Federal State Autonomous Educational Institution of Higher Education

NATIONAL RESEARCH UNIVERSITY

"HIGHER SCHOOL OF ECONOMICS"

Faculty of Economic Sciences

GRADUATE QUALIFICATION WORK

Carry trades in the cryptocurrency market

bachelor of Economics

educational program "Economics"

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Moscow, 2021

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Introduction

The cryptocurrency market investment is a modern alternative to existing ways of investing money. In the context of a business activity slowdown, an increase in the availability of debt (as a result of stimulating government policy) and a decrease in the profitability of risk-free instruments lead to the search for new sources of income from retail investors. For such people there are a lot of ways to gain capital: investing in regular crypto assets, buying or selling futures, or using options. Retail investors choose crypto market, due to the several unique features:

1. Relatively small market size. Due to the small size and little governance, assets value is extremely volatile, which prohibits market from presence of huge institutional investment funds. This causes presence of a lot of market neutral investment opportunities.

2. Volatility is observaly high. For the last 5 months, cryptocurrency market doubled in capitalization.

3. Big leverage choice without external conrol. Traders can extremely increase risks of the investments, by using up to x125 leverage on the derivative market. Such trades require a lot of free capital, which widens gap between spot and future prices.

4. A lot of additional fiat-based capital is attracted through inefficiencies. The wider gaps between spot and future market become – the more opportunities for retail investments are opened and more traders are attracted.

In this research I am trying to apply concepts, researched by (Koijen et al., 2016), which can be used to explain the price of the crypto assets, by introducing the influence of arbitrage opportunities presence. My hypothesis is because of the gaps between future and spot pricing, the arbitrage possibilities arise, which cause predictable price movements. I will show presence of arbitrage, give in details ways of exploiting it and show the way this arbitrage affects pricing in the spot market. By using my hypothesis i was able to construct market-neutral portfolio with Sharpe Ratio of 1.44, which coincides with previous researches (Franz and Schmeling, 2021).

Chapter 1. Theoretical basement

The cryptocurrency market is developing at an incredibly fast pace. According to the data, provided by (Coingecko, 2021), the capitalization of most of the coins of the largest cryptocurrency exchanges has grown on average over the past 4 years from a few billion dollars in 2017 to several hundred billion dollars during 2018-2020 and it has already exceeded one and a half trillion dollars recently. The extraordinary growth rates are explained by the sequential entry of the instituional investment funds RBC (2021d), RBC (2021b), RBC (2021a), RBC (2021c).

1.1 What is Cryptocurrency?

Theoretical part of the study: what is cryptocurrency? I would like to start the theoretical part of the reseacrh with an explanation of what a cryptocurrency is, where it comes from and how it is traded, give general definitions of the main terms and answer basic questions about all the facts that may have an impact on the subject of this study. To better understand the theory, it is worth starting with an introduction to what is called Bitcoin.

Since ancient times, people have participated in economic relations: they, having a good that is in excess, exchanged it for the goods they needed. At the heart of the processes of exchanging goods, there was an unspoken agreement between all participants of the transaction, regarding the value of the exchanged goods. For example, a hunter who exchanged a deer skin for a cart of firewood, estimated the labor costs for the production of both goods, and if, from his point of view, it was easier to get a deer than to chop firewood, he would agreed to the deal. At the very beginning of the development of society, people exchanged goods and services for other goods and services. In such relations, there was an obvious disadvantage – in order to make a deal, it was necessary to have the goods in hand at the time of the transaction. As the society was progressing, people began to need something that is now called money, and could at that time be used for numerous purposes, the main of which, was to satisfy the need for a universal means of expressing value. In order for something to express value, it needs to carry a certain wealth over a long period of time. At first, such a measure of value was precious metals. People believed that there was an item that would always remain valuable to them. As a result of certain historical events, people moved from using precious metals in exchange to using cash, which could be exchanged for metals. In fact, the very model of human faith has been modernized, from the belief that gold is valuable, to the belief that the state, issuing money secured by gold, will be able to provide the holders of money with value. Some time later, many countries of the world began to refuse to provide national currencies with precious metals, and as a result, the model of faith of ordinary citizens also underwent changes. People had to start believing that the government would be solely responsible for the value of the banknotes issued. Greatly simplifying, people agreed to use paper as an exchange, which was secured by nothing more than the promises of governments. Such a system operates nowadays, and the usual currency is called fiat, which is translated from Latin as "by decree". This can be interpreted as follows: a fiat currency carries value, because the state has ordered so. As a result, a centralized system of providing the population with money was formed, in which the main role of management is carried out by the state. It determines the amount of money issued and monitors to whom and in what amount the money is sent. Of course, money is issued by the central bank, not by the government itself, but the key factor here is that one particular organization has an exclusive set of powers.

What are the problems of such a system? At the global level, in times of financial instability, the state can make an unjustified issue of money in order to support some companies. With the additional issue of money, their purchasing power decreases, which is expressed in an increase in the price of goods and services for all citizens. Effective companies may need support, but the problem of corruption may encourage officials to pour money into inefficient organizations. At the local level, things are no better. Let's start with the fact that due to digitalization, money is increasingly moving from a paper form of circulation to an electronic one. We use plastic cards that carry out transactions in systems, that by the way, are also centralized. Banks that issue cards and maintain electronic accounts keep records of transactions that take place on these accounts on their own servers, which are entirely under their own sole banking management. The concentration of power in one institution leads to problems such as the hidden imposition of additional services that customers do not need and other costs caused unnecessarily. In addition, due to the control of banks to state institutions, the accounts of citizens can be seized and frozen. Even cash can stop being served, due to withdrawals from circulation and other government regulations.

Conceptually, the presentation of the above problems is typical not only for financial institutions, here we talk about any interaction of a large number of people, who want to make a common decision and assign transaction responsibilities to the person who causes the greatest degree of trust. For example, if the citizens of a country vote for a presidential candidate, they have to believe that the institution, which is responsible for counting the votes, will be as open-minded and honest as much as possible to do their job. Another example is electronic invoices. Users of online wallets believe that such large organizations as PayPal, Apple Pay, Google Pay, which provide intermediary services in money transfers, will honestly do their job and will not write off money from customers ' accounts at any time. Many attempts to solve the problem of the need for system participants to believe in a single centralized manager have failed due to the fact, that the central manager - is a single source of information, which makes it impossible to manipulate the participants of the relationship, without directly influencing the central government. Imagine that a country, which is represented by a large number of different political parties, starts elections. Obviously, it is in the interests of each of the parties to get as many votes as possible in the ballots. If one of the parties, for example, tries to print a large number of additional forms (to increase the chances of their candidate to win), the central agent can prevent them from doing so by issuing additional requirements, for example, to provide passport data, when voting. With further checks and honest calculations, dishonest forms will be instantly detected. It seemed that it was impossible to achieve a better voting mechanism, but with the advent of blockchain technology, the situation has changed dramatically.

In 2008, a decentralized system for servicing electronic transfers was introduced to the world. In other words, this technology made it possible to make electronic payments without having to trust in the integrity and efficiency of the central institution, which was previously responsible for servicing transactions. This system implied the presence of a special currency (bitcoin), which could be openly redirected from one person to another for each participant of the system. The uniqueness of this system lies in the fact, that in its very architecture, there is a mechanism, according to which, all participants in maintaining the integrity and openness of translations are interested in the performance of their work. In fact, the world has received a much more significant discovery than the system of honest transfers, it has received a way to organize the storage of general information, in which participants work according to agreed conditions. These conditions are formed by companies that issue cryptocurrencies, and the blockchain technology distributes information to all participants of the system, which makes it transparent and inaccessible for manipulations.

After a little more careful study of the blockchain technology, it becomes clear, why the invention of cryptocurrency is assigned with a separate role in the history of human development. Moreover, some compare the emergence of bitcoin with the emergence of the Internet: indeed, if, before the advent of the global network, people learned the latest news through large publishing houses that printed newspapers, then with the advent of the Internet, knowledge about the world became publicly available and decentralized.

1.2 What is Blockchain?

Introduction to blockchain. But back to the blockchain. By what means is decentralization achieved? What exactly allows people to validate and disseminate information? Suppose we have a $100 bill in our hands, how do we know that it is real? The short answer is that the bank that issued the note keeps a record of it, assigning each bill a specific serial number. Similarly, driver's licenses, passports, ballots and other elements of public life are arranged. There is even a separate public institution, the notary public, whose main purpose is to confirm the authenticity of documents. It is obvious that all the above-described elements of human life have one very important common property – they are subject to a centralized management system. In the previous discussions, we have highlighted in details the possible risks of excessive concentration of power in one hands – having access to information, you can modify it in your own favor, since none of the participants of the relationship has access to the data in the possession of the central authority. This means that no one physically has the opportunity to check its accounting. To avoid such risks, it is necessary to somehow move from the need to transfer the reins of information to a central person. But it is impossible to simply abandon, for example, banks as financial intermediaries, because without a central observer, it is impossible to determine the authenticity of money. In addition, banks cannot be forced to disclose information about all movements in the accounts of each resident of the country, since this opens a breach in the national security of the entire country. So what should society do?

In 2008, Satoshi Nakamoto proposed a system in which a computer network is organized, where each participant is represented by its own computing power. All the information, generated by the participants is stored simultaneously on all devices, and each person can observe its historical change. It is already becoming clear that such a system provides absolute transparency of historical data. In fact, it describes the concept of a distributed data storage system. The next question to be answered is where does the information appear on computers and who distributes it? The short answer is the system members themselves. Within the framework of the interaction model, special roles were proposed: the so-called miners, who provide the entire network with the computing resources necessary to maintain the integrity of the data validation mechanism, generated by the network participants, and ordinary system participants. People who create information should contact the miners, so that they "verify" it and after such verification, send it to all network participants. In this way, the integrity of relationships between people is maintained. The same principle applies to bitcoin: people transfer money into bitcoins by buying them on various exchanges, located in different countries, just as dollars are converted into euros on exchanges. Having bitcoins on electronic wallets, people become to participate in a distributed information service system:

they can generate it by transferring bitcoins to other participants in the system, or act as miners, verifying the transactions of other people who have decided to send their bitcoins to someone. By the way, all companies that issue cryptocurrency use a similar mechanism: they organize a system of roles and their interactions, in which they do not have any advantages, but give control to all members at the same time. This fact is important for understanding how, for example, one cryptocurrency differs from another.

So, we have two roles: an ordinary participant who follows the rules described by the company that issued the cryptocurrency, and a miner who supports the public availability and transparency of data. If everything is clear with a simple participant, then the miner is some abstract person who owns powerful computers that can quickly perform serious mathematical calculations. The miner, as a participant in the system, is granted the right to add new (but not rewrite old) information to a single stream, but only on the condition that he is the first to do a huge job, expressed in solving a mathematical problem. The very concept of the need to solve an artificially created problem is necessary in order to determine a person who can supplement the information, which gives him some power: in the case of bitcoin, for example, the fastest miner gets the opportunity to charge a fixed amount of bitcoins to his account, as well as to choose the participants of the system, information on transactions of which he will enter into the general flow of information. Since there are many people who want to make anonymous transactions, participants add a certain premium for transactions to encourage the miners who won the artificial competition to choose and distribute their transactions to the whole world. To sum up all of the above: people buy cryptocurrency (without paying attention to cryptocurrency as an investment asset) in order to become part of a system in which their coins allow them to perform certain operations by the issuing company. Ordinary participants of the system generate new blocks of information (for example, by initializing transactions with bitcoins, or creating certain smart contracts), and miners solve mathematical problems at speed in order to win and get the right to distribute the transactions generated by ordinary participants to the world, thereby securing and verifying them for a certain fee. The whole system is called the blockchain, because the winning miners, according to the rules, are limited in the amount of information they can write to the general data chain. The amount of data is measured in blocks, which is equivalent to 1 megabyte in volume, and these blocks are built into a common chain of knowledge, which each network participant can at any time, if necessary, review and verify the authenticity of all the events that occurred. Miners can not influence the previous data blocks, because in the process of solving a mathematical problem, the previous data block is encoded, so at any time to change events, that have passed, say, 10 blocks ago, you need to re-encode all the previous blocks again so that the changes take effect, but the artificial task is specially selected for such complexity that a large number of miners, non-stop conducting competitions, do not allow those who want to change the events of the past. Thus, an impeccable system of decentralization is achieved, on which various cryptocurrencies are based in one way or another. Bitcoin, litecoin, dogecoin, luckycoin – decentralized payment systems. Fundamentally, the difference between these coins is only in how exactly the rewards are awarded to the miners, how they change over time and how much the coins themselves are worth. Ethereum is a decentralized system of contracts between people, which serves as a clear indication. An example of the use of ether can be considered on the example of futures: let's say one company wants to insure its business processes against external risks. If its activities are related to the production of goods, the raw materials for which can be purchased on the stock exchange, it will use futures and conclude transactions in accordance with its own expectations about the future. If the company's raw materials are an unusual commodity for which standardized contracts are not issued, then it can independently conclude a futures transaction directly with the supplier of raw materials and at the same time bear the risks of the counterparty, or transfer part of the assets to the ether and use smart contracts to remove all the risks of possible non-payment by the opposite party to the transaction. Of course, with such an approach, risks of a different kind may arise, namely, the risks of market fluctuations, but they can be neutralized by futures positions in the cryptocurrency market. By the way, futures play a big role in this study, it's time to get down to business.

From the theoretical fundametals above, we got what people mean by cryptocurrency: different decentralized solutions. Cryptocurrency in its core gives holders rights to be used in a systems, which company issuers construct through decentralization principles.

1.2 What is Carry Trading?

Introduction to strategies. So, when we have figured out what a cryptocurrency is and how some coins differ from others, it is consistent to move on to the issues of using this knowledge in practice. All cryptocurrencies are exchanged on a large number of different exchanges. According to the rating data there are more than 300 such exchanges around the world. On each of the exchanges, you can make transactions to exchange one cryptocurrency for another. For example, if you enjoyed the benefits that Bitcoin gave you and want to use the services provided by the company that issued the Ether, you can exchange Bitcoin for Ether on any of the exchanges you like at a price set by an open market relationship. Today, the largest cryptocurrency exchange is Binance, with trading volumes exceeding 7 trillion rubles! On some exchanges, in addition to cryptocurrency, derivative financial instruments are traded, such as futures, perpetual swaps and options. The key difference between cryptocurrency trading and trading in ordinary stock market is the fact, that exchanges provide access to the high-risk instruments. For example, on Binance, you can open futures positions using financial leverage in the amount of x125, without having to confirm your financial literacy with any certificates. Most likely, such conditions contribute to the volatility of the cryptocurrency, and until the political elites do their part in controlling market relations and regulating the cryptocurrency in general, many players will make desperate attempts to get rich quickly. But while some traders, inspired by the unprecedented growth of individual cryptocurrencies, are betting on an increase, others are using volatility to create high-yield and at the same time risk-free strategies. In what way? With cash & carry strategy!

Introduction to Cash & Carry. The main ingredient of Cash & Carry strategy is futures. It is no secret that the pricing of futures is closely related to the pricing of the asset that provides the value of futures. By its nature, a futures contract is a contract that is concluded between market participants. According to this contract, the party who bought this contract is obliged to buy (and the opposite party - to sell) a certain amount of a pre-agreed asset at a certain point in time in the future. The theory says that within the framework of a healthy market relationship, the price of a futures contract for a financial asset that does not generate income and does not require any storage costs for the entire period of the contract, up to the day of its execution, is linked by a simple ratio to the price of the asset itself:

$$F_t = S_t e^{rT}$$

Where S_t is the price of the asset on the spot market, r is the risk-free interest rate, and T is the time for which the futures were issued. This equality is easily proved by considering the consequences of its violation: there will always be a profitable risk-free strategy that will bring a greater return than a risk-free instrument with a rate of r, which means, that market participants, provided that there are no other factors affecting the value of the futures, will turn the inequality into equality. Taking into account the impact of the coronavirus on the global economy, as well as the stimulating attempts to increase the economic activity of the population, it becomes clear why the interest rate is now at record low levels. For example, the U.S. 3-Year Treasury Rate is 0.35% (Figure 1), and in the middle of the 2020th year, the central banks of Europe and England practiced a policy of negative interest rates.

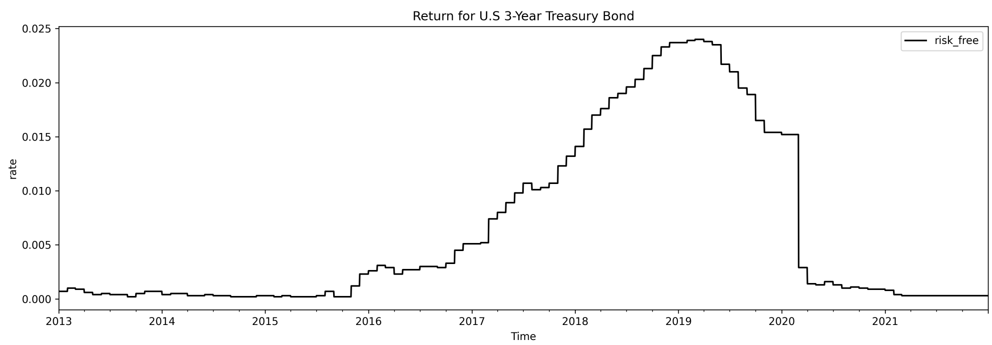

Figure 1. Risk free rate. Source: treasury.gov

The consequence of a low interest rate should be a relatively small difference in the value of futures relative to the spot price. But if you look at the data provided by the Bitmex exchange, you can see the following patterns (Figure 8).

Until 2018, the average difference between the value of a futures and a spot asset was a huge 20%–30%. Most likely, such large differences are explained by the rudimentary development of the derivatives market on cryptocurrency exchanges and small trading volumes. After 2018, the spreads are reduced in size to 10% and today they are about 10-7%. The most interesting thing is that this difference is extremely volatile over the time. On almost all charts, the contango mode is very often replaced by backwardation and vice versa, which in turn provides opportunities for early closing of arbitrage positions, which increases the profit of traders incredibly. In Empirical Results section, I'll show you what this means in practice. At the moment of writing this research, difference between spot and future prcies for different coins was as described in Table 1:

Table 1. Binance spot and future prices for different coins of two contract types.

Exp. in		ADA	BTC	BNB	BCH	DOT	ETH	LTC	XRP
52 days	Spot	1.35	58,403	632.8	1,016	37.6	3,145.1	279	1.589
	Future	1.38	60,926	661.3	1,063	39.32	3,272.1	292.1	1.634
	Premium	**2.44%**	**4.32%**	**4.5%**	**4.64%**	**4.62%**	**4.04%**	**4.65%**	**2.83%**
143 days	Spot	1.35	58,403	632.8	1,016	37.6	3,145.1	279	1.589
	Future	1.44	64,650	703.3	1,126	41.79	3,481.9	309.1	1.709
	Premium	**6.93%**	**10.7%**	**11.14%**	**10.82%**	**11.19%**	**10.71%**	**10.93%**	**7.53%**

Source: author's calculations, Binance exchange

There are many points of view as to why risk premiums remain relatively high. Some (CMC, 2019) argue that the nature of the big difference between spot and futures lies at the heart of decentralization: in the fiat currency market there is a central bank that controls the key rate, while in the cryptocurrency market, rates are entirely determined by demand and supply. Others insist on the widespread availability of large leverage options, provided by exchanges, being a main reason for such a volatility. Another opinion is that, due to decentralization of the trading process, there is high margin requirements, which require collateral, not only for currency, but even for the instruments. This consequently makes trades really capital intensive. However, historical data shows, that the spread remains on market, suggesting retail investors new horizons for profits.

Chapter 2. Novel approaches to the Crypto Market analysis

This section describes previous studies, which will be helpful in order to understand what affects crypto asset pricing. I will introduce some ideas, which worked fine for the fiat, commodity and cryptocurrency markets. In the end, these ideas will be explained by existence and availability of arbitrage opportunities.

2.1 Literature review

In their research (Koijen et al., 2016) used so-called *carry-factor* to construct portfolios of different types of assets. They provided empirical evidence for this factor to be able to explain some part of future price of the asset, achieving average Sharpe Ratio of 1.2.

From author's point of view, any asset's return can be decomposed into expected return and unexpected shocks:

$$r_t = \underbrace{C_t + \mathbb{E}(\text{price appreciation})}_{\text{expected return}} + \varepsilon_t \tag{1}$$

The carry factor itself can be calculated ex-ante and is derived from equation (2).

$$C_t = \frac{S_t - F_t}{F_t} \tag{2}$$

where C_t – carry factor, F_t – observable future price, S_t – spot price of an asset. Derivation of the decomposion (equation 1) is presented in the Appendix. (Koijen et al., 2016) constructed a portfolio, consisted of a wide variety of asset classes, such as equity index futures, currecies, commodities, bonds, credit and index options. The main methodology was to long top x% of leaders and sell bottom x% of loosers. Overall result was the empirical proof of usefullness of carry factor for assets price explanation.

In the another research (Franz and Schmeling, 2021) generalized the idead of carry factor to cryptocurrency market. Authors collected historical data for perpetual swaps and used funding rate as a carry approximation.

They managed not only staticially explain the funding rate, but also construct market-neutral portfolio of coins. The results for funding rate prediction were as follows in the following table:

Table 2. Estimations of the model $y_{t+1} = \alpha + \beta' X_t + \varepsilon_t$. Returns and Funding rates are from bitmex perpetual swaps, Fear-and-Greed is 1-day lagged

y: Funding Rate t+1 (bp)	All	2019	2020
constant	-60.25***	-59.52**	-52.29***
Funding Rate (bp)	0.76***	0.74***	0.81***
Return (%)	16.36***	12.13***	24.40***
Fear-and-Greed (0-100)	1.52***	1.66***	1.15***
R^2	64.06%	58.57%	71.98%

Source: (Franz and Schmeling, 2021)

To sum up their achievment, they managed to explain more than 70% of variance in funding rate, which can be interpreted as carry factor. So, by knowing the next period funding rate, you can construct market neutral positions as well as explain futher market movements, because (Franz and Schmeling, 2021) proved that this factor is useful in terms of constructing market neutral portflio of coins on data from Huobi exchange. Their porfolio simaltion results were: overall cumulated return 82%, β very close to zero (0.06) and, once again, Sharpe Ratio of 1.24.

Chapter 3. Empirical results

Firtsly, let us prove, that there are arbitrage opportunities in the cryptocurrency market, which make people buy assets and sell futures, when the futures are traded with premium in the bullish market. When the market is bearish, people sell assets and buy futures. By doing so, they entry market-neutral positions and get rid of market movements risks. In the later chapters we will see, how this concept is interconnected with carry factor idea.

3.1 Cash and carry modelling

3.1.1 Data description

Spot prices. In general, the use of derivative financial instruments in the cryptocurrency market began in 2017, on a very few exchanges. A pioneer in this direction was the Bitmex exchange, the data from which, we will use to simulate the use of arbitrage opportunities. In total, the data contains 24 coins traded on the spot market from 2014 to 2021. As you can see from the graph below:

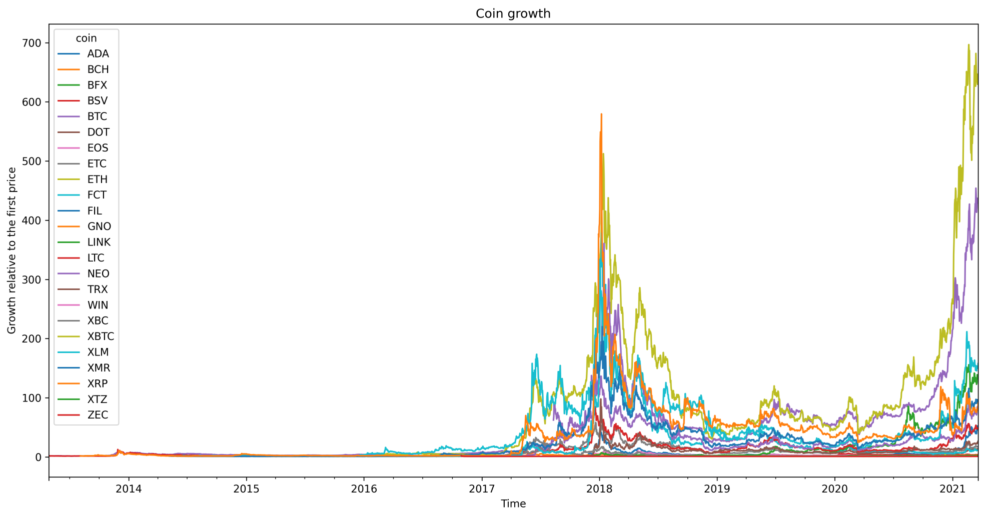

Figure 2. All spot prices for arbitrage simulations from Bitmex.

Most cryptocurrencies have changed very much in price over the course of their existence. For example, bitcoin has grown 700 times, and stellar-150 times. On average, each of the currencies was traded for 1500 days. Another interesting feature of crypto assets is the fact that their returns are very strongly interrelated. The pair correlation of each of the assets in the sample is illustrated in Figure 9

That is, on average, with a correlation of 0.5, almost all assets move in the same direction in the event of price changes, spreading the effect of the fall of one currency to the entire market.

Futures prices. Since cryptocurrency derivatives appeared much later than the cryptocurrency itself, there was very little historical data on contracts, and even less of what is available for research in open form. In total, futures contracts of various durations for 14 different cryptocurrencies were available for the study. On average, 7 contracts were issued for each cryptocurrency over the entire history, which is shown in the graph below:

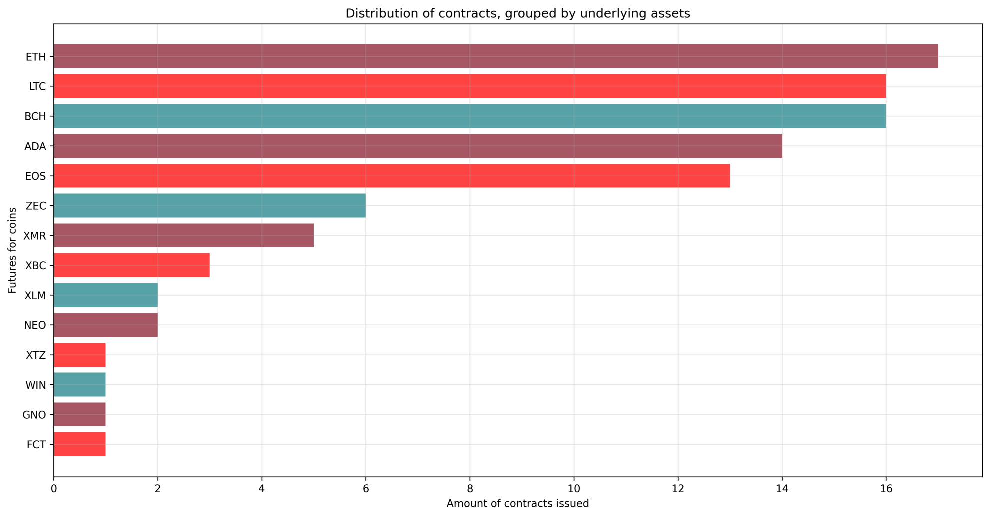

Figure 3. Amount of contracts, distributed for all time period, for each coin.

In addition to the relative change in the value of the basis, it is interesting to look at how the size of the basis is correlated with each other. For this purpose, lets to look at the pair-wise correlation of relative bases (Figure 10 in Appendix). From the graph , we can conclude that the basis is a relatively less correlated value than the asset value. This means, that when the market as a whole moves in one direction, the basis will not behave unambiguously naturally.

3.1.2 Cash and carry implementation

Trading simulation. So, taking into account the available spot and futures prices for the cryptocurrency, we will proceed to the simulation of trading. To do this, for each contract, we calculate the value of the relative basis. Relative basis is simply the following:

$$C_t^* = \frac{F_t - S_t}{S_t},$$

where S_t – spot price of the asset, F_t – its future price and C_t^* – relative basis. The notation of relative basis is chosen carry alike on purpose: in the end we will explain their connection.

Considering the transaction costs on the bitmex exchange in the amount of 0.075% of the transaction volume, it becomes clear that if the futures price differs from the spot asset price by more than $0.075\%+r$, it is profitable to open arbitrage positions. How are these arbitrage positions opened? At any given time, a futures contract can be traded for more or less than the asset it is issued for. If the futures are worth more than the asset, then they say that the futures are traded in contango mode and, roughly speaking, the price of the asset is expected to rise in the future. The reverse situation – when the futures are cheaper than the asset itself on the spot market is called backwardation and reflects the general negative expectations about the future price of the spot asset. If for a certain coin, the futures are traded in contango and the difference is significantly greater than $0.075\% + r$, then to make a risk-free transaction, you need to buy a spot asset and sell the futures on it. By the time of expiration, the prices of the futures and the asset will be equalized due to natural market mechanisms, and the trader will be able to close the position by receiving coins on the futures and sell them on the spot market. As a result of such a transaction, a risk-free profit will be extracted in the amount of the spread between the value of the asset and the futures on it. If the futures are traded in the backwardation mode, then to make a risk-free transaction, you need to sell the asset and buy futures on it. On the expiration day, a mirror trade is made and the trader also receives a risk-free profit. As we noted earlier, the cryptocurrency market is characterized by the fact that contango modes are very often replaced by backwardation and vice versa, which allows you to exit positions before the expiration of the futures. Let's demonstrate trading on the example of one of the contracts:

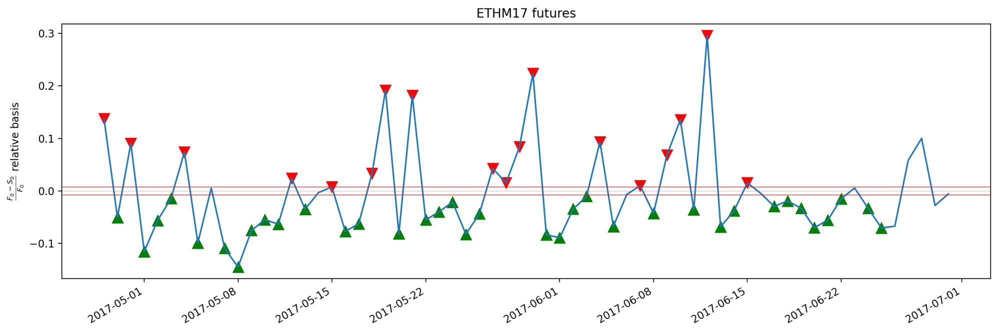

Figure 4. Cash and carry trades for ETH coin.

For a 2 month Ether asset futures contract, transactions would take place as shown in the image (4) above. The red horizontal lines reflect the upper and lower break-even limits and include the risk-free rate of return and the exchange commission. If the relative basis is located inside the area bounded by horizontal lines, then it is not advisable to open trades. As can be seen from the figure, the first position was opened at a positive basis of 1%, and closed a few days later at a negative basis of -0.5%. In the course of this strategy, 1.5% was earned, without taking into account the exchange commission, within a few days. It is important to note here that when opening a position, we do not know in advance whether we will be able to close it ahead of schedule or not. If we manage to close ahead of schedule, then we get a super profit, and if not, then only an arbitrage in the amount of the spread by the expiration day. During the simulation, for each currency, each trading day, the value of the relative basis between the futures and spot markets was calculated, and if it was greater in absolute values than $r + 0.075\%$, then money was taken at the rate of 4% per annum and the necessary positions were opened. If the positions were closed early, the borrowed funds were paid immediately together with the interest. During the simulations, the following results were obtained.

As you can see from the table below, the profitability of transactions has changed over time. And this is not surprising, because in different years,

Table 3. Cash and carry simulation results for expiry futures on Bitmex at different years.

Year	sharpe	Win Rate	Average r	Average r per day
2016	0.716646	1	0.727983	0.079172
2017	1.464044	1	0.164906	0.091361
2018	0.214490	0.991896	0.042548	0.016783
2019	0.101538	0.991283	0.013924	0.002582
2020	0.967281	0.988618	0.010843	0.002882
2021	1.467089	0.995181	0.037007	0.002982

Source: author's calculations

the crypto market has been volatile in different ways. This can be clearly seen from the Figure 5.

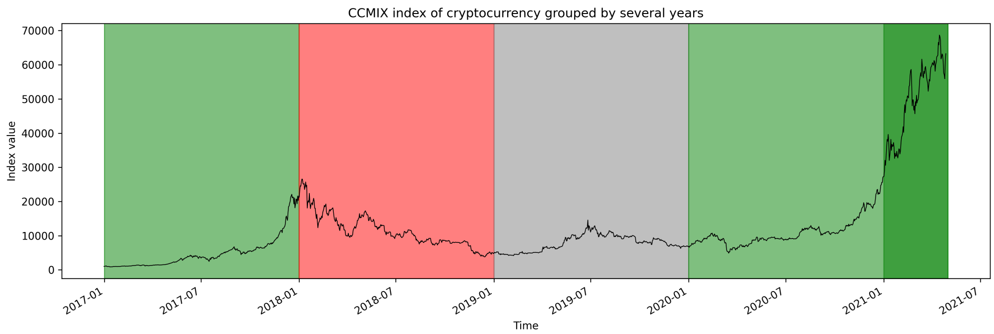

Figure 5. Crypto market.

In 2017, 2018, at the end of 2020 and at the beginning of 2021, a single trend could be observed in the cryptocurrency market. It was either positive or negative, but in any case, there was volatility in the market. Due to this volatility, the underlying spread changed, which allowed the strategy to generate high returns. When the spread remained unchanged, the excess yield was not extracted. Let's see what this means in practice by looking at the deals of 2019. For example, consider the September Ether futures.

From the Figure 6, it is clear that the basis never crossed the boundaries in which it was possible to get out of positions. Accordingly, each red arrow is a newly opened position (borrowed money for opening positions) with the expectation of an early termination of the contango mode. All of these positions were closed on the expiration day, which brought the highest loan costs. This partly explains, why the sharpe ratio for the 2019$^{\text{th}}$ year was the

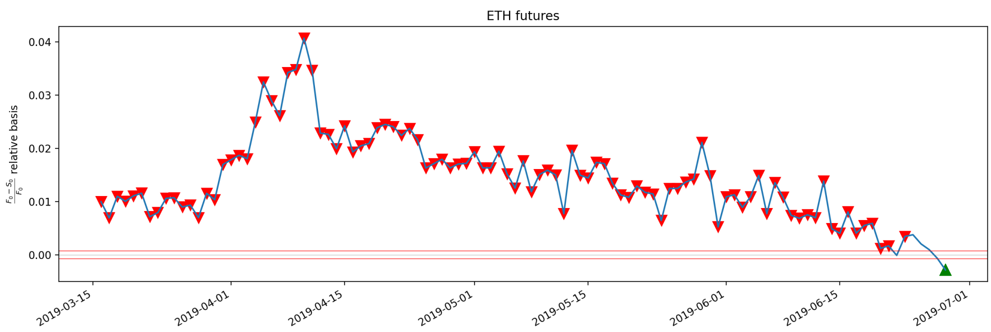

Figure 6. Cash and carry trades in not volatile market.

smallest one. In addition, it is interesting to look at the Table 4, which was obtained during the following regression:

$$r_t^{coin} - r_t^{free} = \alpha + \beta(r_t^{market} - r_t^{free})$$

where r_t^{coin} - return for the coin, at date t, r_t^{free} - U.S 3 Year Treasury yield, and r_t^{market} - return of the market, expressed in change of the CCMI index.

Table 4. Coefficient estimations for coins' contracts of different expiration dates.

Year		ADA	BCH	EOS	ETH	FCT	GNO	LTC	NEO	XMR	XLM	ZEC
2017	α		0.19***	0.11***	0.19***	0.19***	0.15***		0.12***		0.15***	
	β		-0.04	0.15	0.1	-0.12	0.4		0.33		0.2	
2018	α	0.07***	0.05***	0.02***	0.03***			0.03***	0.03***	0.1***	0.07***	0.1***
	β	0.03	-0.07	-0.02	0.02			0.02	-0.111	-0.04	-0.01	0.13
2019	α	0.03***	0.01	0.02**	0.02***			0.01***				
	β	-0.001	-0.02	-0.02	-0.01			-0.004				
2020	α	0.03***	0.02***	0.02***	0.01***			0.02***				
	β	0.03	0.02	0.01	-0.01			0.004				
2021	α	0.08***	0.03***	0.04***	0.01***			0.03***				
	β	0.08	0.02	0.08	-0.01			0.01				

Source: author's calculations

From Table 4 it can be seen, that strategy predictably beats market in terms of excess returns. The pure cash and carry strategy is perfectly market neutral, since, without any leverage, it doesnt expose to any market risk. But as we used active trading and asset's borrowing, we were exposed to the risk of small volatility, which is a situation, when future's basis doesnt change sign quite often. It is also not surprising, that BCH in 2019^{th}, in a year of uncertain market direction, was not statistically better, than market.

Another interesting approach to the analysis of the strategy from the point of view of its profitability was proposed by (Dobrynskaya, 2014) and consists in the inclusion of such a factor as the direction of the market in the analysis. According to this approach, the impact of the overall market condition is added to the analysis and the following model is evaluated:

$$r_t^{coin} - r_t^{free} = \alpha + \beta(r_t^{market} - r_t^{free}) + \beta_{dd} D_t$$

Where D_t takes the value 1 if the market is rising and 0 if it is falling. (Dobrynskaya, 2014) in the original study proposed to consider the dummy variable looking at the market's return sign. In my research, I slightly modified her approach using moving averages. If the 10-day moving average of the market price exceeds the 20-day moving average, the market rises, otherwise it falls. As a result of the evaluation of the models, the following results were obtained:

Table 5. Coefficient estimations for coins' contracts of different expiration dates.

Year		ADA	BCH	EOS	ETH	FCT	GNO	LTC	NEO	XMR	XLM	ZEC
2017	α			0.18***	0.087**	0.17***	0.09***	0.1***		0.1***		0.16***
	β			-0.1	0.2	0.2	-0.14	0.337		0.28		0.18
	β_{dd}			0	0.02	0.02	0.11	0.06		0.04		-0.01
2018	α	0.05***	0.04***	0.02***	0.03***			0.03***	0.03***	0.1***	0.07***	0.06***
	β	0.07	-0.1	-0.004	0.03			0.03	-0.1	-0.01	0.13	-0.01
	β_{dd}	0.033	0.015	0.003	0.016			0.023	0.003	0.004	0.004	0.1
2019	α	0.03***	0.01*	0.06**	0.01***			0.02***				
	β	-0.007	0.073	0.063	0.086			-0.003				
	β_{dd}	-0.004	0.001	-0.006	-0.001			0				
2020	α	0.02***	0.02***	0.02***	0.01***			0.02***				
	β	0.016	0.026	-0.002	-0.059			0.009				
	β_{dd}	0.006	0.004	-0.001	0			-0.001				
2021	α	0.06***	0.02***	0.02***	0.01***			0.03***				
	β	0.100	0.033	0.101	0.011			0.050				
	β_{dd}	0.019	0.012	0.021	0.001			0.008				

Source: author's calculations

As you can see from the Table 5, returns are still market-neutral, even, when considering market drops periods separetly. Conclusions: in all cases, the strategy showed market-independent significantly positive excess returns.

3.2 Portolio modelling

In this section i would like to summarise all ideas, we have discussed earlier and try to construct the portfolio selection method, based on this ideas. For the whole section we will use (Fama and French, 2008) approach to portfolio construction, which consists of several steps:

1. During the selection procedure, sorting all possible coins by factor value
2. Long top-k and short bottom-k coins by factor value
3. Averaging returns for selected time-period

Once simulation is constructed, returns for every trading day is obtained and can be tested for significance in different regression models.

3.2.1 Data description

In order to conduct a robustness test, we will simulate portfolios on a new data. For this purpose, we will use futures from the Huobi exchange. This futures data contains of futures for 11 coins, where each coin has contracts for several time periods: weekly, bi-weekly, quarterly and bi-quarterly. Those contracts have been launched separately in time, so they have different historical length. Each contract is continuously traded, meaning that once expiration date is over, new contracted is set up. The amount of days each contract type has been traded is illustrated on the chart 11 in Appendix.

3.2.2 Portolio modelling, using factors from literature review

For portfolio modelling we will use (Fama and French, 2008) approach. This approach implies hyperparameter search and optimization. We will use carry factor, described in literature review section, specifically:

$$C_t = \frac{S_t - F_t}{F_t}$$

as a sorting factor. Each future contract of four types (weekly, bi-weekly, quarterly, bi-quarterly) of each coin, have been used to calculate coin's individuals carry factor on a daily basis. Then, the strategy prescribes longing losers and shorting leaders. In the result of simulation procedure the following estimations were obtained:

Table 6. Portfolio simulation results, divided by future type.

		Week	Bi-week	Quarter	Bi-Quarter
	Win Rate	98%	100%	98%	99%
General performance	Sharpe	1.44	1.44	1.35	1.21
	Avg return	2.7%	2.6%	2.5%	2.4%
$r^{\text{exc}} = \alpha + \beta r_m^{\text{exc}} + \varepsilon$	α	2.6%***	2.5%***	2.4%***	2.3%***
	β	4.6%	4.3%	5.6%	6.7%
	α	1.5%***	1.5%***	1.4%***	1.3%***
$r^{\text{exc}} = \alpha + \beta r_m^{\text{exc}} + \beta_{dd} D + \varepsilon$	β	5.4%***	5%***	6.3%***	7.3%***
	β_{dd}	1.4%***	1%***	1.3%***	1.2%*

Source: author's calculations

As for returns' distribution, you can check the Figures 12. As we may see from the results (Table 6), carry factor can be used to extract alpha, which is significant. The rebalancing is done everyday, since the volatility is huge, so carry can gain 2.6% on an average daily basis. Sharpe ratio is 1.3 on average, which coincides with results retrieved by (Koijen et al., 2016) and Franz and Schmeling (2021). As for market neutrality, the strategy shows low correlation with market, which is expressed in insignificant betas of the first model. But once we include market direction in our analysis, both betas become significant, despite the fact that they are relatively small, which also coincides with (Franz and Schmeling, 2021). The influence of market direction can be explained by the amplitude of market movement which is different for bullish and bearish markets. Huge market raises rewarded strategy with higher returns, whereas drawndowns - with lower, but still positive returns.

3.2.3 Results explanation

So from previous subsection we have seen, that carry is a powerful factor, which can be useful in the explaining coins' returns. But, the question is, what exactly makes carry factor special and why, during simulations, we shorted leaders and bought loosers? I will try to explain this with the help of arbitrage existence. But first, let's get back to the fundamental formula:

$$C_t = \frac{S_t - F_t}{F_t}$$

From its derivation, we remeber, that the denominator of carry expresses the amount of money, which trader invests in futures. So this could be any number, expressing the position size of a trader. If we substitute it with S_t, which means, that trader will invest in futures amount of money, which equals to the spot price, and slightly transform the numinator we get:

$$C_t^* = \underbrace{\frac{F_t - S_t}{S_t}}_{\text{relative basis}} = -\frac{F_t}{S_t} C_t$$

$$C_t(C_t^*) = -\frac{S_t}{F_t} C_t^* \tag{3}$$

We can see that now C_t^* represents *relative basis*. Basically, carry factor is negative *relative basis*, which is used by traders, who trade market neutral Cash & Carry strategy, which we described earlier. When the market is in contango, futures are traded with premium and relative basis is positive, or $C_t < 0, C_t^* > 0$. If there is a contango and market premium is higher than trading costs (which is the case as we have seen previously), to be market neutral, trader should buy spot and use it as collateral for selling futures. Actually, this means, the higher C_t^* the more profit is gained through C&C. Increasing C_t^* deacreases C_t, as they are linearly negatively connected. So what carry actually indicates is the situations when people should buy spot assets to gain risk free profits. When carry is negative and big in absolute value, that is the signal, that there is a profitable entry point for C&C trades. Once they begin to entry positions, they have to buy spot assets and consequently increase its market price. As more cash and carry traders join the race for arbitrage profits, the less risk free opportunities is left on the market and closer relative basis gets to zero. To close C&C trade it is needed to make an opposite trade: buy the futures and selll the spot. This logic explains the influence of future premiums/disconts on the spot market.

To address this ideas visually, let us look at the Figure 7 of accumulated relative basis rates versus market prices:

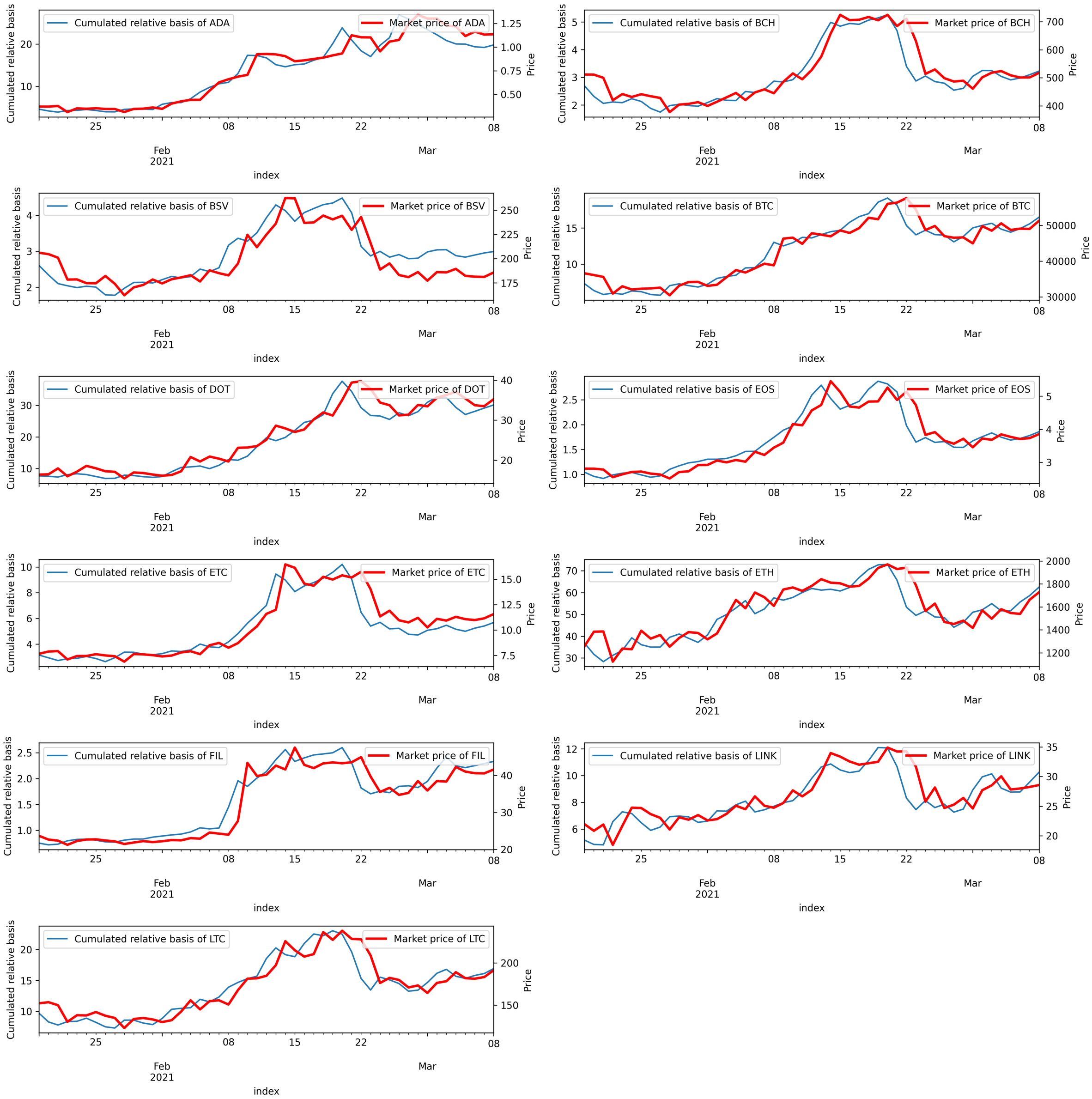

Figure 7. Cumulated relative basis for weekly futures of huobi exchange. This chart illustrates the way futures market affects spot market. Source: author's calculations

It is clear from the chart, that cumulated relative basis forms the shape of a spot asset in advance, making it possible to predict next period spot price in advance.

Another question is what makes futures and spot prices to be priced so differently, that traders are stimulated to entry the C&C trades. There are a lot of opinions for this question. The most basic one is the fact, that the cryptocurrency market is rapidly growing market and people, who invest funds in crypto assets require extra premium in compensation for market volatility. It is still profitable to open long future contracts with 4% premium in the bullish market, to be able to buy asset, which growth rate could be extremely higher. Another opinion is that there are much more important risks than market volatility. For example, due to the lack of regularization, nobody can prevent stable coins from falling in price down to zero, making crypto assets worth nothing, if this happens for any reason. This will make crypto investors poor, because stable coin is the only bridge between cryptocurrency and fiat worlds.

Chapter 4. Conclusions and further work

In the first part of this study, i demonstrated the presence of arbitrage opportunities in the cryptocurrency market (in terms of cash and carry strategy), and also conducted a simulation of the C&C, increasing the risk within acceptable limits, to demonstrate how traders can benefit more, in conditions of high market volatility.

In the second part of this study, i have put forward a hypothesis about the impact of arbitrage on the value of assets in the cryptocurrency market, as well as proposed a market-neutral portfolio, that is not inferior to the market in terms of profitability. By constructing market-neutral portflio with Sharpe of 1.44 the possibility of Carry factor usage as fundamental term, which is capable of explaining crypto assets returns have been proved. In the end i provided theoretical explanation of why carry factor works in the cryptocurrency market and to what degree it is interconnected with existing inefficiencies.

There is still a place for further research: there were a few futures available for portfolio simulations (due to the novelty of futures on the crypto market and lack of publickly available data), more confident statisticial analysis is required. It will also be useful to consider more exchanges at the same time, but futures data is hard to acquire.

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Appendix

Proof for any asset return decomposition

The derivation of the decomposition (equation 1) is retrieved from the following assumptions:

1. The asset is traded in the spot and future market and has S_t – spot price and F_t – future price.
2. There is a risk free rate, denoted as r_t^f
3. At any point of time a trader can buy/sell asset, futures and invest his initial capital under risk free rate of return.

If trader decides to buy futures for an asset, his holdings will look like the following:

$$X_t(1 + r_t^f) + F_{t-1} - F_t$$

Which can be rewritten in terms of return as following:

$$r_{t+1} = \frac{X_t(1 + r_t^f) + F_{t-1} - F_t - X_t}{X_t} = \frac{F_{t+1} - F_t}{X_t} + r_t^f$$

Excess return is then:

$$r_{t+1}^{\text{excess}} = r_t - r_t^f = \frac{F_{t+1} - F_t}{X_t}$$

Additionally assuming, that price in the future will not be different from the current spot price ($F_{t+1} = S_t$), we can consider carry as an excess return for the future contract:

$$C_t = \frac{S_t - F_t}{X_t}$$

One more step is needed, to access carry formula: we can assume, that investor uses investment of F_t size. Thus, applying this carry representation to return decomposition, we obtain:

$$r_{t+1} = \frac{F_{t+1} - S_t + S_t - F_t}{X_t} = \underbrace{C_t + \mathbb{E}\left(\frac{\Delta S_{t+1}}{X_t}\right)}_{\mathbb{E}(r_{t+1}^{\text{excess}})} + u_{t+1}$$

where $\Delta S_{t+1} = S_{t+1} - S_t$ and $u_{t+1} = (S_{t+1} - \mathbb{E}_t S_{t+1})/X_t$ – unexpected change of the price, which has zero mathematical expectation.

Charts and tables

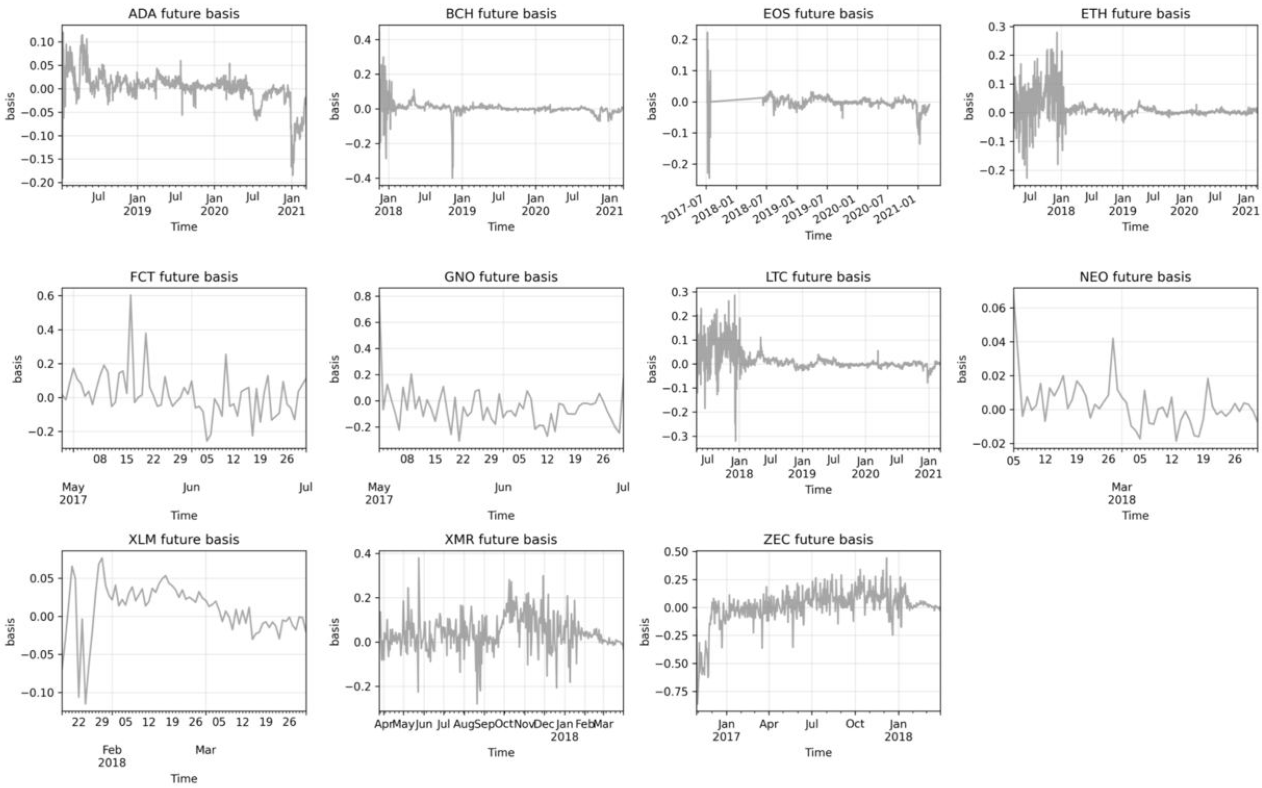

Figure 8. All future basises from bitmex.

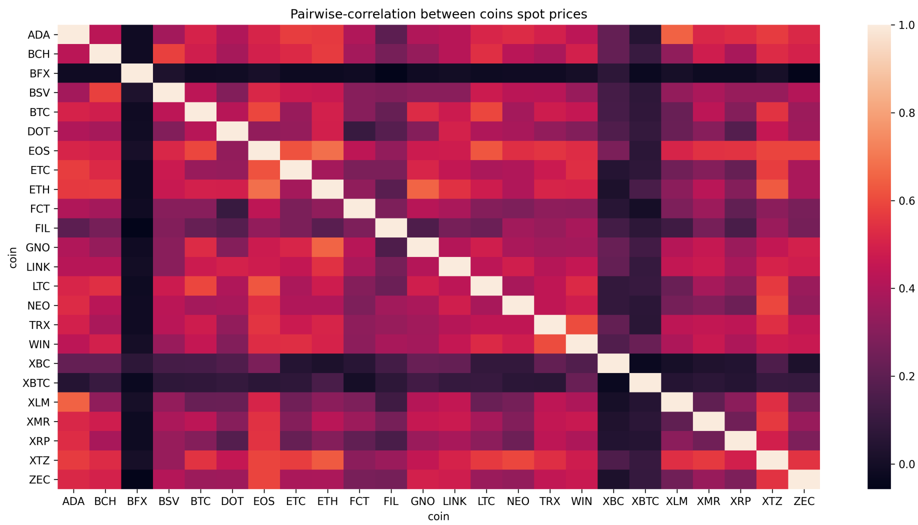

Figure 9. All spot price correlations for arbitrage simulations from Bitmex.

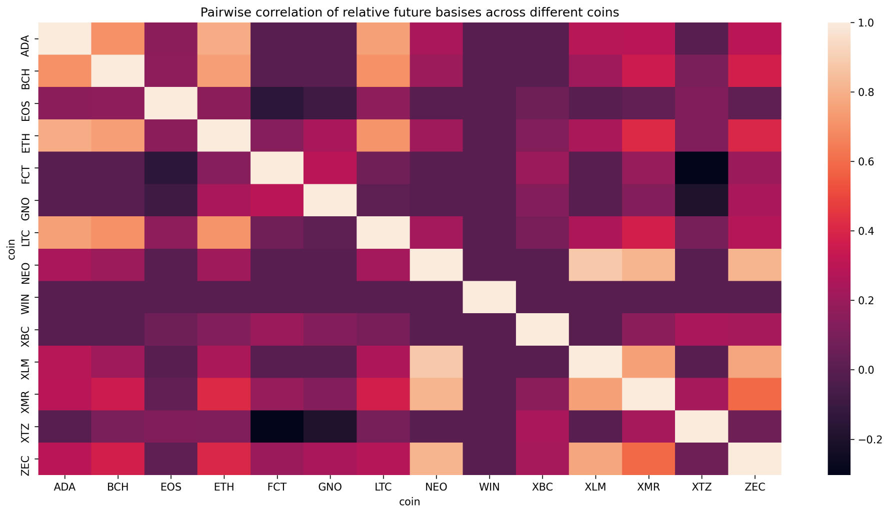

Figure 10. Amount of contracts, distributed for all time period, for each coin. Data source: bitmex exchange, author's calculations.

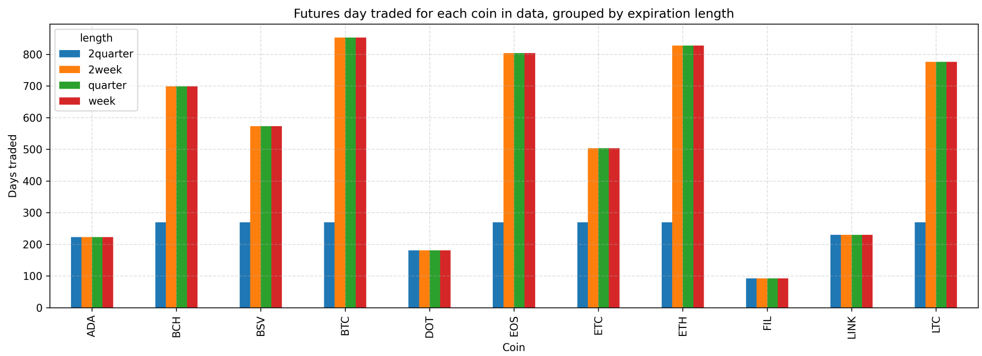

Figure 11. Futures data from huobi exchange. Source: author calculations

Carry portfolio simulations

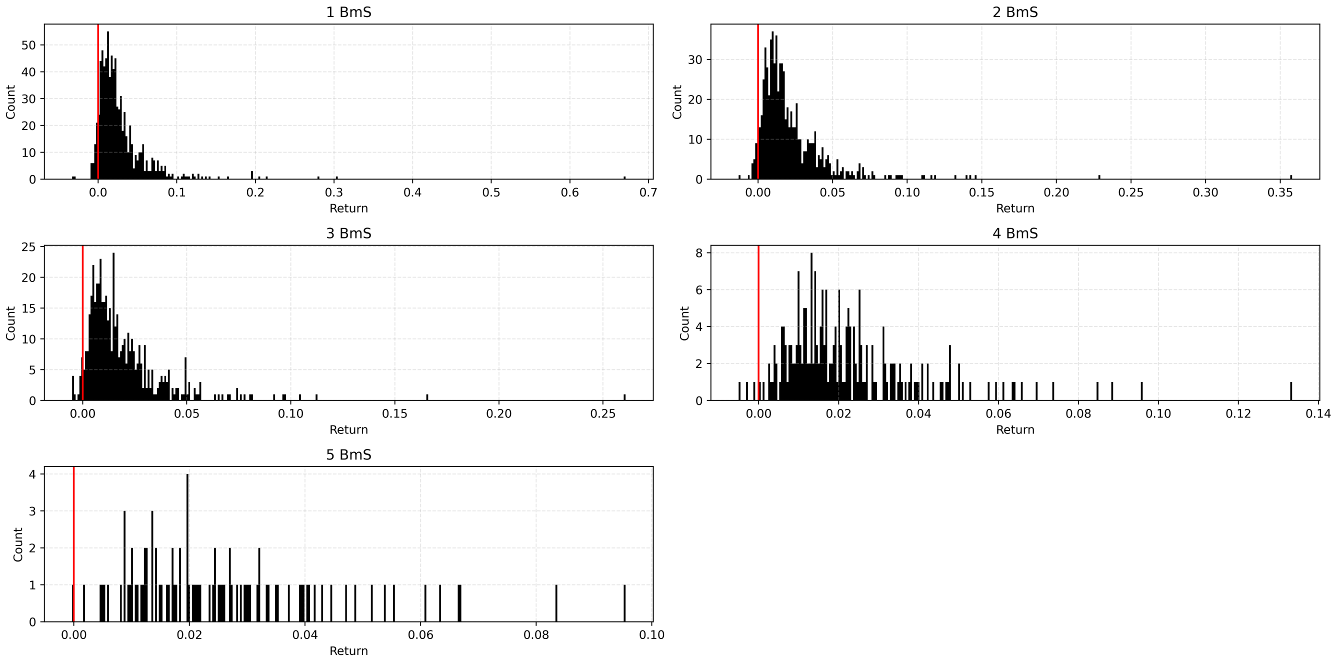

Figure 12. Distribution of returns for portfolio in different variations on *weekly* futures for 11 coins on huobi market data. For every coin in selection carry factor was calculated and leaders were sold, whereas loosers were bought. Source: author calculations.

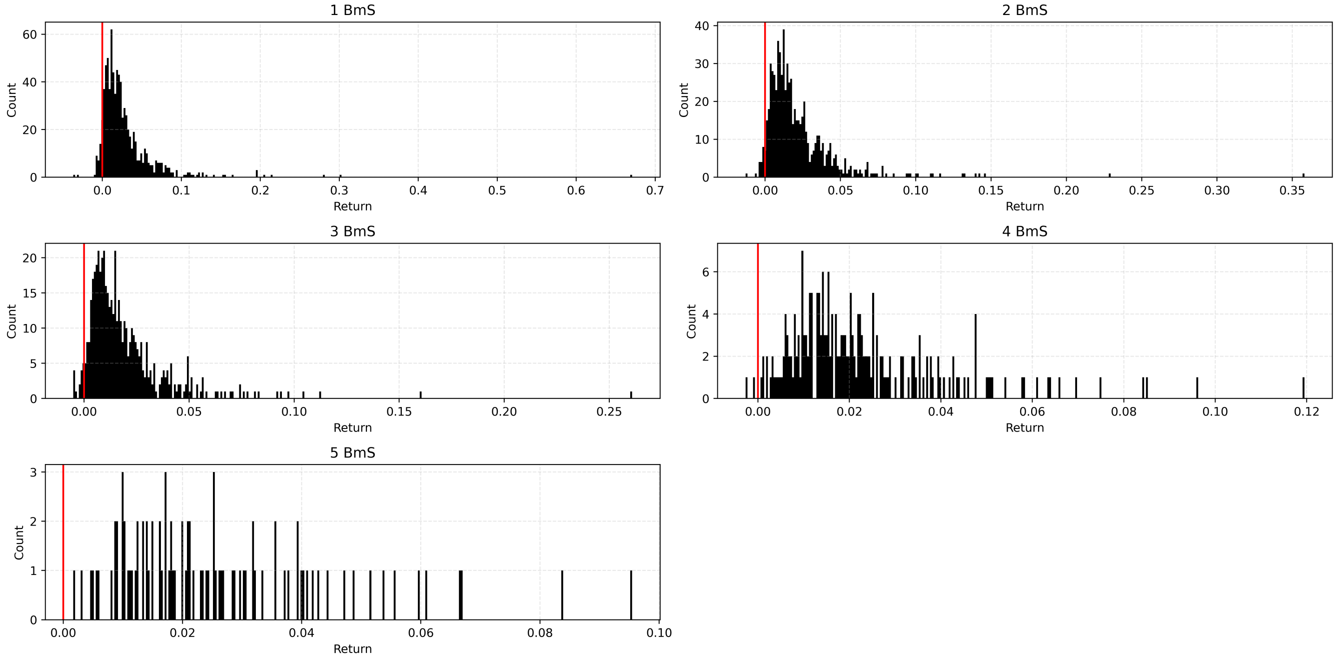

Figure 13. Distribution of returns for portfolio in different variations on *bi-weekly* futures for 11 coins on huobi market data. For every coin in selection carry factor was calculated and leaders were sold, whereas loosers were bought. Source: author calculations.

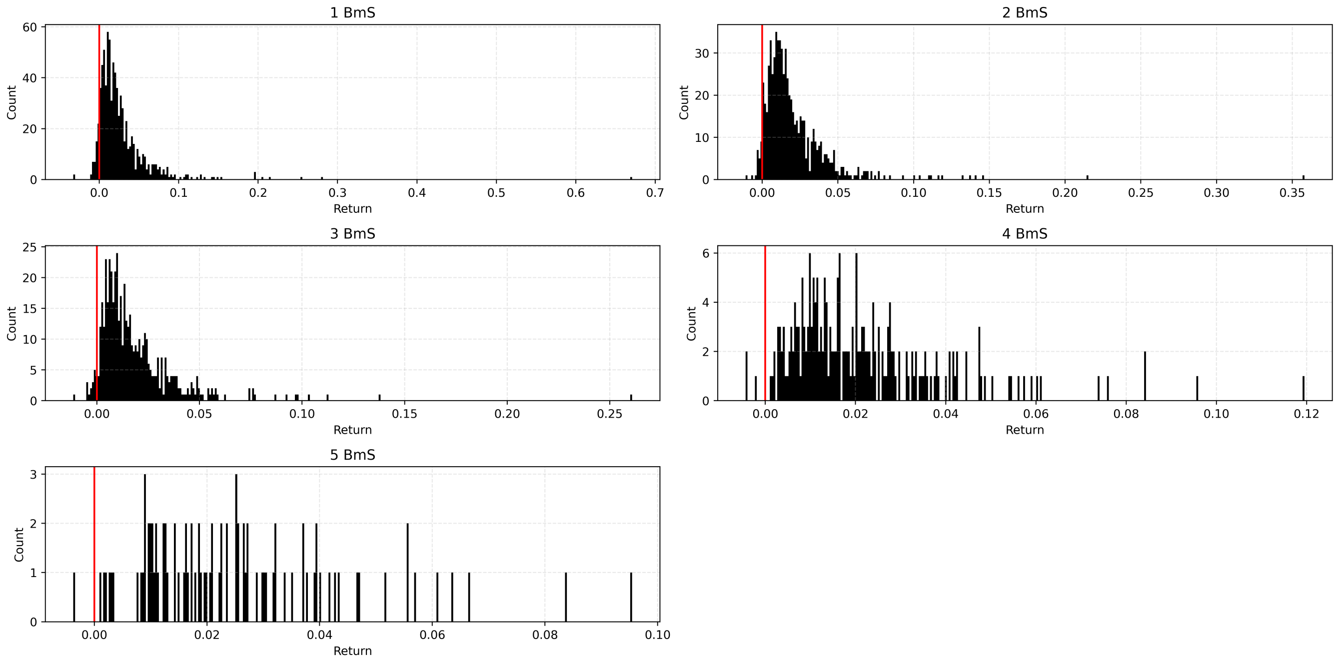

Figure 14. Distribution of returns for portfolio in different variations on *quarter* futures for 11 coins on huobi market data. For every coin in selection carry factor was calculated and leaders were sold, whereas loosers were bought. Source: author calculations.

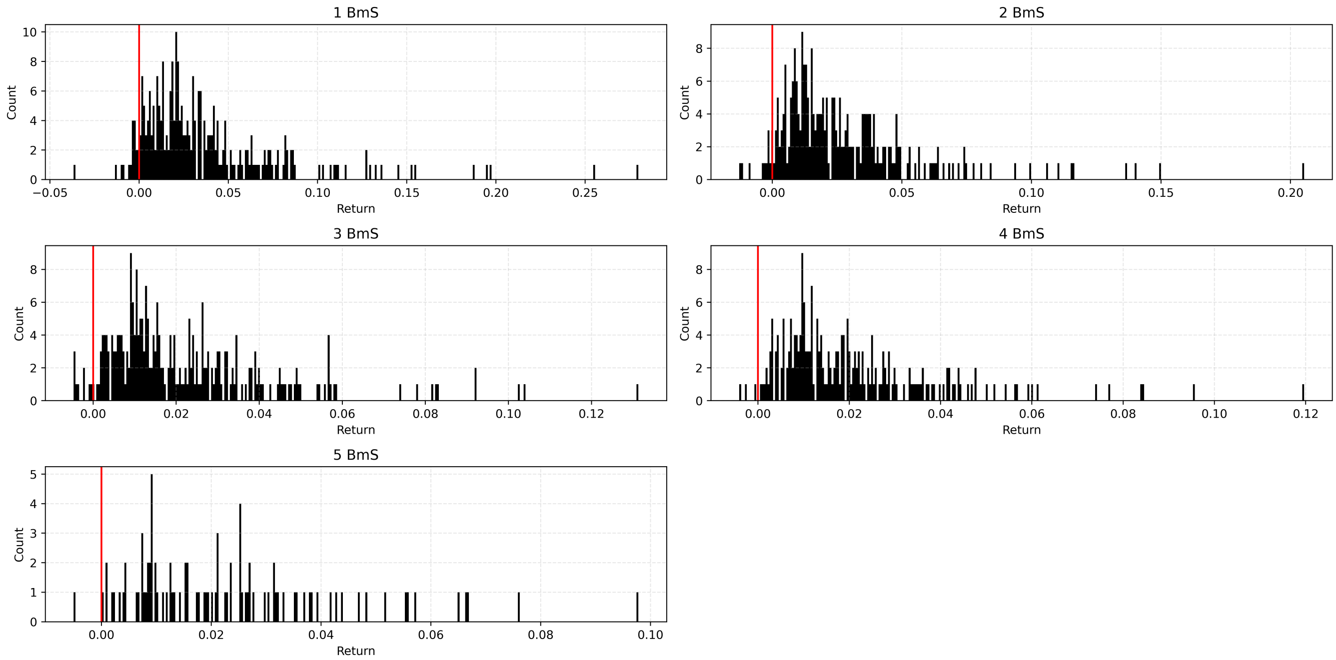

Figure 15. Distribution of returns for portfolio in different variations on *bi-quarter* futures for 11 coins on huobi market data. For every coin in selection carry factor was calculated and leaders were sold, whereas loosers were bought. Source: author calculations.