstationary process—implying that its mean market price changes over time. In contrast, COVID-19 health outcomes follow a weakly dependent process—hence, may have long-term reproduction effect—increasing both reported cases and deaths. We further observed a mean daily increase in market price of Ethereum, Bitcoin, Litecoin, and Bitcoin Cash by 0.58%, 0.44%, 0.36%, and 0.15%—when COVID-19 confirmed cases and deaths increase by 3.77%, and 3.65% daily. The structural assessment of the various cryptocurrencies reveals an N-shaped relationship with COVID-19 pandemic. This infers the point of maximization of market price with positive market signals whereas recession of market price may be driven by negative market signals and unobserved common factors. With the characteristic of rebound-effect associated with cryptocurrencies, investors need to diversify investments to avoid selling out all cryptos during recession of market price—in this way, investors will accrue more dividend during the rebound-effect triggered by positive market signals.

CRediT authorship contribution statement

Samuel Asumadu Sarkodie: Conceptualization, Formal analysis, Funding acquisition, Methodology, Software, Validation, Visualization, Writing – review & editing. **Maruf Yakubu Ahmed:** Writing – original draft. **Phebe Asantewaa Owusu:** Writing – original draft, Writing – review & editing.

Declaration of Competing Interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

Ahmed, Maruf Yakubu, Sarkodie, Samuel Asumadu, 2021. Counterfactual shock in energy commodities affects stock market dynamics: Evidence from the United States. Resources Policy 72 (August 2021). https://doi.org/10.1016/j.resourpol.2021.102083.

Baek, C., Elbeck, M.J.A.E.L, 2015. Bitcoins as an investment or speculative vehicle? A First Look 22 (1), 30–34.

Barber, S., Boyen, X., Shi, E., & Uzun, E. (2012). *Bitter to better—how to make bitcoin a better currency.*Paper presented at the International conference on financial cryptography and data security.

Bloomberg. (2021). Bitcoin investors may lose everything, central bank warns. Retrieved from https://www.bloomberg.com/news/articles/2021-01-29/bitcoin-investors-may-lose-everything-central-banker-warns.

Bouoiyour, J., & Selmi, R. (2020). Coronavirus spreads and Bitcoin's 2020 rally: is there a link?

Briere, M., Oosterlinck, K., & Szafarz, A. (2015). Virtual currency, tangible return: portfolio diversification with bitcoin. 16 (6), 365-373.

Clarke, D., Romano, J.P., Wolf, M., 2020. The Romano–Wolf multiple-hypothesis correction in Stata. Stata J. 20 (4), 812–843.

Dickey, D.A., Fuller, W.A., 1979. Distribution of the estimators for autoregressive time series with a unit root. J. Am. Stat. Asso. 74 (366a), 427–431. Retrieved from. http://www.tandfonline.com/doi/abs/10.1080/01621459.1979.10482531.

Dwyer, G.P.J.J.O.F.S. (2015). The economics of Bitcoin and similar private digital currencies. 17, 81-91.

FRED. (2020). Coinbase cryptocurrencies. *Federal Reserve Bank of St. Louis.*Retrieved from https://fred.stlouisfed.org/series/.

Handagama, S. (2021). Bitcoin and inflation: everything you need to know. Retrieved from https://www.coindesk.com/bitcoin-and-inflation-everything-you-need-to-know.

IMF. (2020). World economics outlook, a long and difficult ascent. Retrieved from https://www.imf.org/en/Publications/WEO/Issues/2020/09/30/world-economic-outlook-october-2020.

Jakub, B. (2015). Does Bitcoin follow the hypothesis of efficient market. 4 (2), 10-23.

Lauren, G. (2020). Center for systems science and engineering at John Hopkins university, blog post. Retrieved from https://buff.ly/2O69IR8.

López-Cabarcos, M.Á., Pérez-Pico, A.M., Piñeiro-Chousa, J., Šević, A., 2019. Bitcoin volatility, stock market and investor sentiment. Are they connected? Finan. Res. Lett., 101399

Lux, T., 1995. Herd behaviour, bubbles and crashes. Econ. J. 105 (431), 881–896.

Naeem, M.A., Bouri, E., Peng, Z., Shahzad, S.J.H., Vo, X.V.J.P.A.S.M., & Applications, i. (2021). Asymmetric efficiency of cryptocurrencies during COVID19. 565, 125562.

Nakamoto, S. (2008). A peer-to-peer electronic cash system. 4.

OWID. (2020). Our world in data. Retrieved from https://ourworldindata.org.

Phillips, P.C., Perron, P., 1988. Testing for a unit root in time series regression. Biometrika 75 (2), 335–346. Retrieved from. http://biomet.oxfordjournals.org/content/75/2/335.

Reid, F., Harrigan, M., 2013. An analysis of anonymity in the bitcoin system. Security and Privacy in Social Networks. Springer, pp. 197–223.

Sarkodie, S.A., & Owusu, P.A. (2020). Global assessment of environment, health and economic impact of the novel coronavirus (COVID-19). 1-11.

WorldBank. (2020a). Annual report 2020. Retrieved from https://www.worldbank.org/en/about/annual-report.

Worldometer. (2020). Coronavirus Pandemic Retrieved from https://www.worldometers.info/coronavirus/.

Yakubu, M., Sarkodie, S.A., 2021. How COVID-19 pandemic may hamper sustainable economic development. J. Public Affairs. https://doi.org/10.1002/pa.2675.