Do Candlestick Patterns Work in Cryptocurrency Trading?

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2021 IEEE International Conference on Big Data (Big Data) | 978-1-6654-3902-2/21/$31.00 ©2021 IEEE | DOI: 10.1109/BigData52589.2021.9671826

***Abstract*—This paper investigates the effectiveness of candlestick patterns in cryptocurrency trading. Our data set includes historical daily opening, high, low, and closing prices of the top 23 cryptocurrencies by market capitalization. We examine 68 commonly used candlestick patterns using statistical analysis and find that the studied candlestick patterns are of little use in cryptocurrency trading. On the contrary, there are more patterns with relatively low accuracy. Investors should be cautious with their trading strategies and decisions when these patterns appear, as they may be a false trading signal that could cause losses rather than gains. To the best of our knowledge, this paper is one of the first research studies to investigate the effectiveness of candlestick patterns in cryptocurrency trading. Our findings could serve as a reference for investors when developing cryptocurrency trading strategies.**

I. Introduction

Technical Analysis (TA) is widely used to predict the future trends of stocks. Among the many existing TA methods, candlestick patterns aim to illustrate the behaviour of stock market participants [1]. Many investors are using candlestick patterns to trade their stocks in the market. However, few studies have focused on studying candlestick patterns in the cryptocurrency market. In contrast, many articles on the Internet promote the use of candlestick patterns on cryptocurrency trading (e.g., enter the keyword "cryptocurrency candlestick pattern" into search engines). Therefore, this is an interesting opportunity to analyse how effective candlestick charting techniques are in cryptocurrency trading. This paper analyses 68 common candlestick patterns using historical daily pricing data (opening, high, low, and closing) of 23 cryptocurrencies with the highest market capitalization. Our results based on statistical data analysis find that the studied candlestick patterns are of little use in cryptocurrency trading. Thus, investors should make their trading strategies and decisions using candlestick patterns with caution, as they may be a false trading signal that could cause losses rather than gains. To our best knowledge, this paper is one of the first research studies investigating the effectiveness of candlestick patterns in cryptocurrency trading. Our findings could serve as a guide for investors making their trading strategies.

II. Literature Review

Some previous studies analyzed the effectiveness of candlestick patterns in stock markets. On the one hand, [2-5] found that candlestick trading strategies do not have predictive value in some stock markets worldwide, including the United States, Japan, Taiwan, and Sweden. On the other hand, [6-10] supported the effectiveness of candlestick trading strategies using patterns such as Engulfing and Harami. The only work that analysed candlestick patterns for cryptocurrency Bitcoin trading was done in [11]. The work modified the classical Engulfing patterns to achieve improved net trading profit. [11] also found that reversed Harami pattern was a fertile trading strategy while Kicker patterns could not help Bitcoin traders as they seldom appear in the market. This paper fills the gap by analyzing the effectiveness of a complete set of candlestick patterns on trading a larger number of cryptocurrencies using statistical data analysis.

This work was supported in part by the Deep Learning and Cognitive Computing Centre, The Hang Seng University of Hong Kong, in part by the National Natural Science Foundation of China under Grant 62001298, and in part by the Natural Science Foundation of Guangdong Province under Grant 2021A1515012601.

III. Dataset

We use historical daily pricing data (i.e., opening, high, low, and closing prices) of the top 23 cryptocurrencies by market capitalization (as of 8 July 2021), downloaded from Yahoo! Finance [12], which represents nearly 90% of the total market capitalization. The period of the data for each cryptocurrency starts from the earliest available date until 8 July 2021. The cryptocurrency data is shown in Table I.

TABLE I. List of 23 studied cryptocurrencies

Cryptocurrency	Start Date	Market Capitalization	Cryptocurrency	Start Date	Market Capitalization
Bitcoin (BTC)	17-Sep-2014	46.92%	Chainlink (LINK)	20-Sep-2017	0.55%
Ethereum (ETH)	7-Aug-2015	17.76%	Etherrum Classic (ETC)	24-Jul-2016	0.45%
Tether (USDT)	25-Feb-2015	3.91%	Polygon (MATIC)	28-Apr-2019	0.45%
Binance Coin (BNB)	25-Jul-2017	3.46%	Stellar (XLM)	17-Sep-2014	0.42%
Cardano (ADA)	1-Oct-2017	2.82%	Theta (THETA)	17-Jan-2018	0.41%
Ripple (XRP)	17-Sep-2014	1.99%	VeChain (VET)	3-Aug-2018	0.36%
Dogecoin (DOGE)	17-Sep-2014	1.92%	Filecoin (FIL)	13-Dec-2017	0.31%
HEX (HEX)	17-Dec-2019	1.39%	Tron (TRX)	13-Sep-2017	0.29%
Polkadot (DOT1)	20-Aug-2020	0.95%	Monero (XMR)	17-Sep-2014	0.26%
Uniswap (UNI3)	31-Mar-2021	0.76%	EOS (EOS)	1-Jul-2017	0.24%
Bitcoin Cash (BCH)	23-Jul-2017	0.61%	Bitcoin SV (BSV)	9-Nov-2018	0.16%
Litecoin (LTC)	17-Sep-2014	0.58%			

IV. Research Methods

The basic shapes of bullish and bearish candlesticks are illustrated in Figure 1.

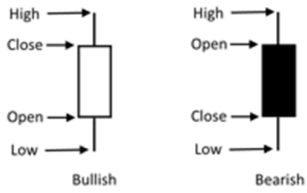

Fig. 1. Basic shape of bullish and bearish candlesticks.

A. Candlestick Patterns

The trend before and after the occurrence of a candlestick pattern is called *prior trend* and *forecast trend*, respectively. In addition to this, the upward and downward forecast trend determines the bullish and bearish pattern, respectively. When the movement of both prior and forecast trend follows the same direction, the pattern is a continuation pattern. Otherwise, it is a reversal pattern when their movement is in the opposite direction. Table II shows four types of candlestick patterns.

When a bullish continuation or a bullish reversal pattern occurs, investors are suggested to buy into cryptocurrencies. On the contrary, investors are recommended to short sell

their cryptocurrencies when a bearish continuation or a bearish reversal occurs. In this paper, 68 commonly used candlestick patterns provided by Python library TA-Lib [13] are studied. Of these patterns, only those that have a deterministic prior and forecast trend are studied. Hence, the patterns with the indecisive trend are excluded. Table III shows the list of the studied candlestick patterns.

TABLE II. FOUR TYPES OF CANDLESTICK PATTERNS

Pattern Type	Prior Trend (before the pattern occurs)	Forecast Trend (after the pattern occurs)	Illustration
Bullish Continuation	Uptrend	Uptrend	
Bullish Reversal	Downtrend	Uptrend	
Bearish Continuation	Downtrend	Downtrend	
Bearish Reversal	Uptrend	Downtrend	

TABLE III. LIST OF 68 STUDIED CANDLESTICK PATTERNS

Pattern	Candle Lines	Type	Pattern	Candle Lines	Type
Two Crows	3	Bearish Reversal	Bullish Harami Cross	2	Bullish Reversal
Three Black Crows	3	Bearish Reversal	Homing Pigeon	2	Bullish Reversal
Three Inside Up	3	Bullish Reversal	Identical Three Crows	3	Bearish Reversal
Three Inside Down	3	Bearish Reversal	In Neck Pattern	2	Bearish Continuation
Bearish Three Line Strike	4	Bearish Continuation	Inverted Hammer	2	Bullish Reversal
Bullish Three Line Strike	4	Bullish Continuation	Bearish Kicking	2	Bearish Reversal
Three Outside Up	3	Bullish Reversal	Bullish Kicking	2	Bullish Reversal
Three Outside Down	3	Bearish Reversal	Ladder Bottom	5	Bullish Reversal
Three Stars In The South	3	Bullish Reversal	Matching Low	2	Bullish Reversal
Three White Soldiers	3	Bullish Reversal	Bearish Mat Hold	5	Bearish Continuation
Bearish Abandoned Baby	3	Bearish Reversal	Bullish Mat Hold	5	Bullish Continuation
Bullish Abandoned Baby	3	Bullish Reversal	Morning Doji Star	3	Bullish Reversal
Advance Block	3	Bearish Reversal	Morning Star	3	Bullish Reversal
Bearish Belt Hold	1	Bearish Reversal	On Neck Pattern	2	Bearish Continuation
Bullish Belt Hold	1	Bullish Reversal	Piercing Pattern	2	Bullish Reversal
Bearish Breakaway	5	Bearish Reversal	Rising Three Methods	5	Bullish Continuation
Bullish Breakaway	5	Bullish Reversal	Falling Three Methods	5	Bearish Continuation
Concealing Baby Swallow	4	Bullish Reversal	Bearish Separating Lines	2	Bearish Continuation
Bearish Counterattack	2	Bearish Reversal	Bullish Separating Lines	2	Bullish Continuation
Bullish Counterattack	2	Bullish Reversal	Two-Candle Shooting Star	2	Bearish Reversal
Dark Cloud Cover	2	Bearish Reversal	Bearish Stalled Pattern	3	Bearish Reversal
Bearish Doji Star	2	Bearish Reversal	Bullish Stalled Pattern	3	Bullish Reversal
Bullish Doji Star	2	Bullish Reversal	Bearish Stick Sandwich	3	Bearish Reversal
Bearish Engulfing Pattern	2	Bearish Reversal	Bullish Stick Sandwich	3	Bullish Reversal
Bullish Engulfing Pattern	2	Bullish reversal	Takuri	1	Bullish Reversal
Evening Doji Star	3	Bearish Reversal	Downside Tasuki Gap	3	Bearish Continuation
Evening Star	3	Bearish Reversal	Upside Tasuki Gap	3	Bullish Continuation
Up-gap Side-by-side White Lines	3	Bullish Continuation	Thrusting Pattern	2	Bearish Continuation
Down-gap Side-by-side White Lines	3	Bearish Continuation	Bearish Tri-Star	3	Bearish Reversal
Hammer	1	Bullish Reversal	Bullish Tri-Star	3	Bullish Reversal
Hanging Man	1	Bearish Reversal	Unique 3 River	3	Bullish Reversal
Bearish Harami	2	Bearish Reversal	Upside Gap Two Crows	3	Bearish Reversal
Bullish Harami	2	Bullish Reversal	Downside Gap Three Methods	3	Bearish Continuation
Bearish Harami Cross	2	Bearish Reversal	Upside Gap Three Methods	3	Bullish Continuation

B. Trend Definitions

The works in [1] and [14] emphasize that it is inappropriate to use a candlestick pattern as a valid trading signal without considering its prior trend, especially when the price in an uptrend or downtrend alternates direction, which may represent a real reversal point or just a temporary fluctuation [6]. This highlights the importance of identifying a prior trend. Two commonly used approaches to identify the trend are:

1) Moving Average: the work in [7] adopts Moving Average (MA) over the past six days to identify a trend. The *n*-day moving average on day *t* is measured as:

$$MA_n[t] = \frac{1}{n}\sum_{i=0}^{n-1} p^c_{(t-i)} \quad (1)$$

where p^c_t is the closing price of a cryptocurrency on day *t*. An upward prior trend on day *t* is defined as:

$$MA_n[t-6] < MA_n[t-5] < MA_n[t-4] < MA_n[t-3] < MA_n[t-2] < MA_n[t-1] < MA_n[t] \quad (2)$$

Conversely, a downward prior trend on day *t* is defined as:

$$MA_n[t-6] > MA_n[t-5] > MA_n[t-4] > MA_n[t-3] > MA_n[t-2] > MA_n[t-1] > MA_n[t] \quad (3)$$

One may relax the inequalities above when the MA has been rising or falling for at least five of the last six days [15]. We define $m_{t,t-1}$ to be a variable indicating whether two consecutive days (i.e., day $t-1$ and t) is uptrend or downtrend:

$$m_{t,t-1} = \begin{cases} 1 & if\ MA_n[t] > MA_n[t-1] \\ 0 & otherwise \end{cases} \quad (4)$$

A prior trend is an uptrend if:

$$\sum_{i=0}^{5} m_{t-i,t-i-1} \geq 5 \quad (5)$$

Similarly, it is a downtrend when:

$$\sum_{i=0}^{5} m_{t-i-1,t-i} \geq 5 \quad (6)$$

Hence, a prior trend is valid when at least five out of the six inequalities in equation (2) or (3) are satisfied.

2) Exponential Moving Average: the *n*-day Exponential Moving Average on day *t* is defined as:

$$EMA_{n,t} = \chi p(t) + (1-\chi)EMA_{n,t-1} \quad (7)$$

where $\chi = 2 / (10 + 1)$. When the close price on day *t* is greater than its EMA, the prior trend is upward, and vice versa. Since the work in [16] has found that the effectiveness results of using candlestick patterns for stock trading do not depend on which trend definition is used, this paper uses the MA approach which is more commonly used.

C. Holding Strategies

Buy-and-hold is a passive investment strategy where investors buy any types of stocks or securities, and then keep them for a holding period in terms of days regardless of fluctuations in the market. Many legendary investors such as Warren Buffett and Jack Bogle have advised the buy-and-hold strategy in their investment rules. In this paper, the buying price is the opening price on the next day when the candlestick pattern is detected, while the selling price is the closing price on the day at the end of the holding period. Furthermore, the holding strategy consists of exit strategies. Two commonly used exit strategies are:

1) Caginalp-Laurent (CL) Exit: the return is defined as the average exit prices over the holding period of *n* days:

$$R_{CL(n)} = \frac{\sum_{i=1}^{n} p^c_{t+i} / n - p^o_{t+1}}{p^o_{t+1}} \times 100\% \quad (8)$$

where p^o_t and p^c_t are opening and closing price on day *t*, respectively.

2) Marshall-Young-Rose (MYR): the return is defined as the exit prices after the holding period of *n* days:

$$R_{MYR(n)} = \frac{p^c_{i+n} - p^o_{t+1}}{p^o_{t+1}} \times 100\% \quad (9)$$

Regardless of the exit strategy, the returns are multiplied by 1 and -1 if the patterns are bullish and bearish, respectively.

This is to make the desired outcomes of the bullish and bearish pattern to be positive returns, which indicates making a profit and saving from loss, respectively.

D. Transaction Cost

It is important to consider transaction fees when trading cryptocurrencies. The work in [17] estimates that the maximum Bitcoin exchange fee is about 0.5%. Therefore, the transaction-cost-adjusted return is to subtract the transaction fee of 0.5% from the original returns calculated in equation (8) and (9).

E. Hypothesis Testing

It is necessary to test the independence of the results against randomization since there are only two possible outcomes, namely "hit" and "fail". "Hit" represents positive outcomes in terms of profit or saving from loss. Conversely, "fail" represents negative outcomes such as suffering loss from trading. Hence, the binomial test is employed to test the null hypothesis H_0: $p = 0.5$ for the winning rate (i.e., the hit rate):

H_0: the winning rate is not statistically different from the expected results ($p = 0.5$) under a binomial distribution.

Furthermore, since our empirical results have exhibited skewness, the skewness adjusted t-test is employed to test the null hypothesis H_1: $\mu = 0$ for the average return:

H_1: the average return is not statistically different from 0.

This skewness-adjusted t-test is calculated using the formulas:

$$t_{sa} = \sqrt{m}\left(s + \frac{1}{3}\Upsilon s^2 + \frac{1}{6m}\Upsilon\right) \tag{10}$$

$$s = \frac{\bar{r}}{\sigma_r} = \text{standardized mean of returns,} \tag{11}$$

$$\Upsilon = \sum_{i=1}^{m} \frac{(r_i - \bar{r})^3}{m\sigma_r^3} = \text{estimated skewness of returns.} \tag{12}$$

where m is the number of returns and r_i is the i^{th} return. Therefore, a candlestick pattern is considered helpful for trading if it achieves a higher winning rate than a random decision while producing a positive return. In other words, an effective candlestick pattern should satisfy the following four statistical conditions simultaneously:

1. The binomial test p-value is smaller or equal to 0.05 to reject hypothesis H_0 (i.e., the winning rate is statistically different from 50% at a 5% level of significance)
2. The winning rate is greater than 50%
3. The skewness-adjusted t-test p-value is smaller or equal to 0.05 to reject hypothesis H_1 (i.e., the average return is statistically different from 0 at a 5% level of significance)
4. The average return is positive.

V. EMPIRICAL RESULTS

This section uses statistical analysis to investigate if any of the studied candlestick patterns are effective in cryptocurrency trading. Table IV - VII show the statistical analysis results of the candlestick patterns using different trend definitions, exit strategies, and holding periods. In these tables, "Total" represents the number of occurrences of the corresponding pattern with its prior trend satisfying equation (5) or (6). "Hit" represents the number of occurrences that the pattern in "Total" produces a positive

TABLE IV. EMPIRICAL RESULTS (MA_3 + CL + HOLDING DAYS = 3)
(* REPRESENT THE LEVEL OF SIGNIFICANCE AT 5%)

Cryptocurrency	Total	Hit	Returns (%)				Standard Deviation	Skewness	Skewness adjusted t-test p-value	Winning rate (%)	Binomial test p-value
			Max	Min	Median	Average					
Bearish Belt Hold	489	212	20.92	-125.34	-0.69	-1.30	0.10	-5.03	< 0.01*	43.35	< 0.01*
Bullish Engulfing	464	193	62.05	-27.13	-0.66	-0.44	0.08	1.60	0.28	41.59	< 0.01*
Bullish Belt Hold	453	179	132.27	-40.17	-1.17	0.10	0.12	4.33	0.81	39.51	< 0.01*
Bearish Engulfing	407	176	20.92	-57.63	-0.68	-1.34	0.08	-1.29	< 0.01*	43.24	0.01*
Hammer	248	114	46.01	-39.88	-0.42	0.02	0.09	0.07	0.96	45.97	0.23
Three Outside Up	209	97	60.42	-32.24	-0.54	-0.23	0.08	1.58	0.75	46.41	0.33
Three Outside Down	186	79	18.82	-34.22	-0.40	-0.29	0.07	-0.86	0.58	42.47	0.05*
Bullish Harami	183	74	46.01	-42.31	-0.96	-1.58	0.10	0.67	0.07	40.44	0.01*
Bearish Harami	168	73	25.27	-44.55	-1.42	-2.07	0.09	-1.19	< 0.01*	43.45	0.10
Takuri	137	63	42.55	-20.44	-0.36	1.21	0.09	1.25	0.12	45.99	0.39
Matching Low	105	40	50.07	-31.28	-1.20	-1.20	0.09	1.42	0.37	38.10	0.02*
Advance Block	65	34	16.49	-74.43	0.49	-1.70	0.15	-3.03	0.25	52.31	0.80
Downside Gap Three Methods	61	27	21.35	-16.28	-0.26	-0.47	0.06	0.42	0.59	44.26	0.44
Hanging Man	55	33	25.81	-26.99	0.76	-0.29	0.10	-0.63	0.83	60.00	0.18
Inverted Hammer	49	17	13.64	-30.68	-1.93	-2.19	0.07	-0.87	0.05*	34.69	0.04*
Upside Gap Three Methods	46	21	46.06	-14.79	-0.68	2.53	0.12	1.90	0.08	45.65	0.66
Bearish Harami Cross	40	19	14.05	-36.58	-0.78	-1.80	0.09	-1.49	0.16	47.50	0.87
Bullish Doji Star	39	19	36.82	-12.98	-0.11	0.17	0.08	2.37	0.76	48.72	1.00
Bullish Harami Cross	35	16	36.84	-20.44	-0.35	0.55	0.08	1.86	0.64	45.71	0.74
Two-Candle Shooting Star	35	16	13.01	-22.30	-0.37	-0.98	0.08	-0.52	0.48	45.71	0.74
Bearish Doji Star	33	16	14.82	-23.72	-0.61	-1.20	0.09	-0.66	0.42	48.48	1.00
Evening Star	29	13	12.29	-17.15	-0.38	-0.82	0.07	-0.81	0.50	44.83	0.71
Three Inside Down	27	9	8.42	-23.26	-1.22	-2.13	0.07	-1.22	0.06	33.33	0.12
Morning Star	24	14	12.54	-10.03	0.45	1.13	0.06	-0.06	0.37	58.33	0.54
Three Inside Up	21	11	17.64	-12.69	0.49	0.30	0.08	0.11	0.86	52.38	1.00
Thrusting Pattern	21	10	9.03	-25.67	-0.06	-2.01	0.08	-1.17	0.19	47.62	1.00
Bullish Separating Lines	20	8	168.40	-15.63	-2.23	8.67	0.40	3.54	0.08	40.00	0.50
Bearish Separating Lines	18	8	18.53	-12.38	-0.95	0.78	0.08	0.53	0.64	44.44	0.81
Dark Cloud Cover	17	10	14.76	-20.79	2.63	0.72	0.08	-0.66	0.84	58.82	0.63
Bullish Three Line Strike	15	7	24.98	-15.26	-0.32	-0.23	0.10	0.79	1.00	46.67	1.00
Bearish Three Line Strike	14	9	20.39	-37.07	1.64	-1.35	0.12	-1.51	0.52	64.29	0.42
Evening Doji Star	10	3	6.79	-17.15	-1.94	-3.17	0.07	-0.75	0.14	30.00	0.34
Bearish Stalled Pattern	10	3	13.11	-9.54	-3.37	-0.94	0.07	0.94	0.70	30.00	0.34

TABLE V. EMPIRICAL RESULTS (MA_3 + CL + HOLDING DAYS = 10)

Cryptocurrency	Total	Hit	Returns (%)				Standard Deviation	Skewness	Skewness adjusted t-test p-value	Winning rate (%)	Binomial test p-value
			Max	Min	Median	Average					
Bearish Belt Hold	489	237	40.64	-114.65	-0.28	-1.23	0.17	-2.12	0.10	48.47	0.53
Bullish Engulfing	464	207	84.94	-30.02	-0.76	0.43	0.13	1.69	0.48	44.61	0.02*
Bullish Belt Hold	453	199	225.17	-33.29	-1.26	2.29	0.23	5.32	0.01*	43.93	0.01*
Bearish Engulfing	405	169	37.94	-448.34	-1.11	-3.54	0.26	-12.18	< 0.01*	41.73	< 0.01*
Hammer	248	115	70.32	-38.22	-0.49	-0.27	0.13	0.97	0.77	46.37	0.28
Three Outside Up	209	103	58.89	-38.74	-0.30	0.15	0.12	0.68	0.84	49.28	0.89
Three Outside Down	185	88	37.12	-64.16	-0.22	-1.77	0.14	-1.50	0.07	47.57	0.56
Bullish Harami	183	79	70.58	-40.76	-0.93	-0.67	0.14	1.38	0.60	43.17	0.08
Bearish Harami	167	83	27.29	-162.08	-0.34	-6.06	0.22	-3.60	< 0.01*	49.70	1.00
Takuri	137	63	130.74	-31.50	-0.40	3.65	0.22	2.98	0.01*	45.99	0.39
Matching Low	105	45	55.79	-44.93	-0.95	-2.09	0.13	0.16	0.16	42.86	0.17
Advance Block	65	32	24.24	-132.57	-0.36	-6.42	0.25	-2.89	< 0.01*	49.23	1.00
Downside Gap Three Methods	61	24	31.12	-28.65	-1.07	-0.93	0.10	0.15	0.51	39.34	0.12
Hanging Man	55	29	26.10	-30.02	0.11	-0.45	0.13	-0.12	0.78	52.73	0.79
Inverted Hammer	49	17	18.67	-32.01	-2.28	-2.75	0.10	-0.34	0.08	34.69	0.04*
Upside Gap Three Methods	46	23	68.12	-27.01	-0.09	7.97	0.21	1.38	< 0.01*	50.00	1.00
Bearish Harami Cross	40	20	18.57	-89.14	-0.21	-7.84	0.23	-1.80	< 0.01*	50.00	1.00
Bullish Doji Star	39	17	36.87	-12.79	-0.92	-0.21	0.10	1.47	0.98	43.59	0.52
Bullish Harami Cross	35	19	70.58	-27.04	0.38	1.71	0.15	2.31	0.48	54.29	0.74
Two-Candle Shooting Star	35	15	27.00	-38.20	-2.30	-4.64	0.14	-0.47	0.04*	42.86	0.50
Bearish Doji Star	33	17	19.98	-27.19	0.07	-1.74	0.13	-0.45	0.40	51.52	1.00
Evening Star	29	13	24.48	-67.73	-1.49	-6.06	0.19	-1.68	0.02*	44.83	0.71
Three Inside Down	27	11	18.00	-29.80	-3.02	-3.00	0.10	-0.74	0.11	40.74	0.44
Morning Star	24	13	24.28	-13.18	0.06	2.39	0.10	0.56	0.22	54.17	0.84
Three Inside Up	21	12	27.45	-32.41	2.77	2.62	0.13	-0.45	0.44	57.14	0.66
Thrusting Pattern	21	9	15.16	-81.51	-2.03	-5.30	0.19	-3.01	0.04*	42.86	0.66
Bullish Separating Lines	20	8	515.58	-24.43	-1.32	29.45	1.16	3.97	0.07	40.00	0.50
Bearish Separating Lines	18	13	29.93	-12.60	4.10	4.05	0.11	0.70	0.14	72.22	0.10
Dark Cloud Cover	17	10	23.25	-37.15	2.78	0.41	0.15	-0.85	1.00	58.82	0.63
Bullish Three Line Strike	15	8	29.77	-20.61	0.89	0.31	0.13	0.48	0.88	53.33	1.00
Bearish Three Line Strike	14	7	23.90	-31.97	-1.09	-2.49	0.13	-0.51	0.47	50.00	1.00
Evening Doji Star	10	5	13.56	-23.45	-1.25	-1.81	0.10	-0.57	0.64	50.00	1.00
Bearish Stalled Pattern	10	3	24.24	-34.62	-10.20	-9.41	0.17	0.50	0.23	30.00	0.34

TABLE VI. EMPIRICAL RESULTS (MA_3 + MYR + HOLDING DAYS = 3)

Cryptocurrency	Total	Hit	Returns(%)				Standard Deviation	Skewness	Skewness adjusted t-test p-value	Winning rate (%)	Binomial test p-value
			Max	Min	Median	Average					
Bearish Belt Hold	489	215	28.74	-143.93	-0.60	-1.81	0.14	-4.41	< 0.01*	43.97	0.01*
Bullish Engulfing	464	199	110.96	-38.01	-0.80	-0.56	0.11	2.51	0.36	42.89	< 0.01*
Bullish Belt Hold	453	178	254.58	-40.17	-1.57	0.78	0.20	6.33	0.33	39.29	< 0.01*
Bearish Engulfing	407	168	29.37	-126.35	-0.77	-1.71	0.13	-2.71	< 0.01*	41.28	< 0.01*
Hammer	248	120	93.00	-39.36	-0.25	0.48	0.13	1.23	0.58	48.39	0.66
Three Outside Up	209	100	52.02	-37.30	-0.42	-0.25	0.10	0.49	0.75	47.85	0.58
Three Outside Down	186	84	50.02	-43.69	-0.44	-0.37	0.10	-0.26	0.62	45.16	0.21
Bullish Harami	183	82	93.00	-41.61	-0.45	-0.92	0.14	1.82	0.47	44.81	0.18
Bearish Harami	168	79	26.93	-74.05	-0.60	-2.83	0.14	-2.14	< 0.01*	47.02	0.49
Takuri	137	62	48.76	-31.79	-0.55	0.87	0.12	0.81	0.40	45.26	0.31
Matching Low	105	48	51.35	-42.79	-0.46	-1.20	0.12	0.42	0.40	45.71	0.44
Advance Block	65	34	19.29	-112.65	0.56	-3.26	0.22	-3.62	0.09	52.31	0.80
Downside Gap Three Methods	61	29	26.90	-26.65	-0.16	-0.44	0.10	-0.02	0.74	47.54	0.80
Hanging Man	55	29	30.00	-27.34	1.05	0.85	0.12	-0.03	0.62	52.73	0.79
Inverted Hammer	49	17	20.58	-47.41	-1.59	-2.69	0.11	-0.97	0.12	34.69	0.04*
Upside Gap Three Methods	46	22	68.93	-20.93	-0.60	4.28	0.19	1.96	0.04*	47.83	0.88
Bearish Harami Cross	40	21	14.56	-66.43	0.19	-2.85	0.15	-2.37	0.12	52.50	0.87
Bullish Doji Star	39	20	48.76	-16.49	0.52	1.47	0.11	2.03	0.33	51.28	1.00
Bullish Harami Cross	35	18	36.14	-20.85	0.51	0.91	0.09	1.08	0.59	51.43	1.00
Two-Candle Shooting Star	35	19	18.62	-32.57	1.00	-1.29	0.12	-0.67	0.49	54.29	0.74
Bearish Doji Star	33	18	13.39	-27.44	1.85	-0.83	0.09	-0.80	0.58	54.55	0.73
Evening Star	29	13	16.29	-32.00	-0.86	-2.25	0.10	-1.30	0.17	44.83	0.71
Three Inside Down	27	11	13.13	-30.43	-1.58	-2.99	0.09	-1.09	0.05*	40.74	0.44
Morning Star	24	13	25.65	-14.27	1.57	3.67	0.10	0.29	0.05*	54.17	0.84
Three Inside Up	21	2	25.65	-18.11	1.47	1.23	0.11	0.05	0.62	9.52	< 0.01*
Thrusting Pattern	21	10	15.09	-27.15	-1.69	-1.80	0.10	-0.40	0.45	47.62	1.00
Bullish Separating Lines	20	9	241.20	-20.99	-1.95	14.49	0.57	3.41	0.03*	45.00	0.82
Bearish Separating Lines	18	10	32.10	-11.62	1.48	2.12	0.10	1.35	0.31	55.56	0.81
Dark Cloud Cover	17	10	16.97	-13.18	1.47	1.36	0.08	0.13	0.57	58.82	0.63
Bullish Three Line Strike	15	7	26.63	-19.64	-0.14	-0.40	0.12	0.74	0.98	46.67	1.00
Bearish Three Line Strike	14	6	20.53	-35.67	-0.73	-2.48	0.13	-0.92	0.42	42.86	0.79
Evening Doji Star	10	4	8.14	-32.00	-1.54	-4.38	0.11	-1.59	0.06	40.00	0.75
Bearish Stalled Pattern	10	3	13.39	-11.88	-3.25	-1.91	0.08	0.63	0.65	30.00	0.34

TABLE VII. EMPIRICAL RESULTS (MA_3 + MYR + HOLDING DAYS = 10)

Cryptocurrency	Total	Hit	Returns (%)				Standard Deviation	Skewness	Skewness adjusted t-test p-value	Winning rate (%)	Binomial test p-value
			Max	Min	Median	Average					
Bearish Belt Hold	489	256	66.95	-224.53	0.97	-2.21	0.29	-2.70	0.07	52.35	0.32
Bullish Engulfing	464	213	188.60	-52.27	-0.69	1.90	0.22	1.99	0.06	45.91	0.09
Bullish Belt Hold	453	220	676.80	-59.07	-0.52	4.30	0.48	9.20	< 0.01*	48.57	0.57
Bearish Engulfing	405	184	68.13	-745.72	-0.81	-6.88	0.46	-11.05	< 0.01*	45.43	0.07
Hammer	248	109	86.61	-43.14	-2.12	-0.38	0.19	0.84	0.79	43.95	0.07
Three Outside Up	209	96	70.59	-53.29	-0.98	0.10	0.19	0.45	0.93	45.93	0.27
Three Outside Down	185	88	51.32	-123.57	-0.87	-4.07	0.24	-1.47	0.01*	47.57	0.56
Bullish Harami	183	79	86.61	-55.41	-1.69	-0.32	0.20	1.07	0.84	43.17	0.08
Bearish Harami	167	83	33.50	-282.78	-0.13	-11.05	0.41	-4.19	< 0.01*	49.70	1.00
Takuri	137	65	211.12	-43.14	-0.71	6.23	0.36	3.38	0.01*	47.45	0.61
Matching Low	105	48	50.48	-54.31	-1.38	-3.21	0.18	-0.14	0.10	45.71	0.44
Advance Block	65	31	45.68	-190.26	-0.88	-11.91	0.40	-2.32	< 0.01*	47.69	0.80
Downside Gap Three Methods	61	28	32.61	-45.65	-1.17	-0.24	0.17	-0.32	0.90	45.90	0.61
Hanging Man	55	28	30.89	-60.20	0.79	-1.09	0.19	-0.64	0.65	50.91	1.00
Inverted Hammer	49	20	30.36	-40.96	-4.06	-4.21	0.16	0.06	0.09	40.82	0.25
Upside Gap Three Methods	46	24	116.84	-41.83	1.41	15.81	0.34	1.10	< 0.01*	52.17	0.88
Bearish Harami Cross	40	22	31.36	-214.94	0.71	-14.56	0.43	-2.79	< 0.01*	55.00	0.64
Bullish Doji Star	39	17	36.76	-21.86	-4.14	-0.32	0.15	0.79	0.92	43.59	0.52
Bullish Harami Cross	35	19	86.02	-37.04	0.26	3.02	0.21	1.64	0.39	54.29	0.74
Two-Candle Shooting Star	35	15	43.11	-67.76	-2.42	-9.86	0.24	-0.56	0.01*	42.86	0.50
Bearish Doji Star	33	18	29.68	-67.50	0.68	-4.54	0.24	-1.14	0.20	54.55	0.73
Evening Star	29	11	37.20	-117.84	-1.08	-10.12	0.31	-1.78	0.02*	37.93	0.26
Three Inside Down	27	13	21.13	-54.06	-1.20	-5.00	0.18	-1.09	0.09	48.15	1.00
Morning Star	24	12	29.17	-26.97	-0.04	2.54	0.17	-0.05	0.48	50.00	1.00
Three Inside Up	21	13	29.60	-39.54	3.42	3.34	0.15	-0.84	0.44	61.90	0.38
Thrusting Pattern	21	7	27.57	-106.49	-2.68	-4.63	0.28	-2.37	0.32	33.33	0.19
Bullish Separating Lines	20	11	787.45	-45.82	1.41	45.58	1.77	3.93	0.04*	55.00	0.82
Bearish Separating Lines	18	13	42.93	-23.91	9.93	7.28	0.17	0.00	0.24	72.22	0.10
Dark Cloud Cover	17	11	35.87	-93.79	3.10	-2.50	0.29	-1.72	0.61	64.71	0.33
Bullish Three Line Strike	15	7	44.03	-26.37	-2.20	1.19	0.18	0.53	0.78	46.67	1.00
Bearish Three Line Strike	14	5	31.76	-36.60	-3.93	-4.37	0.17	0.31	0.52	35.71	0.42
Evening Doji Star	10	5	27.41	-24.11	-2.78	-1.61	0.14	0.49	0.82	50.00	1.00
Bearish Stalled Pattern	10	2	31.00	-64.92	-24.61	-22.50	0.30	0.22	0.09	20.00	0.11

return. "Winning rate" is defined as "Hit" divided by "Total", which represents the probability of producing a positive return using the pattern. The candlestick patterns with "Hit" smaller than 10 are not excluded as their sample sizes are too small.

The tables show that the binomial test p-value results of some patterns are significant at a 5% level (i.e., p-value $\leq$ 0.05), which rejects the null hypothesis H_0 and indicates the usefulness of these patterns. Of these useful candlestick patterns, however, most of their winning rates are below 50%. This reveals that a random or arbitrary decision on cryptocurrency trading may perform as good as or even better than the decision made by the candlestick patterns. There are some cases that have caught our attention:

- The Bearish Separating Lines pattern under MA_3, CL/MYR and 10 holding days has reached the highest winning rate of 72% and is statistically significant at 10% level. However, its average return is not statistically different from 0 given its high winning rate.
- The Three Inside Up pattern under MA_3, MYR and 3 holding days is statistically significant at 1% level but has reached the lowest winning rate of 9.52%. Moreover, its average return is not statistically different from 0.

Therefore, investors should be cautious in their trading strategies and decisions when these patterns emerge, as they may represent a false trading signal that could result in losses rather than gains.

On the other hand, even if there existed patterns of which their binomial test results and winning rates were significant and over 50%, the skewness adjusted t-test p-value results have shown that their average returns are not statistically different from 0. In fact, most of them produce negative returns. Overall, none of the studied candlestick patterns satisfy all the four statistical conditions. Hence, they are of little use to investors to make profits or avoid losses. The reason is probably due to the high volatility of cryptocurrencies, which cannot be well captured by candlestick patterns. On the contrary, some candlestick patterns have generated signals to investors. When these patterns that lead to negative returns appear, they should avoid cryptocurrency trading.

VI. CONCLUSIONS

In this paper, we investigate 68 candlestick patterns on 23 cryptocurrencies using statistical analysis. We find that none of the studied candlestick patterns is effective in cryptocurrency trading. In contrast, some candlestick patterns have relatively low winning rates, and they may be a false trading signal that would cause losses rather than gains in cryptocurrency trading. Our finding may serve as a reference for investors not to solely make their trading strategies and decisions on candlestick patterns. As future work, we will explore the reasons in more detail why candlestick patterns are of little use in cryptocurrency trading.

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