A Profit-Maximizing Strategy for Cryptocurrency Arbitrage

Naratorn Boonpeam

A Thesis Submitted in Fulfillment of the Requirements for the
Degree of Master of Science in Computing
Prince of Songkla University
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I hereby certify that this work has not been accepted in substance for any degree, and is not being currently submitted in candidature for any degree.

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ABSTRACT

In this study, the researchers examined the use of arbitrage as a strategy for identifying investment opportunities in the cryptocurrency market, specifically on decentralized exchanges (DEX) and centralized exchanges (CEX). The results of their investigation indicated that arbitrage could yield high profits and carries a lower level of risk compared to simply holding cryptocurrency. Additionally, the researchers found that dividing their equity among multiple exchanges increased profits due to the system's ability to operate more efficiently and lower withdrawal costs. The study also identified several factors that may impact the success of arbitrage, including gas prices, transaction fees, and the timing of trades. In addition to exploring arbitrage, the researchers also examined other tactics for earning profits through cross-exchange trading, using a selection of six token pairs, including UNI, SUSHI, BADGER, LINK, COMP, and CRV. Ultimately, the cross-exchange strategy demonstrated an average profit and loss (PNL) of 0.054%, which was higher than the arbitrage strategy in DEX.

Keywords: Cryptocurrency, Arbitrage Strategy, DEX, CEX, Blockchain

ชื่อวิทยานิพนธ์ กลยุทธ์การเพิ่มผลกำไรสูงสุดสำหรับการเก็งกำไรสกุลเงินดิจิทัล
ผู้เขียน นาย นราทร บุญเปี่ยม
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ปีการศึกษา 2564

บทคัดย่อ

ในการศึกษานี้นักวิจัยได้ตรวจสอบการใช้การเก็งกำไรเป็นกลยุทธ์ในการระบุโอกาสในการลงทุนในตลาด cryptocurrency โดยเฉพาะการแลกเปลี่ยนแบบกระจายอำนาจ (DEX) และการแลกเปลี่ยนแบบรวมศูนย์ (CEX) ผลการตรวจสอบสามารถระบุว่า การเก็งกำไรสามารถให้ผลกำไรสูงและมีความเสี่ยงในระดับที่ต่ำกว่าเมื่อเทียบกับการถือครองสกุลเงินดิจิทัล นอกจากนี้ นักวิจัยยังพบว่าการแบ่งส่วนทุน ระหว่างการแลกเปลี่ยนหลายรายการจะเพิ่มผลกำไรเนื่องจากความสามารถของระบบในการทำงานอย่างมีประสิทธิภาพมากขึ้นและค่าใช้จ่ายในการถอนเงินที่ลดลง การศึกษายังระบุปัจจัยหลายอย่างที่อาจส่งผลต่อความสำเร็จของการเก็งกำไร รวมถึงราคาแก๊ส ค่าธรรมเนียมการทำธุรกรรม และระยะเวลาของการซื้อขาย นอกเหนือจากการสำรวจการเก็งกำไรแล้ว นักวิจัยยังได้ตรวจสอบกลยุทธ์อื่น ๆ ในการรับผลกำไรผ่านการซื้อขายข้ามการแลกเปลี่ยน โดยใช้คู่โทเค็น 6 คู่ ได้แก่ UNI, SUSHI, BADGER, LINK, COMP และ CRV ในท้ายที่สุด กลยุทธ์การแลกเปลี่ยนระหว่างการแลกเปลี่ยนแบบกระจายอำนาจ และ การแลกเปลี่ยนแบบรวมศูนย์ แสดงให้เห็นกำไรและขาดทุนเฉลี่ย (PNL) ที่ 0.054% ซึ่งสูงกว่ากลยุทธ์การเก็งกำไรในการแลกเปลี่ยนแบบกระจายอำนาจ

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คำสำคัญ: คริปโตเคอเรนซี่ กลยุทธ์การเก็งกำไร ตลาดแบบกระจายตัว ตลาดแบบรวมศูนย์ บล็อกเชน

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CHAPTER 1

INTRODUCTION

1.1 Background and Rationale

The primary method of investing in digital currencies is through cryptocurrency trading. Due to the market's great return, more people participate in it. However, volatility is the primary drawback of the cryptocurrency market (Katarzyna 2019). An investor has no prior experience studying the market, he or she may lose money owing to unfavorable market conditions, as well as make an error. Our research investigates DEX market speculation, and the results can help explain why trading in the same or different markets is not always successful. It can help investors who lack investment expertise, according to the conclusions of the research.

It can enter and profit while reducing the amount of time it takes to find a successful market. Some people may panic according to the high amount of money they waste. People commit suicide because of the stress caused by the loss of investment costs. Thus, investigating and introducing lower-risk strategies are crucial for researchers. These studies produced the centralized exchanges (CEX) arbitrage system, which is now widely used.

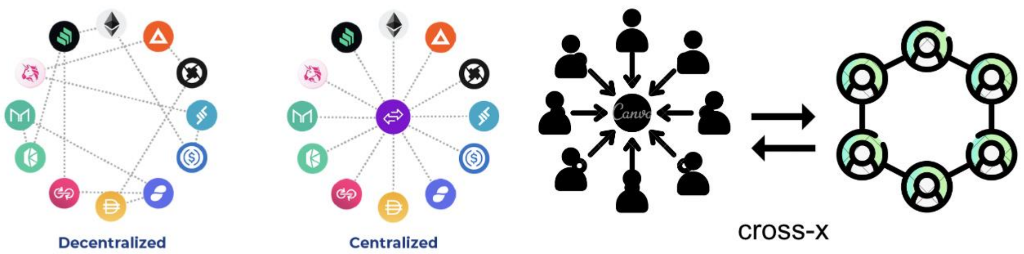


Figure 1.1 Exchange Architecture

From Figure 1.1, we have explained that each market following a centralized exchange is a market with a database for recording users' data and an intermediary for checking our data, which is different from other markets.

A decentralized exchange (DEX) is a peer-to-peer (P2P) marketplace that connects cryptocurrency buyers and sellers, and it works on the blockchain.

On the other hand, Cross-exchange is one strategy that is almost as meaningful as CEX. We change the default exchange from CEX to DEX because the price fluctuation may not be the same. Thus, to this reason, it is an advantage that allows us to create more arbitrage opportunities.

Research has not yet been done on innovations like decentralized exchanges, which came about with larger returns and dangers. In this paper, we investigate how to reduce the use of the "Arbitrage" list approach on DEX. We use and recommend a search tool that is inefficient for the market. The tool automatically determines the listed tokes highest profit route. The suggested technique is used in conjunction with a few well-known DEX platforms to determine which one will yield the highest profits in each row.

However, we look more closely at the crucial elements influencing arbitrage profit. The findings show that variables like the state of the market and port size have an impact on earnings. More significantly, enlarging the port does not always result in higher earnings.

We study and research speculation in other markets, such as the CEX market, because it can lower transaction costs more than the DEX market. In other markets, such as the CEX market, there are also external factors that affect speculation both positively and negatively.

Therefore, a change and reversal are owing to the flow of tokens in cryptocurrency every day, and new tokens are created every day that present prospects for profit. We have selected two markets: Satang Pro, the domestic market in Thailand, and Binance, the market with the biggest volume and value in the world right now. We currently regard the onset of speculation and profit-making as a serious issue. Therefore, in the final Section, we can profit from the CEX. The explanation for this inspired us to examine both speculative activities in the cryptocurrency market and develop a more intriguing and difficult proposal. Later, we can build arbitrage possibilities on CEX and DEX. We are currently considering fresh opportunities. We have picked the DEX to CEX, price difference, and volume of both markets. Arbitrum network is one of the chains that use Ethereum Layer 2 and was picked by the Exchange (DEX). Transaction costs have decreased since Arbitrum network charges lower transaction fees than other chains. Additionally, enough tokens are available to support a certain level of speculation. It opens many more chances than speculating in the same market when determining the combined price with Binance CEX. The following chapter contains a complete description of every aspect of our arbitrage.

1.2 Research Questions

RQ1: How to maximize arbitrage profit on DEX platform?

RQ1.1: Is the cross-market speculation profitable on DEX?

RQ1.2: What is the effective arbitrage strategy for DEX?

RQ2: How to maximize arbitrage profit on CEX platform?

RQ2.1: What are differences between DEX and CEX arbitrage that impact the profit?

RQ2.2: How the single market arbitrage compared to cross-market arbitrage?

RQ2.3: What factors affect arbitrage profit?

RQ3: How to maximize arbitrage profit on the Cross exchange platform?

RQ3.1: What are the factors that affect an arbitrage profit?

RQ3.2: Which strategy is more profitable between CEX strategy and DEX strategy?

1.3 Objectives

1.3.1 To study arbitrage opportunity searching tools in the decentralized finance system.

1.3.2 To compare the arbitrage capability of CEX and DEX.

1.3.3 To create a tool that can maximize arbitrage profits.

1.4 Outcomes

1.4.1 The analysis suggests that the proposed system is low-risk compared to other types of investments, such as holding.

1.4.2 The experiment results demonstrate that the proposed system can increase opportunities to speculate on the DEX.

1.4.3 According to the analysis, arbitrage profit is affected by many factors, including transaction fee, gas price, investment size, and platform mechanism.

1.5 Thesis Outline

The rest of the chapters are organized as follows: we research and discuss background knowledge and literature review in Chapter 2. Chapter 3 provides the research methodology and proposed framework. We present the system design and evaluation method in this chapter. The experiment results are illustrated in Chapter 4. We discuss the experiment result in Chapter 5. The discussion will imply the adoption of the arbitrage system in both exchanges. Eventually, we give observation, contribution and further work in Chapter 6.

CHAPTER 2

BACKGROUND KNOWLEDGE AND REVIEW OF LITERATURE

2.1 Blockchain and Smart Contract

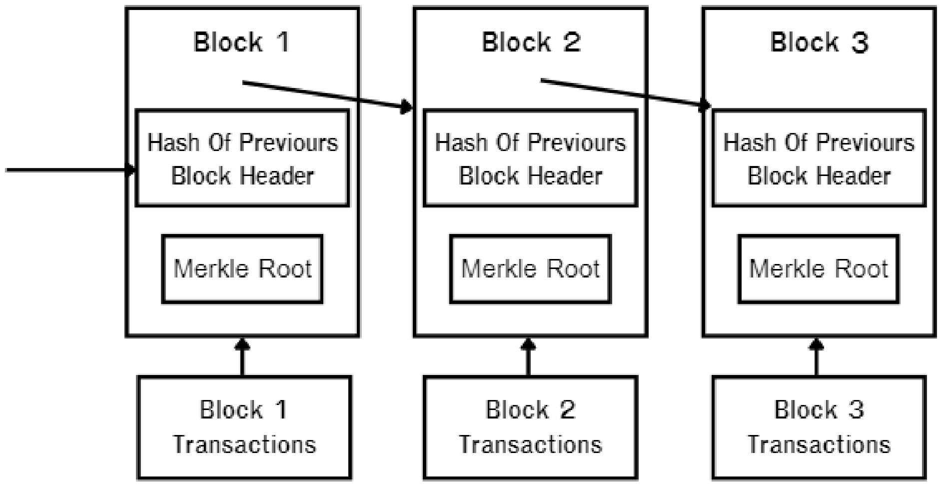


Figure 2.1 Blockchain Structure

Figure 2.1 as blocks are cryptographically connected to form a blockchain. Each block includes a transaction, a timestamp, and a cryptographic hash of the preceding block. The blockchain offers a high level of transparency and security. Bitcoin (Nakamoto 2009) is the first peer-to-peer cryptocurrency that enables token transfers between any two users on the Bitcoin network. Transactions are tracked by nodes, which record them in a block known as a blockchain. Bitcoin had reached a high of $17,249.36 at the time of writing (August 2021). It piques the attention of many developers and investors in the cryptocurrency blockchain, which is used for more than simply financial transactions. However, it is also being developed in a variety of ways.

2.2 Strategy and Opportunity

We previously described the background of blockchain technology and smart contracts. In this Section, we presented the speculative techniques which can be used by investors.

The cryptocurrency known as Bitcoin has gained popularity since its launch in 2008. The authors (David Kuo Chuen et al. 2017) presented the prospect of using tokens as cryptocurrency to make a profit. Due to the potentially high returns, most investors prefer to speculate and trade tokens on the CEX and DEX platforms. The advantages and disadvantages of cryptocurrencies and fiat money were compared by the writers in (Chakravaram et al. 2021) and (Fauzi et al. 2020) . We may conclude that tokens have more benefits than drawbacks. It is more challenging to convert fiat money into another currency because fiat currencies are country specific, and each has its currency.

Cryptocurrency can be stored in digital wallets that are accessible online and does not need a third party to verify data or transactions. Before the development of cryptocurrencies, speculative methods were used. According to studies, real estate speculation involves making small-scale purchases of houses and other buildings to sell them in the future (Tsang et al. 2016) in Hong Kong. There are other speculative strategies accessible; momentum trading strategies, for instance, can be successful in Germany (Weil 2017) (Obizhaeva and Wang 2013). However, a complex trading technique is the ideal one. An arbitrage strategy may be used in the gold market (Peter 2019). Combining multiple techniques can significantly lower execution costs. We developed the strategy of speculating to increase investor profits. In addition, a good arbitrage strategy and an understanding of investment risks will make more profits.

2.3 Arbitrage Factors and Risk

In cryptocurrency speculation, many external factors could impact the price and profit, such as price slippage, front running, transaction fee, gas, and trading amount. Researchers have examined the effects of arbitrage on the issues and the price of Bitcoin. It is also the main factor in terms of risk. As Bitcoin impacts other cryptocurrencies available on the market. Some investors used strategies for reducing the occurrence of increased speculative risk by using the technique of appropriately segmented investment portfolios (Dong and Dong 2015) (Krückeberg and Scholz 2020) (Pieters and Vivanco 2017) since the port equity split approach is employed. The price of Bitcoin and the other elements mentioned above will aid in reducing the issue of investment losses, also known as diversification.

On the other hand, it affects long-term token ownership or speculative activity. Therefore, the token distribution portfolio will assist in minimizing these issues.

Many publications have discussed various factors that could affect arbitrage, including the following: variables of size, jump, and volatility (Wang and Chong 2021) (Ahmed 2022). Alternatively, a study of centralized exchanges (CEX) such as a DEX, Kraken, and Bitstamp, where each market has a different volumes, can make opportunities to arbitrage between buying and selling in a foreign market.

Because of this, we saw a profitable opportunity. Some researchers can now develop speculative opportunities (Bruzgė and Šapkauskienė 2022a). Similarly to that, six-tokens pairs (Bitcoin, Ethereum, Monero, Dash, Litecoin, and Ripple). We have brought all 6 tokens to analyze market conditions, opportunities, and risks that affect speculation. This will be consistent with the next research, which is the analysis of the results of market conditions. and its impact which directly affects the change in the token's price (Al-Yahyaee et al. 2020) and random by using raw MF-DFA theory to determine the duration and liquidity of each token We can conclude that the market's performance is significantly influenced by high liquidity and low volatility and factors that might or might not happen are included.

We tried to examine numerous risk variables in our study, which depend on the token price at the time. All of this has been expressed by allowing us to lower the initial risk in our work. We have discussed the different markets employed in our work in each of the preceding sections. We will describe the markets in cryptocurrency we work with in the next chapter.

2.4 Cryptocurrency Exchanges

Platforms for exchanging cryptocurrencies offer profit potential for investors. For the convenience of usage, these CEX platforms keep track of user wallets and offer customer assistance. Most investors become interested in CEX typically because of this. Compared to stock trading, they can provide significant gains. However, cryptocurrency's high level of volatility comes with great risk. Prior studies have been done on risk management for cryptocurrency trading (Kim and Lee 2018).

There has been a new advancement in the blockchain industry that has the potential to quickly produce a large amount of income. The phrase is Decentralized Finance (DeFi) (Dirk A. et al. n.d.). Uniswap (Lo and Medda 2020) is a widely used technique in DeFi. It is a decentralized cryptocurrency market where the value of each token is determined by actual trades. Uniswap falls under the DEX category. Popular DEX systems used in this work include Bancor, Kulap, Kyber Network, and 1inch. DEX has a larger risk than CEX, although producing higher rewards. However, there is research that offers recommendations for DEX investment. Most of them concentrate on bitcoin trading, which is still very risky. As a result, we partition each exchange market in the manner described below.

2.5 Arbitrage in Decentralized Exchange

A DEX is a market that does not have an intermediary to handle user transactions, and it is also a distributed market for all users to monitor. They can validate transactions easily. 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 allows users to trade without intermediaries, with a high degree of decentralization and censorship resistance. Based on open-source software, liquidity providers create liquidity pools. The depth of the order book is smoothed out using this method, which employs a decentralized pricing strategy. Users can easily switch between ERC-20 tokens without the requirement for an order book.

There is no listing procedure (as CEX has) since the Uniswap protocol is decentralized. Basically, any ERC-20 token may be issued if traders have access to a liquidity pool. As a result, there are no listing costs charged by Uniswap. In certain ways, the Uniswap protocol serves as a public good. Thus, the underlying technology that inspired its implementation was first described by an Ethereum co-founder, Vitalik Buterin. The Kyber Network is a technology that allows anybody to immediately trade token. It enables merchants to accept a variety of cryptocurrencies while still receiving payment in their chosen token. It is primarily designed for Ethereum, and it follows the same principles as Uniswap to be designated as a DEX.

Thus, DEX is working based on blockchain on a decentralized network, it can be exploited using broadcast information from insider nodes, called front running (Daian et al. 2019) . Front running is a technique in conventional finance when traders or brokers execute a deal before a major order is executed. Because of the huge order's slippage tolerance, the stated trader or broker would then sell their trades higher to the large order. In traditional finance, this is extremely unlawful and immoral. Frontrunning in DEXs works the same way as traditional finance, where orders are broadcast to the blockchain for all. By paying sufficient fees to have the transaction mined faster than the target's orders or the bot that can automate the writing of such transactions, a front-runner will attempt to listen to the blockchain for appropriate orders to front-run. Users can choose from a range of currencies to trade and earn because of its tremendous popularity. However, the disadvantage is that the price varies frequently. This widens the window for potential arbitrage possibilities.

There are many publications associated with our work and describing the token cryptocurrency, speculation in this work using API data of the token price in each market that people and investors are interested in a great deal of the Top 10 at that time and analyzing the vulnerability of the price of each market as well as describing customer groups. That engages in market trading in search of arbitrage possibilities (Makarov and Schoar 2020), (Crépelière and Zeisberger 2020) gave important details regarding the state of the cryptocurrency market. We said that there are several ongoing arbitrage opportunities in exchanges due to the growth of the digital currency market. It investigated how cross-exchange arbitrage worked. According to their testing, the price differences between tokens and between countries are substantially smaller. When the price of Bitcoin rises, the price deviations rise as well.

Each country's exchanges have a unique pricing variation. On each transaction, the writers disassembled the signed volume. Their suggested framework explains the spread between exchanges for arbitrage. Finding a chance for lucrative trading is a technique known as statistical arbitrage. In that piece, the authors used machine learning to examine market pricing. As a result, early statistical arbitrage tactics based on machine learning have appeared in the United States. It supported space to forecast whether a token outperforms the cross-sectional median of all 40 tokens on minute-binned data. Lindsay X. Lin conducted extensive research on the significant advantages of DEXes (Lin n.d.). People do not have to believe in centralized authority. In decentralized services, they can manage and invest their resources. Any tokens may be listed without restriction on DEXes. A greater number of token pairs available on DEXes creates several options for profit-making. He invented DEX investment studies with his work. We adopt strategies from conventional investments for DEX. The DEX arbitrage approach is illustrated in this work.

The current popular speculation is mostly in the ETH Mainnet chain. At this point, the gas and transaction fee tend to increase day, causing the chances of arbitrage to be reduced as well. There are currently chains functioning on the Blockchain, each with its own set of benefits and drawbacks, such as Rnkeby, Kovan, and Mainnet. The ETH chain has progressed to layer 2 (Li et al. 2021) (Khalil and Dulay n.d.).

Compared to the original version, this version has cheaper transaction and gas storage expenses. Layer 2 has a quicker transaction confirmation speed than layer 1. Due to its benefits, the layer2 chain named Arbitrum (Gudgeon et al. 2020) is built on the ETH chain in our endeavor to commence market speculation on the DEX. The Arbitrum transaction costs and speed are lower than those of other chains, making it suitable for data storage and arbitrage. Arbitrum chain benefits, which include cheaper gas costs and faster transaction speeds than other chains, allow us to perceive considerable arbitrage chances. In the DEX and CEX markets, speed and precision are critical components of arbitrage. So, in our work, any arbitrage, whether it be cross-exchange or De-only, always starts with USDT since it is the most reliable and stable token and is suited for all chains.

There are many strategies today. For investors to choose and make profits investors, the accuracy is not always the same depending on the market opportunity at that time, and many factors may affect the profit of investors as well in our work, arbitrage is performed using different algorithms for arbitrage opportunities divided into two markets: the DEX and the CEX. For DEX, we have chosen Uniswap (Angeris et al. 2021) as our main profitability market since Uniswap has developed the system to Uniswap V3 (Hayden et al. 2021) (Michael et al. n.d.) making it easier to develop the system and, has developed new functions such as a function to calculate the tokens pair path where the system will randomly find the number of tokens pairs within the system according to the user input. It works similarly to the algorithm (Lyre 2020) that randomly finds all possibilities within the number of input tokens that the user enters.

Uniswap V3 is much easier and simpler to simply run the Uniswap V3 system library. However, in our work, the Permutation algorithm (Perkins and Barto n.d.) (Gao and Wang 2003) (ROBERT n.d.) (Song Xiaomei et al. 2010) was used to swap additional tokens pairs to find every possible pair by taking the original data retrieved from Uniswap V3 to increase the chances of speculating more In the last section, our work is cross-exchange speculation, it starts speculating on both markets by buying and selling across exchanges, which the opportunity depends on. The system calculates and analyzes the market's chances of being a starter. They research and evaluate the lucrative DEX market prospects, or Cyclic (Wang et al. 2022), by conducting only one market and using limited-supply currencies as opposed to our work, where various tokens pairings are utilized, and there are more tokens alternations, which increases the likelihood of arbitrage. We have tried to study the

DEX market arbitrage alone by randomizing the tokens pairs and experimenting with different markets (Levus et al. 2021) and having research that analyzes the market using data extraction through today's well-known chains such as Binance Smart Chain, Polygon Chain, and ETH chain to identify speculative opportunities (Bruzgė and Šapkauskienė 2022b). There is a study that mimics the gathering of arbitrage data from the most well-liked markets in the world.

The cryptocurrency market contains research and studies on arbitrage using notions comparable to ours. It is speculation by crossing different chains (Obadia et al. 2021) Purchasing from a different location and comparing prices with another approach that has the potential to be profitable but differs from our work by employing calculations are the best ways to generate money using a concept similar to ours. And make correct guesses based on the system's calculations.

2.6 Arbitrage in Centralized Exchange

A CEX is a marketplace where all transactions can be controlled by an exchange owner. Several exchanges, like Kyber and Binance, are currently accessible online. Binance provides users access to a cryptocurrency wallet to store their digital currency. Additionally, the exchange offers services that support traders' investment choices. The company's blockchain-based currency is called Binance tokens (BNB). In some nations, there are various cryptocurrency exchanges. Although it does not restrict or prevent investors from transacting internationally, one issue to consider is how to convert cryptocurrencies back to the fiat money of the original investment (e.g., Thai baht).

The arbitrage opportunities are not limited to the DEX market described in the previous section, there are also the CEX markets. However, there are speculative strategies that entail assessing and comparing the dangers related to practices that could be advantageous for investors. By learning or reading, novice investors can lower their chance of financial loss (Ruf 2011) (Harvey and Liu 2014). Because of a price gap in exchanges, speculative techniques are currently popular among investors. Some articles describe what speculation is (Schwartz n.d.) 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 et al. 2006) .

Because of its predictability, accuracy, and precision, machine learning research (Fischer et al. 2019) is becoming more and more popular in the financial sector. Investors can choose from a variety of tools to predict a token's price that is likely to change. The algorithm employs a random forest for 40 cryptocurrencies, and only users gather past financial data to analyze the results, the study claims. Based on historical data from June to September 2018 and more than 100,000 trades, it seeks to forecast that a token will outperform the median of 40 tokens in 120 minutes (about 2 hours).

Thus, the speculation of today is quite different. The decision to use it is up to each investor. It is thought to be an intriguing possibility and can satisfy the needs of market investors in the CEX, where the works we have cited have employed such tactics, to use fiat money as an intermediary for the exchange of speculative tokens (Czapliński and Nazmutdinova 2019) and utilizing a technique known as Automated Market Maker (AMM). It allows for the automated trading of digital assets across the liquidity pool rather than traditional buyer-seller markets. 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. This conventional market system is used to exchange stocks, gold, real estate, and most other properties. AMM, on the other hand, provides a variety of asset trading options, and it is a dedicated financial instrument for Ethereum and Decentralized Finance (DeFi).

A trading algorithm, called automated triangular arbitrage (Bai and Fred, Robinson 2019), finds chances for arbitrage and states that, on average, over many runs, it will be profitable. It is challenging to follow because it does not fully discuss all procedures (for example, position size and price management). Moreover, it never does actual trades at our tested CEXs, which may have several factors (e.g., network latency, execution delay, and numbers of arbitrageurs, etc.) affecting the arbitrage results instead of the historical dataset. In this work, Binance is selected for a target CEX, since it has a large liquidity pool. Another side of the targeted CEX is Satang Pro. It was chosen because it does not provide a well-programmed document, which results in fewer automated arbitrageurs. For this reason, a price gap between Binance and Satang will appear for a while compared to other exchanges. There is another type of speculation besides betting on the DEX and CEX. This strategy takes the price of tokens from the CEX and uses the current price to sell it on the DEX at the same price. This kind of arbitrage will be referred to as "cross-exchange arbitrage," and we will explain this in the next section.

2.7 Arbitrage in Cross Exchange

The opportunity to speculate on a dispersed market has been discussed in prior work, where the issue has related but distinct possibilities. The possibility of altering the price of digital currencies may benefit speculation, which is different from our work at utilizing all cryptocurrencies and engaging in market speculation from the CEX to the DEX markets to increase your chances as opposed to employing fiat currencies like the USD and EUR, which have fewer possibilities than cryptocurrency tokens,

Due to, opportunities can arise in both the CEX market and the DEX market and there is also research work like ours on speculation by extracting prices from the Forex market and prices from the market.

Thus, opportunities can arise in both the CEX market and the DEX market, and there is also research like ours on speculation by extracting prices from the Forex market for the analysis of results in each model as well (Nan et al. 2019). On the other hand, they use methods to divide the results into two groups, starting with the outcome study using the arbitrage triangle for speculation and the second using arbitrage in different markets and comparing the results obtained (Gandal and Halaburda n.d.). They have experimented with both speculations. Cross-market and single-market arbitrage are the two types. When we bring the differences between each job to compare between our work and their work, the number of pairs of tokens in our event is more than 3, and we will let the system be the one that controls the order of tokens for arbitrage. Our work can create more speculative opportunities. when compared with the results mentioned above.

2.8 Arbitrage in Memory Pools

In addition, to the 3 types of speculation mentioned above, there is another type of speculation, which is the extraction of transactions within a blockchain running in that chain. We can see that kind of information first, and it allows investors to increase the size and similar token pairs so that our transactions are mined first. The transaction is classified as another interesting form of speculation (Qin et al. 2021). There are many speculations that we have not researched and referenced in this work. Both new and old investors are interested in Defi markets. The more people pay attention, the more chances of speculation are increased. In the next section, we will explain an overview of the systems and algorithms.

CHAPTER 3

RESEARCH METHODOLOGY

First, this work examines the speculative strategy of our work. We speculation on the blockchain or factors such as transaction costs and speed. This section introduces the variables that we use in the algorithm. A purposeful system design of our system is also proposed. Including testing methods will be described in detail.

3.1 Methodology in Decentralized Exchange (DEX)

3.1.1 Definitions

We define the terms used throughout this study. The techniques, outcomes of our experiments, and analyses will be described using these definitions. The following values correspond to this task:

1) Token List (T): List of tokens that we have sorted for speculation.

2) Price graph (P): The price of each token pair that we speculate.

3) Current routing (n): Number of routings of selected token pairs and retrieve the price from exchange to the last token.

3.1.2 Arbitrage Procedures

This Figure 3.1 is the flow chart that we use to speculate on the DEX. The necessary variables are as follows: initial token and initial amount. When we send all 2 tokens into the system. The system will randomly select the number of token pairs until a profitable token pair is found.

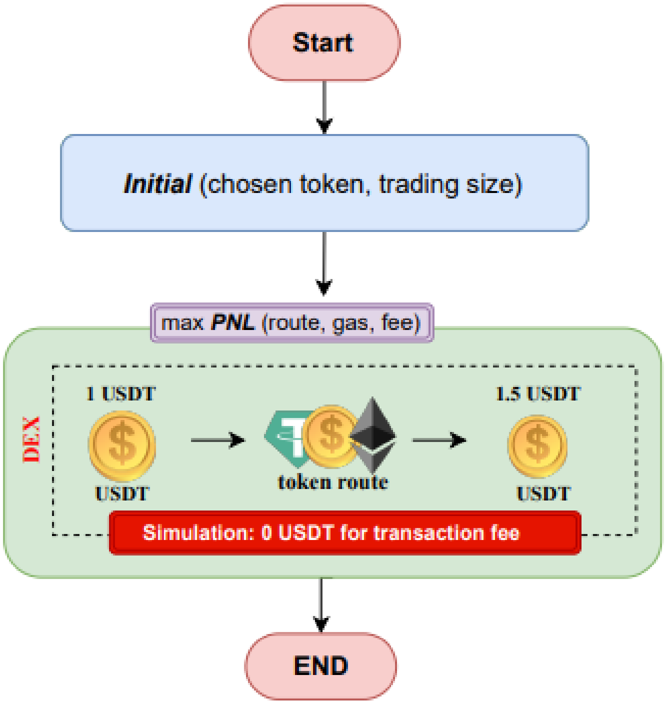


Figure 3.1 Arbitrage Decentralized architecture

We implement the arbitrage approach using the steps below: Investing is a basic technique in which investors purchase low and sell high. In this study, we utilized the most lucrative exchange of token pairings, which yielded a higher profit than our original tokens when converted. We spent 0.0001 ETH on the task, and when we converted it back in the last step, we earned 0.0002 ETH. The system will match the currency in the illustration, which is ETH -> USDC -> MKR -> ETH, as shown in Figure 3.2. They will be purchased and traded as if they were a new token. Finally, it will be changed to the original tokens and a profit will be made. If the algorithm can arbitrage at a high profit, the procedure will be taken a profit and terminate.

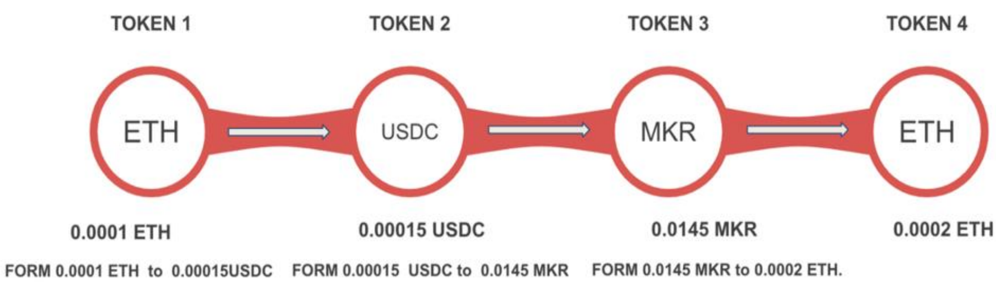


Figure 3.2 Example for swap

The state space-search algorithm is modified by the automatic arbitrage system to apply the methods. The maximum profit route can be found by searching through all of the mentioned tokens' potential directions. The equation represents the system notation (1). Let R(n!) denotes the maximum profit route from DEX exchange. The current profit is calculated by r[n_i,a]. The maximum profit routes of the remaining tokens are calculated on R(nj).

$$R(n_i) = \max_a(\{r[n_i, a], R(n_j)\}) \qquad (1)$$

State-space search is modified to create the optimized route-searching tool, and Algorithm 1 pseudo-code serves as an example of the suggested framework.

The function requires three input arguments: the current path (n), price graph (P), and tokens list (T). A user can manually define the tokens list. The prices of all token pair combinations are used to create the price graph. The chosen platform is used to retrieve the pricing for token pair prices. The initial current route is defined as an empty set. The algorithm starts calculating the profit of each route by using the get_profit(n) function, which receives a route (n) as a parameter and returns the profit in Ether. A recursive call to the searching algorithm is used to compute the remaining route revenues. The present route profit is then contrasted with the remaining route returns. When all potential routes are calculated, the maximum price route (p) is then compiled.

Algorithm 1: Maximum Profit Route Searching (R)

```
Input: T(token list), P(price graph), n(current route)
for i = 1,...,T
    r = get_profit(n+i)
    for j = 1,...,P[i]
        p = max (r, R (T, P, n_i))
return p
```

The algorithm is used to find the platform's highest-priced route. We look for the best paths on each platform and contrast them. The system can make it easier to find token routes with the highest profit margins. We assess the structure. Furthermore, by applying the suggested system, significant arbitrage aspects are researched. We used the algorithm state-space search method and pseudo code mentioned earlier to evaluate and identify the same market and different markets for searching arbitrage outcomes, which are detailed in the following section.

3.2 Methodology in Centralized Exchange (CEX)

3.2.1 Definitions

In this subsection, we define the relevant variables that are used throughout this work for your benefit. We will use these definitions to explain our technique, as well as the findings from our experiments. The values listed below apply to this work:

1) Total Equity (E): Size of the initial investment.
2) Withdrawal Fee (W): The withdrawal fee is constantly controlled by the exchange platform.
3) Profit Threshold (Th): Value is the minimum of the profit (%) margin that triggers arbitrage.
4) Profit Per Round ($P = \frac{E}{4} \cdot Th$): A quarter of the entire equity (divided at the wallet setup phase in 3.2) multiplied by the profit threshold equals the profit each round. The equity in the wallets on either side of the runout determines a round (or row).
5) Cumulative Profit and Loss ($C = \sum_{i=0}^{n} P_i$): The total gain or loss since the start of investing. The number of deals is indicated by (n).
6) Maximum Drawdown ($D = \max(C_i - C_j),\ where\ i < j$): The investment port's maximum rate of decline. It can be used to represent the risk of an investment.
7) Sharpe ($S = \frac{\max(C)}{D}$): The value that is used to confirm whether a given investing plan is profitable.

3.2.2 Wallet Setup

The equity-split strategy's primary goals are to maximize trading efficiency and reduce withdrawal costs. An arbitrager must divide his ownership equally between the two exchanges. A currency pair will get an unbiased distribution of the equity. An investor, for instance, starts with $10,000. He must allocate $5,000 among the two trades (i.e., Binance and Satang in this work). Tokens are purchased with $2,500 of the split equity (i.e., BNB and USDT in this work). This configuration lowers the trading amount to one-fourth of the beginning equity ($2,500 each trade as opposed to $10,000 per trade). The arbitrage can, however, be carried out concurrently.

The equity-split technique can continue to be used until rebalancing is necessary (i.e., withdraw equity from one exchange to another exchange to retain the wallet setup). This avoids incurring exorbitant withdrawal fees. We anticipate that the profit of each round (P) will exceed the withdrawal cost (W). The experiment's wallet setup is thus governed by the model below:

$$P \geq 2W$$

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

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

The profit cutoff was established at 0.3%. This indicates that the algorithm only places trades when it discovers an arbitrage opportunity that offers a minimum 0.3% trading size profit. For both systems, the withdrawal charge is roughly $5 for each round. As a result, the model advises employing an initial equity of at least $13,333. For the experiment, we loaded $15,000 into the wallet. Similar to the case above, the $3,750 worth of USDT and BNB are dispersed to the exchange wallets.

3.2.3 Arbitrage Execution in CEX

Since equity has been set up on both exchanges, the execution can be flexibly operated. The system can automatically select one exchange to buy the token and the other to sell the token. Figure 3.4 displays the execution when the BNB price in Satang is cheaper than Binance. Satang does not support cross-pair tokens. Traders need to use THB as a media currency to convert tokens. As a result, the system must 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 3.3.

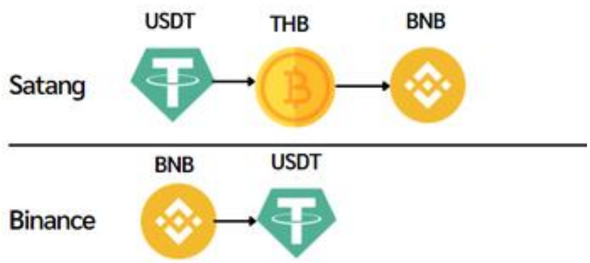


Figure 3.3 Arbitrage Procedure (Satang as the buying side)

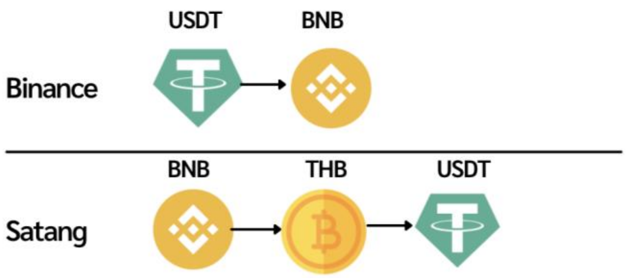


Figure 3.4 Arbitrage Procedure (Binance as the buying side)

The system must identify the trading opportunity and structure the transaction before the execution happens. Calculating the availability of arbitrage uses algorithm 2.

```
Algorithm 2: Calculate_Oppotunity (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)
```

The algorithm uses order book data from both exchanges (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) to simulate arbitrage like the above figures. The opportunity and execution are then determined by comparing the output amounts of the two sides (out1 represents the output of the Satang buying side and out2 represents the output of the Binance buying side). The system determines if the outcome exceeds the profit criteria. In that circumstance, arbitrage is carried out.

Trading commissions and slippages are additional factors to take into account for actually executed arbitrage. On the one hand, trading commissions may completely wipe out a fair trade's profit. Due to this, slippages might negatively impact a high trade size and result in losses. As a result, order books (which include trading costs) are used to calculate the buying and selling outputs in Algorithm2 rather than mid-price books. The calculation of the order book is shown in Algorithm 3.

Algorithm 3: 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)
```

Algorithm 3 requires input quantities, trading fees (referred to as *fees*), and order books (referred to as *ods*) (denoted as *inp*). It cycles through order books, uses up input, and builds up output. The algorithm chooses a value between the input volume (i.e., *inp/od.p*, where *od.p* stands for the order price) and order volume to calculate trading volume (denoted as *v*) for each loop (denoted as *od.v*). The output amount is then added up after the input amount has been subtracted. In the end, it returns the output amount less the cost.

Table 3.1 Data recorded in the experiment

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

The system has the data collection process in place. For the sake of not degrading performance, we segregate it from the arbitrage process. Following each trade, data is gathered.

3.3 Methodology in Cross Exchange (CROSS-X)

This section gives an overview of the proposed ASCEX and describes the data modeling and profit maximization algorithms, with details as follows.

3.3.1 Arbitrage System Overview

Figure 3.5 describes the overview of the proposed ASCEX strategy, which consists of parameter initialization and processes involving profit maximization on a CEX and a DEX. The series of processes aim to search for the trading paths in which the arbitrageur obtains the best opportunity from the initial parameters given by the arbitrageur.

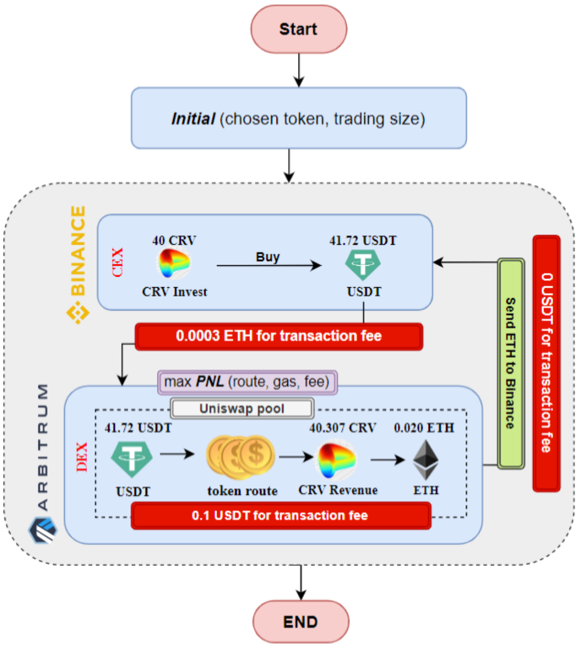


Figure 3.5 Arbitrage strategy of cross-cryptocurrency exchanges

First, the user parameters are initialized, including the user's token and trading size. At Binance, the USDT is obtained from CRV Invest. After that, the trading is only done on the Arbitrum platforms, which allows us to search through multiple tokens; the trading route that gives a maximum per- centage of profit and loss (PNL) will be chosen. For example, an investment worth 40 CRV has increased to 40.307 CRV while trading on a DEX using the proposed ASCEX strategy.

Finally, the CRV revenue will be converted to ETH and sent back to Binance. These processes can be done repeatedly to continue the cross platforms arbitration. Algorithms for maximizing the PNL are described in the following sections.

3.3.2 Preparation

Any blockchain transaction performed on a DEX requires gas (i.e., transaction fee). Gas is one of the most crucial factors in arbitrage. In this research, we choose the Arbitrum Chain because it is a layer-2 technology; hence, it offers fewer transaction fees and is faster than the Ethereum Mainnet (Robinson, 2020), which is a layer-1 technology.

Arbitragers will need wallets on both CEX and DEX. In the Binance wallet (CEX side), we convert FIAT (THB) to CRV tokens. In the Arbitrum wallet (DEX side), we convert CRV to ETH, then directly bridge tokens to Binance without fees. Note that, Binance waives the trade-in fee to attract more investors to the platform.

3.3.3 Profit and Loss Calculation

In this section, we explain methods used to calculate profit and loss from arbitration using the ASCEX cross-exchange arbitrage strategy. The following variables and functions in Table 3.1 will be used throughout the section.

Table 3.2 Variable and function terminology

Term	Description
E_{CEX}	A CEX trading function which takes CRV as input and provides USDT as output.
E_{DEX}	A DEX trading function which takes USDT as input and provides CRV as output.
CRV	An amount of CRV tokens, where **CRV_{invest}** refers to the invest-ment, and **$CRV_{revenue}$** denotes the revenue
$USDT$	An amount of USDT tokens, where **$USDT_{init}$** refers to the initial investment.
$f(x_{route_i})$	A function to obtain a maximum amount of the trading token from an exchange route, denoted x_{route_i}, in DEX.
fee	Binance trading fee, cross (bridge) fee, or gas fee.
$Profit$	The arbitrage profits.
$PNL(\%)$	Percentage of Profit and Loss.

Equations (1) - (4) explain calculations of various variables required for the max_{pnl} module in Figure 3.4 to search for the best trading route. We begin with CEX, by choosing CRV as an investment CRV_{invest}, fixing trading size (i.e., 40 USDT), and then computing the exchanged value from *E_DEX (CRV, USDT)* and fee_{trade} from Binance as in Equation (1).

$$USDT_{init} = E_{DEX}(CRV_{invest}, USDT) - fee_{trade} \quad (1)$$

At DEX, the $USDT_{init}$ from E_{cex} is used to find different token routes which maximize a profit by receiving more $CRV_{revenue}$ (compared to CRV_{invest}) after deducted the fee_{gas} as shown in Equation (2).

$$CRV_{revenue} = E_{DEX}(USDT_{init}, argmax_x(f(x_{route_i}) - fee_{gas})] \quad (2)$$

Note that the value of $CRV_{revenue}$ will be estimated to USDT for comparison with the $USDT_{init}$. Equation (3) calculates *Profit it* as follows.

$$\begin{aligned} Profit &= CRV_{revenue} - CRV_{invest} - fee_{cross} \\ &= [E_{DEX}(USDT_{init}, argmax_x(f(x_{route_i}) - fee_{gas})] \\ &\quad - [E_{CEX}(CRV_{invest}, USDT_{init}) - fee_{trade})] - fee_{cross} \end{aligned} \quad (3)$$

Finally, the $CRV_{revenue}$ will be converted to ETH to bridge back to Binance when we obtain profit greater than the fee to convert $CRV_{revenue}$ to ETH. Additionally, we have to pay fee_{cross} which is a fee for bridging from CEX (Binance) to DEX (Arbitrum); however, no fee is required for bridging back from DEX to CEX. We calculate PNL (%) by dividing the *Profit* by initial investment CRV_{invest} as shown in Equation (4).

$$PNL(\%) = \frac{Profit}{[CRV_{invest}]} x100 \quad (4)$$

3.3.4 PNL Maximization Algorithms

Algorithm 4 traverses all given token routes to find the best possible route that maximizes the PNL. This step is done before executing the actual trading transaction. Three (3) input parameters are (i) token list which consists of all available target tokens on DEX, (ii) input that denotes the input amount of tokens, e.g., 40 USDT, and (iii) fee which refers to a current gas fee in the network.

Algorithm 4 : search_all_routes(token_list, input, fee)

```
routes = generate_route(token_list)
repeat:
    for each route, do
    profits_i = Quote_Exact_Input (route, input, fee)
until search_all_route
return (routes, profits)
```

Firstly, routes are generated from a permutation of the token list. Using *Quote_Exact_Input (route, input, fee)*, each route is then picked and verified for its availability (Uniswap, 2022). Then, we check route availability using the fetcher function to verify the profit now. The availability check is repeated until all generated routes are covered. Then ASCEX checks if the net profit (i.e., revenue deducted gas fee) is greater than the profit threshold of 0.3 CRV. The *swapRouter.exactInput()* function in Algorithm 4 basically trades on the actual market using the trading route from Algorithm 5. To minimize the effects of the fluctuation on gas fees, price slippage, network latency, and other factors, the profit threshold is set to 0.3 CRV.

Algorithm 5 : trade (route, input, fee)

```
while route in routes do
    amountIn = ethers. utils. parseUnits (input, route_tokenDecimal)
    swapRouter = SwapRouter_factory. connect(routerAddr, accountAddr)
    params = {route, fee, receipient,deadline,amountIn,amountOutMin}
    swapRouter.exactInput(params)
end while
```

Variables, namely *amountIn*, *swapRouter* and params, are required for the *swapRouter.exactInput()* function. All details of variables and parameters are explained in Uniswap developer document. Previously, we have mentioned algorithms and all the necessary things have already been done. In the next section, we will discuss the results of our work.

CHAPTER 4

EXPERIMENTAL RESULT

On various token routes from within an exchange and among well-known exchanges, trading earnings will be compared. Transaction fees, petrol prices, and market conditions are just a few of the variables considered. The experiment's findings are finally presented.

4.1 Decentralized Exchange (DEX) Experiments

4.1.1 Arbitrage on Different Token Routes Within an Exchange

We begin trading on a token route by choosing from a variety of Uniswap routes (DEX). To be included in the token pathways, we manually select the well-known listed tokens ETH, DAI, USDT, MKR, and BAND. Three token routes are 1) "ETH ⟶ DAI ⟶ USDT ⟶ ETH", 2) "ETH ⟶ DAI ⟶ MKR ⟶ ETH" and 3) "ETH ⟶ DAI ⟶ BAND ⟶ ETH" referred to as token routes 1, 2, and 3 in turn, as shown in Figure 4.1. Investors lose money from these arbitrages, as seen by the trading outcomes from the three token routes. Since identifying the high-profit token routes is one searching challenge that is difficult to be done by hand-selecting, investors confront the problem of choosing token routes to win the market.

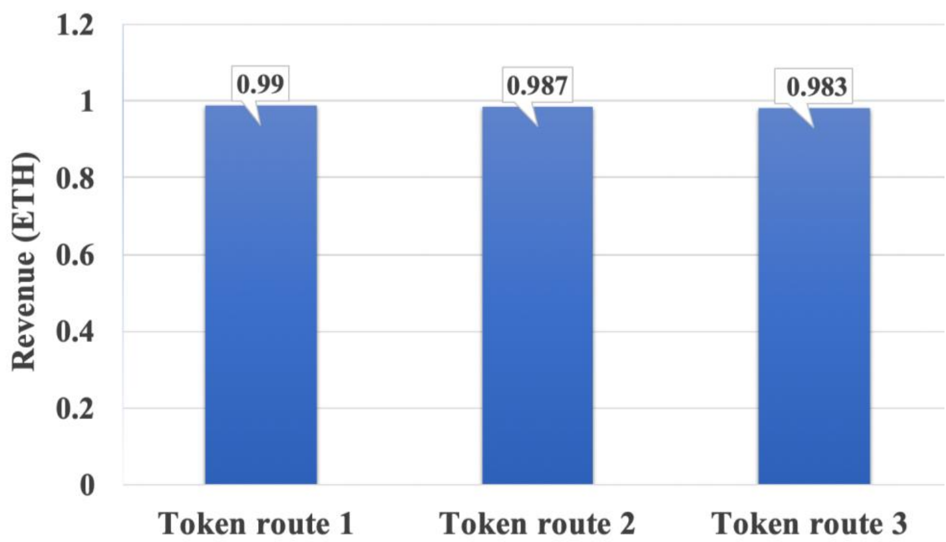


Figure 4.1 Trading profits on different token routes within Uniswap

4.1.2 Arbitrage on The Same Token Route Among Different Exchanges

Considerable risk of loss exists when trading tokens in a token route without knowledge of the price and related factors. Algorithm 1 is implemented as a tool to quickly retrieve the price for investors, and it is used to determine the routes for choosing tokens. The result of the intriguing token route is"ETH ⟶ MKR ⟶ OMG ⟶ USDT ⟶ ETH". As seen in Figure 4.2, this token route is traded on well-known exchanges. We discovered that 1Inch (DEX) provides investors with profit for arbitrage, whilst other exchanges continue to lose money due to the experiment.

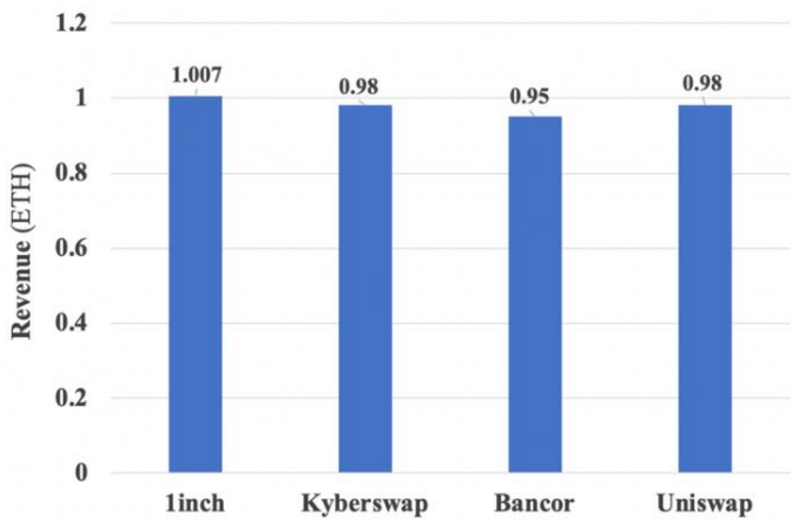


Figure 4.2 Trading profits same token routes within the different exchange

4.1.3 Trading Environment

To increase revenues in this environment, several criterias are considered.

1) Portion size: 1 ETH is the token value utilized in exchange trades. To make more money, investors also trade larger amounts, such as 10 ETH, 100 ETH, or more. However, a process known as an automated market maker (AMM) in the market automatically modifies token pair prices based on supply and demand. Large portion sizes do not result in higher earnings. However, as shown in Figure 4.3, it causes investors to lose their profits.

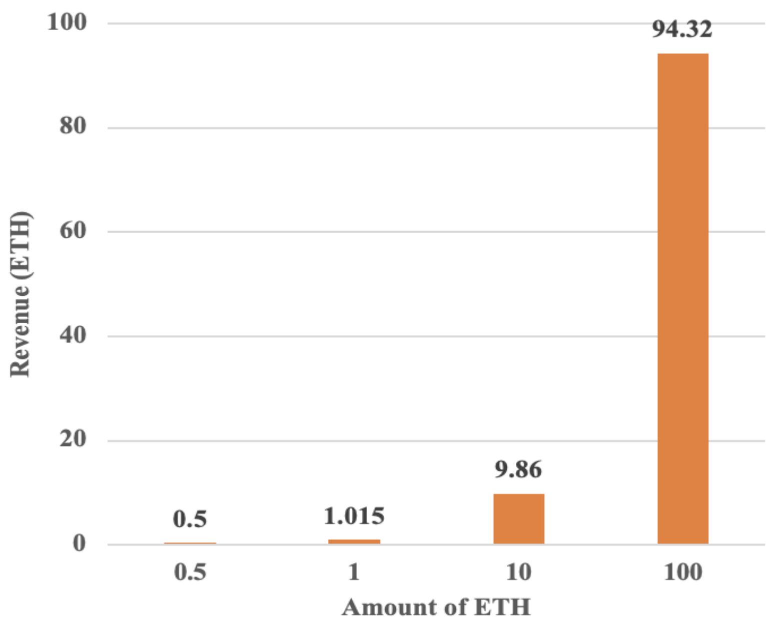


Figure 4.3 Trading revenue in different portion sizes

2) Transaction fees: These fees may have an impact on trading earnings. The gas price and the value of the gas utilized are used to determine the transaction charge. The aggregate values of costs from numerous transactions are shown in Table 4.1. The trading outcome indicates that, when compared to the high volume of token exchange, the transaction charge has less of an impact on profits.

Table 4.1 Review posting transaction cost

Transaction fee	1inch	Kyber	Bancor	Uniswap
Avg	0.112	0.057	0.016	0.98
Max	0.338	0.214	0.059	0.986
Min	0.020	0.0156	0.0050	0.98
S.D.	0.097	0.040	0.0112	0.001

3) Other factors to consider: Token exchange price is a crucial variable to increase earnings since, as 1inch (DEX) demonstrates, it delivers greater profits than other exchanges even if it charges the highest transaction fee.

One aspect that affects the outcome of the trade is the price effect (also known as price slippage). The price impact will be lessened if an exchange can offer a sizable liquidity pool. The transaction charge excludes the liquidity fee. The sum of all revenues is nevertheless determined by all variables. Due to the constant cost of the transaction fee and the very low volume of token exchange, it is challenging to turn a profit.

On the other hand, excessive token exchange volume is not advised due to price slippage and the percentage of exchange liquidity costs. Finding an appropriate volume (sweet spot) that yields higher money is the essence of arbitrage.

4.2 Centralized Exchange (CEX) Experiments

For a month, we have been using the system (i.e., from April 27 to May 27, 2021). To assess the equity-split cryptocurrency arbitrage technique, the acquired data is analyzed.

4.2.1 Profitability

The most important result of investing is profitability. We have been using $15,000 to execute the equity-split cryptocurrency arbitrage strategy for a month to demonstrate it. Figure 4.4 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.

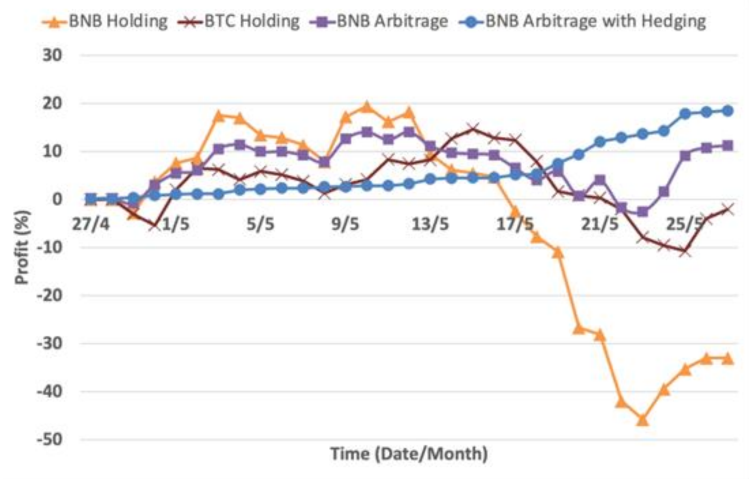


Figure 4.4 PNL Comparison

The token price has a significant impact on cryptocurrency holdings. When the token price rises, they make a large profit. In contrast, a decline in token price might result in significant losses for the investing port. The BNB price change has some impact on BNB arbitrage. However, under unstable market situations, it can generate a bigger profit than BNB holds with the aid of arbitrage profits.

BNB arbitrage with hedging decouples market risks from the investing port. Applying to hedging requires at most one-third of equity to be put in the hedging position. It constantly generates profit compared to other strategies. However, minimizing risks produces the highest profit in the long run. Sharpe ratios for each strategy use the equation from Section 3.2.1, 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 findings suggested that arbitrage tactics could be profitable in both types of market environments (i.e., rising and falling token prices). Long-term arbitrage with the hedging approach yields high profits (i.e., with a projected annual percentage rate of 225.32%). Consequently, the suggested technique produces profitability.

4.2.2 System Accuracy

As illustrated in Section 3.2.3, 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, there are factors, such as network traffic, other users' trades, and execution speed, that impact the actual trade results. On the one hand, those factors can cause potentially profitable trades to be lost trades and trade might give a higher profit than the calculation.

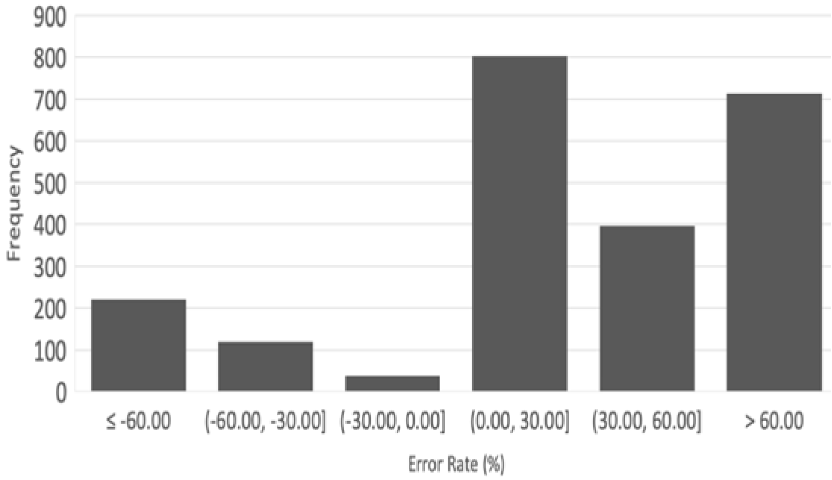


Figure 4.5 Error Rate

We recorded both calculated and actual arbitrage results during the experiment, which took a month. To demonstrate the system's accuracy, we calculate the percent difference between both results to identify the system accuracy. Figure 4.5 illustrates the frequency of the 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 actual profits are higher than the calculated profits (i.e., only profitable trades).

Most trades displayed in Figure 4.5 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 executes 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 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, (e.g., 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 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. However, the positive error rate is excellent in the profitability aspect, which is 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.

4.2.3 Utility

To maximize profits from arbitrage, investors must 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's 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 the cryptocurrency market's basic elements, including price and trading volume, with the profit generated by the proposed system. Figure 4.6 displays the differential rate of the mentioned values. We collected trading volume and price data from Trading View. These values are scaled from 0 to 10 to compare their changing rates and correlation. The highest profit in the Figure is 5.962% ($15,000 port size), which is scaled to be 10. Trading is $11.498 million peak, and the BNB price is a maximum of $690.93 during the experiment. Both values are also scaled in the same way as the arbitrage profit value.

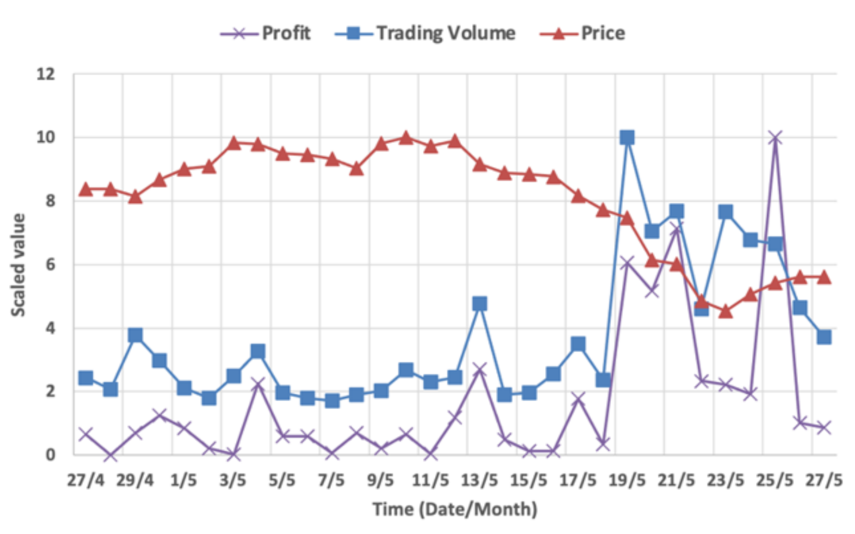


Figure 4.6 Correlation Between Basic Elements and Arbitrage Opportunity

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 if 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 4.7 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.

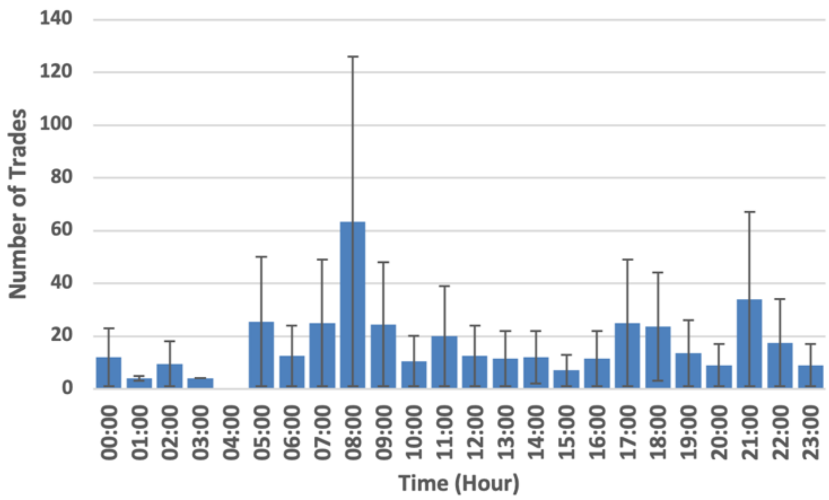


Figure 4.7 Number of Trades per Hour

4.3 Cross Exchange (CROSS-X) Experiments

The main goal of arbitration is to gain as much profit as possible. In this experiment, (1) we do arbitrage in DEX only, (2) Cross exchanges, and (3) eventually compare profits from (1) and (2), respectively. We then examined the profit and loss (PNL) for each strategy.

4.3.1 Arbitrage in DEX

The arbitrage system started from USDT, swapped to other tokens using the routing algorithm described in Section 3.3.1 and then exchanged back to a higher amount of USDT.

We observed the maximum percentage of the average PNL from arbitraging was about 0.017, as swapping tokens in each hop costed transaction fees. Figure 4.8 compares PNL between different numbers of trading hops. It shows that the higher number of hops generated less PNL. For instance, an average of 4.3 hops generated just below 0.02% PNL, whereas 5.0 hops generated only 0.003% PNL.

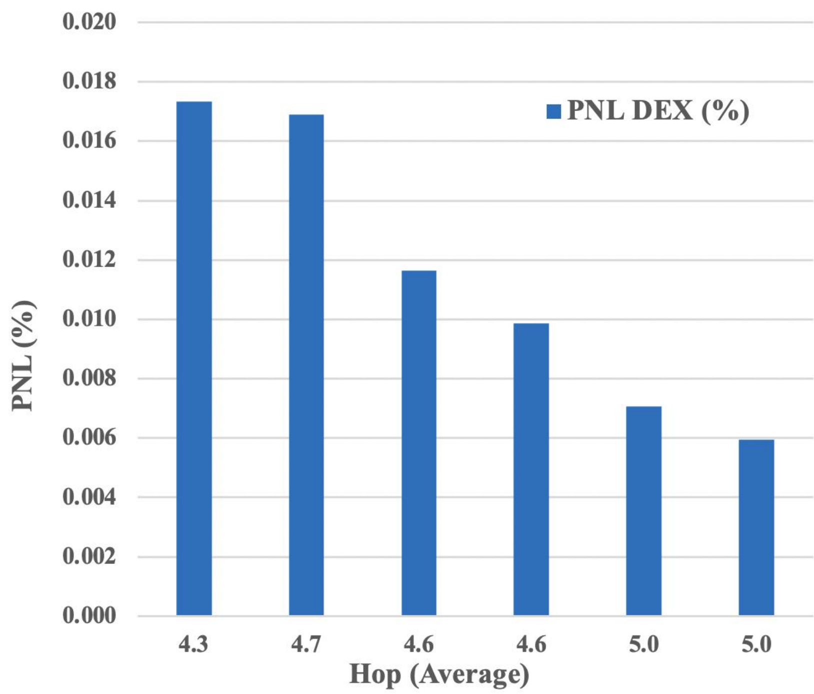


Figure 4.8 Percentage of average PNL and average hops on DEX

First, we needed to check the token's availability on CEX (Binance) and DEX (Arbitrum). All five token pairs (UNI, CRV, COMP, BADGER, LINK, and SUSHI with USDT) were chosen because they were supported on both exchanges and could be market inefficient from their prices. The aim was to find token pairs before going to perform the cross-exchange arbitration.

The token size was fixed to 40 USDT for all USDT token pairs. We bought an investment token in CEX and sold it on DEX using a trading route calculated from ASCEX to earn a profit. The results in Figure 4.9 show revenues from six (6) different pairs; we observed that only USDT-CRV generated a positive revenue (earning 40.7 from 40). Therefore, we chose CRV to speculate on cross-exchanges and measure the percentage of PNL.

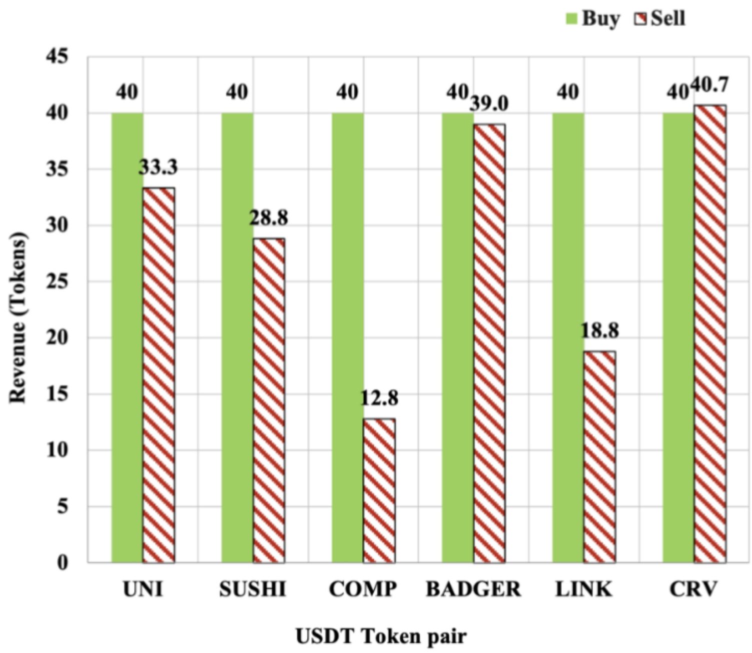


Figure 4.9 Arbitrage among USDT token pairs

4.3.2 Arbitrage Position Size For a Sweet Spot

In many situations, position sizing affects trading success. Due to the dynamic nature of the market, one cannot simply tell what position size is the best for investing. The straightforward method to find the sweet the spot is trial and error. We examined different position sizes from 20 to 200 USDT to answer the question of what the sweet spot is the trading position. In Figure 4.10, all arbitraging token pairs had an equal value of 40 USDT.

The result reveals that only the position size of 40 USDT yielded positive revenue, i.e., 0.6 CRV. A smaller or larger size caused losses. While the too-small position size gave negative profit due to the transaction fees, the bigger investment also caused the token price to increase.

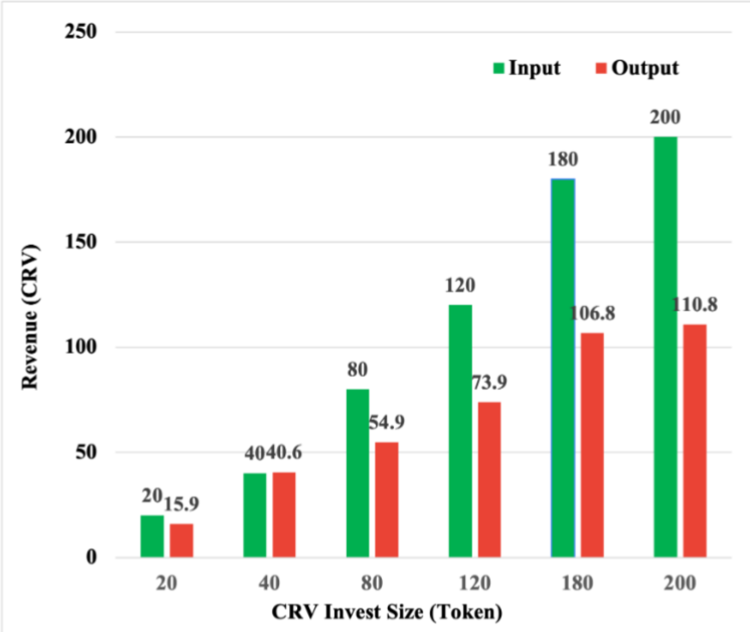


Figure 4.10 CRV investment size sweet spot

4.3.3 PNL on Cross Exchanges

The results from the cross-exchange arbitrage are shown in Figure 4.11. We invested using CRV token and earned up to 0.054% PNL during 14-19 August 2022. The average number of hops ranged from around 3 to 4 hops, which was like the average number of hops on DEX (see Figure 4.10), depending on fee_{gas}.

Finally, we checked for the profit by calculating the CRV earned on DEX compared to the initial investment CRV. However, the process of taking back the revenue was not automated. This was because Binance (CEX) did not buy CRV from DEX. Hence, we needed to convert the CRV to ETH before moving the asset from the Arbitrum back to Binance. This process was done manually when we earned more than the minimum fee of 0.0003 ETH (approximately 0.4 USD).

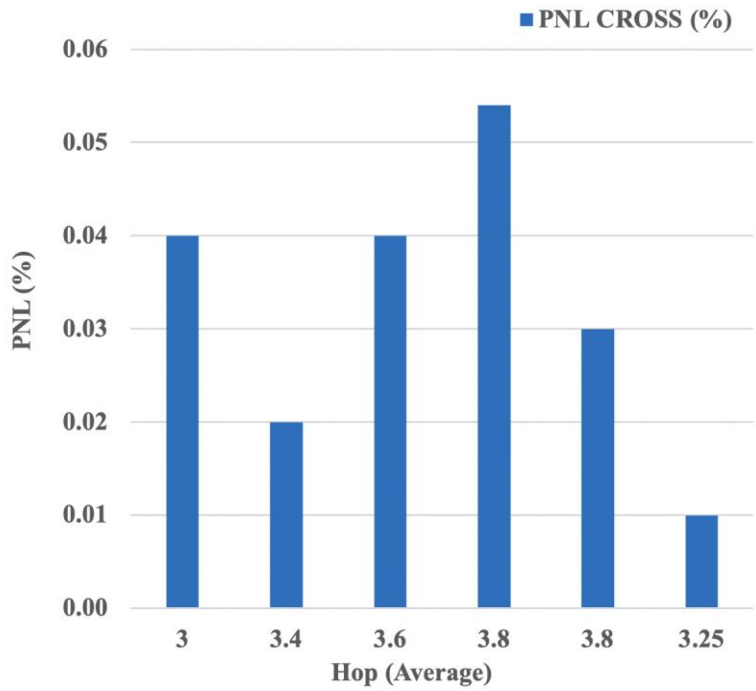
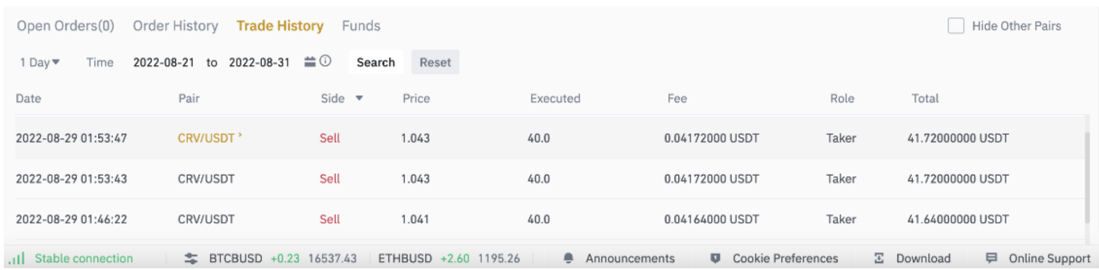


Figure 4.11 Percentage of average PNL and average hops on DEX

4.3.4 Examples of the Actual Trade

Figure 4.12 demonstrates an example trading screenshot on Binance. The ASCEX sold 40 CRV and received 41.72 USDT, and immediately exchanged 41.72 USDT with WETH. In the end, we received 40.30 CRV from the trading on the DEX, as shown on Arbitrum. Note that the Arbitrum transaction was shown in UTC timezone while the Binance transaction was a local time in Bangkok (GMT+7).



Open Orders(0) Order History Trade History Funds Hide Other Pairs

1 Day Time 2022-08-21 to 2022-08-31 Search Reset

Date	Pair	Side	Price	Executed	Fee	Role	Total
2022-08-29 01:53:47	CRV/USDT	Sell	1.043	40.0	0.04172000 USDT	Taker	41.72000000 USDT
2022-08-29 01:53:43	CRV/USDT	Sell	1.043	40.0	0.04172000 USDT	Taker	41.72000000 USDT
2022-08-29 01:46:22	CRV/USDT	Sell	1.041	40.0	0.04164000 USDT	Taker	41.64000000 USDT

Stable connection BTCBUSD +0.23 16537.43 ETHBUSD +2.60 1195.26 Announcements Cookie Preferences Download Online Support

Figure 4.12 Trade on CEX – Binance

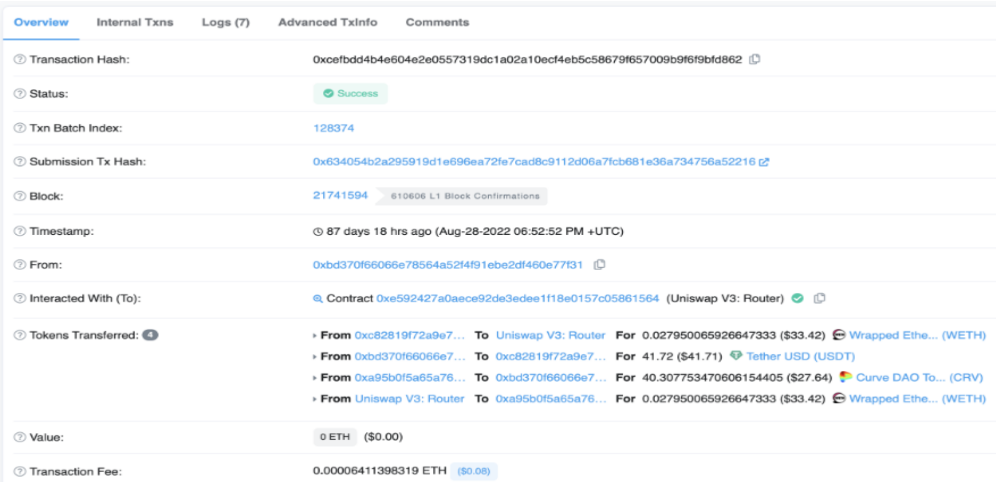


Figure 4.13 Arbitrage on DEX – Arbitrum

4.3.5 DEX and Cross Exchange Arbitrage Comparison

In comparison, Binance provided high liquidity and volatility with all tokens available in the Arbitrum chain. Hence, the arbitrage cross-exchange strategy should offer a better opportunity than the DEX-only approach in terms of PNL. The experimental result in Figure 4.14 confirmed our hypothesis. The percentage of PNL on the cross-exchange compared to the one on DEX is better. Throughout the whole time that we conducted this experiment, the cross-exchange outperformed the DEX-only approach. Particularly, the cross-exchange approach performed the best during 14-19 Aug 2022; it yielded up to 0.054% PNL. Arbitrage on cross exchanges opens more opportunities to gain profits over DEX at 0.95% PNL in a month.

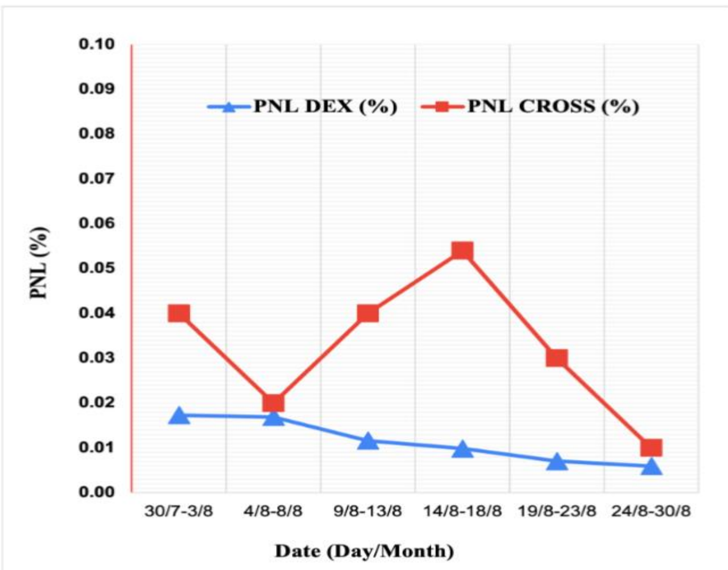


Figure 4.14 PNL comparison between DEX and Cross

CHAPTER 5

DISCUSSION

This section discusses the issues we encounter and includes discusses, throughout data collection, and the variables affecting speculation and outcome collection, which we discuss in the next section.

5.1 The arbitrage System on DEX

The experimental results show the potential of this strategy to speculate on blocks or in different markets. We use results from section 4.1 to discuss this section. The results are satisfactory because there is a profitable market. In addition, we have explained other related factors in the next section.

5.1.1 Principles Necessary for The Implementation The Arbitrage in DEX.

The results of analyzing and collecting speculative data in DEX concluded that the system can only speculate on certain token pairs or certain markets. We have selected a niche market that is highly respected and has many trusted users. There are other factors that we have not studied enough: Front runner sandwich attack, and flash loan. All factors affect all speculation.

5.1.2 Mistakes in Researching Insufficient Information

Although we first focused on a small number of markets, there are now more DEX markets than when we first began our research. Many investors want to speculate more by using an auto program for arbitrating. Thus, we have done our analysis in this work; therefore, it is possible that the data we gather is inaccurate or done more slowly than other investors' automated methods. With the growing number of tokens, the likelihood of speculation may exceed what we first calculated.

5.2 The Automated Equity-Split Crypto Currency Arbitrage Strategy

After we have already described how to engage in DEX speculation. There are other market sectors that may also be lucrative and include various internal and external influences.

5.2.1 Market Selection

In our work on “3.2.3 Arbitrage Execution in CEX”, we have explained the outcomes, and our chosen market segments are Binance and Satang. Nowadays, there are more market opportunities as well, including the token pairs that we mainly use are BNB and USDT. We use this strategy of our work to speculate on the CEX market, you do not need to use the BNB USDT token pair like us. Due to, there are also a few other tokens that may be more profitable in our work. This part may be a mistake that we started to research and did not cover all of them.

5.2.2 Mistakes in Our Strategy

We control our systems by using algorithms and need time to execute transactions every time. It might not be equal, which would be errors in speculation.

When we buy from Binance and sell them back to Satang, it may get some mistakes i.e. price fluctuation. In the event of issues with delayed token transfers, the system already assesses the chances. As a result, it can lose money after the transfer from the Binance market to Satang is finished.

5.3 Cross-cryptocurrency Exchange on Arbitrage System

To the best of our knowledge, even though there exist previous arbitrage strategies in cryptocurrency markets, it is very difficult to compare the performance between each of them. This is because there are too many uncontrollable factors affecting arbitrage opportunities. Also, several papers need to publish all setup parameters like position size, equity, duration, token route, network chain, etc.

Some arbitrage approaches fix a token route path to do arbitrage for simplicity, while our work searched among tokens in DEX or even cross DEXes to extend arbitrage opportunities. Regarding the evaluation method, we believe that doing the actual trade experiment is the most effective way to confirm that all related factors are considered. Although we must compete with other arbitrageurs or bots in the real markets with limited resources, we still get profits from speculation with our cross exchanges experiment.

To confirm the novelty of this research, we have tried our best to compare previous strategies in DEX, CEX, or Cross exchanges by categorizing them as summarized. Our paper is the only work that proposes a solution based on cross exchanges, supports dynamic token routing, and most importantly evaluated on the real cryptocurrency markets. Although the result shown in section 4.3 is not very high. This is because we had limited trading budgets. Still, the accumulative % PNL is interesting due to low-risk investment and offers comparable % PNL to other greater investments with similar risk.

Table 5.1 Arbitrage approach comparison

Solution	**Exchange**	**Dynamic route**	**Evaluation**
Cyclic arbitrage; (Wang et al. 2022)	DEX	No	Simulation
Trading and arbitrage; (Makarov and Schoar 2020)	DEX	No	Simulation
Arbitrage system; (Boonpeam et al. 2021)	DEX	No	Simulation
Formalization MEV; (Obadia et al. 2021)	DEX	Yes	Simulation
Dark forest; (Qin et al. 2021)	DEX	Yes	Actual trade
Equity split; (Boonpeam et al. 2022)	CEX	Yes	Actual trade
Triangular; (Bai and Fred 2019)	CROSS	No	Simulation
Bitcoin; (Nan et al. 2019)	CROSS	No	Simulation
Using Fiat; (Czapli´nski and Nazmutdinova 2019)	CROSS	N/A	Simulation
The Automated Arbitrage Strategy of Cross Cryptocurrency Exchanges (Section 3.3)	CROSS	Yes	Actual trade

CHAPTER 6

CONCLUSION

6.1 Remarks and Observations

6.1.1 Decentralized Exchange (DEX)

We attempt to provide a framework for DEX speculation using algorithm-based concepts such as state-space-search to rapidly retrieve the token price. Being present at this event entails more than just showcasing the arbitrage system on DEX but also showing gains from token trials traded on various DEX. Furthermore, DEX refers to important in-market components like 1inch, Kyber, Bancor, and Uniswap, where we have experimented with modifying the number of input tokens and tried to change the route in each exchange. Eventually, this system used an identical set of tokens.

The 1-inch market provides the most earning potential. Currently, arbitration in exchanges or other routes depends on the current market price as well as the price of the token pair, there might not always be profit regarding arbitrage factors and risk. This element enables us to begin developing a system and generating opportunities for speculation. The next part is a summary of our work's experimental findings.

6.1.2 Centralized Exchange (CEX)

Our primary area of development focuses on providing automated arbitrage strategies across many markets. We demonstrate how to gain profit and factors that affect our system, like the number of starting tokens.

The token price and duration of each transaction between CEXs are obtained by considering several factors such as error rate, limit, trading time, etc. When we trade cryptocurrencies as opposed to storing them long-term gains from speculation are possible due to the volatility in cryptocurrency prices.

Even if the price goes up or down, our approach allows the arbitrage method to be successful in both directions; a 51.9% error rate was calculated; 1,914 out of 2,294 trades (83.44%) had positive mistakes when calculated using orders and produced greater profits than what was anticipated.

6.1.3 CROSS Exchange

We have been trying to speculate in both the DEX market and the CEX market. The challenges of bringing knowledge from the first and the second publications increase the opportunity to arbitrage across the exchanges and bring the results obtained compared to speculation in the same market. Finally, it can be concluded that cross-market speculation can make more profits than speculation in DEX.

Due to factors and the opportunity to make a profit on the side of CEX and DEX has different volumes and prices. We chose the Arbitrum chain because it has a small number of arbitrageurs and fewer transaction fees.

6.2 Contributions

All the potential in our work, starting with data collection and analysis from DEX (Boonpeam et al. 2021) and CEX (Boonpeam et al. 2021), has led to a variety of outcomes. We start with the journal's inaugural issue

Online review systems can be applied with blockchain technology (Karode and Werapun 2021). In addition, we generate PSUCOIN (Boonpeam et al. 2020) token to replace traditional activity hours. Because relatively few students participate in inactivity, this is an important problem at the Prince of Songkhla University Phuket campus. Students will receive tokens only when they are participating in activities. PSUCOIN helps create a cryptocurrency ecosystem that is used in the arbitrage system on DEX (Boonpeam et al. 2021). The arbitrage system provides opportunities for investors who would like to arbitrage on CEX or DEX. Investors can be highly profitable by pulling the prices of the tokens from Uniswap, which is the most famous DEX marketplace. The price from Uniswap is used for analysis and calculation. The state-space search method assesses the token prices throughout the entire market to identify profitable opportunities. In the DEX market, the arbitrage approach might match tokens and bring in returns for investors. Investors can check historical transactions from a smart contract and a transaction flow in advance without intermediaries (e.g., banks). The parties will have previously agreed to a mechanism for conducting such transactions. This breakthrough affects a traditional banking model. A smart contract was born from the idea that blockchain could be used to record an actionable contract on its own. There is no need for a mediator or to use employees to sit and inspect documents. All of these allow computer programs to manage these actions automatically. From these advantages, research has analyzed the advantages and disadvantages of security-related smart contracts. At this point, blockchain and smart contracts are the main components in cryptocurrency exchanges. Online review systems can be applied with blockchain technology. In addition, we generate PSUCOIN tokens to replace traditional activity hours.

Because relatively few students participate in inactivity, this is an important problem at the Prince of Songkhla University Phuket campus. Students will receive tokens only when they are participating in activities. PSUCOIN helps create a cryptocurrency ecosystem that is used in the arbitrage system on DEX. The arbitrage system provides opportunities for investors who would like to arbitrage on CEX or DEX. Investors can be highly profitable by pulling the prices of the tokens from Uniswap, which is the most famous DEX marketplace. The price from Uniswap is used for analysis and calculation. The state-space search method is used to assess the token prices across the board to identify profitable opportunities. The DEX market's arbitrage approach can match tokens and bring in returns for investors. Investors can check historical transactions from a smart contract and a transaction flow in advance without intermediaries (e.g., banks). The parties will have previously agreed to a mechanism for conducting such transactions. This breakthrough affects a traditional banking model. A smart contract was born from the idea that blockchain could be used to record an actionable contract on its own. There is no need for a mediator or to use employees to sit and inspect documents. All of these allow computer programs to manage these actions automatically. From these advantages, research has analyzed the advantages and disadvantages of security-related smart contracts (Alharby et al. 2018). At this point, blockchain and smart contracts are the main components of cryptocurrency exchanges and contents of the CEX and DEX markets have been described.

6.2.1 From the experiment collecting results in the DEX market, four markets were randomly drawn: 1inch, Kyberswap, Bancor, and Uniswap. We use the same tokens pairs: ETH -> MKR -> OMG, USDT, ETH, with the most prominent being the 1inch market. More profitable than other markets by amount since we started with 1 ETH for test data. Based on the original result that was profitable in the 1-inch market, we tried to change the amount from 1 ETH to a value amount. We try to change amount of input such as 0.5 ETH, 10 ETH, and 100 ETH, where the result is the number of different sites. The profit amount is not guaranteed to investors and with other related factors which we have already described in the section risk.

6.2.2 The results of arbitrage in the DEX market are quite satisfactory for us. On the topic on which we speculate in the CEX market, the result is that using our system can be more profitable than holding high-value tokens. That is, it is at 10% when compared to holding BTC, and BNB, with results in BNB holding at -35% or holding BTC alone at 0.5%. In my work, have a few percentage error rates, which makes it possible to trust our system as well.

6.2.3 In our final section, we combine our information from both markets to make cross-market predictions. There will be 2 strategies in our job that are the best result for only DEX arbitrage is 0.017%, with an average HOPS count of 4.9-5.1. CROSS -X arbitrage follows, with the best result of 0.054% and an average HOPS count of 4.9-5.1. Due to this, by comparing the result with the prior DEX arbitrage and CROSS-X. The cross-market arbitrage outcomes can be more profitable than the only DEX arbitrage.

6.3 Further works

This thesis can be developed further on the following topics:

Research on arbitrage in CEX and a DEX is currently being done. Cross-chain speculating is therefore novel. However, we believe that doing trials with actual users is the best method to assess whether the system we designed for users to test the results can truly be used as we calculated.

Finally, investing in and out of NFT is seen as a speculative strategy. Therefore, we can purchase and sell NFT to speculate if we can correctly forecast the moment and opportunity.

BIBLIOGRAPHY

Ahmed, W. M. A. (2022). "Robust drivers of Bitcoin price movements: An extreme bounds analysis." *The North American Journal of Economics and Finance*, 62: 101728. doi : 10.1016/j.najef.2022.101728.

Alharby, M., A. Aldweesh, and A. van Moorsel. (2018). "Blockchain-based Smart Contracts: A Systematic Mapping Study of Academic Research (2018)." *2018 International Conference on Cloud Computing, Big Data and Blockchain (ICCBB)*, 1–6. Fuzhou, China.

Al-Yahyaee, K. H., W. Mensi, H.-U. Ko, S.-M. Yoon, and S. H. Kang. (2020). "Why cryptocurrency markets are inefficient: The impact of liquidity and volatility." *The North American Journal of Economics and Finance*, 52: 101168. doi : 10.1016/j.najef.2020.101168.

Angeris, G., H.-T. Kao, R. Chiang, C. Noyes, and T. Chitra. (2021). "An Analysis of Uniswap markets." *Cryptoeconomic Systems*, (1). doi : 10.21428/58320208.c9738e64.

Bai, S., and Fred, Robinson. (2019). "Automated Triangular Arbitrage: A Trading Algorithm for Foreign Exchange on a Cryptocurrency Market." *Degree Project*.

Boonpeam, N., W. Werapun, and T. Karode. (2020). "Student Activity Credit Framework (PSUCOIN)." *2020 - 5th International Conference on Information Technology (InCIT)*, 249–253. Chonburi, Thailand.

Boonpeam, N., W. Werapun, and T. Karode. (2021). "The Arbitrage System on Decentralized Exchanges." *2021-18th International Conference on Electrical Engineering/Electronics, Computer, Telecommunications and Information Technology (ECTI-CON)*, 768–771. Chiang Mai, Thailand.

Bruzgė, R., and A. Šapkauskienė. (2022). "Network analysis on Bitcoin arbitrage opportunities." *The North American Journal of Economics and Finance*, 59: 101562. doi : 10.1016/j.najef.2021.101562.

Bruzgėė, R., and A. Šapkauskienė. (2022). "Dataset for Bitcoin arbitrage in different cryptocurrency exchanges." *Data in Brief*, 40, 107731. doi : 10.1016/j.dib. 2021.107731.

Chakravaram, V., S. Ratnakaram, E. Agasha, and N. S. Vihari. (2021). "Cryptocurrency: Threat or Opportunity." *ICCCE 2020*, Lecture Notes in Electrical Engineering, A. Kumar and S. Mozar, eds., 747–754.

Crépelière, T., and S. Zeisberger. (2020). "Arbitrage in the Market for Cryptocurrencies." *SSRN Journal*. doi : 10.2139/ssrn.3606053.

BIBLIOGRAPHY (Continued)

Czaplinski, nT., and E. Nazmutdinova. (2019). “Using FIAT currencies to arbitrage on cryptocurrency exchanges.” *Journal of International Studies*, 12(1). doi: 10.14254/2071-8330.2019/12-1/12.

Daian, P., S. Goldfeder, T. Kell, Y. Li, X. Zhao, I. Bentov, L. Breidenbach, and A. Juels. (2019). *Flash Boys 2.0: Frontrunning, Transaction Reordering, and Consensus Instability in Decentralized Exchanges*. Retrieved December 1, 2022 from *https://arxiv.org/abs/1904.05234*

David Kuo Chuen, L., L. Guo, and Y. Wang. (2017). “Cryptocurrency: *A New Investment Opportunity?*” *JAI*, 20 (3),16–40. doi: 10.3905/jai.2018.20.3.016.

Dirk A., Z., A. DouglasW, and B. Ross P. (n.d). “Decentralized Finance.” 32. doi: 10.1093/jfr/fjaa010.

Dong, H., and W. Dong. (2015). “Bitcoin: Exchange Rate Parity, Risk Premium, and Arbitrage Stickiness.” *Journal of Economics, Management and Trade*, 105–113. doi: 10.9734/BJEMT/2015/13308.

Fauzi, M., N. Paiman, and Z. Othman. (2020). “Bitcoin and Cryptocurrency: Challenges, Opportunities and Future Works.” *The Journal of Asian Finance, Economics and Business*, 7(8), 695–704. doi: 10.13106/JAFEB.2020.

Fischer, T., C. Krauss, and A. Deinert. (2019). “Statistical Arbitrage in Cryptocurrency Markets.” *JRFM*, 12(1), 31. doi: 10.3390/jrfm12010031.

Gandal, N., and H. Halaburda. (n.d). C*an We Predict the Winner in a Market with Network Effects? Competition in Cryptocurrency Market.* Retrieved December 1, 2022 from https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2832836

Gao, J., and D. Wang. (2003). *Permutation Generation: Two New Permutation Algorithms.* Retrieved December 1, 2022 from https://arxiv.org/abs/cs/0306025

Gudgeon, L., P. Moreno-Sanchez, S. Roos, P. McCorry, and A. Gervais. (2020). S*oK: Layer-Two Blockchain Protocols*. Retrieved December 1, 2022 from https://eprint.iacr.org/2019/360.pdf

Harvey, C. R., and Y. Liu. (2014). “Evaluating Trading Strategies.” *The Journal of Portfolio Management*, 108–118.

Karode, T., and W. Werapun. (2021). “Robustness against fraudulent activities of a blockchain-based online review system.” *Peer-to-Peer Netw. Appl.* doi : 10.1007/s12083-021-01225-z.

BIBLIOGRAPHY (Continued)

Katarzyna, C. (2019). *Cryotocurrencues: Opportunities, Risks and Challenges for Anti-corruption Compliance Systems.* Retrieved December 1, 2022 from https://digitalmoneyforum.biz/wp-content/uploads/2020/05/09_Cryptocurrencies_AntiCorruption_K.Ciupa_.pdf

Khalil, R., and N. Dulay. (n.d). *Adaptive layer-two dispute periods in blockchains.* Retrieved November 8, 2021 from https://eprint.iacr.org/2020/1601

Kim, C. Y., and K. Lee. (2018). "Risk Management to Cryptocurrency Exchange and Investors Guidelines to Prevent Potential Threats." *2018 International Conference on Platform Technology and Service (PlatCon)*, 1–6. Jeju: IEEE.

Krauss, C. (2017). "Statistical Arbitrage Pairs Trading Strategies: Review and Outlook." *Journal of Economic Surveys*, 31(2), 513–545. doi: 10.1111/joes.12153.

Krückeberg, S., and P. Scholz. (2020). "Decentralized Efficiency? Arbitrage in Bitcoin Markets." *Financial Analysts Journal*, 76(3), 135–152. doi : 10.1080/0015198X.2020.1733902.

Levus, R., A. Berko, L. Chyrun, V. Panasyuk, and M. Hrubel. (2021). "Intelligent System for Arbitrage Situations Searching in the Cryptocurrency Market" *Modern Machine Learning Technologies and Data Science Workshop. Proc. 3rd International Workshop (MoMLeT&DS 2021).*

Li, K., Y. Tang, J. Chen, Y. Wang, and X. Liu. (2021). "TopoShot: uncovering Ethereum's network topology leveraging replacement transactions." *Proceedings of the 21st ACM Internet Measurement Conference*.Virtual Event: ACM.

Lin, L. X. (n.d). *Deconstructing decentralized exchanges*. Retrieved November 8, 2021 from https://assets.pubpub.org/ob89i66u/61573938834913.pdf

Lo, Y., and F. Medda. (2020). "Uniswap and the Rise of the Decentralized Exchange." *SSRN Journal*. doi: 10.2139/ssrn.3715398.

Loncarski, I., J. ter Horst, and C. Veld. (2006). *The Convertible Arbitrage Strategy Analyzed.* Retrieved November 8, 2021 from https://pure.uvt.nl/ws/portalfiles/portal/779871/98.pdf

Lyre, H. (2020). "The State Space of Artificial Intelligence." *Minds & Machines*, 30(3), 325–347. doi: 10.1007/s11023-020-09538-3.

Makarov, I., and A. Schoar. (2020). "Trading and arbitrage in cryptocurrency markets." *Journal of Financial Economics*, 135(2), 293–319. doi: 10.1016/j.jfineco.2019.07.001.

BIBLIOGRAPHY (Continued)

Michael, N., R. Rithvik, M. Daniel J., and P. David C. (n.d). *Strategic Liquidity Provision in Uniswap v3.* Retrieved October 24, 2021 from https://arxiv.org/ abs/2106.12033

Nakamoto, S. (2009). *Bitcoin: A Peer-to-Peer Electronic Cash System.* Retrieved October 24, 2021 from https://bitcoin.org/bitcoin.pdf

Nan, Z., T. Kaizoji, Z. Nan, and T. Kaizoji. (2019). “Bitcoin-based triangular arbitrage with the Euro/U.S. dollar as a foreign futures hedge: modeling with a bivariate GARCH model.” *QFE*, 3(2), 347–365. doi: 10.3934/QFE.2019.2.347.

Obadia, A., A. Salles, L. Sankar, T. Chitra, V. Chellani, and P. Daian. (2021). *Unity is Strength: A Formalization of Cross-Domain Maximal Extractable Value.* Retrieved October 24, 2021 from https://arxiv.org/abs/2112.01472

Obizhaeva, A. A., and J. Wang. (2013). “Optimal trading strategy and supply/demand dynamics.” *Journal of Financial Markets*, 16 (1): 1–32. https://doi.org/10.1016/j.finmar.2012.09.001.

Perkins, T. J., and A. G. Barto. n.d. “Heuristic Search in Infinite State Spaces Guided by Lyapunov Analysis.”

Pieters, G., and S. Vivanco. (2017). “Financial regulations and price inconsistencies across Bitcoin markets.” *Information Economics and Policy*, 39,1–14. doi: 10.1016/j.infoecopol.2017.02.002.

Qin, K., L. Zhou, and A. Gervais. (2021). *Quantifying Blockchain Extractable Value: How dark is the forest?.* doi:10.48550/ARXIV.2101.05511.

Ruf, J. K. D. (2011). “Optimal Trading Strategies Under Arbitrage.” *Ph.D. Thesis, Graduate School of Arts and Sciences, Columbia University*, 119.

Song Xiaomei, Changxiu Cheng, and Zhou Chenghu. (2010). “Research on permutation generation algorithm based on sorting.” *The 2nd International Conference on Information Science and Engineering*, 1–4. Hangzhou, China.

Tsang, C.-K., W.-K. Wong, and I. Horowitz. (2016). “Arbitrage Opportunities, Efficiency, and The Role of Risk Preferences in The Hong Kong Property Market.” *SEF*, 33 (4), 735–754. doi: 10.1108/SEF-03-2015-0079.

Wang, Q., and T. T.-L. Chong. (2021). “Factor pricing of cryptocurrencies.” *The North American Journal of Economics and Finance*, 57,101348. doi: 10.1016/j. najef.2020.101348.

Wang, Y., Y. Chen, H. Wu, L. Zhou, S. Deng, and R. Wattenhofer. (2022). “Cyclic Arbitrage in Decentralized Exchanges.” *Companion Proceedings of the Web Conference 2022*" USA: Association for Computing Machinery.

BIBLIOGRAPHY (Continued)

Weil, O. (2017). "The Profitability of Momentum Trading Strategies: A Comparison Between Stock Markets in the Netherlands and Germany." *Master's Thesis International Financial Management (Double Degree) University of Groningen and Uppsala University*, 1–59.

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Awards

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- First runner-up in “National Software Contest - NSC Thailand 2020”, (PSU COIN)
- First runner-up in “National Software Contest - NSC Thailand 2020”, (The Arbitrage on Decentralized Exchange)
- First runner-up in "Thailand ICT Awards 2020 - 2021", (PSU COIN)
- Merit award in "The Asia Pacific ICT Alliance Awards 2020 - 2021", (PSU COIN)

Scholarship

College of Computing Graduate Scholarship

List of Proceedings

N. Boonpeam, W. Werapun, T. Karode. 2020. "Student Activity Credit Framework (PSUCOIN)", **The 5th International Conference on Information Technology: (InCIT2020), ChonBuri, Thailand, 21-22 October 2020**

N. Boonpeam, W. Werapun and T. Karode. 2021. "The Arbitrage System on Decentralized Exchanges", **The 18th International Conference on Electrical Engineering/Electronics, Computer, Telecommunications, and Information Technology: (ECTI-CON 2021), pp. 768-771, Chiang Mai, Thailand, 19-22 May 2021**

List of Journals

N. Boonpeam, W. Werapun, T. Karode, and E. Sangiamkul. 2022. "The Automated Equity-Split Cryptocurrency Arbitrage Strategy" **Songkslanakarin Journal of Science and Technology,** 44(3) May - Jun 2022,, 845-851, doi: 10.14456/sjst-psu.2022.113, Scopus Q3

List of submitted Journal

W. Werapun, N. Boonpeam, J. Suaboot, and E. Sangiamkul, "The Automated Arbitrage Strategy of Cross Cryptocurrency Exchanges", **North American Journal of Economics and Finance, ISI Q2 (Submitted)**