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Original Article

The automated equity-split cryptocurrency arbitrage strategy

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Abstract

Cryptocurrency prices frequently fluctuate, which creates price differences in each market. The price gap presents an excellent opportunity for arbitrage in cryptocurrency markets. Arbitrage occurs when a token is purchased in one market and simultaneously sold in another market for a higher price. This paper proposes the arbitrage strategy with automated equity-split cryptocurrency between the largest market and the Thai market. We program the algorithm to match order books with a fee deduction for capturing an investment position size. A suitable threshold helps prevent investment losses from other factors, such as execution risk or price slippages. The strategy is proven by verifying it with a calculated trade compared to actual execution at targeted markets. The strategy is examined in terms of profitability, accuracy, and utility. It could generate high profits in the long run. It incorporates hedging to produce approximately 225.32% APY (of $22,500 port size) without price risk. The system has positive errors, which induce more profits than the predicted results. The strategy requires automation to maximize a profit, which is infeasible with manual execution. Eventually, the proposed system achieves all aspects of the analysis.

Keywords: cryptocurrency, arbitrage, strategy, equity, market

1. Introduction

Presently, cryptocurrency markets are more widely known and used by investors to gain profits. Many newcomers are interested in this opportunity and have started to invest in it. If they do not have enough investment knowledge, they may be lost in a cryptocurrency game. However, many of them are still interested in trading or arbitrage, which has become a huge trend in Thailand and worldwide. Some investors may be concerned about the considerable expense they have lost without a good strategy. Once they cannot control their minds and do not have a suitable management plan with a stop loss and hurry to revenge a game to recover their loss rapidly, they are likely to lose more.

An interesting cryptocurrency investment strategy is arbitraging, which buys low-priced tokens from a market and sells them at a higher price to another market in a second. This will be considered a low-risk investment compared to trading without a good strategy. Arbitrage in exchanges requires several indicators to make opportunities for making profits; however, these parameters must be analyzed on time to gain profits because of the variety of them, such as what is a suitable price gap between token pairs and fees, what are token amounts, and when will it be executed.

This work demonstrates the equity-split cryptocurrency arbitrage strategy with actual execution in markets automatically. We aim to evaluate the framework in three main aspects: profitability (RQ1), accuracy (RQ2), and utility (RQ3). The profitability is determined by comparing the profit and risk from the strategy with token holding. We compute the accuracy of the system by comparing the calculated trades and the actual trades. The utility is determined by the difficulty of manual arbitrage without tools and strategy. More specifically, we use the randomness of arbitrage opportunity, trading size, and profit margin to imply the difficulty of manual arbitrage.

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2. Literature Review

2.1 Cryptocurrency and exchanges

Bitcoin (Nakamoto, 2009) is the first peer-to-peer cryptocurrency that allows anyone on the Bitcoin network to transfer Bitcoin to others. Blockchain technology was proposed as a backbone of the peer-to-peer cash system.

Several studies are available (Bariviera & Merediz-Solà, 2021) on the economic and integrated analysis of cryptocurrency. While a blockchain enhances a financial application, it also applies to other use cases. An online review system with blockchain technology promotes the credibility of information and discourages fraudulent activities (Karode & Werapun, 2021). In addition, we generate PSUCOIN (Boonpeam, Werapun, & Karode, 2020) coins to replace traditional activity hours at Prince of Songkla University, Phuket Campus. Students can use PSUCOIN in many cases, such as getting promotions from grocery stores and voting for student leaders. The number of students participating in activities increases because they are incentivized with PSUCOIN. Today, there is a large amount of cryptocurrency available on blockchains. Each of them has its functionalities. However, a common use case of cryptocurrencies today is an investment, which includes buying and selling tokens. A cryptocurrency exchange is a digital marketplace where traders can buy and sell tokens. This allows investors to convert between cryptocurrency tokens and digital cash.

An exchange can be controlled by a party. This kind of exchange is called “Centralized Exchange” (CEX), friendly for general users. It provides fast and low-cost transactions. Several centralized exchanges (e.g., Binance, FTX) are available online. Binance offers its traders a crypto wallet to keep their electronic funds. The exchange helps services assist traders in their investing decisions. There are different cryptocurrency exchanges in some countries. It does not limit or prevent investors from trading across countries; however, an issue to consider is converting cryptocurrency back to fiat currency, an original investor currency (e.g., Thai baht). That is one constraint to select exchanges for the arbitrage strategy. The centralized trading exchanges (Bitkub and Satang Pro) are well known and used by many users in Thailand. A recognized financial organization also regulates them. As a result, CEX is interesting to examine speculative opportunities.

Blockchain technology and smart contracts enable decentralized exchanges (DEX) (Alharby, Aldweesh, & Moorsel, 2018). Uniswap is a DEX protocol built on Ethereum. To be more precise, it is an automated liquidity protocol. There is no order book or any centralized party required to make trades. Uniswap is an open-source software operating based on which liquidity suppliers form liquidity pools. This method uses a decentralized pricing technique to smooth out the depth of the order book. Without the need for an order book, users may effortlessly switch between ERC-20 tokens. We analyzed the arbitrage opportunity on DEX in prior research (Boonpeam, Werapun, & Karode, 2021). Profit opportunities were determined by using the state-space search algorithm to analyze the token prices of the entire market. The arbitrage strategy can match tokens and generate profits for investors in the DEX market.

Once DEX is operated based on blockchain over a distributed network, it can be exploited using broadcast information from insider nodes, called the front running (Daian *et al.*, 2019). A front-runner will try to listen to the blockchain for eligible orders to front-run by placing enough fees to have the transaction mined faster than the target's orders, or the bot that writes those transactions can be automated. Because of its enormous popularity, users may select from various currencies to trade and earn. However, the drawback is that a price fluctuates often. This amplifies the gap for arbitrage opportunities.

2.2 Arbitrage

There are speculative strategies that involve examining and evaluating the risks associated with methods that benefit investors. Inexperienced investors can decrease their risk of losing money by studying (Ruf, 2011) and (Harvey & Liu, 2014). Speculative techniques are currently popular among investors because of a price gap in exchanges. Some articles describe what speculation is (Schwartz, 2009) and how speculating techniques may be created in a variety of sectors, such as stock matching (Krauss, 2017) and banknote conversion in the Canadian market, to enhance returns for investors (Loncarski, Horst, & Veld, 2006).

Machine learning research (Fischer, Krauss, & Deinert, 2019) is gaining popularity in finance because of its predictability, accuracy, and precision. The authors collect historical financial data to interpret the findings, and the algorithm uses a random forest for 40 cryptocurrencies. It aims to predict that a token will outperform the median of 40 tokens in 120 minutes, based on historical data from June to September 2018 and more than 100,000 trades.

The arbitrage strategy can increase investor profits by using Bitcoin as an intermediary for converting cryptocurrency to fiat money (Czapliński & Nazmutdinova, 2019) and utilizing a technique known as Automated Market Maker (AMM). Buyers and sellers bid at different rates for the commodity on a standard trading site. When other users deem the listing price appropriate, they trade, and the asset’s market price is established.

A trading algorithm, called automated triangular arbitrage (Bai & Robinson, 2019), identifies arbitrage opportunities and claims to turn a profit on average over many runs. However, it does not describe all mechanisms (e.g., position size, price management), making it difficult to follow.

2.3 Strategy and opportunity

Since its inception in 2008, Bitcoin has become a popular cryptocurrency. The authors in (David Kuo Chuen, Guo, & Wang, 2017) described the possibility of earning money using a coin as a cryptocurrency. Most investors are more interested in speculating and trading coins in the CEX and DEX marketplaces due to the potentially high returns. The authors in Chakravaram, Ratnakaram, Agasha, and Vihari (2021) and (Fauzi, Paiman, & Othman, 2020) compared the pros and cons of cryptocurrency and fiat currency. We may conclude that the advantages of tokens outweigh the disadvantages. Specifically, fiat currencies are country-specific, with each country having its own currency, making it more difficult to convert fiat money to another currency.

Cryptocurrency is kept in online digital wallets and does not require a third party to validate data or transactions. Before the creation of cryptocurrencies, speculative techniques were employed. Real estate speculation is utilized to speculate on small-scale purchases of homes and structures for future sales, according to research (Tsang, Wong, & Horowitz, 2016) in Hong Kong. There are a variety of speculative tactics available; for example, momentum trading strategies can be effective in Germany (Weil, 2017). Anna *et al.* (Obizhaeva & Wang, 2013) stated that the optimal trading strategy is complex. An arbitrage approach may be employed in the gold market (Peter, 2019). Mixing many strategies can substantially reduce execution costs. We devised the approach in the speculating section to enhance profits for investors. This is explained in the following section, based on all released papers that have been detailed about the proposed work.

3. Methodology

This section demonstrates how to optimize the cryptocurrency arbitrage execution using the equity-split strategy. The settings and procedures of the strategy are presented. We then construct models that reflect the strategy's effectiveness, which will validate the framework. Eventually, we provide the evaluation environment and workflows.

3.1 Definitions

We define the related variables used throughout this work in this subsection. These definitions will be used to explain our methodology and experimental results and analyzes. The following values correspond to this work:

1) Total Equity (E): The initial investment size.
2) Withdrawal Fee (W): The withdrawal fee is constantly assigned by the exchange platform.
3) Profit Threshold (Th): The profit threshold is the minimum percentage of the profit margin that triggers arbitrage.
4) Profit Per Round ($P = \frac{E}{4} \cdot Th$): The profit per round is determined by a quarter of the total equity (split at the wallet setup step in 3.2) multiplied by the profit threshold. Round (or row) is defined by the equity in the wallets in either side runout.
5) Cumulative Profit and Loss ($C = \sum_{i=0}^{n} P_i$): The overall profit and loss since the beginning of investing. n denotes the number of trades.
6) Maximum Drawdown ($D = \max(C_i - C_j)$, where $i < j$): The maximum decreasing rate of the investing port. It can be used to indicate investment risk.
7) Sharpe ($S = \frac{\max(C)}{D}$): The sharpe is used to validate the profitability of an investing strategy.

3.2 Wallet setup

The main purpose of the equity-split strategy is to maximize the trading speed and minimize the withdrawal cost. An arbitrager must split his equity into both exchanges equally. The equity will be divided impartially into a currency pair. For example, an investor initially has $10,000. He must split $5,000 to both exchanges (i.e., Binance and Satang Pro in this work). Half of the split equity (i.e., $2,500) is used to buy tokens (i.e., BNB and USDT). With this setup, the trading size is reduced to a quarter of the initial equity (i.e., $2,500 per trade instead of $10,000 per trade). However, the arbitrage can be executed simultaneously. The equity-split strategy can continuously work until it requires rebalancing (i.e., withdraw equity from an exchange to another exchange to retain the wallet setup). This prevents high costs from withdrawal fees.

We expect the profit per round (P) to be more than double the withdrawal cost (W). Thus, the wallet setup for the experiment is determined by the following model:

$$P \geq 2W$$

$$\frac{E}{4} \cdot Th \geq 2W$$

Such that, $E \geq \frac{8W}{Th}$

We set the profit threshold at 0.3%. This means that the system executes trades only when it finds an arbitrage opportunity with at least a 0.3% profit of trading size. The withdrawal fee for both platforms is approximately $5 per round. Thus, the model suggests using at least $13,333 as the initial equity. We set up the wallet with $15,000 in the experiment. The $3,750 worth of USDT and BNB are distributed to the exchange wallets similarly to the above example.

3.3 Arbitrage execution

Since equity has been set up on both exchanges, the execution can be flexibly operated. The system can automatically select one exchange to buy tokens and the other to sell tokens. Figure 1 displays the execution when the BNB price in Satang Pro is cheaper than Binance. Satang Pro does not support cross-pair token exchanges. Traders need to use THB as a media currency to convert tokens. As a result, the system has to convert (i.e., sell) USDT to obtain THB and then use THB to buy BNB on Satang Pro. It then sells the same amount of BNB to get USDT in Binance. If BNB is cheaper on Binance, the system will proceed with the opposite execution, as shown in Figure 2.

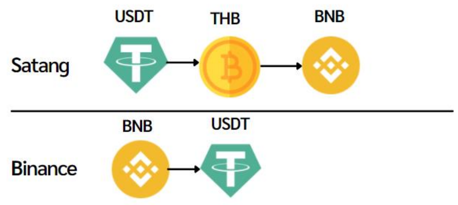

Figure 1. Satang-to-Binance

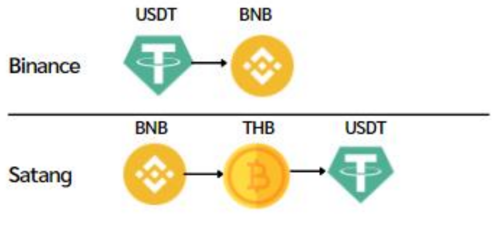

Figure 2. Binance-to-Satang

Before the execution takes place, the system has to determine the trading opportunity and structure the trade. Table 1 is utilized to calculate arbitrage opportunities.

The algorithm takes order book data (i.e., Satang BNB orders as s_bnb_ods, Satang USDT orders as s_usdt_ods, and Binance BNB orders as b_bnb_ods) and trading fees (i.e., s_fee is Satang trading fee, and b_fee is Binance trading fee) from both exchanges and attempts to simulate arbitrage similarly as the above figures. It then compares the output amounts (i.e., out1 is the output of the Satang buying side, and out2 denotes the output of the Binance buying side) of both sides to determine opportunity and execution. The system checks whether the result is above the profit threshold value. If that is the case, it executes arbitrage.

Additional considerations for real executed arbitrage are trading fees and slippages. On the one hand, the profit from a small trade might be obliterated by trading fees. On the other hand, a large trade size can be affected by slippages, which cause losses. Thus, the buying and selling outputs in Table 1 are computed using order books (including trading fees) instead of mid-price books. Table 2 demonstrates the order book calculation.

The algorithm takes order books (denoted as ods), trading fees (denoted as fees), and input amounts (denoted as inp). It iterates through order books, consumes input amount, and accumulates output. For each loop, the algorithm calculates trading volume (denoted as v) by selecting a value between the input volume (i.e., inp/od.p, where od.p denotes the order price) and order volume (denoted as od.v). It then deducts the input amount and sums up the output amount. Eventually, it returns the output amount with a fee deduction.

3.4 Data collection

The data collection procedure is implemented in the system. We isolate it from the arbitrage procedure to avoid performance degradation. Data are collected after each trade. Table 3 displays the data recorded for each row of arbitrage.

4. Results

We have been executing the system for a month (i.e., from April 27 to May 27, 2021). The collected results are analyzed to evaluate the equity-split cryptocurrency arbitrage strategy in terms of profitability (RQ1), accuracy (RQ2), and utility (RQ3). This section illustrates the execution results, which can answer the research questions.

4.1 Profitability (RQ1)

The most important result of investing is profitability. We have used $15,000 to execute the equity-split cryptocurrency arbitrage strategy for a month to demonstrate it. Figure 3 displays the profit-and-loss (PNL) comparison among the proposed strategy, BNB holding, and BTC holding. The arbitrage profits and withdrawal costs are accumulated every day during the experiment. Since half of the equity is BNB, it is affected by BNB price profit and loss (with half of the impact compared to BNB holding). The BNB arbitrage PNL is compared to the BNB holding to indicate the strategy's profitability. We also include BTC holding PNL because it is a baseline to validate the efficiency of the system.

Cryptocurrency holdings are fully impacted by the token price. They produce a high profit when the token price appreciates. In contrast, a token price fall can cause considerable losses to the investing port. BNB arbitrage is partially affected by the BNB price moving. However, with the help of arbitrage profits, it can produce a higher profit that BNB holds under unpredictable market conditions. BNB

Table 1. Calculate_opportunity

```
Algorithm 1: Calculate_opportunity (ods, fees, input)

[s_bnb_ods, s_usdt_ods, b_bnb_ods] = ods
[s_fee, b_fee] = fees
thb1 = sell(s_usdt_ods, s_fee, input)
bnb1 = buy (s_bnb_ods, s_fee, thb1)
out1 = sell (b_bnb_ods, b_fee, bnb1)
bnb2 = buy (b_bnb_ods, b_fee, input)
thb2 = sell (s_bnb_ods, s_fee, bnb2)
out2 = buy (s_usdt_ods, s_fee, thb2)
return max (out1, out2)
```

Table 2. Calculate_order_book

```
Algorithm 2: Calculate_order_book (ods, fee, inp)

out = 0
for each od in ods do
    if inp > 0
      v = min (inp/od.p, od.v)
      inp = inp - v * od. p
      out = out + v
return out * (1 - fee)
```

Table 3. Data recorded in the experiment

Name	Type	Description
time	Date	Timestamp of a trade
input	Number	Input amount of a trade
output	Number	Output amount of a trade
cal_profit	Number	The calculated profit provided by the algorithm
act_profit	Number	The actual profit from trades

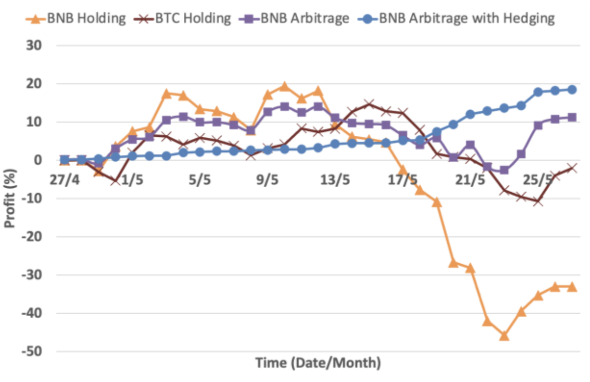

Figure 3. PNL Comparison

arbitrage with hedging decouples market risks from the investing port. Applying to hedge requires at most one-third of equity to be put on the hedging position. It constantly generates profit compared to other strategies. However, minimizing risk**s** produces the highest profit in the long run.

Sharpe ratios for each strategy use the equation from Section 3.1 (7), calculated as follows:

1) Sharpe ratio (BNB Holding) = 20/(20-(-40)) = 0.33

2) Sharpe ratio (BTC Holding) = 15/(15-(-11)) = 0.57

3) Sharpe ratio (BNB Arbitrage) = 15/(15-(-2)) = 0.88

The experimental results indicated that arbitrage strategies could generate profits under both market conditions (i.e., rising and falling token prices). In particular, arbitrage with the hedging strategy produces high returns in the long run (i.e., with 225.32% annual percentage rate projection). Consequently, profitability is achieved by the proposed strategy.

4.2 System accuracy (RQ2)

As illustrated in Section 3.3, the system computes arbitrage opportunities before executing trades. The calculated results offer a possible profit value and trading structure. If the system executes trades according to the trading structure provided by the algorithm, it is potentially profitable. However, factors (e.g., network traffic, other users' trades, and execution speed) impact the actual trade results. On the one hand, those factors can cause potentially profitable trades to be lost trades. On the other hand, a trade might give a higher profit than the calculation.

We recorded both calculated and actual arbitrage results during the experiment, which took a month. To demonstrate the system accuracy, we calculate the percent difference between both results to identify the system accuracy. Figure 4 illustrates the frequency of error rate. A number close to zero indicates that the system is highly accurate. The negative values reflect that the actual trades provide lower profit than the calculated values (i.e., profitable or loss trades). The positive values demonstrate that the real profits are higher than the calculated profits (i.e., only profitable trades).

Most trades displayed in Figure 4 have error rates close to zero. From the observation, we found that these trades are executed under normal market conditions, where the price margin is moderate. Many trades offer higher profit than the calculation since they are executed during the appreciation of the price margin. The calculation suggests that the system manages arbitrage while the profit margin expands. This condition frequently happens in the experiment since the trading sizes are small compared to the order book sizes. In contrast, negative error rates occur when the system executes trades while the market condition flips back to normal (or even worse if it flips the cheaper exchange to be the more expensive exchange). In the experiment, the internet speed does not affect the trading results much since the system checks the response of the exchange servers every time before it executes trades. However, there are many cases in which the platform does not accept requests. We must include a request repeating mechanism to solve this problem. This is a factor that produces an error rate.

According to the recorded data, the average error rate is 51.9%. Even though it can generate higher profit than expected, it is risky from an accuracy perspective because the system cannot precisely suggest results. Additionally, the system cannot ensure that the executed trades are profitable. From our observation, it is safer to add delays between each arbitrage because it can protect the system from opportunity flipping. The positive error rate ensures that the profits are higher than the profit threshold value (i.e., 0.3% in the experiment). Thus, increasing the profit threshold value can reduce the negative error rate.

The proposed framework can handle microstructural effects because the selected exchange (i.e., Binance) provides a large liquidity pool, is difficult to manipulate the price, and can be accessed every minute. The bid-ask bounce effect has both positive and negative reflections in the experiment. If the price changes in a profitable direction, the system can generate more profit. On the other hand, when the system encounters a loss possibility, the system refuses that transaction. Therefore, the risk of loss is reduced. There is a possible case in which the system detected arbitrage opportunities and lost from executing that trade affected by the bid-ask bounce effect. However, it is rarely occurred according to the results of the experiment. We cannot conclude that the system provides a highly accurate calculation by considering the error rate result. Nevertheless, the positive error rate is excellent profitability, the most important factor for investing. Furthermore, the negative error rate can be reduced by utilizing delay and profit threshold mechanisms. As a result, the system performs well with this accuracy rate.

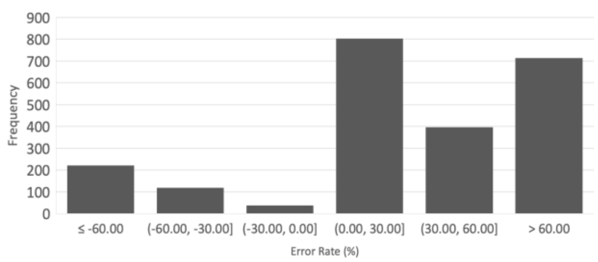

Figure 4. Error rate

4.3 Utility (RQ3)

To maximize profits from arbitrage, investors have to incorporate advanced elements into their plans and executions. The previous experimental results show that the strategy's profitability is feasible. We can achieve it by integrating advanced elements into the system, including the equity-split wallet setup, the opportunity searching tool, and the rapid automated trading server. Almost every element automatically works to gather profits whenever an opportunity exists. In this subsection, we study the utility of the system. The research question can reflect the need for automation in arbitrage strategies. In other words, the experimental results indicate the difficulty of manual arbitrage execution. We measure the system utility by comparing the automatic trading results with the possible manual trading results. More specifically, the uncertainty of the market is observed.

We first observe the correlation of cryptocurrency market essential elements, including price and trading volume, with the profit generated by the proposed system. Figure 5 displays the differential rate of the mentioned values. We collected trading volume and price data from TradingView. These values are scaled from 0 to 10 to compare their changing rates and correlation. The highest profit (25 May) in Figure 5 is 5.96% ($15,000 port size), which is 10 in the scaled value axis. Trading volume peaks at $11.49 million (19 May), and the BNB price is a maximum of $690.93 (10 May) during the experiment respectively. All three values are scaled to be fit in Figure 5 for ease of comparison.

We found that the profit generated in the experiment is correlated with market trading volumes. It can be implied that arbitrage opportunities usually exist when people trade tokens with high volumes. This information is helpful for arbitrage opportunity prediction, where the trading volume is taken to be the core component. Arbitrageurs can use the prediction tool to manage their assets more efficiently and maximize profit with a limited port size.

However, manual arbitrageurs might not be able to leverage the opportunity prediction tool since most procedures require automation. This means that they cannot efficiently execute trades even if they can predict when the profit margin exists. We further investigate the average number of trades per day the automatic system made. Figure 6 illustrates the number of trades for each hour. We aggregate data by averaging trading numbers during the experiment (i.e., 30 days), which contains a total of 2,294 trades. Since the hourly trading numbers are varied for each day, the error values are included in the figure.

The arbitrage strategy focuses on small-sized but rapid profit generation. Figure 6 emphasizes this fact. With a $200 size per trade, the system usually generates between $1 and $5 profits, which are small values compared to the investing size. Additionally, 25 out of 2,294 trades (i.e., 1.09%) are negative profit trades even if they are executed with a computer-level speed. Thus, manual trades have a greater possibility of amplifying losing trades because arbitrageurs cannot follow the speed of market volatility.

The system utility was analyzed by comparison with manual execution. Because of the randomness of opportunities, manual arbitrageurs might waste much time to obtain only low profits from arbitrage. Moreover, they might encounter many opportunities in a short period but small profits for each of them. It is infeasible to manually trade under this nature of arbitrage strategy. Since maximizing arbitrage profit with manual execution is almost impossible, we can conclude that the system achieves the utility factor. It reduces workload and increases profit-generating opportunities in an unpredictable market.

5. Conclusions

The main contribution of our work is to propose the automated equity-split arbitrage strategy, illustrating a way to gain profits. Several experimental conditions and parameters, such as the quantity of starting tokens, the value of each trade, the duration of each deal, error rates, and period are considered. Three questions are posed throughout the work; here are the results. 1) Profitability (RQ1): When arbitrage in a cryptocurrency versus holding a cryptocurrency, arbitrage can profit in the long run since a cryptocurrency price is swung. Even if a price increases or decreases, the arbitrage strategy can gain profit in both ways. 2) Accuracy (RQ2): The system was executed with a 51.90% error rate, infeasible from an accuracy perspective. However, 1,914 of 2,294 trades (83.44%) were positive errors, generating more profits than the predicted result. 3) Utility (RQ3): We determine investment periods regarding the number of trades and frequency of arbitrage profits. The results reveal that manual arbitrageurs potentially encounter rapid opportunities of 126 trades per hour, making it impossible to manually execute the strategy because of the randomness of opportunities and time to monitor and execute. Eventually, the proposed arbitrage strategy brings benefits to investors. It can be extended for broader markets to have more opportunities and lower the risk of loss for investors with no prior trading experience or speculation expertise.

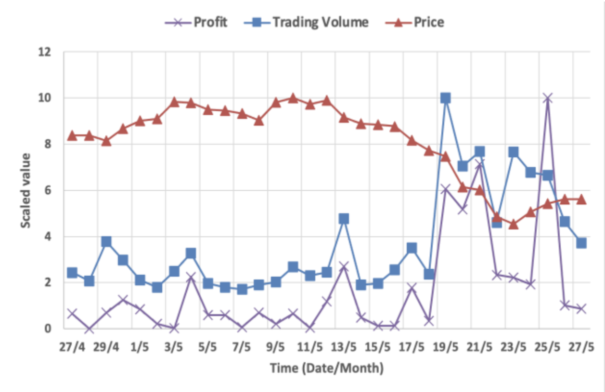

Figure 5. Correlation

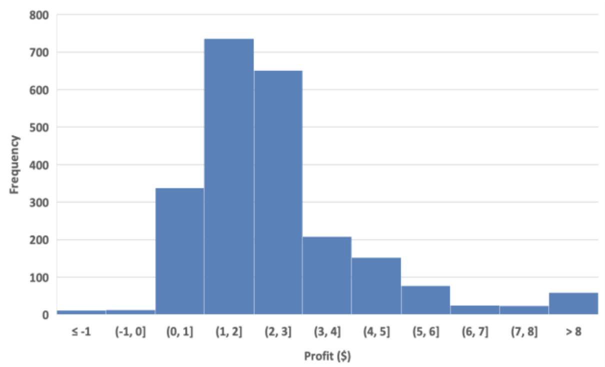

Figure 6. Profit

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