



# Price explosiveness in cryptocurrencies and Elon Musk's tweets

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## ABSTRACT

We detect episodes of price explosivity and collapse in Bitcoin and its contender Dogecoin using four-hourly data. The results show multiple bubble episodes in both cryptocurrencies, with a more frequent occurrence in Bitcoin. Collapse episodes are only observed in Bitcoin. We relate price explosivity to Elon Musk's tweets. His cryptocurrency-related general tweets have contributed to the price explosivity of Bitcoin, whereas his Dogecoin-specific tweets have contributed to price explosivity in Dogecoin. Our findings highlight the influential role of key persons through social media on the formation of bubbles, which matters to the decision-making of cryptotraders and market efficiency.

## 1. Introduction

Cryptocurrencies represent a popular asset class that has shown a high sensitivity to behavioural factors such as popularity (Krisoufek, 2013), speculative and manipulative activities (Gandal et al., 2018), animal spirit (Bouri et al., 2019a), and the fear-of-missing-out (see, Baur and Dimpfl, 2018). Their remarkable exponential price growth coupled with unexpected massive crashes continue to attract the attention of speculators and investors. The fact that no traditional fundamental models exist for their price evaluation further magnifies the exuberance of cryptocurrency prices and the formation of booms and busts in this immature and fragile market, where herding seems to play a key role (Bouri et al., 2019a). The prices of Bitcoin and other major cryptocurrencies have been shown to exhibit bubble<sup>1</sup> behaviours (Fry and Cheah, 2016; Bouri et al., 2019b; Gronwald, 2021). Notably, during 2013's Bitcoin bubble, Bitcoin was swayed by two investors, which led the price of Bitcoin to increase with their trading activity (Gandal et al., 2018).

In this regard, the social media platform, Twitter, can be regarded as a virtual trading floor for cryptocurrencies, such as Bitcoin, and emotionally reflects its trading dynamics (Shen et al., 2019).<sup>2</sup> Some studies have provided evidence on the association between peer opinions and the cryptocurrency market (Urquhart, 2018; Ahn and Kim, 2020), which suggests that some social influences can affect cryptocurrency prices (Aggarwal et al., 2019; Philippas et al., 2019) and ultimately the formation of price explosivity. The

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<sup>1</sup> "Bubble" and "explosiveness"/"explosivity" are used interchangeably.

<sup>2</sup> Shen et al., (2019) have recommend Twitter as a better gauge of attention from more informed investors.

existing literature on Twitter an asset prices has so far analysed the effect of tweets from political persons such as President Trump on the equity markets (Klaus and Koser, 2021) and the Bitcoin market (Huynh, 2021), while overlooking the potential association between tweets and the likelihood of bubble formation in cryptocurrency prices. During 2020–2021,<sup>3</sup> Elon Musk, one of the richest people in the world and an influential person on social media and the cryptocurrency market, would frequently tweet about cryptocurrencies few times a day, and the market seemed to interpret this behaviour as short-term noise. To date, only two academic studies have focused on the role of Elon Musk's tweets on cryptocurrencies: one study has examined the response of Elon Musk's tweets on the short-term return and trading volume of the cryptocurrency market (e.g., Ante, 2021); the other one has considered the correlation between Elon's tweets and Bitcoin prices (e.g., Tandon et al., 2021). However, it remains unclear whether Elon Musk's tweets affect the likelihood of bubble formation in cryptocurrency markets. Therefore, we seek to answer the following two research questions: (1) is there a bubble behaviour in the prices of Bitcoin and Dogecoin? (2) Are Elon Musk's tweets influential enough to affect the likelihood of bubble formation in the prices of Bitcoin and Dogecoin? Answering these questions allows us to provide the first empirical evidence on how Twitter influencers can affect price explosivity in two major cryptocurrencies, Bitcoin and Dogecoin. This has implications not only for asset pricing and return predictability, which concerns the decision-making and trading strategies of crypto-traders but also for market efficiency, which concerns regulators and policy-makers.

In this paper, we examine the bubble formation in the prices of Bitcoin and Dogecoin and whether Elon Musk's tweets can affect the likelihood of that bubble formation. To this end, we first employ four-hourly price data and the novel model of Phillips and Shi (2019) for detecting episodes of price bubbles and collapse. Then, we employ logistic regressions to relate Elon Musk's tweets to the likelihood of the formation of bubble periods in Bitcoin and Dogecoin prices, while considering the COVID-19 outbreak.

Our current study brings together two important strands of research. The first concerns bubbles and crashes in the highly volatile and immature cryptocurrency market (e.g., Fry and Cheah, 2016; Corbet et al., 2018; Bouri et al., 2019b; Gronwald, 2021), which is particularly sensitive to sentiment, speculative, manipulation, and herding activities. The second concerns the rising importance of social media, including Twitter, on cryptocurrency prices (e.g., Shen et al., 2019; Philippas et al., 2019; Naeem et al., 2020; Kraaijeveld and De Smedt, 2020; Ante et al., 2020, 2021; Choi, 2021; Öztürk and Bilgiç, 2021; Tandon et al., 2021), which matters to the market efficiency of cryptocurrencies. In fact, the market efficiency of major cryptocurrencies such as Bitcoin remains a debatable issue. Several studies have denied the efficiency of Bitcoin, while others have argued that Bitcoin has been gaining efficiency over time (e.g., Le Tran and Leirvik, 2020).

Our contributions are on two fronts. First, by using the new model recently developed by Phillips and Shi (2019) to capture discontinuities, i.e., price explosion and crash episodes, which has some advantages over Phillips and Shi (2018; PS) and Phillips et al. (2015; PSY),<sup>4</sup> we add to studies that have used the PSY test in the universe of cryptocurrencies (e.g., Bouri et al., 2019b; Gronwald, 2021). Specifically, the advantages of the test Phillips and Shi (2019) includes its ability to (1) generate logical patterns of market behaviour during a crisis including the abrupt market falls, (2) incorporate an asymmetrically distributed input process which enhances the probability of sustained, but not inevitably monotonic, unidirectional market movements, (3) detect the new data generating process for a market crash and continuously estimate the crash dates which means that the model possesses the capability of detecting market downfalls and expansions. Second, by considering the impact of Twitter activity of Elon Musk on the price explosivity in the cryptocurrency market, we complement studies focusing on Bitcoin-specific tweets and trading volume (e.g., Shen et al., 2019; Philippas et al., 2019), cryptocurrency returns and Twitter market sentiment (e.g., Naeem et al., 2020; Kraaijeveld and De Smedt, 2020), the number of tweets and Bitcoin liquidity (e.g., Choi, 2021), and the number of influential Twitter accounts on Bitcoin return and trading volume (Öztürk and Bilgiç, 2021). Therefore, we have moved beyond focusing on certain sentiment indicators such as the number of users of Twitter (Shen et al., 2019) or the number of tweets (Philippas et al., 2019; Naeem et al., 2020), and instead we have crawled the text of tweets related to all cryptocurrencies i.e., Bitcoin and Dogecoin from the most influential Twitter user, Elon Musk (CEO of SpaceX and Tesla), to provide first evidence on the significant impact of Elon Musk's tweets on their price explosivity. This is an unexplored research topic.

## 2. Data and methodology

Our dataset covers four-hourly prices<sup>5</sup> on Bitcoin and Dogecoin,<sup>6</sup> collected from Binance, one of the largest cryptocurrency exchanges. The sample period was 1 January 2020 - 19 June 2021, yielding a total of 3216 observations. We consider only these two

<sup>3</sup> The interest in cryptocurrencies has re-emerged during the COVID-19 era when digitalization manifested rapidly in many societal and business aspects.

<sup>4</sup> First, it generates logical patterns of market behaviour during a crisis including the abrupt market falls. Second, it incorporates an asymmetrically distributed input process which enhances the probability of sustained, but not inevitably monotonic, unidirectional market movements. Third, it can detect the new data generating process for a market crash and continuously estimate the crash dates which means that the model possesses the capability of detecting market downfalls and expansions.

<sup>5</sup> We use 4 hours data because application of PSY bubble detection method is computationally demanding and hence there is a trade-off between use of high frequency data and computational time. Furthermore, 4 hours represent an adequate time window to reflect the impact of a tweet on the prices.

<sup>6</sup> Dogecoin is understudied in the academic literature because before 2020, it was not considered as potential asset to invest in. In this paper, the reason of investigation it is its affiliation to Elon Musk's tweets rather than any other intrinsic property, not to forget that Dogecoin has a market value of around \$18 Billion USD that makes it the 10th largest cryptocurrency. Comparatively, the largest cryptocurrency – Bitcoin – has a market cap of approximately 800 Billion USD. These figures are as of September 2021.

cryptocurrencies because they have been a particular focus of Elon's tweets over the two examined years. Information about Elon's tweets (see Section A of the Appendix) is extracted manually from his Twitter account (<https://twitter.com/elonmusk>).

### 2.1. Market explosivity and collapse detection (Phillips and Shi 2019)

The PSY process of Phillips et al. (2015; PSY) is widely applied for examining bubbles in financial variables. It has been effectively used as a crisis-dating tool and a timely cautionary alert method for market exuberance. The recursive rolling process of PSY depends on the right-tailed t-ratio or unit root test to focus on market exuberance. The regression model that is employed for estimation and inference takes the following form:

$$\log(P_t - P_{t-1}) = \alpha + \beta P_{t-1} + \sum_{i=1}^j \phi^i P_{t-i} + \varepsilon_t \quad (1)$$

where  $P_t$  is the price of cryptocurrency at time  $t$ ,  $\alpha$ ,  $\beta$  and  $\phi$  are parameters whose coefficients are estimated by ordinary least square,  $j$  is the number of lags that are set according to BIC,  $\varepsilon_t$  is the error term that is assumed to follow a normal distribution.

A more recent model of Phillips and Shi (2019) adapts the standard efficient market price mechanism by covering the effects of asymmetric shocks that accompany fundamentals. In general, the model considers the change in logarithmic asset price or return that is led by the superposition of martingale differences and a random sequence ( $-L_t$ ) that is locally and temporarily asymmetric in the negative direction, representing the negative sentiment of the trader or the direction of fundamentals:

$$\log(P_t - P_{t-1}) = -L_t + \varepsilon_t \quad (2)$$

where  $\varepsilon_t \sim^{mids} (0, \sigma^2)$ ,  $L_t$  = random sequence that tracks a scaled symmetric distribution and  $\varepsilon_t$  and  $L_t$  are supposed to be independent. This formulation may be such that the  $L$ -process switches off or on with respect to the trader's sentiment and the overall financial environment, i.e., taking zero value during tranquil periods or a positive value when the market maintains collapses or declines.

Let us denote the market collapse date by  $T_c = \lfloor Tr_c \rfloor$  for sample fraction  $r_c > 0$ , where the floor function  $\lfloor \cdot \rfloor$  provides the integer component of its argument. In the two-regime specification, the logarithmic asset price follows the data generating mechanism (DGP),

$$\log(P_t) = \begin{cases} cT^{-\eta} + \log P_{t-1} + \varepsilon_t & \text{if } t \in N \equiv [1, T_c] \\ -L_t + \log P_{t-1} + \varepsilon_t & \text{if } t \in C \equiv [T_c, T] \end{cases} \quad (3)$$

where  $N$  denotes the normal market and  $C$  denotes collapse periods. In a normal regime, the log price is expected to follow a martingale with asymptotically negligible drift (i.e.,  $cT^{-\eta}$  with  $c$  as constant and  $\eta > 1/2$ ), as used in PSY and PS. However, the logarithmic price switches to the  $L$ -process dynamic (eq-2) in a collapsing regime.

We date stamp the possibly multiple explosive and collapse episodes for each cryptocurrency using the backwards sup augmented Dickey Fuller (BSADF) statistics (see Section B of Appendix). The BSADF test repeatedly estimates the supremum ADF statistic by considering the backwards expanding time windows ending at 4 h.

### 2.2. Logistic regression

After identifying the explosive episodes via the test of Phillips et al. (2019), we apply logistic regression<sup>7</sup> to discover whether Elon's tweets and the COVID-19 outbreak impacted the likelihood of explosivity in Bitcoin and Dogecoin prices. In other words, we explain the periods of price explosivity, as reflected by a dummy variable  $Y$ , based on Elon's tweets using the following logistic regression:

$$\log\left(\frac{P(Y=1|X)}{1-P(Y=1|X)}\right) = \beta_0 + \beta_i X_{i,t} + \varepsilon_t \quad (4)$$

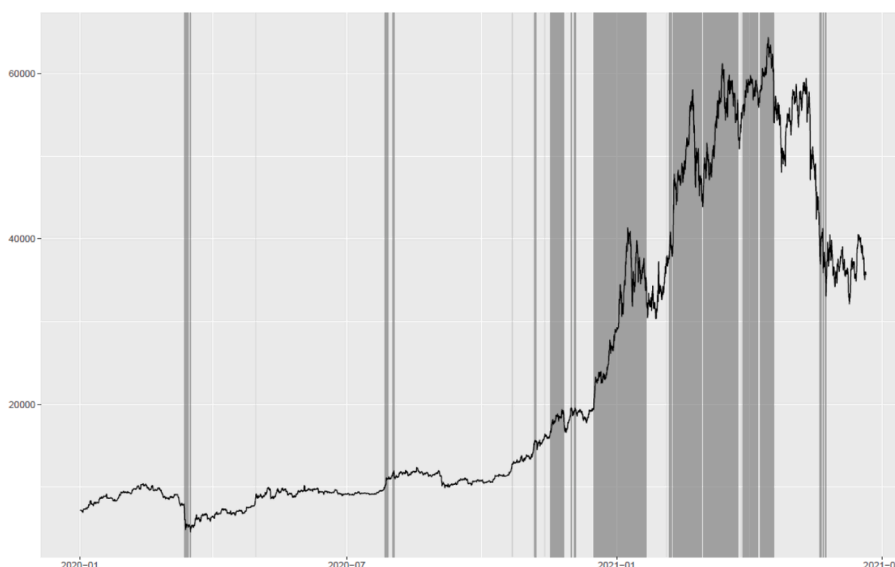
where  $Y$  denotes the dummy variable that takes the value of 1 in the presence of price explosivity (i.e., if  $BSADF_{r_{2,t}} \geq cv_{r_{2,t}}^{\alpha_T}$ ) and 0 otherwise (i.e., if  $BSADF_{r_{2,t}} < cv_{r_{2,t}}^{\alpha_T}$ ).  $\beta_0$  denotes the constant;  $X_{i,t}$  is a set of two dummy variables, i.e., one reflecting Elon's tweets and the other accounting for the COVID-19 period (21 March 2020, until 18 February 2021); and  $\varepsilon_t$  is the error term that follows a logistic distribution.

## 3. Results and discussion

### 3.1. Crisis and bubble periods in Bitcoin and Dogecoin markets

The visual observation from Figs. 1–2 indicates that Bitcoin and Dogecoin prices show multiple episodes of explosivity, especially in 2021. Explosive episodes occur more frequently in Bitcoin than Dogecoin, implying more irrational trading activities in the largest cryptocurrency.

<sup>7</sup> Bouri et al. (2019b) have applied a logistic regression model to study co-explosivity in the cryptocurrency markets.



**Fig. 1.** Crisis and Bubbles in Bitcoin prices.

Notes: The solid line in the plots reflects the individual coin prices, whereas the shaded areas within the plot represent the explosive episodes. The shaded areas reflect time intervals when the PSY statistic is higher than the 95% critical value.

Subsequently, [Tables 1–2](#) provide the starting and ending dates of explosivity, crisis episodes and the duration in hours based on the PSY analysis. As shown in [Table 1](#), there were 28 explosive episodes in Bitcoin prices, and only six crisis periods (i.e., two times in March 2020 and four times in May 2021). The two crisis episodes in March 2020 coincided with sudden lockdowns and downward pressure on economic activities, spike in market uncertainty, and downward pressure on Bitcoin prices. On Friday 12 March 2020, the price of Bitcoin dropped \$4000 but recovered on Monday 14 March 2020. The four crisis episodes in May 2021 coincided with the ban of the Chinese government on cryptocurrencies, which restricted financial institutions from providing services and rising climate concerns about energy-intensive cryptocurrencies. Following [Etienne et al. \(2014\)](#), who defined the minimum duration of a bubble episode to be three days, Bitcoin prices exhibited 5 bubble periods in 2021, with the highest duration lasting 23 days and 20 h in March 2021.

The crisis period had a prolonged maximum of two days and 20 h in December 2020. However, the minimum duration of explosivity and crisis periods was 4 h. Notably, neither explosivity nor collapse periods are observed in five months of 2020 (i.e., Jan, Feb, May, Jun, and Sep), during which prices were generally moving sideways.

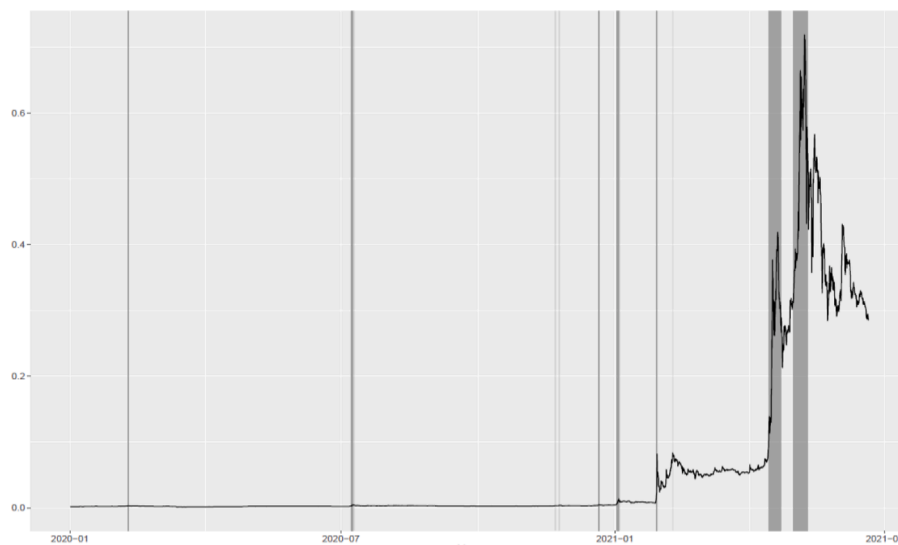
In [Table 2](#), no episodes of crisis are detected for Dogecoin. However, 20 episodes of price explosivity are shown, with only two lasting for more than three days, in April 2021. The longest explosivity period was 8 days and 16 h, whereas the shortest episode of explosivity lasted only 4 h.

### 3.2. Co-explosivity- Elon Musk's twitter, bitcoin and dogecoin

The coexplosivity results are reported in [Table 3](#). The presence of all cryptocurrency market-related tweets by Elon Musk enhances the probability of price explosivity in Bitcoin (see panel A in the Bitcoin column). In contrast, his Bitcoin-specific tweets have a smaller effect on the presence of explosivity in Bitcoin (see Panel B in the Bitcoin column). These results suggest that Elon's tweets regarding cryptocurrency can drive explosivity in Bitcoin prices. The Bitcoin market's response to Elon's tweets seems to vary from tweet to tweet rather than depending on Bitcoin-specific tweets. In fact, Elon's Bitcoin-specific tweets have a negligible impact on the explosivity of Bitcoin prices. For example, Elon changed his Twitter bio to "Bitcoin" on 29 January 2021, resulting in a rise in minute-by-minute returns to over 2%. Our result partially supports Ante's evidence (2021) that Bitcoin prices increase in response to Elon's Bitcoin-specific tweets. However, it contradicts [Tandon et al. \(2021\)](#), who argue that no one can control cryptocurrency markets through social media.

The occurrence of price explosivity in Dogecoin is least dependant on Elon's all-crypto market-related tweets (see Panel A in the Dogecoin column). Instead, it depends on the occurrence of Elon Musk's specific tweets about Dogecoin (see [Table 1](#), Panel B in the Dogecoin column). Again, this indicates that Elon Musk can move the cryptocurrency markets with his tweets. For example, Elon's Dogecoin-specific tweet "I only sell Doge" boosted the price of Dogecoin. His other tweet, in which he claimed that Dogecoin is a joke, also led to a positive response in the Dogecoin market. This means that Elon's tweets, whether they are serious or a joke, impact the Dogecoin market. We find that Elon's Dogecoin-specific tweets (see [Table A.1](#) in the Appendix) lead to bubbles in Dogecoin prices. This result supports [Ante \(2021\)](#), who reports a rise in Dogecoin prices in response to Elon's tweets. Yet it contrasts with the argument of [Tandon et al. \(2021\)](#) that no one can control the highly volatile cryptocurrency market and that if Elon Musk could influence the Dogecoin, then its value should have reached at least one US dollar.

Our results also suggest that the COVID-19 outbreak reduces the likelihood of explosivity in the Bitcoin and Dogecoin markets, which contradicts earlier studies ([Goodell and Goutte 2021](#)), showing that COVID-19 positively affected the prices of Bitcoin. The result also



**Fig. 2.** Crisis and Bubbles in Dogecoin prices.

Notes: See notes to Fig. 1.

**Table 1**

Date stamping of crises and bubbles in Bitcoin prices.

Date start	Date end	Crisis/Bubble	Duration
3/12/2020 12:00	3/15/2020 4:00	Crisis	2 Days 20 h
3/16/2020 8:00	3/16/2020 12:00	Crisis	8 h
4/30/2020 4:00	4/30/2020 4:00	Bubble	4 h
7/27/2020 4:00	7/29/2020 4:00	Bubble	2 Days 4 h
7/29/2020 16:00	7/29/2020 16:00	Bubble	4 h
8/1/2020 8:00	8/1/2020 12:00	Bubble	8 h
8/1/2020 20:00	8/2/2020 4:00	Bubble	12 h
10/21/2020 16:00	10/21/2020 16:00	Bubble	4 h
10/22/2020 0:00	10/22/2020 0:00	Bubble	4 h
11/5/2020 16:00	11/5/2020 16:00	Bubble	4 h
11/6/2020 0:00	11/7/2020 4:00	Bubble	1 Day 8 h
11/13/2020 4:00	11/13/2020 4:00	Bubble	4 h
11/16/2020 20:00	11/17/2020 0:00	Bubble	8 h
11/17/2020 8:00	11/26/2020 4:00	Bubble	9 days
11/30/2020 16:00	12/1/2020 16:00	Bubble	1 Days 4 h
12/2/2020 20:00	12/3/2020 0:00	Bubble	8 h
12/3/2020 8:00	12/4/2020 0:00	Bubble	20 h
12/4/2020 8:00	12/4/2020 8:00	Bubble	4 h
12/16/2020 16:00	1/11/2021 12:00	Bubble	26 days
1/12/2021 0:00	1/20/2021 8:00	Bubble	8 Days 12 h
1/20/2021 20:00	1/21/2021 8:00	Bubble	16 h
2/4/2021 8:00	2/4/2021 8:00	Bubble	4 h
2/6/2021 0:00	2/7/2021 16:00	Bubble	1 Day 20 h
2/8/2021 0:00	2/8/2021 0:00	Bubble	4 h
2/8/2021 8:00	2/28/2021 0:00	Bubble	19 Days 20 h
3/1/2021 4:00	3/24/2021 20:00	Bubble	23 Days 20 h
3/27/2021 0:00	3/27/2021 0:00	Bubble	4 h
3/27/2021 20:00	3/28/2021 16:00	Bubble	1 day
3/29/2021 0:00	4/7/2021 8:00	Bubble	9 Days 12 h
4/8/2021 16:00	4/18/2021 0:00	Bubble	9 Days 12 h
5/19/2021 4:00	5/20/2021 8:00	Crisis	1 Day 8 h
5/20/2021 16:00	5/20/2021 16:00	Crisis	4 h
5/21/2021 20:00	5/22/2021 0:00	Crisis	8 h
5/23/2021 8:00	5/23/2021 20:00	Crisis	16 h

**Table 2**

Date stamping of crises and bubbles in Dogecoin prices.

Date start	Date end	Crisis/Bubble	Duration
2/8/2020 16:00	2/9/2020 12:00	Bubble	1 day
7/7/2020 8:00	7/7/2020 8:00	Bubble	4 h
7/8/2020 0:00	7/8/2020 12:00	Bubble	16 h
7/8/2020 20:00	7/9/2020 0:00	Bubble	8 h
7/9/2020 12:00	7/9/2020 12:00	Bubble	4 h
7/9/2020 20:00	7/9/2020 20:00	Bubble	4 h
11/21/2020 16:00	11/21/2020 16:00	Bubble	4 h
11/22/2020 0:00	11/22/2020 0:00	Bubble	4 h
11/24/2020 8:00	11/24/2020 8:00	Bubble	4 h
11/25/2020 0:00	11/25/2020 0:00	Bubble	4 h
12/21/2020 0:00	12/21/2020 8:00	Bubble	12 h
1/2/2021 4:00	1/3/2021 16:00	Bubble	1 Day 16 h
1/4/2021 4:00	1/4/2021 4:00	Bubble	4 h
1/28/2021 16:00	1/29/2021 4:00	Bubble	16 h
2/8/2021 16:00	2/8/2021 16:00	Bubble	4 h
4/14/2021 0:00	4/14/2021 16:00	Bubble	20 h
4/15/2021 0:00	4/22/2021 0:00	Bubble	7 Days 4 h
4/22/2021 16:00	4/22/2021 16:00	Bubble	4 h
4/30/2021 20:00	5/9/2021 8:00	Bubble	8 Days 16 h
5/9/2021 20:00	5/10/2021 8:00	Bubble	16 h

**Table 3**

Logistic regression results.

	Bitcoin		Dogecoin	
	Panel A	Panel B	Panel A	Panel B
Tweets_all	1.590*** (0.263)		1.088*** (0.383)	
Tweets_Bitcoin		1.040** (0.524)		
Tweets_Dogecoin				1.653*** (0.409)
COVID-19	−0.510*** (0.085)	−0.531*** (0.085)	−1.805*** (0.205)	−1.793*** (0.205)
Constant	−0.939*** (0.065)	−0.892*** (0.064)	−2.346*** (0.103)	−2.358*** (0.103)
McFadden R-squared	0.022	0.012	0.091	0.096

Note: \*\*\*, \*\*, \* depict statistical significance at the 0.01, 0.05, and 0.10 levels, respectively.

matters to the ongoing debate on the efficiency of Bitcoin and other cryptocurrencies (e.g., [Le Tran and Leirvik, 2020](#)) by showing evidence that undermines the efficiency in the Bitcoin and Dogecoin markets. In fact, our results suggest the possibility of cryptotraders to focus on the contents of Twitter related to Elon Musk to foresee episodes of price explosivity in Bitcoin and potentially generate abnormal returns. Such a possibility is relevant given the continuing debate about the lack maturity in the Bitcoin market and the cryptocurrency market in general and therefore its weak-form efficiency ([Le Tran and Leirvik, 2020](#)), which necessitates more analysis on the effect of social media such as Twitter on the efficiency of the cryptocurrency markets. The substantial variation in cryptocurrency prices across different exchanges and markets allows for arbitrage, which is characteristic of inefficient markets and can be helpful in constructing a profitable strategy (Baker and Wurgler, 2006). According to [Shiller \(2015\)](#), price explosivity occurs through psychological contagion where the news regarding the increase in prices spreads contagiously, prompting investors' enthusiasm and bringing a larger group of investors by drawing in with excitement about the past price accelerations. This definition or view makes it possible to foresee future price dynamics or explosivity based on past information. Moreover, new traders rely on the public than private information that leads to herding behaviour ([Banerjee, 1992](#)). The herding behaviour can also be caused in response to some news or reports anticipating certain events, which may be helpful in predicting the price explosivity in the cryptocurrency markets.

#### 4. Conclusions, implications and future research

We present the first evidence pointing to the joint dynamics of Elon Musk's tweets and price explosivity in the Dogecoin and Bitcoin markets. The results suggest that the explosive behaviour in Bitcoin prices is enhanced by Elon Musk's general crypto market-related tweets. Therefore, cryptotraders can focus on the contents of Twitter or social media influencers to foresee episodes of price explosivity in Bitcoin and adjust their trading decisions accordingly. In fact, there is a possibility of using evidence on the significant association between Elon Musk's tweets and bubble formation to generate trading strategies capable of making abnormal returns. However, the

application and statistical significance of such strategies are left to future studies. In this regard, it is worth noting that the application of multi factor models such as the model of Fama and French while examining the significance of abnormal returns would not be suitable as the factors constructed by Fama and French are not available on a four-hour data frequency. The price explosivity of Dogecoin is only affected by Elon Musk's specific tweets on Dogecoin, which might reflect the potential segmentation of Dogecoin from the Bitcoin market. This issue needs to be addressed in future studies.

Future studies should consider the price explosivity in cryptocurrencies and Elon Musk's Tweets, while accounting for the trading volume and market capitalization.

### CRedit authorship contribution statement

**Syed Jawad Hussain Shahzad:** Conceptualization, Formal analysis, Methodology, Software, Supervision, Writing – review & editing. **Muhammad Anas:** Conceptualization, Writing – original draft, Visualization. **Elie Bouri:** Data curation, Resources, Supervision, Validation, Writing – original draft, Writing – review & editing.

### Declaration of Competing Interest

None.

### Appendix

#### A. Elon Musk's tweets

#### B. PSY test for explosivity (BSADF test)

Phillips and Shi, (2019) introduced a model to capture breaks in the financial environment that may turn into sudden price falls in different assets. The model can be understood as a martingale drift process that is constructed to apprehend the variety of asymmetric driving factors of the market sentiments and can accommodate both expansionary and crisis phases. One particularly useful feature of this model is that it demonstrates a fascinating empirical property of the explosivity detection process of Phillips et al. (2015a, b; PSY). The PSY's recursive moving window detection process is devised to identify speculative bubbles during the expansionary episode and to continually assess the start and end dates of such explosive episodes. Whereas the PS 2019 model offers a new data generating process that continuously estimates the crash dates. This means that the PS 2019 model possesses the capability of detecting market downturns and expansions.

The detection of explosivity is based on the characteristics of defining time series. During the expansionary episode of a bubble, the prices of assets follow a mildly explosive procedure contrasting the martingale behaviour which is typical during tranquil market conditions. In crisis phase, the dynamic of assets prices usually switches to a random drift martingale accompanying a large or sequential negative shock. The PSY method which gives a joint test for autoregressive coefficients and drift of the ADF model can detect the explosive and crash episodes.

The process of estimating BSADF statistic is explained as follows:

Let the regression run from  $T_1 \equiv [r_1 T]$  to  $T_2 \equiv [r_2 T]$ . The conforming sub-sample t-ratio (unit root) test statistic is symbolized by  $DF_{r_1}^{r_2}$  and demarcated as follows:

$$DF_{r_1}^{r_2} = \frac{\sum_{j=T_1}^{T_2} \tilde{X}_{j-1} (\tilde{X}_j - \tilde{X}_{j-1})}{\left[ \hat{\sigma}_{r_1 r_2}^2 \sum_{j=T_1}^{T_2} \tilde{X}_{j-1}^2 \right]^{1/2}} \quad (B1)$$

where  $r_1$  and  $r_2$  are the initial and ending points of the regression sample.  $\tilde{X}_{j-1}$  is the demeaned logarithmic price and  $\hat{\sigma}_{r_1 r_2}^2$  is the OLS estimator of the regression's error variance over  $[T_1, T_2]$ . Notably, it is the numerator that determines the sign of the Dicky-Fuller (DF) statistic.

The DF statistic is estimated from the fitted autoregressive coefficient  $\rho$  and is usually used to directly test the  $\rho$  related hypotheses. Particularly, the value of the  $\rho$  helps in the identification of the bubble. For instance, if  $\rho = 1$ , then it indicates normal market conditions or if  $\rho > 1$ , then it indicates speculative bubble or sub martingale conditions. It is eminent that the DF statistic does not only rely on  $\rho$  but also on the requirement of any drift term in generating mechanism. Phillips et al. (2014) focus on a martingale procedure like equation-1 with parameterized drift process that allows several beneficial asymptotic variants. Particularly, the DF statistic's limit distribution takes various forms with respect to  $\gamma < 1/2$ ,  $\gamma > 1/2$  or  $\gamma = 1/2$ .

For every observation of interest  $[rT]$ , conforming to a certain sample fraction  $r$ , the backward expanding sub-sample sequence is constructed by fixing the endpoint of regression on  $[rT]$  (i.e., set  $r_2 = r$ ) and the starting point is allowed to vary within its possible range like that  $r_1 \in [0, r - r_0]$ , where  $r_0$  is the required least size of the window to start the regression. In general, the endpoint of the moving window is fixed at  $r_2$  and the size of the window is expanded from  $r_0$  to  $r_2$ .

The test statistic for  $[rT]$  is termed as Backward Supremum Dickey-Fuller, symbolized by  $BSDF_r(r_0)$  and drawn as follows:



**Table A.1**

Date and time details of Elon's tweets.

Date	Time	Tweet	CryptoCoin	Text/Pic
7/18/ 2020	05:53AM	Excuse Me, I only sell Doge!	Dogecoin	Text
7/18/ 2020	05:58AM	It's inevitable "Dogecoin standard-global financial system or a cloud named Dogecoin standard which is overrunning the global financial system"	Dogecoin	Text+"Picture"
12/20/ 2020	01:21PM	Bitcoin is my safe word	Bitcoin	Text
12/20/ 2020	01:54PM	"Me trying to live a normal life Bitcoin (showing its ass) or Bitcoin keeps a person from living a productive life"	Bitcoin	"Picture"
12/20/ 2020	02:24PM	Bitcoin is almost as bs as fiat currency	Bitcoin	Text
12/20/ 2020	02:30PM	One word: Doge (Musk Changed Twitter Bio to Former CEO of Dogecoin)	Dogecoin	Text
12/25/ 2020	09:47PM	Merry Christmas & happy holidays! "Dogecoin Symbol"	Dogecoin Symbol	Text+"Picture"
1/29/ 2021	03:47AM	"Dogue- 10 tips on how to get the best trends"	Dogecoin	"Picture"
1/29/ 2021	01:22PM	In retrospect, it was inevitable (referring to the decision to change his Twitter bio to #Bitcoin)	Bitcoin	Text
2/4/ 2021	12:35PM	Doge	Dogecoin	Text
2/4/ 2021	12:57PM	ur welcome "Dog to sky expression"	Dogecoin	Text+"Picture"
2/4/ 2021	01:15PM	Dogecoin is the people's crypto	Dogecoin	Text
2/4/ 2021	01:27PM	No highs, no lows, only Doge	Dogecoin	Text
2/6/ 2021	09:51AM	The future currency of Earth (Dogecoin poll 71.3%)	Dogecoin	Text
2/7/ 2021	12:41PM	So it's finally come to this ... (Dog to sky expression)	Dogecoin	Text+Picture
2/8/ 2021	03:12AM	Hodl the rainforests!!	Dogecoin	Text
2/8/ 2021	03:25AM	(Multiple musical notes) Who let the Doge out (Multiple musical notes)	Dogecoin	Text
2/8/ 2021	05:09AM	The people have spoken ... The future currency of Earth	Dogecoin	Text
2/8/ 2021	06:13AM	Ð for Dogecoin! Instructional video	Dogecoin	Text+"Video"
2/10/ 2021	08:08PM	Bought some Dogecoin for lil X, so he can be a toddler hodler	Dogecoin	Text
2/10/ 2021	12:18PM	This is true power haha. "CHUK NORIS (Thumb up expression) CAN WITHDRAW BITCOUNS FROM MT. GOX"	Bitcoin	Text+"Picture"
2/11/ 2021	02:08PM	Frodo was the underdoge, all thought he would fail, Himself most of all. "One coin to rule them all"	Crypto	Text+"Picture"
2/15/ 2021	04:25AM	If major Dogecoin holders sell most of their coins, it will get my full support. Too much concentration is the only real issue imo	Dogecoin	Text
2/15/ 2021	03:05PM	I will literally pay actual \$ if they just void their accounts	Dogecoin	Text
	01:52AM	Heard a rumor that some crypto coin was pegging the dollar (laughter expression)	Crypto	Text

(continued on next page)



Table A.1 (continued)

Date	Time	Tweet	CryptoCoin	Text/Pic
2/21/ 2021				
2/21/ 2021	02:06AM	Or did they say pegged to the dollar? Something like that...	Crypto	Text
2/21/ 2021	04:42AM	Cryptocurrency explained (Bitcoin explained ep 1-video)	Crypto	Text+Video
2/22/ 2021	02:27AM	Dojo 4 Doge	Dogecoin	Text
2/22/ 2021	02:59PM	Hypernominalization	Dogecoin	Text
2/24/ 2021	06:00PM	Literally "Doge Wow (Dogecoin symbol)"	Dogecoin	Text+"Picture"
2/24/ 2021	06:10PM	On the actual moon	Dogecoin	Text
3/2/ 2021	12:57AM	Doge meme shield (legendary item). "Dogecoin value dropping-Memes-Dogecoin (sleeping expression)"	Dogecoin	Text+"Picture"
3/2/ 2021	10:50PM	Scammers & Crypto should get a room	Crypto	Text
3/6/ 2021	09:40AM	Doge spelled backwards is Egod	Dogecoin	Text
3/12/ 2021	11:58PM	BTC (Bitcoin) is an anagram of the TBC (The Boring Company) What a coincidence!	Bitcoin	Text
3/13/ 2021	12:00AM	Both do minings & use block & chains	Crypto	Text
3/14/ 2021	04:40AM	Doge Day afternoon	Dogecoin	Text
3/14/ 2021	04:46AM	Origin of the Doge Day Afternoon: The ancient Romans sacrificed a Dogcoin at the beginning of the Doge Days to appease the rage of sirius, believing that the star was the cause of the hot, sultry weather.	Dogecoin	Text
3/14/ 2021	04:51AM	Why are you so Dogmatic, they ask	Dogecoin	Text
3/24/ 2021	12:02PM	You can now buy tesla with Bitcoin.	Bitcoin	Text
3/24/ 2021	12:09PM	Tesla is using only internal & open source software & operates Bitcoin notes directly. Bitcoin paid to tesla will be retained as Bitcoin, not converted to fiat currency.	Bitcoin	Text
3/24/ 2021	12:10PM	Pay by Bitcoin capability availabe outside US later this year	Bitcoin	Text
4/1/ 2021	03:25PM	SpaceX is going to put a literal Dogeocin on the literal moon.	Dogecoin	Text
4/15/ 2021	09:33AM	Doge Barking at the moon.	Dogecoin	Text+"Picture"
4/28/ 2021	11:20AM	The Dogefather SNL May 8	Dogecoin	Text
5/7/ 2021	09:24AM	Cryptocurrency is promising. Please invest with caution! Elon Musk says Dogecoin can be the future of Cr (Video)	Dogecoin	Text+"Video"
5/8/ 2021	02:05AM	Guest starring ... (Dogecoin symbol)	Dogecoin	"Dog Picture"
5/10/ 2021	03:41AM	SpaceX launching satellite Doge-1 to the moon next year. -Mission paid for in Doge, –1st crypto in space, –1st meme in space. "Dogecoin song-To the Moon"	SpaceX & Dogecoin	Text+"Video"
5/11/ 2021	01:13PM	Do you want tesla to accept Doge?	Tesla & Dogecoin	Text

(continued on next page)

Table A.1 (continued)

Date	Time	Tweet	CryptoCoin	Text/Pic
5/13/ 2021	03:06AM	Tesla & Bitcoin "Tesla has susupended vehicle purchase using Bitcoin. We are concerned about rapidly increasing use of fossil fuels for Bitcoin mining and transactions, especially coal, which has the worst emissions of any fuel. Cryptocurrency is a good idea on many levels and we believe it has promising future, but this cannot come at great cost to the environment. Tesla will not be selling any Bitcoin and we intend to use it for transactions as soon as mining transitions to more sustainable energy. We are also looking at other cryptocurrencies that use <1% of Bitcoin's energy/transaction"	Tesla & Bitcoin	Text+"Picture"
5/13/ 2021	02:54PM	Energy usage trend over past few months is insane cbeci.org "Bitcoin energy consumption Twh (annualized)"	Bitcoin & Energy	Text+"Picture"
5/14/ 2021	02:11AM	To be clear, I strongly believe in Crypto but it can't drive massive increase in fossil fuel use, especially coal.	Crypto	Text
5/14/ 2021	03:45AM	Working with Doge devs to improve system transaction efficiency. Potentially promising.	Dogecoin	Text
5/20/ 2021	03:41PM	How much is that Doge in the window? "CYBERVIKING"	Dogecoin	Text+"Picture"
5/23/ 2021	03:22AM	"Stranger with a Dog you can pet him if you'd like-Me"	Dogecoin	"Dog Picture"
5/25/ 2021	12:42AM	Spoke with North American Bitcoin miners. They committed to publish current & planned renewable usage & to ask miners WW to do so. Potentially promising.	Bitcoin	Text
5/25/ 2021	12:49AM	If you'd like to help develop Doge, please submit ideas on GitHub & Reddit.com.	Dogecoin	Text
5/25/ 2021	01:29PM	Someone suggested changing Dogecoin fees based on phrases of the moon, which is pretty awesome haha.	Dogecoin	Text
6/2/ 2021	12:05PM	Found this pic of me as a child "I Have to keep my passion hiddden from the Public or I'll be socially ostracized".	Dogecoin	Text+ "Dog Picture"
6/4/ 2021	06:07AM	Her: I know I said it would be over between us if you quoted another Linkin Park song but I've ound someone else. Him so in the end it did'nt even matter?	Bitcoin	Picture

$$BSDF_r(r_0) = \sup_{r_1 \in [0, r-r_0], r_2=r} \{DF_{r1}^2\} \quad (B2)$$

This formulation helps to identify whether time series depicts explosive behaviour or bubbles. The bubble starts when BSADF is found to be higher than the critical value and ends when it is lower than that.

Under the null hypothesis, the limiting form of sup variate determines the limit distribution of the BSDF. As recommended in Phillips et al. (2015), the limit distribution is computed with the significance testing on the right tail by simulation and the least window size  $r_0$ , is  $r_0 = 0.01 + 1.8/\sqrt{T}$ .

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