CHARLES UNIVERSITY

FACULTY OF SOCIAL SCIENCES

Institute of Economic Studies

Bachelor's Thesis

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Non-Fungible Tokens (NFTs): A hype or hope?
Analysis of random NFT portfolios

Bachelor's Thesis

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Year of the defence: 2023

Declaration

1. I hereby declare that I have compiled this thesis using the listed literature and resources only.
2. I hereby declare that my thesis has not been used to gain any other academic title.
3. I fully agree to my work being used for study and scientific purposes.

In Prague on 01.01.2023 Ana Iordosopol

References

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Abstract

This thesis reflects on the newly emerged alternative asset class of non-fungible tokens (NFTs). We perform both qualitative and quantitative analyses on the matter. In the empirical part, we construct different types of random portfolios to investigate the performance of cryptocurrency-based portfolios after the possible inclusion of NFTs in such. Our results suggest that as of the end of 2022, portfolios of Bitcoin and Ether perform better without NFTs, thus rejecting the previous assumptions of limited diversification potential of NFTs, which was detected during the last crisis period during the COVID-19 pandemic. The qualitative analysis on the topic, however, suggests that NFTs are not just the hype and the innovative blockchain solutions that NFTs represent may be of greater use in the near future. Therefore, despite of non-efficiency of NFTs as a financial asset in 2022, they still display significant potential as a disruptive technology.

Abstrakt

Tato práce se zabyva nově vzniklou alternativní třídou aktiv nenahraditelných tokenu. Provádíme kvalitativní a kvantitativní analýzy dané záležitosti. V empirické části tvoříme různé typy náhodných portfolií, abychom prozkoumat výkonnost portfolií založených na kryptoměnách po možném zařazeni NFT do nich. Naše výsledky naznačují , že na konec 2022 roku si portfolia bitcoinů a ethereumů vedou lépe bez NFT, čímž jsou odmítnuty předchozí předpoklady omezeného diverzifikačního potenciálu NFT, který byl zjištěn během posledního krizového období během pandemie COVID-19. Kvalitativní analýza na toto téma však naznačuje, že NFT nejsou jenom humbukem , ale inovativní blockchainová řešení, která NFT přestavují mohou mít větší využití v blízké budoucnosti. Tím pádem i přes neefektivitu NFT v roli finančního aktiva v roce 2022, to stále vykazuje významný potenciál jako progresivní technologie.

Keywords

NFT, Random Portfolio, Non-Fungible-Token, Blockchain

Klíčová slova

NFT, Random Portfolio, Non-Fungible-Token, Blockchain

Title

Non-Fungible Tokens (NFTs): A hype or hope? Analysis of random NFT portfolios

Název práce

Nezaměnitelné tokeny (NFTs): Šílenství či naděje? Analýza náhodných NFT portfolií

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Introduction

Even before the Internet Protocol gained popularity and became a part of our everyday life, the markets for unique assets had existed and fulfilled their purpose as a good tool for portfolio diversification. It is common practice for investors to seek alternative investment opportunities to diversify their portfolios from traditional assets such as bonds, mutual funds, stocks, etc. Until recently, the most popular markets of unique assets, such as fine arts, real estate, wine, and collectables, were the ones of consideration. Nevertheless, since 2017 a new digital asset class has emerged, combining both a unique asset's heterogeneity and cryptocurrency's blockchain-based technology. This type of asset is called a Non—Fungible Token (NFT) and, despite its infancy, has already gathered significant media coverage. The overall hype over NFTs in 2021 was enormous, so Collin's dictionary even chose it as a word of the year[1]. However, for the absolute majority, the NFT phenomenon remains something they heard of but know nothing about[2].

Then what exactly is an NFT or Non-Fungible token? Shortly, it is a token that certifies the provenance of a digital asset. Non-fungible tokens represent the ownership of a unique asset secured by a blockchain network, which cannot be copied, altered or substituted. A wide range of assets could be minted and sold as NFT. The underlying asset can be digital art, music, memes, tweets, collectable cards, or tickets. Originally NFTs existed only on the Ethereum blockchain but eventually, other blockchains implemented their own versions of NFTs too. In the Ethereum Network documentation for NFTs could be found the following statement:
"If Andy Warhol had been born in the late 90s, he probably would have minted Campbell's Soup as an NFT. It's only a matter of time before Kanye puts a run of Yeezys on Ethereum. And one day, owning your car might be proven with an NFT."[3]

The primary characteristics of an NFT are "non-fungibility" and "non-tangibility". Unlike currencies, cryptocurrencies, or shares, NFTs are not interchangeable and cannot be exchanged like-for-like. For example, a 10-dollar bill will have its permanent value of 10 dollars, and if we exchange it for another 10-dollar bill, it will still have the same value. The equivalent "non-fungible" property have art pieces, real estate objects or collectibles; however, they are "tangible" like traditional currencies. Some time ago, the emergence of the digital world led to the creation of the "non-tangible" currencies - cryptocurrencies - "fungible" but "non-tangible". Ultimately, establishing smart contracts and new token standards could make the creation of non-fungible tokens possible.

[1] https://www.theguardian.com/books/2021/nov/24/nft-is-collins-dictionary-word-of-the-year
[2] https://money.com/people-know-what-nft-is/
[3] https://ethereum.org/en/nft/

Trautman (2022) described NFTs in the following way: “The underlying strange brew of cryptography, game theory, interest in art collection, need for the creation of true unique digital ownership interests, and a solid dose of speculative hype has now fermented into a term that has become one of the driving law and technology stories of the year: non-fungible tokens (“NFTs”)”.

It is impossible to ignore that the NFT boom occurred not only in Google Search statistics but also in its market cap, which surpassed over $11.3 billion across 2.46 million unique wallets as of September 2022. In the year 2021, NFTs exploded with parabolic growth. The third quarter of 2021 saw NFT trading volume increase by more than 700% compared to Q2 of the same year[4]. Thousandfold returns were obtained by early NFT investors. The novel idea of NFT helped the creation of an entirely different market, which allowed content creators have free access to new markets where they could sell their art without intermediaries. Before the NFT disruption, there has been limited access to the creative industries market with high barriers to entry. The best example is Beeple's case, a digital artist whose real name is Mike Winkelman. Until October 2020, he was selling his digital prints for merely $100. Mike decided to start selling his artworks as NFTs because he believed there was no other easy way to sell digital art at traditional auctions. This issue has been present for a long time. The digital artists have been around since the 60s, but there was no way for them to prove that their work was original. The exclusionary part of art otherwise could not be certified. Not long after Beeple launched his first "drop" on the Nifty marketplace for NFTs in late 2020, his works' prices started to rise exponentially. The popularity of Beeple's NFTs drew for the first time attention of traditional auction houses. Later, in March 2021 his work "Everydays: The First 5000 Days" was sold at Christie's for more than $69 million. Beeple, now, is considered the third best-selling artist alive[5].

The numbers are impressive, aren’t they? Besides the impression, such extreme values usually raise many questions and concerns in people's heads. We are not the exception. Primarily these events and the lack of scientific literature on the topic motivated us to study NFTs. To be fully honest, some simple human curiosity has been involved in it too. Since the original idea’s inception, many changes have occurred, some questions have been answered but some have not. In 2022, The NFTs significantly declined in price and the motive of them being the next “big” thing now may seem to be doubtful. In later chapters, we cover these events in more detail together with the key characteristics of NFTs. However, at present, we move along to highlight several views from which it may be favourable to study the topic and to which we aim.

First, we are interested in whether the demand for NFTs is persistent over time and if the price drop signifies the end of its “era”. Are the NFTs just traded “jpegs” or there is something more underneath? Given the NFT provenance, we would like to investigate whether it reflects similar behaviour patterns compared to cryptocurrencies and other assets. Another area of focus is the determination of the asset class the NFT represents since it empathises to some extent features of both financial and alternative asset classes. Consequently, this thesis investigates the possible impact of including NFTs in different types of portfolios. More specifically, our

[4] https://www.nansen.ai/guides/nft-statistics-2022
[5] https://abc11.com/nfts-enter-the-metaverse-trailer-beeple-non-fungible-tokens-what-does-nft-stand-for/11844945/

research is designed to analyse the implications of including NFTs in different sets of cryptocurrency portfolios given the present market conditions and using the random portfolio construction method. We evaluate the relative performance of two sets of portfolios: portfolios constructed only from the top two cryptocurrencies by market cap and the mixed portfolios of cryptocurrencies and NFTs included. The results are aimed to discover whether the bear market of 2022 affected the NFTs as financial assets and if so, to what extent. Given, the novelty of the market changes, so far, there has been implemented no research covering these premises thus, making this study a pioneering one.

This thesis is constructed in the following way: first, we give readers some insight into the NFT market structure, and its history, then inspect the key technical components of the NFT ecosystem. Subsequently, we evaluate the properties of NFTs and existing literature on the given topic. Next, we define our dataset and methodology for our empirical calculations. Later on, we present our results and check our initial hypothesis. In the end, we discuss the possible future use cases of NFTs given our empirical results and conclude.

NFTs 101

This chapter is created as a brief introduction to the new disruptive technology NFTs represent. We aim to discuss the current NFT market condition and its interpretation. Then, we demonstrate the structural representation of the market for NFTs and its main categories. Besides that, we introduce the key technical concepts related to NFT, which are essential for understanding the market processes. Afterwards, based on the fundamentals explained in this part we will be able to get more into the specifics associated with our study objectives.

The Change

In the very beginning of the thesis we alluded to the success of non-fungible tokens in early 2021 and the “hope” associated with that. The NFT craze of 2021, nonetheless, was followed by an extreme downturn in the market of the following year. On short notice, by the second half of 2022, the tabloid's headlines had been stating the exact opposite of what in 2021.
As of June 2022, Bloomberg wrote that "NFTs have fallen off the cliff"[6] with a corroborative report by Reuters in October same year - "NFT sales plunge in Q3, down by 60% from Q2"[7]. The media's criticism of NFTs started flourishing under these conditions, and the sales statistics aligned with it. As for the period from January 2022 to December 2022, nansen.ai reported an annual decrease in its NFT-500 index by 28% [8].

The main questions of concern: "What happens to NFTs now? Is it over?" were attempted to be answered by many. Overall, there could be distinguished three types of suggestions regarding the NFT collapse that exist right now.

The first one is the most pessimistic. The sceptics say that the NFTs are over, the hype is gone and considering NFTs as an investment asset is a mistake. This cohort maintains that the lack of inherent value behind NFTs will eventually lead to their complete doom.

The second type of assumption "blames" the present bear market in most markets as of fall 2022 and the "crypto-winter" of 2022 for this drastic decline. As reported by Morgan Stanley in September 2022, The Treasury yield curves are inverted, with 2-year/30-year curves being the most inverted since 2000. Together with a third consecutive interest rate hike of 75 basis points, it implies high uncertainty and recession expectations in investment markets. Moreover,

[6] https://www.bloomberg.com/news/articles/2022-06-29/nfts-have-fallen-off-the-cliff-as-sales-sink-to-lowest-in-year
[7] https://www.reuters.com/technology/nft-sales-plunge-q3-down-by-60-q2-2022-10-03/
[8] https://pro.nansen.ai/nft-indexes/nft-500?platform=All&washtrading_filter=none

the Global Investment Committee of Morgan Stanley believes that this bear market is far from being over. [9]
The price and correlation comparison of Bitcoin and SPX done by Crypto.com as of July 2022 showed a positive correlation of 91.13% between these two indices. Thereby, they assume the present bear market or, in other words, "crypto winter" to be not only crypto-specific but as a natural consequence of general market decline.[10]
In line with the Crypto.com report, Cointelegraph.com suggests the general market conditions and Federal Reserve stringent measures to be some of the catalysts of the 2022 "crypto winter". According to their predictions, the same as for traditional markets, the crypto bear market is expected to last [11]. More so, the inside market issues like the FTX collapse can lead to an even more extended "winter," as implied by Coindesk.com [12].

Given all the above, with the assumption of NFT price connectedness to the rest of the crypto market, we can presume the earlier-mentioned factors to explain at least a partial decline in this specific market. Compared to the most pessimistic scenario, this type of suggestion is more optimistic towards the future of NFTs. It reflects some beliefs in possible NFT recovery along with the general market.

The third type relies on the idea of hype cycles, implying that the NFT hype cycle may be over, meaning the start of NFT transformation from an investment asset to a community-building tool. The underlying idea of cycles is essentially based on Gather's Hype Cycle, introduced back in 2009. The cycle provides a conceptual representation of the adoption of emerging technologies and their applications over time. This research methodology proposes five consecutive key phases of the technology's lifecycle: the innovation trigger, the peak of inflated expectations, the trough of disillusionment, the slope of enlightenment and the plateau of productivity. [13]

[9] https://www.morganstanley.com/ideas/how-to-invest-in-bear-market-2022-q4
[10] https://crypto.com/research/crypto-bear-markets

[11] https://cointelegraph.com/news/how-long-will-the-bear-market-last-signs-to-watch-for-a-crypto-market-reversal
[12] https://www.coindesk.com/markets/2022/11/16/coinbase-ftxs-collapse-will-likely-lead-to-an-extended-crypto-winter/
[13] https://www.gartner.com/en/research/methodologies/gartner-hype-cycle

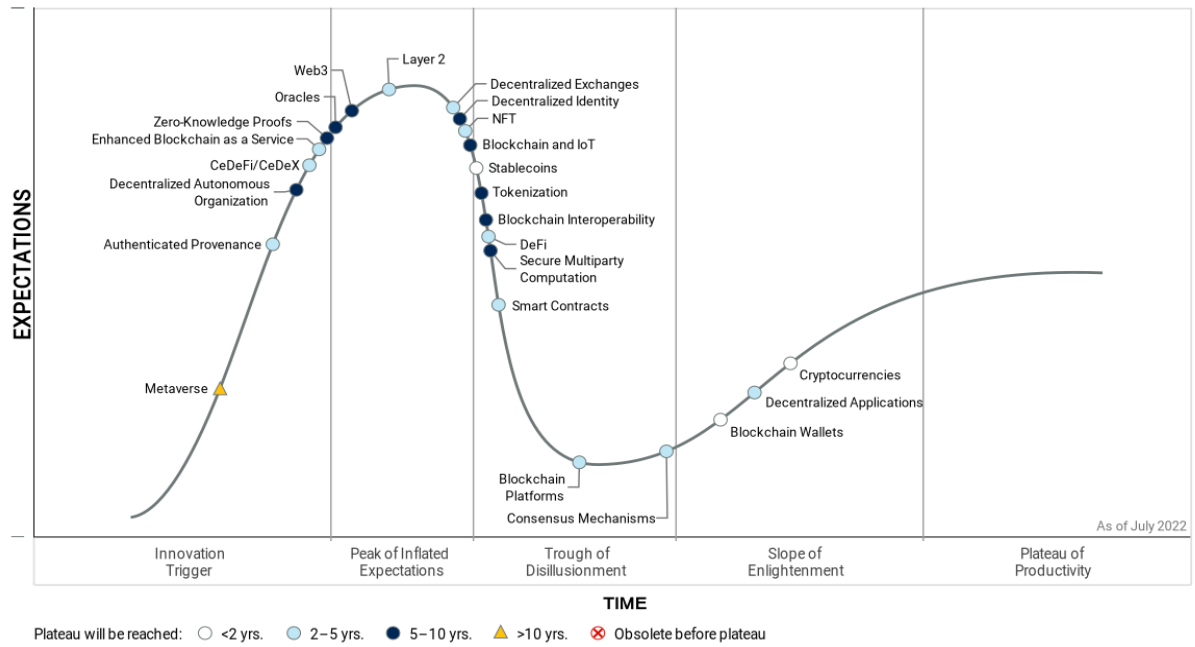


Figure 1: Image from Gather.com

In the annual report of the Hype Cycle of Blockchain and Web3 for 2022 by Avivah Litan, they positioned NFTs closely to the separating point between the Peak of the Inflated Expectations period and the Trough of Disillusionment. According to this methodology, a further fall in the market of NFT must be expected in the near future, with the NFT reaching the "plateau" in 2-5 years, hence finishing the cycle. For most blockchain innovations, Gather expects it to reach maturity within two to 10 years. [14]

Despite the wide use of Garther's Hype Cycle in different industries, it is important to mention the existence of critique on this methodology.

Generally, the defenders of NFTs and crypto are advocating this approach, asserting that the market's downturn should be read as a sign of cyclicality and that the market will recover; therefore, it is a sign of its normalisation. Hence, this prognosis can be differentiated from the two previously presented as the most optimistic one.

Due to the very novelty of changes in the price and volume sales for NFTs, no research regarding the underlying reasons of those has been done yet. We believe it could become a topic of interest for future studies. Accordingly, to this point in time, none of those mentioned above scenarios can be fully supported or denied.

Now, after a brief history of NFTs we move on to the exploration of the newly emerged market for non-fungible tokens and its components.

[14] https://blogs.gartner.com/avivah-litan/2022/07/22/gartner-hype-cycle-for-blockchain-and-web3-2022/

The NFT Market Structure

In the NFT industry, new use cases appear regularly and are not limited to digital art only. Therefore, proper categorisation of this market cannot be ultimately realised at this point in time.
To highlight the main categories of NFTs by their practical usage we will address the seven segments of the NFT industry proposed by (Gecko, 2022).

1. Art

The Art NFTs serve as a logical extension of traditional art. A form of digital art but with proof of ownership fosters more and more digital creators and not only them to safely reach the art lovers interested in their art. Besides the example, we provided in the Introduction, there are several other ones worth mentioning. A project named Art Blocks has a series of works "Ringers", that are algorithmically generated artworks of loops around pegs, each one having a unique combination of them. "Ringer" can take different "forms" a 3D image, an interactive feature, or a static picture.
The Merge, by Pak, is unique digital artwork in its way, because instead of being a single piece of work, it is a form of fragmented art. The Merge has 28,983 collectors that hold it, with a total maximum price reaching US$91.8 million[15] .

2. Music

Besides being visual, NFTs can also be minted in a form of audio art. The music we are all accustomed to can be an NFT, thus helping the artist or the piece owner to secure its digital ownership as in the case of Art NFTs. There is however an alternative approach to music powered by NFTs. What if a melody is not made through an instrument but was randomly generated by the power of math and AI? The project Euler Beats brought it to reality and issued a limited series of audio NFTs created vis Euler's totient function.

3. Collectibles

Probably the most famous and the biggest segment of the NFT market. The NFT collectibles generally "work" in the same way as regular tangible collectibles, like Pokemon cards from the 90s. Collections have a limited number of pieces included which cannot be extended. Similarly, as for other types of collectibles the NFT with the rarest feature is valued the most. One of the first NFTs ever created were the CryptoPunks collectibles dating back to 2017. There is a total of 10000 punks in the collection, that were algorithmically generated and each possessing a number of attributes like an earring, a beanie or dreads. Some of these attributes turned out to be rarer than others thus forming a unique value for the individual punk. Ironically, in 2017 they were distributed for free to anyone who claimed it. Now, the rarest punk was sold for US$23.7 million[16].

[15] https://www.barrons.com/articles/paks-nft-artwork-the-merge-sells-for-91-8-million-01638918205
[16] https://hypebeast.com/2022/2/cryptopunk-5822-record-breaking-8000-eth-23-7-million-usd-sale-info

4. Games

The emergence of NFT helped the gaming industry to set itself "free" from being controlled by centralised entities, usually game developers. For decades, players were able to purchase in-game items and upgrade them but never sell them to third parties using fiat currencies. Moreover, if ever something happened to the game servers, their achievement would be lost forever. NFTs as a technology, however, allow the players to do whatever they want with their possessions. Additionally, these innovations enforced the establishment of Play-to-Earn (P2E) gaming, allowing the players to earn an income by playing.

5. Sports

Most Sports NFTs have a similar function to trading cards or game pieces, users can play with each other, compete and participate in various of thematic events. Sometimes, owning such an NFT may have a "perk" of meeting your sports hero personally. Several NFT projects including NBA Top Shot and Sorare have licensed the rights to work with major sports franchises too.

6. Metaverse

The 3D virtual worlds or metaverses have the intention to mimic real life to its fullest. Therefore, the use cases of NFTs in metaverses are many, from hanging the Art Blocks piece in your virtual living room to buying virtual land as an NFT too. Two of the most prominent metaverses are Decentraland and The Sandbox.

7. Financial

Unlike the general context of NFTs being spoken of as Art or Collectibles the NFTs also may have some real-world use cases. One of them is Financial NFTs, which generate a new type of upgraded and future-proof financial products that can noticeably change the DeFi. For example, in the case of the floating interest rate problem in DeFi, Financial NFTs define a way for loans to be tokenized as NFTs. This approach allows the owner of the NFT to earn a fixed interest rate throughout the loan period. Moreover, as an NFT, this tokenized loan can be traded on NFT marketplaces, therefore making it easy for owners to swap loans and interest rates and switch from fixed to floating interest rates.

Nadini (2021) in their studies measured to what extent different NFT segments contribute to the size of the total NFT market. Their results suggest that until the end of 2018 the Art segment and one particular type of Collectible - CryptoKitties fully dominated the market by their share of volume transactions. During the next year, other categories started gaining popularity. Consequently, from January 2019 to July 2020, approximately 90% of the total volume exchanged was divided among the Art, Games and Metaverse segments. Further, they noticed the discrepancy between volume and transaction shares in the market. Since July 2020 the most exchanged categories with the largest number of transactions were Games and Collectibles. Overall, it reveals that the prices in the Art segment are higher, on average, compared to other segments. Also, we would like to point out that the authors in this paper divide the NFT market into slightly different categories, the Sports category here is included in Collectibles.

Components of the NFT ecosystem

In this part we present the technical solutions that make an imaginary CryptoPunk different from a regular picture downloaded from the Internet. Hence, we outlined six key elements that constitute the building foundations of a fully functional NFT ecosystem.

- Blockchain

Shortly, blockchain is a technology of distributed ledger, that was created by Satoshi Nakamoto (pseudonym) in 2008, (Zheng et al., 2017). Each transaction on a blockchain is a record, which then is grouped into blocks. Each new block is connected to the previous block, thus forming a "chain". Blocks are linked together using sophisticated cryptography and every new block contains information like the timestamp and transaction data on the previous one. Thus, the information stored on a blockchain cannot be changed, since altering one block will cause altering the whole chain. Adding a new block requires validation which is done through a consensus algorithm protocol. The key characteristics of blockchain are transparency (all the records are public) and decentralised nature. Bitcoin was the first created blockchain protocol, later other protocols emerged, among those Ethereum being the most prominent one. An important notion is that cryptocurrencies and blockchain protocols are not the same things, protocols allow the creation of cryptocurrencies.

- Smart Contract

The term "smart contract" was originally established to refer to the automation of legal contracts, (Szabo, 1997) . Now, however, it is mostly used to refer to a legal contract (or at least parts) which can be expressed and implemented in software. In other words, a "smart contract" is a program that runs on a blockchain and is designed to automatically execute different types of transactions under anticipatorily specified conditions. The main objective of smart contracts is eliminating the need for trusted intermediaries, like the ones for "classic" contracts. They were first introduced by Ethereum, (Buterin, 2014), and became an indispensable technological pillar for the future emergence of Decentralised Finance (DeFi) and NFTs. Based on smart contracts there have also been developed Dapps – Decentralised Applications or smart-contract-powered apps.

- Token Standard

For a smart contract to function effectively, the underlying components need to be compatible with one another and follow the same set of rules. It ensures that smart contracts remain composable, and every newly issued token is consistent in its execution. For these reasons, there were created corresponding token standards. For our research, we will consider token standards attributed to Ethereum Network. The most common standard is ERC-20, which is used for fungible tokens. The non-fungible tokens must comply with the set of "rules" in ERC-721[17] or EIP-1155[18] token standards in order to be integrated.

[17] https://ethereum.org/en/developers/docs/standards/tokens/erc-721/

[18] https://eips.ethereum.org/EIPS/eip-1155

- Wallet

Same as in real life, cryptocurrencies have to be stored somewhere for executing the selling or selling transactions. In the case of NFTs, their price is indicated in cryptocurrency, therefore purchasing an NFT requires owning some cryptocurrency and having a wallet from which the specified amount will be deducted. There are two basic types of blockchain wallets: software and hardware. The "easiest" and the most common are the software ones. Some wallets regardless of type have a feature of storing not only fungible but non-fungible tokens too. Therefore, blockchain wallets may also serve as NFT vaults if needed. The safety of this however can be argued.

- Marketplace

An NFT marketplace is a digital platform where digital collectibles and NFTs can be bought and sold. Some of them even give the ability to users to mint (create) their own NFTs inside the platform. The key difference among the marketplaces is in the range of NFTs offered and in the fee paid for every transaction. One of the most valued features of NFT marketplaces is that it allows royalties to the NFT creators, meaning that they get a particular share of price each time their NFT is resold. The largest NFT marketplaces are OpenSea, Nifty Gateway and Rarible.

- Gas

The gas fee is essentially a transaction cost for each transaction executed on the blockchain and paid to the network validators for their services. The existence of gas is vital for the network, otherwise there would be no incentive to someone to ratify transactions and help in securing the network. The biggest caveat is that the gas fees are subject to price fluctuations caused by network congestion. In other words, the more participants are active during a certain period the more transactions are pending to be executed, thus a larger demand in validation is present.

Now, we know that NFTs are minted in accordance with a token standard, placed on NFT marketplaces, where we can buy them and pay the gas for transaction execution with our crypto wallet.

Properties of NFT

In previous chapter we built the fundamentals of understanding NFTs and showed that non-fungible tokens can be more than just traded “jpegs”. This chapter, however, is dedicated to the implementation of NFTs and to the implications of its possible adoption in different industries. Therefore, we present a throughout and systematic review of the features this new blockchain-based technology possesses. First, we list the properties, the combination of which made it possible to call the NFT a disruptive innovation or, in other words, the advantages. Then, we address both the potential and present shortcomings of this technology.

Advantages

Since NFTs are essentially Dapps and minting an NFT is always done through a smart contract, the NFT itself shares a number of common features specific to the underlying public ledgers, there is three of them:

- Immutability

Once any information is on the blockchain it cannot be changed. The moment smart contracts are released to the network, they can no longer be modified. However, the removal can be done, but only if this function was originally included in the smart contract itself.;

- Autonomous, transparent and decentralized

Smart Contracts work automatically, there is no need to wait for someone to execute it, once all conditions are met, the contract is executed immediately. This digital and automated process eliminates any needs in paperwork and eventually all the possible errors resulted from manually filling in documents. Additionally, smart contracts powering NFTs are trustless and openly auditable, hence the third parties to verify the integrity are not required.;

- Tamper-Resistance & Security

All the NFT's metadata is persistently stored and cannot be manipulated. If any changes in a smart contract, therefore NFT, are made, every other participant on the blockchain will be alerted on this tampering. Moreover, blockchain transaction records are encrypted, each record is connected to the previous and subsequent records, hence for hackers to alter a single record they will have to change the entire chain.

- Accessibility

The World Bank estimates that account ownership has reached 76 per cent of the global population in 2021 [19]. In comparison by the end of 2022, 91 per cent of the world's population owns a smartphone [20]. It results in approximately 1.2 billion of the unbanked population that has access to mobile phones. These people can create their digital wallets and conduct financial transactions, like buying NFTs, without any time-consuming verification processes as usually implemented by traditional banks. Hence, this type of asset can be bought by a much larger share of the global population, if compared to those investing in stocks, bonds, and real estate.

- Ownership Protection

The NFT token possesses a unique identifier which allows the storage of additional parameters on it. This is what makes a token non-fungible and differentiates it from "fungible" ones. This concept helps in combating the problem of fake goods not only in digital but also in the physical world too.

Earlier, there have been only non-digital options for owning artworks, sports collectibles, books or branded clothing and many of these items have a problem of authenticity and their provenance is not clear. The Organisation for Economic Co-operation and Development (2016) reports that global trade in fake branded goods is worth almost half a trillion dollars per year.

The embedding of NFTs into non-digital "tangible" consumer items enhances both the ownership and community experiences of physical items and associated digital ones.

For example, Nike patented "The CryptoKick" - "a computer-generated virtual collectible, a tokenised shoe identifier that is stored on the blockchain and linked to a virtual shoe. CryptoKick Tokens may be created at the time of manufacture or purchase and *traded* as the physical shoes change hands among collectors. They may be traded on NFT marketplaces and stored in ERC721 *wallets* referred to as *lockers*".[21]

- Royalties

One of the most prominent benefits of the NFTs for digital art creators are the NFT royalties, they give artists a percentage of the sale price each time their NFT is sold on a marketplace.

Some details can vary depending on the marketplace, but generally, the creator can determine the royalty percentage at the time of minting the work and the payment will execute automatically by smart contract every time the piece is sold. 5-10% is considered a standard royalty.[22]

In the case of traditional art, the creator benefited only from the first sale of their work. After that sale, all the subsequent sales regardless of the artist's popularity over the years did not bring any profit to the artist, even if the works were sold for millions of dollars.

[19] https://www.worldbank.org/en/publication/globalfindex

[20] https://www.bankmycell.com/blog/how-many-phones-are-in-the-world

[21] https://nftnyc.medium.com/nikes-dec-2019-patent-reveals-revolutionary-nft-use-a74c115bd0c

[22] https://cyberscrilla.com/nft-royalties-what-are-they-and-how-do-they-work/

- Versatility

One of the benefits the NFTs can offer to businesses is their versatility feature as addressed by Chonan (2021). They bring out the fact that NFTs are compatible with anything built on the same blockchain. Companies in the ticketing industry, for instance, can issue an NFT ticket on Ethereum Blockchain and that ticket can easily be traded on every marketplace supporting the ERC-721 token standard. Conversely, the present market for tickets requires companies to develop both their own ticket-issuing app and a ticket exchange, which will limit transactions to their app users only.
It may help in ameliorating the main challenges present in the traditional ticketing system such as black marketing for tickets, lack of exchange protocol, customer trust [23]

- Fractional NFTs

Illiquidity is a significant flaw in most markets for alternative investments like: art, collectibles and antiques. The presence of this kind of natural concern in market for traditional art was pointed out by Artemundi Global Fund (2014). Despite author's suggestions of creating liquidity through the distribution of yearly dividends from art transactions' profit, at the present moment this issue still persist in the market for traditional art.
Alternatively, the relative low liquidity in the NFT system has already been "alleviated" by introducing fractionalised NFTs (F-NFTs). The ownership of an asset can be divided into equal parts - fractionalised NFTs, hence it can allow the NFT to function likewise shares or stocks.
It may be argued that from the perspective of profitability, having a small piece of a popular yet expensive NFT may be a better investment than acquiring full ownership of several insignificant pieces at the same price[24].

- Influencing Legal Practice

The autonomic feature of smart contracts the NFTs are based on, in its turn, may have a significant influence on legal practice. NFTs enable convenient and transparent conversion of assets into crypto-verified tokens, enhancing the ease of movement through these complex systems. The evolvement of NFT smart contracts may lead to a notable reduction of legal services, literally, middlemen required for purchasing/selling activities.
Moreover,
"This has the potential to completely transform markets like property and vehicles, for instance. NFTs could also be part of the solution in resolving issues with land ownership. Only 30% of the global population has legally registered rights to their land and property. Those without clearly defined rights find it much harder to access finance and credit. Also, if more of our lives are spent in virtual worlds in future, the things that we buy there will probably be bought and sold as NFTs too." [25]

[23] https://www.leewayhertz.com/how-nft-ticketing-works/
[24] https://www.leewayhertz.com/fractional-nft/
[25] https://theconversation.com/nfts-are-much-bigger-than-an-art-fad-heres-how-they-could-change-the-world-159563

- Branding and Marketing Tool

Further, in addition to provenance certification, the embedding of NFTs brings new means for businesses to provide access to memberships, clubs, and discounts [26].
The NFTs can also facilitate the production of specialised content for fandoms like Golden Tickets and exclusive offers. Engaging with the NFTs brands can also "rejuvenate" and enlarge their target audience.
In August 2021, Visa announced the purchase of their first NFT - CryptoPunk #7610 for $150,000. It was the first time such a "giant" joined the NFT craze.
Later, Cuy Sheffield, the Head of Crypto at Visa, declared the three main reasons for this purchase:

" We think NFTs will play an important role in the future of retail, social media, entertainment, and commerce. To help our clients and partners participate, we need a first-hand understanding of the infrastructure requirements for a global brand to purchase, store, and leverage an NFT.
We also wanted to signal our support for the creators, collectors, and artists driving the future of NFT-commerce. Enabling buyers and sellers is what we do —whether it's helping small and micro business owners get online, or making it easier for companies to pay their partners across borders. We're excited to work with this growing community to make NFTs usable and accessible in a variety of contexts.
Lastly, we wanted to collect an NFT that symbolises the excitement and opportunity of this particular cultural moment. We're a company steeped in the history of commerce and payments—but with our eyes on the future. With our CryptoPunk purchase, we're jumping in feet first. This is just the beginning of our work in this space. " [27]

However, as noted by Gecko (2022), there was also a fourth underlying reason that has not been spelt out - marketing. The authors also brought out that CryptoPunk's post on VisaNews's Twitter page had received far more attention than any other.

Figure 2: Image from twitter.com

[26] https://www.cnbc.com/2021/05/05/gary-vee-launching-art-nfts-linked-to-ethereum-cryptocurrency.html
[27] https://usa.visa.com/visa-everywhere/blog/bdp/2021/08/18/nfts-mark-a-1629328216374.html

Shortly after this announcement, news of Visa purchasing a CryptoPunk “insanely" spread across the Internet [28]. It turned out to be an extensive marketing campaign; $ 150.000 generated more PR value than the cost of procuring the Punk itself.
Embedding NFTs can be implemented not only by purchasing one. Another approach realised by Burberry, Louis Vuitton, Gucci and other brands is the creation of their own NFTs. It may be an NFT game character, as in the case of Burberry[29], or an NFT mobile game, as done by Louis Vuitton[30]. Gucci made it even further and has already implemented several projects like Gucci Vault Land in collaboration with The Sandbox Metaverse[31].

Challenges

Most of the challenges NFTs face are highly interconnected and provoked by the underlying technological solutions. Evolvement and upgrades of those will have a direct positive impact on the NFTs respectively.
The issues coming from smart contract employment:

- Immutability

The immutability of a smart contract may not be only its advantage but a disadvantage too. If a human error was made while creating a contract, once deployed it cannot be corrected.

- Transparency

Openly audible smart contracts may also be the subject of hacker attacks. Anybody can view and find possible exploits in the code of that contact. Therefore, SCs are highly recommended to be written by a highly skilled developer.

Blockchain Network-related caveats:

- Scalability

Presently, most NFTs are minted on Ethereum Blockchain. Due to the rising number of Dapps and other use cases created on Ethereum, the network is becoming highly congested. As a result, the transactions are slower, consequently making the network less secure and more exposed to attacks. The Ethereum platform itself addresses this problem as The Scalability Trilemma[32]. Improvement of both scalability and security can easily be achieved by making

[28] https://www.bloomberg.com/news/articles/2021-08-23/cryptopunk-nft-prices-visa-buys-digital-avatar-7610-for-150-000-in-eth
[29] https://www.voguebusiness.com/technology/burberry-brings-back-the-blankos-block-party-nft-based-game
[30] https://bitcoinist.com/louis-vuitton-nft-game/
[31] ttps://vault.gucci.com/en-CZ/story/metaverse
[32] https://ethereum.org/en/upgrades/vision/

the network more centralised. Still, decentralisation is the keystone of blockchain technology, and there can be no trade-off. The "cost" of keeping the network decentralised and secure is longer the delays in transactions. Amelioration of the scalability issue, with no opting for centralisation, requires a more complex and refined approach.
Currently, two types of "remedy" exist for this issue: on-chain and off-chain solutions.
On-chain scaling refers to any direct modification made to the blockchain, like sharding (dividing the database horizontally to spread the load) or introducing Ethereum 2.0. The latter off-chain option, like layer 2 solutions or rollups, benefit from the existing layer 1 blockchain security and realise innovation outside the Ethereum blockchain. [33]
These methods, however, have been only partial amendments so far.
As of the end of 2022, the Ethereum network is limited to ~15 transactions per second. It needs to handle more transactions per second without increasing the nodes' size. Nodes are essential to network participants who run the blockchain. Bigger nodes require bigger computing powers, therefore, more expensive computers. This approach will create higher entry barriers to network participants and is impractical. To scale, Ethereum needs two things: more transactions per second and more nodes. More nodes will keep the network secure.
Since the 15th of September 2022, Ethereum Network switched from Proof-of-Work (PoW) to the Proof-of-Stake (PoS) consensus mechanism, which is alleged to foster the creation of new nodes and boost transaction speed. This change is called "The Merge" and implies the upgrade to Ethereum 2.0 [34]. Earlier, the Ethereum founder, Vitalik Buterin, announced that PoS, combined with existing sharding and rollups solutions, can increase the number of transactions per second up to 100,000 in the next couple of years.[35]

- High Transaction Cost

Relatively slow transactions and network congestion also resulted in high transaction costs (gas fees).
Validators prioritise higher fees, and these transactions are usually executed faster than ones bringing lesser rewards. Since every transaction on the Ethereum blockchain network costs gas, the process of minting and exchanging any NFT involves a certain fee too. Moreover, every NFT-related transaction is more expensive than a regular transfer transaction because smart contracts require processing more computational resources and storage. Complex operations like minting NFTs demand expensive fees, which may significantly limit its wide adoption.
However, Kong (2021) finds that gas fees, in data for CryptoPunks, on average, account only for 0.13% of the sales prices. Additionally, the number strongly tends to decrease from 0.62% in 2017 to 0.01% in 2022.
From these results, we may imply that if similar behaviour of gas prices exists in the whole NFT market, then it is possible that the gas fee can cease to present a problem in some time. Alternatively, these numbers may indicate this problem's persistence but for the market's low-price segment.
The solution to the scalability issue will primarily lead to a respective decrease in gas prices.

[33] https://ethereum.org/en/developers/docs/scaling
[34] https://ethereum.org/en/upgrades/merge/
[35] https://twitter.com/VitalikButerin/status/1277961594958471168?ref_src=twsrc%5Etfw%7Ctwcamp%5Etweetembed%7Ctwterm%5E1277961594958471168%7Ctwgr%5E%7Ctwcon%5Es1_c10&ref_url=https%3A%2F%2Fdecrypt.co%2F34204%2Fethereum-2-0-will-walk-and-roll-for-two-years-before-it-can-run

- Security and Privacy Issues

The third issue connected to the Blockchain is the security of ownership of NFTs. There have already been instances when the pre-existing digital art was stolen, minted again, and placed on an open NFT marketplace for sale[36]. Such cases create more difficulty locating the original owner and assessing the NFT's uniqueness. One proposed solution involves secure biometric access technology for NFT creators and owners [37].
Alternatively, common password protection solutions must be implemented to keep access control over the NFT assets.
A more detailed overview of the actual security issues in the NFT marketplaces has been carried out by Das (2021).
Regarding privacy, blockchain is not as "anonymous" as it may seem. While crypto wallets may be relatively private, most centralised crypto exchanges use the Know Your Customer Protocol like many other traditional financial institutions[38]. Users that are more protective of their privacy can choose a decentralised exchange instead for their transactions. However, the cost of confidentiality will be higher fees and less security in corresponding exchange protocols.
Secondly, the natural tendency to "show off" the rare NFT piece bought by an individual can easily compromise their wallet data and exterminate privacy entirely. Consequently, Due to the openness of blockchain, anyone can track that person's wallet activity for past transactions, as happened with Jimmy Fallon and his Bored Ape NFT [39].

- Negative Impact on the Environment

The high energy consumption of Blockchain Networks represents a considerable threat to ecology. For example, the total Bitcoin electricity consumption in 2021 was around 105 TWh [40], while in the whole Czech Republic same period consumption was approximately 61 TWh [41]. Such gigantic numbers raised concern in some countries. China, a global leader in Bitcoin mining, attempted to impose a Government Ban on mining back in 2021 [42]. Mining itself, however, is not a single contributor to high consumption. One of the vital processes in every blockchain is the reaching consensus mechanism that ensures that the new block of data added to the chain is legitimate. Under the Proof-of-Work mechanism, this process also requires high electricity consumption to be executed, (Miraz et al., 2021). Moreover, the growing network of computers competing to build a new block improves the system's security but increases energy usage, too.
The ultimate solution has been introduced by Ethereum Blockchain. They decided to shift from the Proof-of-Work consensus mechanism to the more environmentally friendly Proof-of-

[36] https://www.abc.net.au/news/science/2021-03-16/nfts-artists-report-their-work-is-being-stolen-and-sold/13249408#:%7E:text=Many%20artists%20around%20the%20world,work%20posted%20on%20social%20media
[37] https://medium.com/@sshshln/biometric-based-nfts-3c7805372c1c
[38] https://cointelegraph.com/trading-for-beginners/what-is-kyc-and-why-do-crypto-exchanges-require-it
[39] https://www.wired.com/story/nfts-privacy-security-nightmare/
[40] https://ccaf.io/cbeci/index
[41] https://www.enerdata.net/estore/energy-market/czechia/
[42] https://www.bloomberg.com/news/articles/2022-05-17/china-makes-a-comeback-in-bitcoin-mining-despite-government-ban

Stake[43]. The Ethereum Foundation has claimed that the transition reduced Ethereum's energy consumption by 99.95% [44] or 0.2% worldwide [45].
Therefore, it may be implied that as of 2022, the NFTs minted on blockchains with the PoW consensus mechanism cannot be considered a sustainable investment opportunity, unlike those on Ethereum.

- Extensibility Issues

The existing NFT ecosystems can be characterised as highly isolated. One particular type of NFT can be traded only within the same ecosystem/network. The reason is their underlying blockchain platform. Wang (2021) suggest that interoperability and cross-chain communication are the handicaps for the wider adoption of Dapps. According to the observations by Zamiatin (2019), the implementation of cross-chain communications can be realised with the help of external trusted parties. The decentralised nature of blockchain might have become an obstacle, but fortunately, most of the NFT-related projects are created on the Ethereum Platform. It may indicate that they share a similar data structure and could be exchanged under the same rules.
As a partial solution, cross-chain bridges have been developed that enable transactions between various blockchains[46]. Some of them support smart contract technology, which means that Dapps and NFTs could be "bridged" too.
Alternatively, the introduction of NFT 2.0 could ameliorate the extensibility issue in the future. According to this concept, NFT 2.0 token standard makes this type of NFT interactive and interlinked. This feature will allow NFTs to be linked with other NFTs, hold other fungible tokens, be integrated into a Dapp and, most importantly, upgrade. [47]

- Legal Pitfalls

In recent years there have been formed specific circumstances where current laws and regulations struggle to keep up with rapid technological change, while policymakers and law enforcement agents are facing significant new challenges. FTX collapse (very likely a fraud) as an example[48]. Despite possessing the features like full-history tradability, deep liquidity, and convenient interoperability, which facilitate NFTs to become a promising intellectual property (IP)-protection solution, the legal framework for NFTs has to come a long way before reaching the juridical consensus.
Trautman (2021) outlines that use of the new assets like cryptocurrencies and NFTs may have different legal outcomes and raises new issues in law. In particular one of the main questions of concern is whether the NFT or work of art can be characterised as a commodity, security, or usage, subject of money transmitter laws that keep evolving. Authors argue that the legal aspect of digital ownership can be considered as the main hardship that stops NFTs from becoming truly part of our lives.

[43] https://ethereum.org/en/developers/docs/consensus-mechanisms/pos/
[44] https://ethereum.org/en/upgrades/vision/
[45] https://twitter.com/VitalikButerin/status/1570299062800510976?t=jnkoYSq2r0gslOk5rKJMMQ&s=35
[46] https://ethereum.org/en/bridges/
[47] https://fintelics.medium.com/nft-2-0-the-next-version-of-nfts-you-need-to-know-about-d0eafac55e54
[48] https://www.economist.com/briefing/2022/11/17/the-failure-of-ftx-and-sam-bankman-fried-will-leave-deep-scars

Previous studies by Farfield (2021) have emphasised that a legal form of digital ownership is sorely needed and has not yet been clearly established. Moreover, they suggest that because the NFT transactions are in a form of sale, the law of sales of personal property should apply. Enforcement of such law, in their opinion, will characterise those who bought scarce and valuable digital assets as true owners rather than mere users.
The study conducted by Johnson (2021) accentuated on proposes of regulation over the cryptocurrency intermediaries, like exchange platforms, and seems almost prophetical from the last months perspective. Authors argue that their approach on formal registration obligations for such entities recognises the dynamic nature of cryptocurrency secondary market, while protecting investors from fraud, theft, misconduct and manipulation.
So far, the lack of appropriate legal framework for NFTs and cryptocurrencies keeps being the biggest impediment for the ultimate crypto integration in enterprises and financial governance institutions.

- Wash Trading and Money Laundering

Another serious threat to the NFT market represent the instances of wash trading and money laundering. Historically, wash trading has been a problem for cryptocurrency exchanges which attempted to inflate their trade volumes. For instance, Bitwise Asset Management claimed in 2019 that up to 95% of all reported bitcoin (BTC) trading volume on exchanges is faked [49].
Nevertheless, despite wash trades being hard to detect, there already could be found notable examples of NFT market manipulation.
In October 2021, one of the CryptoPunks was traded between two wallets for 124,457 ETH or $532 million at that time. There has been discovered, the buyer used a flash loan to pay 124,457 ETH for CryptoPunk's smart contract. After the transaction, the seller sent the funds back to the buyer account, who repaid the loans. Later, the NFT was listed on the market again but for 250,00 ETH or almost $1 billion, while its initial price before the wash trade was between $300,000 and $400,000. [50]
A recent report by Chainalysis detected significant wash trading and some money laundering in the NFT asset class. They were able to identify 262 who sold an NFT to a self-financed wallet more than 25 times. While there could be no certainty whether all these transactions were illegit, the 25-transaction threshold gives a higher degree of confidence that these users could be habitual wash traders. Further, there has been found that only 110 of those wallets generated revenue in 2021 and noted that most of the wash traders were unprofitable, meaning that their profit did not make up for the gas transaction fee they paid for each execution. However, 110 of those wallets collectively generated an immense amount of $8.9 million in profit in 2021.
Second part of this report dedicated to money laundering could identify some activity of such manner in 2021. However, all this activity represents a tiny part compared to billions of cryptocurrency-based money laundering tracked for the same period.
Authors outlined, that this kind of issue has long been present in the Fine Art world but has always been difficult to quantify. NFTs, on the other hand, due to the transparency of blockchain, can have more reliable estimates of money laundering in the market. [51]

[49] https://www.coindesk.com/markets/2019/03/22/bitcoin-futures-volume-is-more-significant-than-you-think-bitwise-says/
[50] https://www.coindesk.com/learn/what-is-nft-wash-trading/
[51] https://blog.chainalysis.com/reports/2022-crypto-crime-report-preview-nft-wash-trading-money-laundering/

The existence of such activities educes a considerable risk of building trust in NFT ecosystem, therefore, inhibiting its future growth. Marketplaces, regulators, and law enforcement authorities are encouraged to consider bans, penalties and stricter measures to alleviate this issue.

To conclude this chapter: although NFTs demonstrate a colossal potential impact on the present decentralised markets and future business opportunities, the technology itself is still in its infancy. Some caveats are required to be carefully tackled, while some promising features should be highlighted.
Despite plentiful literature on NFTs, like blogs, forum posts, tweets, codes, and other sources being available to the public, a systematic investigation of NFTs is somewhat absent. Therefore, in this section, we tried to systematise all the feasible information across the sources and shed some light on the present challenges and up-and-coming characteristics of NFT giving it a more thorough review.

The NFT's Valuation Dilemma and The Portfolio Specifications

The specific "brew" of art and blockchain technology that NFTs represent creates a yet unsolved dilemma of their price creation. NFTs clearly share some common features with traditional art and there could emerge some mutual patterns in their value formation too. On the other hand, NFTs' tight relationship to cryptocurrencies manifested in the gas fees and price itself paid in Ether may be also reflected in a possible price co-dependence of these two types of assets. Whether to treat NFTs as a "fungible" asset like cryptocurrencies and stocks or as works of art and collectables remains unanswered. We may anticipate that only with time the now nascent NFTs will have their value creation controversy explained.
So far, there has already been realised a number of research papers focusing on the matter. First, we inspect the studies evaluating the inside market features, individual characteristics of a token and non-financial determinants upon their possible influence on NFT price creation. Ulteriorly, we move on to the scientific literature dedicated to NFT exploration in relation to various "fungible" assets.

The NFT valuation problem

We start with a paper analysing the potential predictive power of visual features over the NFT sale price.
Coherent to findings of Vidal-Tomas (2022), Kapoor (2022) detected only limited predictive power of the NFT image features to the ultimate selling price. In contrast, there has been observed that Twitter hype influences the NFT value. These relationships demonstrate that the banding (Twitter features) and metadata (OpenSea features) have a more substantial effect on the price compared to the product image itself (Image features). Moreover, the authors highlight that NFT markets are highly illiquid in nature, bearing very volatile and irregular sale prices. Consequently, due to a low number of historical data points for most NFTs, the traditional price prediction models' estimates are not feasible or robust.

Gutierrez (2022) in their work investigated the factors that draw attention to non-fungible tokens. Their results indicated a positive relationship between NFT search activity and crypto returns. Using the wavelet coherence approach, there has been discovered that Bitcoin and Ether returns predict next week's attention of the investors to NFTs, measured by Google Search queries.

In their studies of CryptoKitties (Serada, 2021), draw quite a surprising conclusion that digital scarcity may turn into digital abundance. From the CryptoKitties example, rare NFTs were losing their value. In addition, author suggests that issues like blockchain's scalability, high gas fees and no legal protection of ownership are very likely to crowd out new wealthy users from the NFT ecosystem. A more comprehensive study on heterogeneous rarity patterns in NFT collections by Mekacher (2022) on the contrary, advocates that according to market performance, on average, rare NFTs sell for higher prices, are traded less frequently, guarantee higher returns on investment and are less prone to yield negative returns. The difference in the results of these papers may be caused by different datasets and methodologies used; Serada (2021) focus on CryptoKitties, while Mekacher (2022) on all collections available on OpenSea. Furthermore, Mekacher (2022) show that most collections present heterogeneous rarity patterns, with few rare NFTs and a large number of more generic ones. Most common NFTs, in its turn, appear to behave more uniformly in the market, which seems to consider them as rather "fungible".

Nadini (2021) in their work proposes dividing the NFT market into individual segments: Art, Collectibles, Games, Metaverse, Utility and Other; since they may be characterised by different price behaviour and volatility transmission. There has been detected evidence of the Art category as being the most expensive. Moreover, they discovered that past history is the best price predictor, and together with visual features, it benefits predictability. In line with past discoveries, Nadini (2021) show that NFTs within the same segment and the same collection tend to be visually homogeneous. Wallet activity analysis showed that most specialised traders have either few or tens of thousands of transactions, the latter ones pursue rather explicit art or game token category. Ante (2021) complements the previous work on NFT market trends analysis by Nadini (2021). The main investigation established that NFT projects despite their widely diverging content can nonetheless have a considerable influence on each other and a shock to younger projects usually invigorates older ones. Another notable uncovering revealed that a decrease in the number of active wallets in emerging projects induces an increase in the number of active wallets in established projects and vice versa.

When addressing the case of soaring NFT prices in 2021 and its premises a potential explanation for it may be wash-trading. This type of fraudulent behaviour is somewhat typical for cryptocurrency exchanges and has been carefully investigated in (Le Pennec, 2021). Researchers in this study also mark their expectations of wash trading being present in the NFT market. However, Urom (2022) finds a significant dependency between NFT volume and return, hence it can ameliorate doubts about wash trading pointed out in (Le Pennec, 2021).

An alternative approach in the investigation of the NFT price inconsistency has been implemented by Maouchi (2022). The Total Value Locked metrics have been used in pursuance of getting insights on bubble presence in the NFT and DeFi markets over time. Under this methodology, the TVL is negatively linked to the price bubble. Originally, there were detected three main periods of somewhat "bubbly" behaviour: the turn of the year 2017/2018, the DeFi summer 2020 and the 2021 bubble. Moreover, the characteristics of the summer 2020 bubble are different between DeFi and NFTs on the one hand, and pure cryptocurrencies on the other hand. This outcome implies that DeFi and NFTs' price dynamics are distinct from cryptocurrencies. These findings are coherent with studies by Corbet et al. (2021) and Dowling (2022b). Furthermore, there has been detected a positive and significant association between the COVID-19 pandemic, Google Trends searches and the probability of digital bubbles occurrence in DeFi and NFT markets. The variables representing economic (EPU) and financial (VIX) conditions, however, gave mixed results with no clear pattern for bubble

detection, confirming the results attained by Enoksen et al. (2020) for eight major cryptocurrencies. Overall, there has been observed that bubbles are less frequent but larger in Defi and NFT markets than in cryptocurrencies'. Ito et al. (2022) extended the studies of bubble occurrence in the NFT market, by applying the Logarithmic Periodic Power Law model to the time-series data of major NFT projects, as of December 2021. Employment of the model resulted in the detection of a small bubble for the general NFT market, predicting a price decline and a medium bubble in the Decentraland project predicting a price decline as well. As of December 2022, the estimates obtained by the LPPL model in 2021 for the respective projects turned out to be correct as the price for Decentraland and NFTs, in general, has declined substantially.

NFT as a financial asset

The subsequent part of the literature review is dedicated to the articles with research objectives of studying the NFTs as a financial asset, and investigating for potential interrelatedness among NFTs, cryptocurrencies and other traditional asset classes.

One of the pioneers in the NFT study is Downing (2022a), which was the first to investigate the pricing of non-fungible tokens. The author shows that the price series for the LAND token is characterised by both price inefficiency and a steady rise in value. These findings are in line with Khuntia and Pattanayak (2018), whose prior research suggests that early-stage markets tend to be driven by a volatile search for suitable pricing models and only slowly start emerging market efficiency.

Next, given the NFT market emerged out of cryptocurrencies, Dowling (2022b) explored if NFT pricing is related to cryptocurrency pricing. The wavelet coherence analysis indicated some co-movement between the two sets of markets. This suggests that cryptocurrency pricing behaviours might be of some benefit in understanding NFT pricing patterns. However, the low volatility transmissions also indicate that NFTs can potentially be considered as a low-correlation asset class distinct from cryptocurrencies. Downing, also, suggests the possibility that there may be present common factors driving both markets, for example, sentiment or uncertainty. Another important conclusion from this study is that relatively little spillover effect was detected between NFT submarkets. This kind of behaviour differs from that of cryptocurrencies (Moraris, 2021) & (Koutmos, 2018) and stock markets (Bhattarai et al., 2020) because they tend to have high spillover effect among their individual markets. In consonance with Downing (2022a), Vidal-Tomas (2022) noticed the positive performance of the non-fungible game tokens in the long run, on average, and no high co-movement with the cryptocurrencies measured by the CCi30 index. Also, there has been reported that the returns of the metaverse and play-to-earn tokens do not outperform cryptocurrencies in general, however, there are some signs of bubble emergence in the NFT market and a consequent increase in IGO may emerge a new crypto bubble. Notably, this paper demonstrates the absence of high correlations between market returns and NFT features (number of transactions, sales, and searches), which emphasises the discrepancies between the financial and real spheres, and therefore affirms the positive performance of game tokens is not justified by the real revolution of NFT sales and investor attention. It implies that some other unknown factors may play a significant role in driving its price up.

In later studies by Ante (2021), they applied the VECM to analyse the interrelationship between NFT sales, NFT users (unique active blockchain wallets) and the cryptocurrency market as measured by the Bitcoin and Ethereum prices, using daily data between January 2018 and April 2021. The results indicated no significant effect of NFT on both cryptocurrencies, although both cryptocurrencies affect NFTs in significant ways. Therefore, it seems likely that larger markets like cryptocurrency affect the growth and development of smaller markets like NFT, but there is no reverse effect. However, this is rather plausible, since cryptocurrencies are common currency for purchasing NFTs - a fall in cryptocurrency price implies lower purchasing power, which in turn is expected to depress the NFT market. Another interesting finding shows that Ether price shocks reduce the number of active NFT wallets, while Bitcoin price shocks trigger an increase in NFT sales. Additionally, Ante argues that different forms of NFTs are/will be very likely influenced by different factors, considering their economic and practical diversity.

Ko et al. (2022) in their research used a wider range of traditional asset classes by including the S&P500 index, MSCI world index, US dollar index, DB commodity index and others for further investigation of the correlations between these assets and NFTs. Their conclusions were similar to those of Dowling (2022b) with respect to Bitcoin and Ethereum, noting low co-movement levels between NFTs and traditional assets. Corresponding correlations are ranging between −0.2 and 0.2, while correlations between traditional asset classes are high. Moreover, the spillover index based on TVP-VAR in these studies produces consistent results and shows that the DY spillover index from and to NFT is lower than that from and to traditional markets, implying that NFTs may be distinct from traditional asset classes in regards to volatility transmission. A more comprehensive description of this kind of dependence and predictability can be found in studies by Urom et al. (2022a). According to their results, the S&P500 index negatively affects NFT sub-markets but not the aggregate NFT market. Additionally, in line with Ante (2021), there has been found that an increase in Bitcoin price reduces the NFT market returns in all quantiles for both submarkets and aggregate. Based on this, it may be highlighted the importance of volume-based trading strategies. Another note-worthy discovery is that NFT submarkets (CryptoKitties, Decentraland, CryptoPunks) in this analysis tend to show stronger dependence on external macroeconomic factors/indices towards the bullish quantile (0.95) unlike the aggregate NFT market which is independent of shocks transmitted from other markets across bearish, normal, and bullish quantiles. The possible interpretation could be as NFT market price variance is mostly determined by internal factors rather than external ones. Other than that, quite an unexpected outcome was obtained when determining the impact of both the oil market uncertainty (OVX) and geopolitical risks on the aggregate NFT market. Under the bearish market condition (0.05 quantile) these indices had a negative impact on NFT.

The next sub-group of papers focused rather on the dynamic interconnectedness between NFTs and other major asset classes in different time horizons. Some of them investigated in more detail the possible impact of the COVID-19 pandemic on respective markets.

Karim et al. (2022) examined the interrelatedness of NFTs, DeFi tokens and cryptocurrencies at the median, extreme low, and extreme high volatility conditions using the quantile connectedness approach. There was observed a sharp increase in the TCI, reaching 93% during the onset of COVID-19 marking extreme volatility in each quantile. Significant overlaps in the volatilities reflected during COVID-19 signify high-risk transmission in the blockchain markets during periods of high uncertainty, consistent with Goodell and Goutte (2021).

Nevertheless, they discover significant risk spillover among blockchain markets with strong disconnection of NFTs. According to this paper, NFTs revealed better diversification and substantial risk-bearing potential compared to DeFis and Cryptocurrencies.

Following that, Aharon and Demir (2021) contribute to the initial NFT studies by analysing the total connectedness, and especially the return connectedness, between NFTs and other financial assets (equities, gold, cryptocurrencies, currencies, oil, and bonds) using the Time-Varying Parameter Vector Autoregressions (TVP-VAR) model. Consistent with earlier research, (Adekoya and Olivide, 2021); (Bouri et al., 2021); (Wang et al., 2021); (Umar et al., 2021), they reported that the overall connectedness between the various system variables increased during the COVID-19 period. Similarly to the spike in mutual interconnectedness detected by Bouri et al. (2021) they found that the overall connectedness between the returns for financial assets increased during the COVID-19 period with NFTs offering diversification avenues during turbulent times like the COVID-19 crisis. As matter of fact, NFTs absorbed risk spillovers also during the crashes in February 2018, when market fears of inflation and interest rate hikes were at their height. The static analysis results show that NFTs have only weak interactions with the financial assets examined, while the dynamic analysis shows that NFTs bear some similarity to gold and the USD index in terms of risk absorption during the COVID-19 crisis. That is, these assets reported relatively low connectivity during normal times, but during the turbulent COVID-19 period they acted as NET absorbers of systemic risk. Note, however, that, unlike the 2018 period, during the COVID-19 period, Ethereum seems to interact in the opposite way to NFTs and is mainly a transmitter of risk spillovers. This underscores the significance of performing dynamic analysis, which can reveal shifts in the role of variables as transmitters or receivers. Similar to Aharon and Demir (2021), Umar et al. (2022) document an increase of coherence among NFTs and major assets caused by the COVID-19 pandemic, however, this approach does account for different investment horizons, which is an important element of investment decisions. They found that NFTs absorbed risk during the outbreak of COVID-19 only in the short run for the below-two-week investment horizons. Therefore, NFTs may seem an attractive diversification attribute but there has to be considered that during the pandemic they offered only short-run risk absorption capacity. The authors suggest the evident increase in coherence among NFTs and other major asset classes may be explained by overall covid-induced "panic", akin to cryptocurrency market behaviour in that period (Umar and Gubareva, 2020).

Urom et al. (2022b) in their work complement the previous research done by Karim et al. (2022) and Yousaf and Yarovaya (2022). They broadened the study by applying the same methodology as Karim et al. (2022) for analysing both volatilities and return connectedness among NFTs, cryptocurrencies and other (un)conventional assets. Additionally, they adopt an empirical network that permits the examination of the propagation of shocks across different market conditions, which were not accounted for in earlier studies. From the results, there has been observed that return and volatility connectedness vary across different market conditions, with the levels of total connectedness during extreme downside and upside market conditions being higher. Urom et al. (2022) suggest that, at best, their result indicates that NFTs are decoupled from (un)conventional assets only during normal market conditions, refining the accustomed narrative that NFTs are disconnected from other assets.
According to their estimates, amid the normal market condition for both the volatility and return connectedness, more than 80% of the NFT error variance is explained by the shocks that are internal to or emanate from the NFT market.

Under normal and bearish market conditions, the NFT is set to be a net return shock receiver unlike under the bullish market condition, where it is a net transmitter. Nonetheless, irrespective of the market condition, the NFT is a net volatility shock receiver.
Moreover, they discovered that at the time periods of the economic crisis the total volatility and return connectedness rise/decrease under the normal and bearish/bullish market, which may advocate for the bullish part of the market to be a more attractive portfolio diversifier.
Notably, there has also been observed that the equity market uncertainly index (VIX) possesses predictive power to volatility connectedness, although limited to the bullish market condition only. Unlike (VIX), the oil market uncertainty index (OVX) is the only variable that significantly predicts volatility connectedness across all the market conditions with the effect under normal market conditions being the highest. Additionally, the results for return connectedness indicate that (OVX) and geopolitical risk (GPRI) possess prediction power under the normal market condition with the effect being positive. Therefore, it suggests that during normal market conditions oil market uncertainty and geopolitical risks escalate cross-market shocks between NFTs and the studied assets. Taking into consideration the relevant findings on the interrelation among (GPRI), (OVX) and NFTs obtained by Urom et al. (2022a), the premises of such a relationship may become a subject of interest for future investigations.

Another research by Kong et al. (2021) also investigated the relationship between the NFT price and other financial assets. In coherence with prior studies, they show that (i) most equity(traditional assets) are unlikely to explain the variations of the NFT price index, (ii) the NFT rarity influences its price, (iii) internet hype on Ether may increase the NFT price and that (iv) NFTs have both higher volatility and return than the stock market, leading to a comparable Sharpe Ratio to the NASDAQ index.
Overall, their results suggest that NFTs may be considered more like a medium for efficiently trading illiquid assets than fiat money as most cryptocurrencies. An interesting notion is the discovery of the positive relationship between the NFT price level and the size of U.S. quantitative easing during the covid period. The evidence shows that when the interest rate is low, the need for investment opportunities stimulates the NFT prices' growth, which is consistent with earlier works by Korteweg et al. (2016); Kraussl et al. (2017) - lenders tend to seek the assets with higher yields in an environment of low interest rates, inducing higher investments in alternative asset markets. Moreover, with regard to Sharpe Ratio, NFTs tend to underperform stocks during the high-interest-rate season but outperform them later on. These findings are consistent with Bekaert et al. (2013) that a lax monetary reduces risk aversion and uncertainty, so investors tend to favour risky investments in the search for yield.
According to the researchers' point of view, the NFTs are superior to certain traditional financial assets, because involve more complex valuation.

Portfolio creation with NFTs and optimisation strategies

Schaar et al. (2022) in their paper used Hedonic Regression to evaluate the investment performance of the CryptoPunks collection, focusing on the variables that determine its prices. Additionally, they investigate the portfolio diversification potential of CryptoPunks and compare its performance to other financial assets. The HR index shows that the CryptoPunks prices have, on average, raised monthly by 34.19% with a standard deviation of 61.76% over the past three years (as of May 2021), thereby having the highest return rate compared to other

investment types included in the analysis. Next to that, the Sharpe Ratio values demonstrate a good return-risk trade-off. In line with earlier studies, the HR analysis indicates the positive effect of the CryptoPunks attributes' rarity on their price. Moreover, the results suggest CryptoPunks collection to be a suitable investment for diversification since its correlation with the benchmark assets, such as art, treasury bills, and major cryptocurrencies is relatively low. Furthermore, in comparison to other studies that have analysed the art market as a source of alternative assets, the NFT market shows some potential to offer a more profitable ROI.

A complementary study on static and dynamic connectedness among NFTs, DeFi and other assets (Oil, Gold, Bitcoin, and S&P500) has been realised by Yousaf and Yarovaya (2022). The particular topic of interest in this paper was the portfolio implication analysis after including NFTs in such. The outcome on connectedness and spillovers argues in favour of previous studies, enforcing the notions of weak static volatility and return spillovers among NFTs, DeFi and other traditional asset classes together with an increase in dynamic volatility and return connectedness during the COVID pandemic and 2021 crypto bubble.
Next to that, there has been observed that net volatility spillovers vary over time for all assets present in the analysis. Moreover, the status of the net recipient or net transmitter of spillovers in most markets also varies. Consequently, a list of 2-asset portfolios has been constructed: NFTs-other assets. Then, there have been estimated optimal weights and hedge ratios using the variances obtained from the VAR-BEKK-GARCH model. The optimal weights are less than 1, meaning that investors may add NFT assets in the undiversified portfolios of the assets such as gold, bitcoin, WTI, and S&P 500. Overall, NFTs are good for diversifying portfolios but the dynamic volatility and return spillovers vary over time, especially over turbulent and non-turbulent periods. Therefore, asset allocation has to be adjusted during crisis periods for a maximised risk-adjusted return.

A study by Ko et al. (2022) constructs portfolios by the inclusion of NFTs (Sandbox, Decentraland, CryptoPunks) to traditional assets under the mean-variance framework proposed by Markowitz. The empirical findings confirm that moderate amounts of NFTs can provide significant diversification benefits to existing asset-based portfolios (stocks, bonds, US dollar, commodity index, and cryptocurrencies) and increases the performance of equally weighted (EW) and tangency portfolio strategies in terms of risk-adjusted returns. This contribution is in line with the corresponding hypothesis addressed by Karim et al. (2022) and Dowling (2022b) which suggest that the NFTs' diversification impact can generate better portfolio investment opportunities. However, it is important to mention that their time-series dataset is limited to June 2021, i.e., before the drastic price drop in the NFT market later that year.

A systematic overview of Art vs NFTs as an alternative asset class

Table 1: Art vs NFTs as alternative financial asset

Art as an alternative asset	NFTs as an alternative asset
"Art's low correlation with the equities market and desirable risk and reward ratio, as price appreciation defies all logic, makes it an attractive investment." (Mamarbachi, 2008)	True for NFTs, there's relatively weak static volatility and return spillovers observed between NFTs and traditional asset classes (Yousaf, 2022).
"The role of art is changing. Art is no longer just appreciated for its aesthetic value and the expression of its lofty ideals but as an investment." (Mamarbachi, 2008)	Similarly, the NFTs a largely perceived as an investment tool and their aesthetic features have a lesser effect on their price creation compared to Twitter hype, metadata (Kapoor, 2022) and search activity.
"Nearly all of the research into art as an investment concludes that it is riskier than stocks". (Mamarbachi, 2008)	As of 2021, NFTs have both higher volatility and return than the stock market (Kong, 2021).
Art is a heterogeneous asset. There are few pieces of art of a specific author traded each year regardless of the number of fairs and auctions in the market.	According to Mekacher (2022), most collections present heterogeneous rarity patterns. Nonetheless, most common NFTs in a collection appear to behave uniformly in the market as homogeneous assets.
The art market is characterised by low liquidity.	The market for NFTs is less liquid than of cryptocurrencies and other securities. However, fractional NFTs partially ameliorate this issue, making NFTs more liquid than traditional art.
Market transparency for art is low.	The NFT market is a highly transparent market, due to its underlying blockchain technology.
For dead artists, the elasticity of supply is equal to zero. Rarity of the work affects the price.	The net low elasticity of supply for NFTs can also be present not only due to the possible artist's death but also due to the artificial scarceness (the number of collectibles originally issued in a project). Analogous to art, the rarest NFTs, in general, also have a higher price.
There is truth to the theory that when the stock market is in a downturn the art market booms. When markets are bad, people like to invest in something they can touch. (ABN AMRO report, 2005)	The evidence shows that during the low interest rate period caused by COVID pandemic, the size of U.S. quantitative easing exhibited a positive relationship with the NFT price level (Kong, 2021).

Transaction costs are far higher than other markets.	Transaction costs for NFTs are significantly lower than those in the traditional art market. Moreover, there are no broker services introduced yet.
"Art presents an alternative approach to the diversification of portfolios, giving investors optimal allocations and an opportunity for risk". (Gerlis, 2007)	There's also been discovered that NFTs can provide significant diversification benefits to traditional asset-constructed portfolios (Ko, 2022).
Investing in art can also have tax benefits. In the United States, for example, the Internal Revenue Service considers an 'investor' in art someone who can claim that their interest is purely as an investment.	There have been no tax benefits for owning an NFT introduced yet. Taking into the consideration the lack of legal framework for digital ownership, there are not to expected such in the short future.
"Art incurs a negative income in the form of storage, insurance, transportation and other associated costs". (Mamarbachi, 2008)	NFTs on contrary, have no fixed costs involved, except the transaction cost in gas paid at the moment of purchase.
"There are large differences in expertise between buyer and seller." (Mamarbachi, 2008)	The novelty of NFT market and its transparency contributes to a more uniformly distributed market information among its participants.
"There are psychological benefits of owning arts, which are not calculated in the case of owning other financial assets." (Mamarbachi, 2008)	The psychological dividends of owning an NFT are also present in this market. For example, CryptoPunks' owners tend to use them like avatars in their social media profiles.
The art market has a much weaker equilibrium process than other securities. (Mamarbachi, 2008)	So far, the market for NFTs can also characterised as inefficient (Dowling, 2021a).
"There is no sustainable formula to assessing a piece's ongoing value. This is normally done through due diligence services, by looking at past sales, and the artist's position in the market in terms of success and decline. The ultimate figure is purely guesswork." (Mamarbachi, 2008)	The notion that NFTs involve a more complex valuation than traditional financial assets has also been highlighted in recent studies several times.

The research on NFTs is in its early stages and the literature on this topic is rather poor. Therefore, a large number of questions regarding Non-Fungible Tokens still remain to be addressed. In this literature review, we analyse and attempt to systematise discoveries from almost all scientific papers on NFTs available now.
Nevertheless, despite the limitations, we could find enough evidence from previous working papers on the behaviour of NFTs as a financial asset. Thus, we can proceed with our empirical part of the thesis designated to answering the questions we introduced in the first chapter.

Research Objectives

From the literature review realised above we can highlight a couple of outtakes that are the most relevant for the study. One of them is that NFTs possess high price volatility and the market for NFT is inefficient. Another one is that NFTs showed relatively low volatility connectedness with other asset classes, thus offering some diversification potential. Moreover, the evidence from COVID pandemic exhibits increase in volatility and return connectedness among all asset classes during the period of market uncertainty. Lastly, the NFTs were found to be risk absorbers during COVID but only for under two-week period. It implies that the research objectives we specified in the Introduction have not been answered yet, but these results, however, provide us with enough empirical evidence to enlarge the existing research horizon for NFTs. By taking into the consideration the abovesaid and the drastic changes in investment markets as of the end of 2022, we may now construct the first hypothesis of our thesis:

The NFTs will be included in the optimised cryptocurrency-based portfolios as of 2022.

Complementary, we test another portfolio creation mechanism not implemented earlier in NFT studies - the Random Portfolio approach. We are interested in whether, under this technique, the NFTs are included in the optimised portfolios and, if so, to what extent and impact it may have on their performance.
Moreover, following this methodology, an extended inference could be obtained on the overall market performance for our period of interest. Specifically, we construct a fundamental "polygon" of alternative portfolios to measure the performance of non-standard asset-based portfolios. Consequently, the second hypothesis can be derived:

The inclusion of NFTs improves the performance of random crypto portfolios.

Methodology

This chapter is dedicated to the methodology chosen for the exploration of the primary research objectives of the thesis. We provide step-by-step explanation of portfolio creation process, altogether with discussion on the approach's advantages and limitations. Then, we specify exactly the key metrics of concern for the portfolio performance evaluation based on the methodology characteristics.

Portfolio construction

Before any process of valuation takes place, there is evidently the process of creation. Therefore, our first step is "assembling" the assets of interest into a portfolio. The key detail is under which rules it is done and to what objectives it serves. Since our main hypothesis is not deriving "the best" ready-to-invest portfolio, but rather the idea of understanding the present tendencies in asset allocation processes. We need to implement a strategy which allows seeing a "bigger picture" and generic characteristics. Therefore, we find random portfolios to be an optimal solution for answering both previously stated hypothesis. Here is why.

The principal idea behind random portfolios is the generation of a large set of program-selected portfolios that obey constraints but ignore utility. This approach is shown to be effective in measuring investment skills. The general take on generating random portfolios for given constraints is using the rejection method. Essentially, it is producing a series of random portfolios and rejecting the ones that violate at least one constraint.

The concept of generating random portfolios via external computational power is not new. The pioneers of early "programmed" portfolios were Dean LeBaron and his colleagues back in the 1970s, (Beaton et al., 1973). Furthermore, the first documented discussion on the importance of randomness in portfolio management can be attributed to Lorie and Fisher (1965). Then, the processors' computational ability to implement such kinds of tests was rather insufficient and time-consuming. Now, with the help of suitable technology, computational speed is not a serious problem anymore.

Conforming to the original theoretical premises, the assumption of only linear constraints in random portfolio creation is considered optimal for the model. However, in practice, the resulting portfolio distribution will not reflect an actual choice a fund manager would make.

Patrick Burns is one of the most significant contributors to this technique's evolvement. According to Burns (2004), the most important constraint when using random portfolios is limiting the volatility, which is not linear. Moreover, integer constraints like setting the number of assets for the portfolio are also necessary. Therefore, when solely using linear constraints, the resulting series will only produce an approximation of the real outcome. Both the explicit and implicit constraints (like growth-oriented) must be considered in favour of more realistic results.

To effectively execute the random portfolio approach in our studies, first, we set the following explicit constraints on each set of portfolios:

- *Allow for long positions only, no short selling.*

There are two explanations for this decision. The first one is that most of the fund managers cannot short sell. The second reason is that long positions' constraint benefits the estimation and reduces the error in the respective covariance matrix, especially in the case of high frequency returns, (Jagannathan and Ma, 2003). The data in our study consists of daily asset's returns, hence this constraint can be advocated for future use in the thesis.

The second and the last explicit constraint in our analysis is:

- *The full investment criteria i.e., all the weights must sum up to 1.*

We impose no further constraints on the number of assets in the portfolio, which means that the optimised portfolio may have fewer assets than offered before the optimisation. Besides that, we set no limit on an asset's maximum or minimum weight. The chosen constraints are rather needed but not strict. Hence imposing stricter requirements would deteriorate the performance of the model.

Next, to the previously set explicit constraints, we add the implicit constraints a fund manager could follow, thus generating four different series of random portfolios.

1. *For the first set of portfolios, we set no implicit objectives, keeping only the initially given constraints (Pure).*

This set is aimed to test the "ideal" case of random portfolios, disregarding the utility, as if there were no initial investment intentions besides scientific interest.

2. *The second set of random portfolios follows the Minimum Variance implicit constraint (MinVar).*

It represents the objective a risk-averse fund manager would seek. It it defined as:

$$\text{Min } \pi' \hat{\Sigma} \pi, \qquad s.t. \quad \pi \geq 0, \pi' 1_N = 1,$$

where 1_N is $N \times 1$ vectors of ones.

3. *The third series follows the Maximum Return objective (MaxR).*

It represents a strategy that targets the maximum return and ignores the risk associated with it. The investment always faces a trade-off between risk and reward, since the most profitable assets usually have a higher volatility, hence higher risk. The approach of Maximum Return is the opposite to the Minimum Variance approach, where the fund manager prioritises lower return over high risks.

4. *The fourth set represents the mean-variance portfolio construction strategy (RiskRet).*

Mean-Variance analysis is part of Modern Portfolio Theory proposed by Markowitz (1952). This type of approach takes both the risk and return into the account, when assigning the weights to portfolio. The main assumption behind mean-variance is that investors tend to seek low risk and high reward at the same time. Thus, under this framework, fund managers may weight how much risk they are going to take in exchange for extra reward. In other words, it helps to find biggest reward for a given level of risk.

After having all the constraints and objectives specified, we perform the randomisation of weights given the earlier enumerated constraints:

- *Generate 10.000 portfolios under the set constraints.*

In a perfect case, we would like to have the population sample of all possible portfolios the manager might have had. Unfortunately, we cannot have the whole "cloud" of portfolios at our disposal. Nonetheless, by the Law of Large numbers, the expected value of a variable can be approximated by calculating the sample mean of the number of independent samples of the variable. The more independent samples are taken the more accurate is the prediction. The Monte Carlo method, similarly, uses the LLN in the simulation process. However, this technique is mainly used in risk analysis for evaluation of risk and uncertainty that could possibly affect the outcome, (Rubinstein and Kroese, 2016).

As a result, we now have four sets of random portfolios each pursuing an individual objective. Every set is constructed of 10000 portfolios with randomised weights. The sets, further, are optimised by random approach with the following features:

- *the training period of 30 days,*

  In other words, we perform in-sample and out-of-sample analysis. The use of training period in portfolio analysis is argued to deliver more robust optimisation than traditional optimisation techniques. According to the studies realised by Portela Santez (2010) the application of in-sample and out-of-sample periods stabilises the portfolio compositions over time.

- *monthly rebalancing allowed,*

This is primarily justified by the reason that the fund managers are allowed to rebalance in real case scenarios too. Portfolios with no rebalancing allow no correction for current market conditions, therefore increasing the chance of profit loss.

- *moving window of 30 days.*

By applying the moving window, we let the optimisation consider the more recent periods, thus improving its responsiveness to the assets' return dynamics.

Additionally, we create a"naïve" artificial benchmark - the equal-weighted portfolio with monthly rebalancing. This portfolio does not undergo any type of optimisation, hence representing the simplest portfolio construction strategy. The weights for the portfolio are obtained in a straightforward way:

$$\pi_i = 1/N, \qquad i = 1,\dots,N,$$

where N is the number of the assets in the portfolios.

Abbreviation	Portfolio Specifics
EW	Equally weighted portfolio with monthly rebalancing
Pure	Random Portfolios with no implicit constraint, out-of-sample and monthly rebalancing
MinVar	Random Portfolios with Minimum Variance objective, out-of-sample and monthly rebalancing
MaxR	Random Portfolios with Maximised Return objective, out-of-sample and monthly rebalancing
RiskRet	Random Portfolios with Risk-Reward objective, out-of-sample and monthly rebalancing

Table 2: List of portfolios

This table systematises all portfolios used in the thesis by their objectives.

The methodology mentioned above produces a ready-to-use portfolio framework allowing testing our first hypothesis.
In the first place, we generate all four sets of portfolios for cryptocurrencies only. Then, we extract the optimal weights for each set together with their mean return and standard deviation.
In the second place, we generate the previously stated types of portfolios but this time including NFTs to the cryptocurrencies' list of available assets. Similarly, we retrieve the optimised random weights, mean return and standard deviation.
Finally, we can answer whether NFTs are included in the random optimised portfolios or not by simply comparing the weights of non-NFT portfolios to the corresponding weights of NFT-included portfolios. To preliminarily assess the relative performance, we also assess the mean returns and the respective standard deviations.

Performance Measurement

To get into testing the second hypothesis, which is dedicated to the random portfolio performance measurement, it would be necessary to justify the appropriateness of the approach chosen. For that purpose, first, we address the most common performance measurement technique - benchmark analysis.

Currently, the vast majority of fund managers use the benchmark in order to measure investment skills. Besides being widely adopted, it also receives some criticism. Sometimes it is applied since deemed reasonable, other times for the lack of an alternative. The Sharpe Ratio, (Sharpe, 1966), as a benchmark of reward-to-variability, primarily is being judged for not distinguishing between good and bad volatilities. Therefore, highly positive returns are penalised by an increase in the portfolio's standard deviation, (Goetzmann et al., 2007). There

have been employed other indicators aiming to address this issue. For example, Sortino and van der Meer (1991) came up with Sortino Ratio, which penalises only the downside risk. Kong et al. (2021) evaluated NFTs' asset performance by some of these alternative risk-reward measures; the results indicated significant outperformance of NFTs compared to all other asset classes in the analysis.

Along with it, Burns (2004) argues that the method of judging fund performance by comparing its returns with the corresponding benchmark has a few other problems. The biggest issue is considered to be time, which it takes to determine that the fund actually beats the benchmark. According to Burns (2007)[52], several years at least may be required to get somewhat reasonable power of such tests. This outcome may have several explanations. One of them is that the benchmark is, most of the time, outside the portfolio's explicit constraints. Second, it may be that in order to do one test, it needs multiple periods. Therefore, an extensive period of historical performance has to be available for analysis to get rid of poor estimates.

Furthermore, this thesis considers relatively new and rather "unexplored" assets. Cryptocurrencies and NFTs are still nascent compared to stocks or bonds. Their sales history is very limited, and none of the existing indexes, like S&P500 or Treasury Bonds, commonly used as benchmarks, account for their different nature and high volatility. Given that and the high volatility these assets possess, the benchmarking proves to be inefficient for performance measurement in our case. Therefore, an alternative approach must be considered.

The accurate assessment of the portfolio performance and the fund managers' skills are well-known to be complex tasks and of great value. As we mentioned earlier in this chapter, random portfolios can offer different application use cases like testing trading strategies, evaluation of constraints, validation risk models, including performance measurement as an alternative approach to benchmarking, (Kontoghiorghes and Gatu, 2007) and (Burns, 2004). In our research, we focus on the latter function of random portfolios to test our second hypothesis and get some insight into the general market performance. In essence, Random Performance Measurement compares the performance of interest to a "cloud" of possible solutions and not to a single solution, as in the case of benchmarking. The results could be argued to be more realistic to the current market conditions for given assets. Additionally, the performance measurement via random portfolios gives more "freedom" for fund managers when choosing a fund they could pick.

The logic behind random performance measurement is quite intuitive.

1. First, Therefore, we generate 10.000 random portfolios with NFTs and without, indicating the constraints of interest. This process was detailly explained in the previous "Portfolio Construction" part.

2. Secondly, we compute the annualised return of each portfolio series over the specified time period. In our analysis, we apply in-sample and out-of-sample time periods. Hence the returns are executed for an out-of-sample optimisation time span.

3. As a next step, we calculate the return distribution for each portfolio group and look at their mean returns and standard deviations.

[52] https://www.burns-stat.com/pages/Working/dart_to_heart.pdf

4. Then, we compare the cryptocurrency-only portfolios' densities of return to the ones with NFTs included. Different aspects are evaluated in each case depending on possible fund managers' incentives. For example, when pursuing maximised portfolio returns, we take the mean, median, and quantile returns of cryptocurrency portfolios only and compare them to the same metrics for the NFTs included case. Alternatively, the standard deviation of returns is the prioritised performance measure for a highly risk-averse portfolio strategy.

5. Alternatively, we construct the time series plot of comparative monthly returns. It is designed to compare two portfolios possessing the same constraints and objectives but differing only in their components. Particularly, we are interested in portfolios with and without NFTs and their relative performance in monthly dynamic.

Ultimately, the metrics mentioned above give us sufficient knowledge on the performance of the portfolios with NFTs. Hence allowing us to answer to the second hypothesis of the thesis.

Nevertheless, some possible issues must be tackled and considered when using random performance measurement. Since at least some constraints have to be imposed regarding the accuracy, an increase in restriction leads to a higher probability of random portfolios being clustered close to the binding constraints. Thus, the uniform distribution of random portfolios' weights is highly desired but likely impossible to achieve in practice. Despite all that, even naively generated random portfolios demonstrated some usefulness, (Mikkelsen, 2001) (Kritzman and Page, 2003). In line with that, Kothari and Warner (1998) choose a technique involving random portfolios and their results show that benchmarking against an index is problematic.

Data & Descriptive Statistics

In this chapter we present the data collected for the thesis and used in our empirical research of random portfolios. We start with the discussion of the assets of interest included in each

group of portfolios. Secondly, we examine the raw data and choose the appropriate data optimisation technique in pursuit of reducing the estimation error. Then, we apply the standard descriptive statistics elements for a better understanding of the assets' characteristics and behaviour.

Data Collection

For the construction of each group of portfolios we use the daily prices of each component.
We begin by retrieving data of prices for the two largest cryptocurrencies by market cup: Bitcoin (BTC), Ether (ETH). Since the primary scope of this study is portfolio analysis, we ignore the stablecoins in this case. This is done because the price of stablecoins always varies approximately between $0.99 and $1.01 for a coin. The dataset of closing prices for the cryptocurrencies consists of the historical values between the 1st of January 2021 and 10th of December 2022. The selection of starting date was mainly influenced by the issuing dates of NFTs later used in the analysis. Before this date, there has been only few non-fungible tokens of relative significance. Moreover, the NFT "moment" happened no earlier than in the beginning of 2021. The values are obtained via finance.yahoo.com and the total of 709 rows are present. Also, we would like to notice that both cryptocurrencies and NFTs are traded on the daily basis with weekends included, unlike stock market in that instance.

The NFTs in our empirical study are divided into two groups based on the time periods.
The first group of NFTs represents the tokens created before the 1st of January 2021 and which later that year went through the first wave of NFT popularity. Just as in the case of cryptocurrencies we followed the market cup "principle" and overall asset's media prevalence when deciding on which one to pick. Therefore, it resulted in the following five NFTs being included: CryptoPunks (PUNKS), Axie Infinity (AXIE), CryptoKitties (CRYKIT), Art Blocks (ARTBL), Sorare (SORARE). Besides that, we attempted to cover NFTs from different segments: Art Blocks - Art; Axie Infinity, Sorare - Games; CryptoKitties and CryptoPunks - Collectibles. The data set for the first group has 709 rows of daily prices from 1st January 2021 to 10th December 2022.
The second group of NFTs represents the tokens released during 2021. Therefore, the respective values cover the period from 1st January 2022 to 10th December 2022. The decision of including such in the analysis was motivated by their performance in that year. As of 2022 these NFTs display relative dominance in the annual market share and number of sales. The following assets are The Bored Ape Yacht Club (APE), Mutant Ape Yacht Club (MUTAPE), The Sandbox (SAND). The subsequent data frame has 344 observations of average NFT price for three respective variables. Information on average sale price for both groups was accessed from cryptoslam.io
We consider existence of an NFT Index to be very handful for the study objectives like ours. However, there has been no market-wide accepted NFT Index introduced yet. Nansen.ai, nevertheless, are the closest to such, offering both indexes for each NFT category and top 500 NFTs too. Unfortunately, the data for the indexes is not publicly available for research purposes, therefore we inclined to an alternative solution from nonfungible.com. They offer the aggregate average daily price history from all NFTs included in their database for the period from 1st January 2022 to 10th December 2022. Thus, the latter option is used in the thesis as a proxy for general NFT performance for the given period.

For better readability, later in the chapters, we apply naming on each NFT group. "NFT 21" for tokens traded since 2021, "NFT 22" for tokens traded mainly in 2022 and "NFT Index" for the aggregate NFT sale price. To the group of cryptocurrencies, we will simply refer as "Crypto".

Asset's name and Abbreviation	Group	Period Covered
Bitcoin (BTC)	"Crypto"	01.01.2021 – 10.12.2022
Ether (ETH)	"Crypto"	
CryptoPunks (PUNKS)	"NFT 21"	
Axie Infinity (AXIE)	"NFT 21"	
CryptoKitties (CRYKIT)	"NFT 21"	
Art Blocks (ARTBL)	"NFT 21"	
Sorare (SORARE)	"NFT 21"	
The Bored Ape Yacht Club (APE)	"NFT 22"	01.01.2022 – 10.12.2022
Mutant Ape Yacht Club (MUTAPE)	"NFT 22"	
The Sandbox (SAND)	"NFT 22"	
NFT Aggregate (NFT)	"NFT Index"	

Table 3: List of NFT portfolio components

Data Processing

The raw data of both cryptocurrencies' and NFT's sale prices had to be accounted for the "notorious" problem of high volatility. Using unprocessed data would lead to the extensive noise and misleading results. As it was multiply mentioned in the literature review section, NFTs tend to have even more extreme price volatility than cryptocurrencies. There are several reasons for such outcome. First, the NFTs are highly illiquid, sold by one in "pieces" and cannot be fractionalised like any currency. Therefore, the price estimates that are derived by total sales divided by the number of sales are highly inefficient. Furthermore, the number of daily sales may vary significantly from day to day for most of the assets. The demand for a niche product like NFTs is more elastic compared to other assets and even the cryptocurrencies. The number of daily sales for a given NFT may decrease to one digit number in some periods, hence the price estimates may differ significantly from the real values.

In order treat our data for extreme volatilities we applied one of the well-known data smoothing techniques - Exponential Moving Average. Despite simple exponential and moving average approaches being the most used ones, each of them had some limitations. Simple exponential is intuitive and quite effective technique; however, it does not successfully account for trends in historical values. Since there has been not enough evidence on existence or absence of trends in cryptocurrencies and NFTs, we still have to consider it possible presence. Moving average, on the other hand, performs better on trends, but does not respond fast enough to the price changes in assets sales history.
The exponential moving average approach has weights applied to historical observations after using the exponential smoothing method. It allows, therefore, to focus more on the latest data observations. Moreover, under this data optimisation technique, a new prediction needs only past volatility prediction for chosen cycle and efficient estimates can be obtained without large period of sales history. Given, that our periods are rather short, compared to other common assets' sales history, this feature is favourited for the present analysis.

The Exponential Moving Average is calculated in the following way:

$$EMA_t = (Price_t * (1+DaysSmoothing)) + EMA_{t-1} * (1-(1+DaysSmoothing))$$

where**:** EMA = Exponential Moving Average.

After comparing different smoothing periods for each group of assets, we could identify the most appropriate ones, that treat volatility effectively, but do not heavily penalise the price dynamics. The smoothing period for "Crypto" was set to 7 days thus accounting for weekly cycle and for all NFT groups to 10 days. The following graphs show the smoothed volatility of each asset per group.

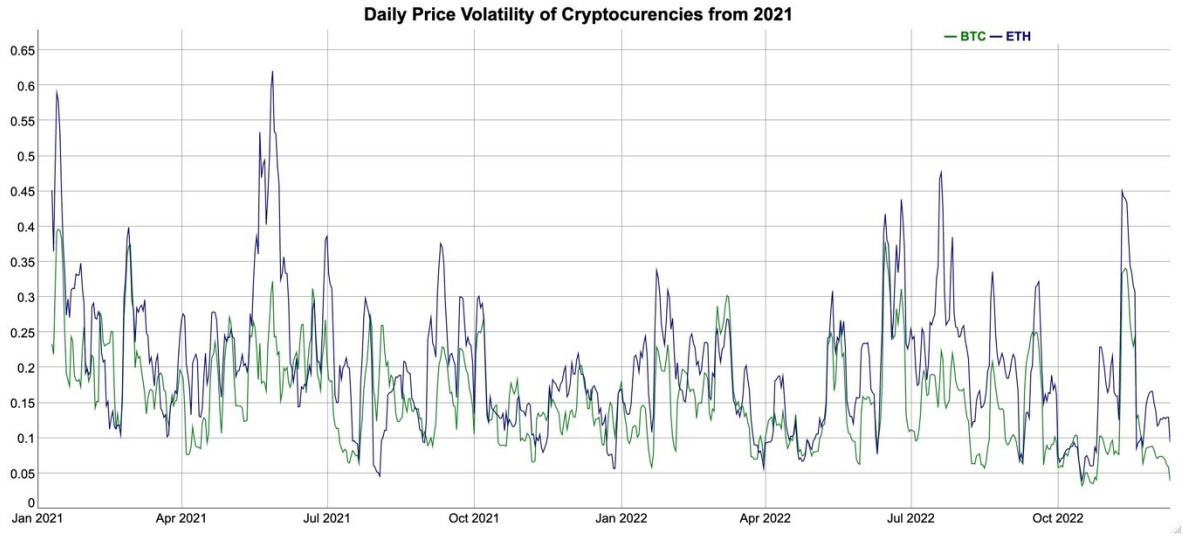


Figure 3: Daily Price Volatility of Bitcoin and Ether from 2021

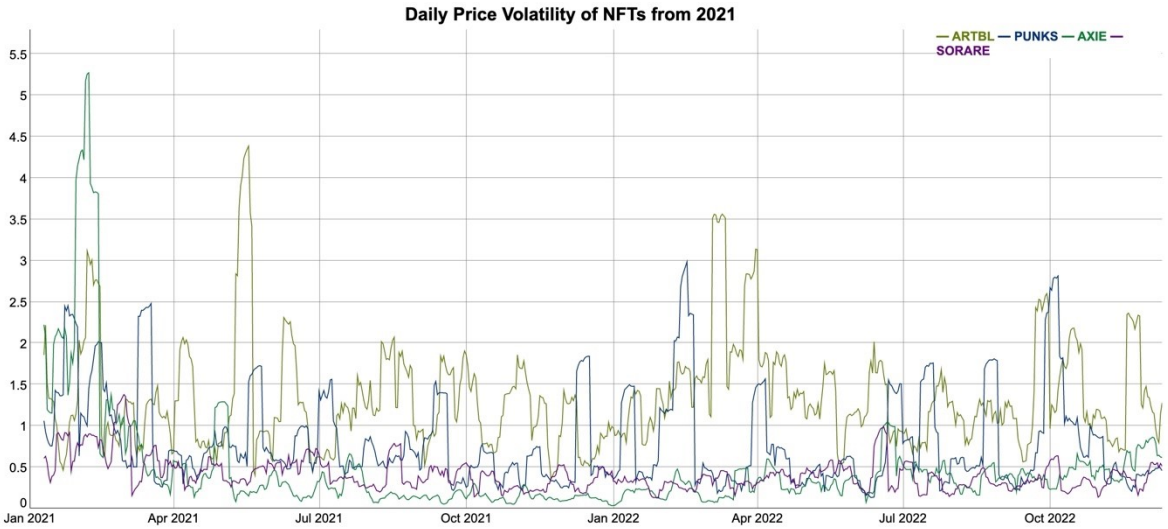


Figure 4: Daily Price Volatility of selected NFTs from 2021

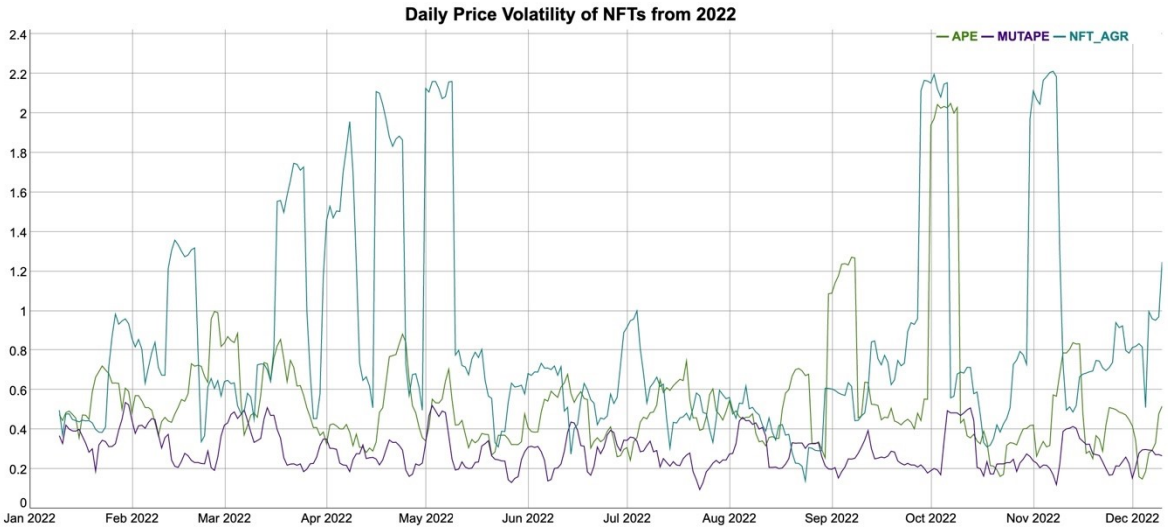


Figure 5: Daily price volatility of selected NFTs from 2022

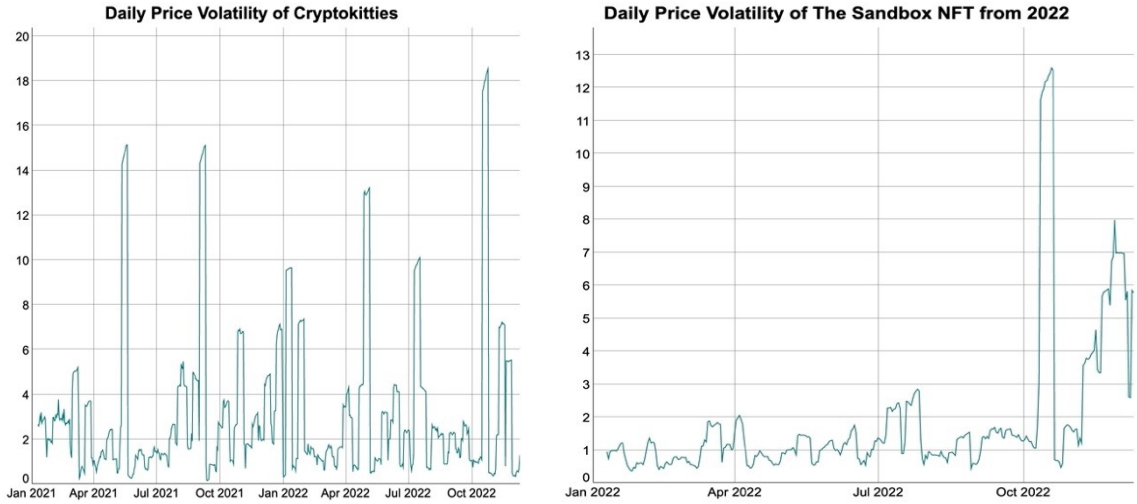


Figure 6: Price Volatilities of CryptoKitties and The Sandbox

These results are in line with the previous notions of higher NFT's price volatility than cryptocurrencies' price volatility. Most of the variations in "Crypto" are limited to 1, except the bull period in the spring of 2021. NFTs however, in both groups show the most volatilities reaching 2.0 - 2.5, which is twice higher that "Crypto". Moreover, we notice that CryptoKitties and The Sandbox NFTs reflect extreme volatilities reaching 18.5 and 12.5 points respectively, even after we smoothed the data. The smoothing period of 10 days we employed for NFTs is already quite restrictive and increasing the period could lead to the deterioration of estimates. Therefore, we decided to calculate the returns first and in case the problem would still significant, we treat the outliers individually.

Then, after the price adjustment, the values must be transformed into returns, that are required for portfolio optimization. The returns are calculated as:

$$R_t = \frac{P_t - P_{t-1}}{P_{t-1}}$$

where P_t and P_{t-1} are smoothed prices at time t and $t-1$, respectively.

The new dataset of returns has 708 observations for 7 variables (Crypto and NFT 21) and 343 observations for other 4 variables (NFT 22 and NFT Index).
The issue of extreme price volatility in CryptoKitties and The Sandbox appeared to be slightly less prominent in time-series plot of returns, but still required to be handled. We approach solving this, by identifying outliers in the upper layer of returns for 97,5% significance level and then replacing them with median values of each asset. Under this technique there has been detected 18 outliers in data for CryptoKitties and 9 outliers in The Sandbox data respectively. The resulting timeseries of returns for each group of assets are presented below:

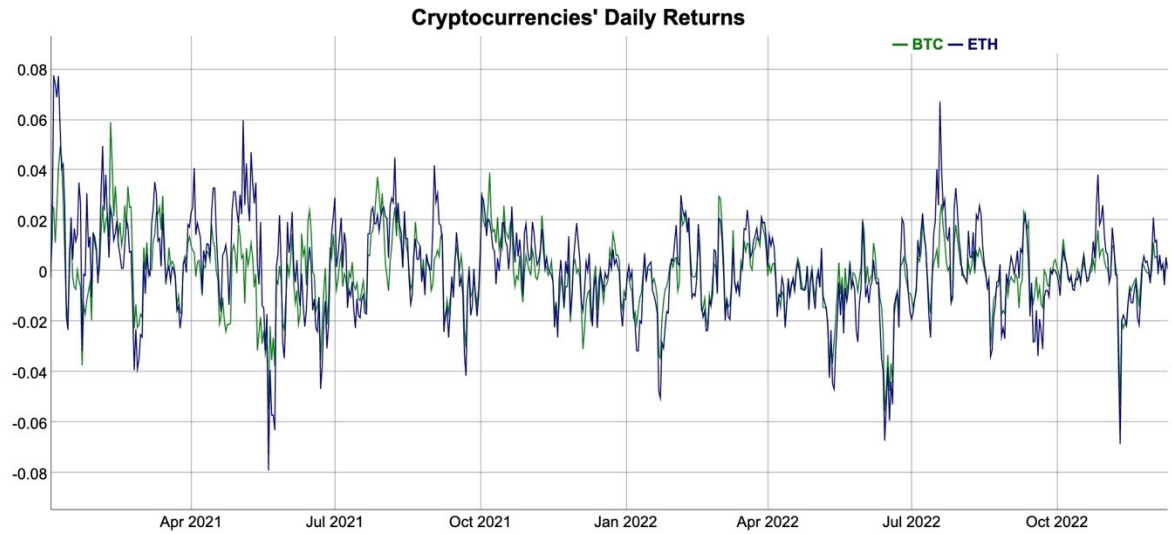


Figure 7: Cryptocurrencies' Daily Returns

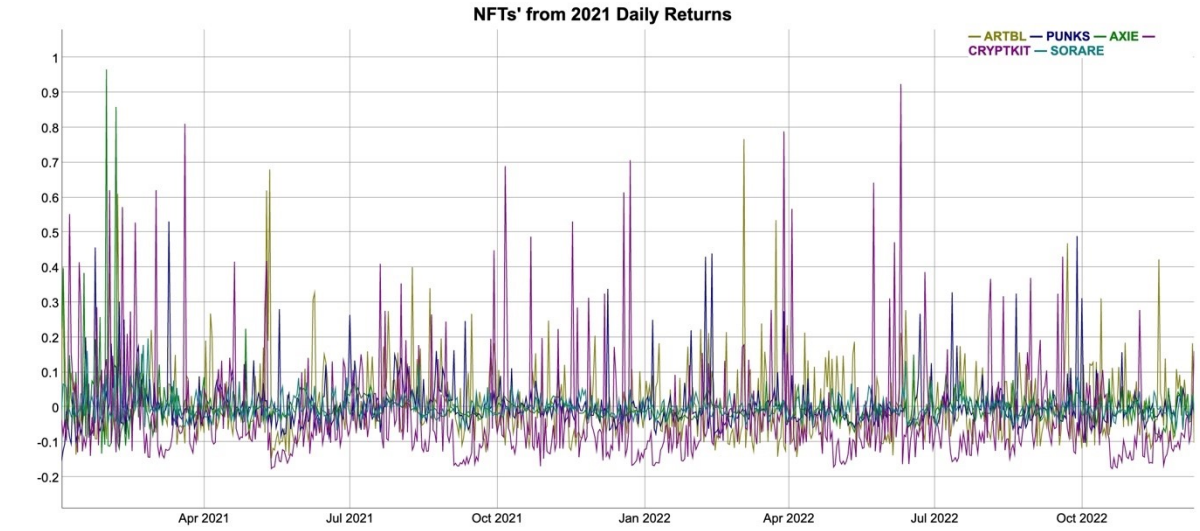


Figure 8: NFTs from 2021 Daily Returns

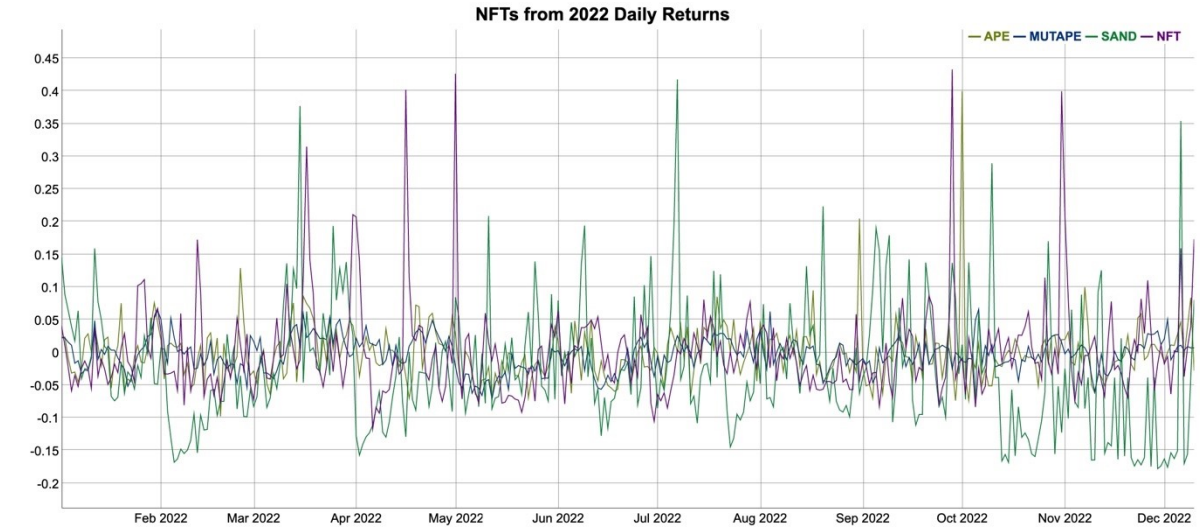


Figure 9: NFTs from 2022 Daily Returns

Notably, quite a significant synchronisation in cryptocurrencies' returns can be observed from the timeseries graph for "Crypto". This finding complements the earlier discoveries of the increase in total connectedness among cryptocurrencies over the years. The covariance matrices of return and price, similarly, indicate very high positive correlations among cryptocurrencies in all periods, both in price and return.

Descriptive Statistics

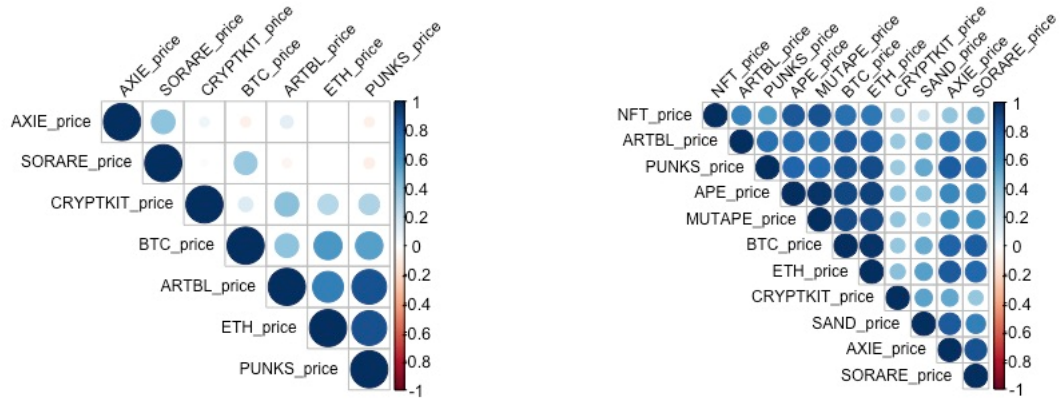


Figure 10: Covariance Matrix of Daily Prices in 2021 vs 2022

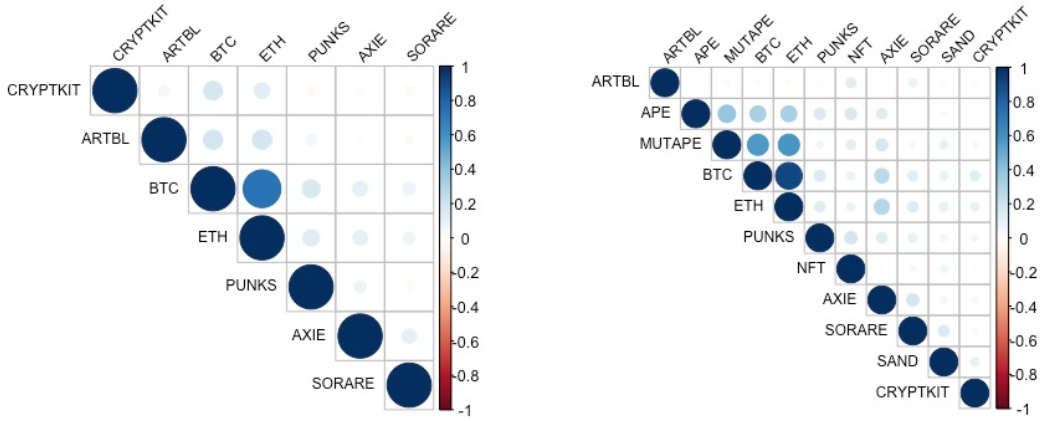


Figure 11: Covariance Matrix of Daily Returns in 2021 vs 2022

Regarding NFTs, we see almost no correlation (close to 0) among NFTs themselves and other assets in covariance matrix of returns for both 2021 and 2022 consecutive years. Covariance

matrix for price, however, detects strong positive relationship between Art Blocks and CryptoPunks in 2021 altogether with relatively high positive correlations of these assets and cryptocurrencies. In 2022, matrix indicates correlations close to 1 among all assets considered in the analysis. One of the possible explanations to this may be that the bear market of 2022 affects all crypto segments.

sumtable {vtable} Summary Statistics

Variable	N	Mean	Std. Dev.	Min	Pctl. 25	Pctl. 50	Pctl. 75	Max
BTC	708	-0.001	0.014	-0.056	-0.008	-0.001	0.007	0.059
ETH	708	0.001	0.019	-0.079	-0.01	0.001	0.013	0.078
ARTBL	708	0.007	0.106	-0.146	-0.061	-0.014	0.053	0.767
PUNKS	708	0.004	0.072	-0.154	-0.031	-0.01	0.018	0.531
AXIE	708	-0.002	0.065	-0.133	-0.023	-0.011	0.008	0.966
CRYPTKIT	708	-0.027	0.149	-0.176	-0.113	-0.072	-0.005	0.924
SORARE	708	-0.001	0.031	-0.067	-0.019	-0.005	0.013	0.197
APE	343	-0.002	0.043	-0.098	-0.027	-0.006	0.02	0.4
MUTAPE	343	-0.003	0.025	-0.071	-0.019	-0.002	0.012	0.066
SAND	343	-0.027	0.095	-0.178	-0.086	-0.038	0.016	0.418
NFT	343	0	0.071	-0.117	-0.041	-0.012	0.023	0.433

Table 4: Summary Statistics for all components

After generating the table of summary statistics for each asset we can identify several key insights. Mean returns for all assets are close to 0, except for CryptoKitties and The Sandbox with a 2,7% mean negative return each. The median return, however, is negative for all NFTs and ranges between 0 and 7 per cent. Bitcoin and Ether, however, have zero median returns both. Expectedly, the maximum returns for NFTs on average are higher than maximum returns for cryptocurrencies.

According to the preliminary analysis of data in this chapter, we can anticipate mean returns close to zero and the total returns slightly negative in the optimised portfolios. Moreover, the inclusion of NFTs in "Crypto" portfolios does not seem to be "surely" positive from this data. Probably, the presence of NFTs will vary depending on the optimisation objectives chosen for each portfolio.
We anticipate, that MinVar portfolio is less likely to have NFTs included, since NFTs have a higher volatility then cryptocurrencies and is penalised under this optimisation method. The MaxR portfolio, nonetheless, may have large shares of weights in NFTs, especially during the 2021, when the NFTs were on their peak. In regards of RiskRet portfolio, we expect the weights of NFTs ranging between those generated for MinVar and MaxR portfolios.

Results

Empirical Findings

In this thesis we applied random portfolio methodology to analyse the performance of cryptocurrency portfolios with and without NFTs included. The optimised portfolios were generated for the following three groups of assets' combinations:

Name	Cryptocurrencies	NFTs	Period
Group I	BTC, ETH	"NFT 21"	01.01.2021-10.12.2022
Group II	BTC, ETH	"NFT 21"+ "NFT 22"	01.01.2022-10.12.2022
Group III	BTC, ETH	"NFT Index"	01.01.2022-10.12.2022

Table 5: Groups of Portfolios by Assets and Periods

Testing the Hypothesis I.

To explicitly see whether the NFTs are present or not in the optimised portfolios described earlier, we retrieved the visual representations of weight distribution across the whole period of interest for each type of portfolio. In this part, we will omit the EW and Pure portfolios, because they include NFTs by default. Therefore, the analysis is performed for the remaining MinVar, MaxR and RiskRet portfolios. We have to notice that the original constraint of full investment i.e., all the weights must sum up to 1, had to be slightly relaxed to the minimum of 0.99 and maximum of 1.01 as requested by the computational software we used. These changes are not significant in regards of our research objectives and are not supposed to influence the eventual outcome.

Group I.
NFTs are included in all types of portfolios across all months, as periods of rebalancing, **Chyba! Nenalezen zdroj odkazů.**. The MinVar portfolio surprisingly has up to 65% of its total weights as NFTs which are present in each rebalanced period. Moreover, AXIE and SORARE are the most prominent among the "NFT 21", thus implying that they bear relatively low volatility across the whole period between 2021 and 2022 included. In case of MaxR portfolio, as it was expected, the NFTs are the dominant asset class in portfolio, in most of the periods carrying weights ranging between 90%-100%. The NFT weights in RiskRet are being distributed differently in 2021 compared to 2022. The proportion of NFTs is much larger in

2021, when their performance skyrocketed, compared to 2022. During the last year of 2022, they are still present in each period of rebalancing, nonetheless to lesser extent than a year before.

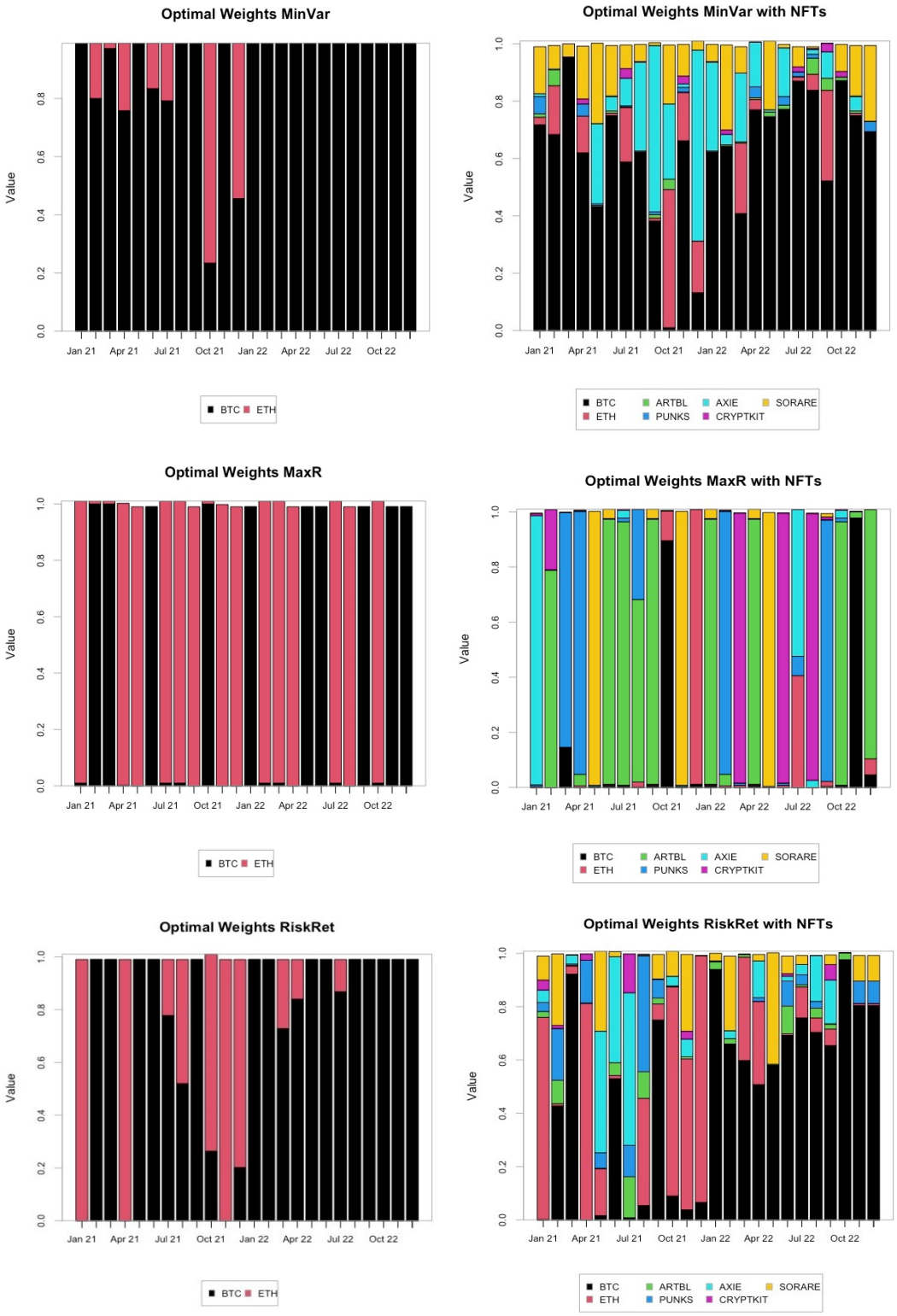


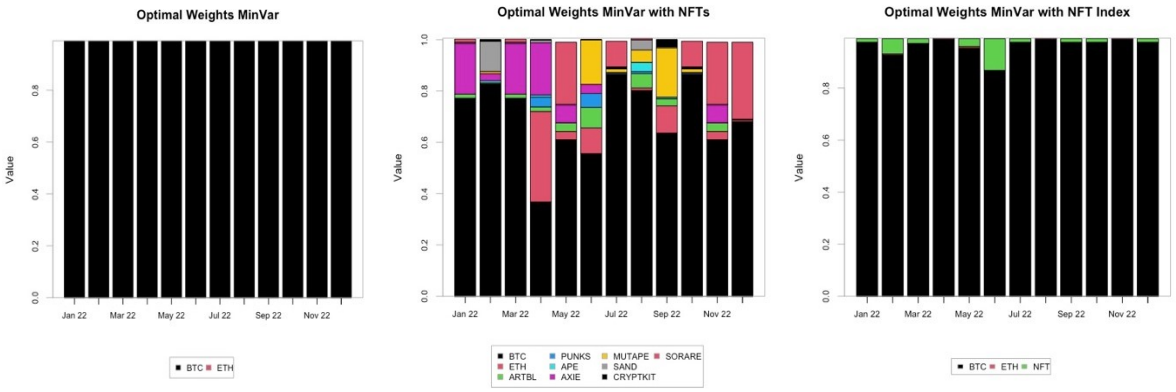
Figure 12: Optimal Weights Histograms for Group 1 portfolio

Group II

Alike in Group 1, non-fungible tokens from “NFT 21” and “NFT 22” combined, are consistently included in each portfolio across the whole period, **Chyba! Nenalezen zdroj odkazů.**. Compared to the MinVar portfolio in Group I, NFTs in Group II carry smaller weights, on average, being around 30% of total weight composition. The MaxR portfolio similarly to the previous result consists mainly of NFTs with the weights across all periods being within 90% to 100% limit. The weights assignment in the RiskRet portfolio, however, seems to be sensitive to the changes in the BTC price over the year. In April 2022, when BTC had the annual high, its portfolio weight that month dropped to less than 5%. Consequently, in October 2022, when BTC experienced one of the lowest price volatilities in 2022 with an almost “static” price, its portfolio weight in the respective month reached 90%+. The overall presence of NFTs in the RiskRet portfolio is significant with approximately 40% dominance, on average.

Group III

The third group showed the lowest share of NFTs across its portfolios, Figure 13**Chyba! Nenalezen zdroj odkazů.**. The minimum variance portfolio has NFT Index only in 9 of out 12 months during 2022, with the respective Index weight ranging between 0 - 15%. As for the RiskRet portfolio, the NFT Index is present in 9 monthly periods out of 12 total. The weights are not as large as in Group I and Group II, being on average between 5-7%. In June however, NFT Index had its maximal weight of about 15-17%. The existence of such “outlier” can be explained by the significant BTC price drop that month, resulting in the NFT Index being “chosen” by the mean-variance optimisation to back it up.



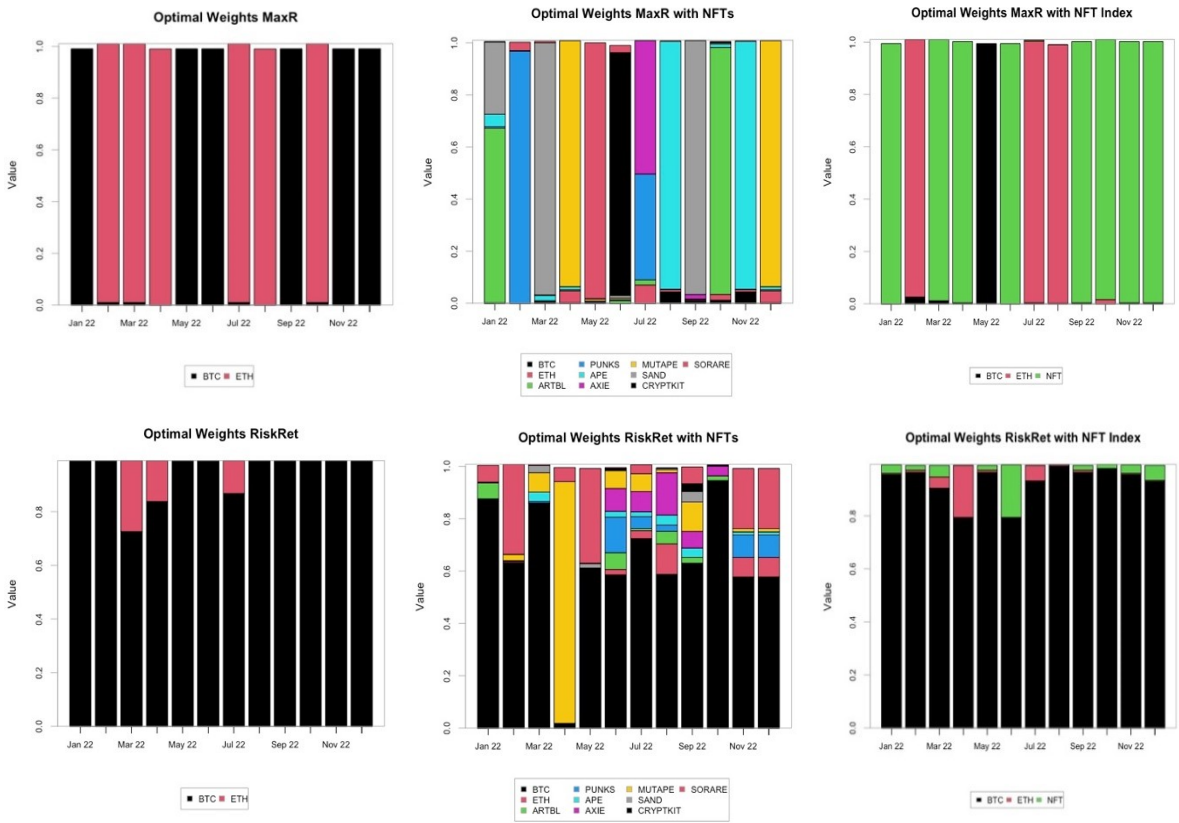


Figure 13: Optimal Weights Histograms for Group 2 and Group 3 portfolios

Considering the results obtained for each group, we cannot reject the hull hypothesis of the NFTs being included in the optimised portfolios of MinVar, MaxR and RiskRet. Additionally, we can highlight a couple of relevant discoveries from the just realised analysis. The first one is that in terms of weight concertation across the portfolios with variance objective, the ETH tends to behave in similar way as NFTs. BTC possesses the absolute weight dominance in the portfolios with variance objective. Furthermore, its price fluctuations intrinsically determine the distribution of other assets' weights in portfolio.

Testing the Hypothesis II.

The performance measurement of optimised portfolios with NFTs and its comparison to the "Crypto"- only ones has been implemented using several metrics. First, we present the density plots of returns for each type of portfolio, as it is generally advised by the random performance measurement originators.

The comparative distributions of return showed similar patterns in each group (Group 1, Group 2, Group 3), Figure 17, Figure 18 and Figure 19. The key outtakes are the following:

- Maximum return in portfolios with NFTs is lower.
- The distributions with NFTs are more skewed to the right than "crypto" portfolios.
- The distributions with NFTs have generally "fatter" tails.
- The densities that are the most resemblant to each other are for MinVar and RiskRet portfolios.

These characteristics indicate the inferior performance of portfolios with NFTs included to the performance of portfolios with cryptocurrencies. As for the higher resemblance in return densities for MinVar and RiskRet portfolios, this is explained by a smaller share of NFT included in the respective portfolios compared to MaxR, for example.

Another metric we used to extend the performance measurement analysis are the time series plots of relative returns for each group considered in the thesis.

Group I
Time periods of under and outperformance vary depending on the type of portfolio, Figure 14. The EW, Pure and MinVar portfolios with NFTs notably outperform in 2021 and underperform later in 2022. The RiskRet portfolio with NFTs, however, greatly outperforms "crypto" portfolios across the whole time period.

Group II
The timeseries of relative returns for the second group, that covers 2022, show strong underperformance tendencies of portfolios with NFTs for all types of portfolios except the MinVar, Figure 15.
The MinVar with NFTs has a short period of outperformance followed by greater underperformance, thus having approximately the same rate of return as MinVar portfolio without NFTs.

Group III
Different results are obtained for the time series plots with NFT Index. The EW portfolio with Index significantly outperforms similar EW without the Index. Generally, the same annual performance have Pure and MinVar pairs of portfolios. The MaxR and RiskRet portfolios with NFT Index underperform, similarly to Group II.

The summary statistics results for each group are in consonance with the outcomes from the density and timeseries plots, indicating the lesser performance of portfolios with NFTs. The annualised returns are negative across all portfolios and periods, except EW weighted portfolio of cryptocurrencies from Group 1, Table 6: Portfolio Statistics for BTC+ETH vs BTC+ETH+NFTS 21. Noticeably, the annualised return for BTC+ETH in Group 1 which covers 2021 and 2022, is negative but is better than for BTC+ETH in Group 2, which covers only 2022.

Expectedly, the inclusion of NFTs increases the annualised standard deviance of every portfolio, Table 7. There is also an increase in the standard deviation in the MinVar type of portfolios, hardly noticeable, but present. Despite the objective of maximised returns, the MaxR portfolios perform "the worst" in all Groups, having the biggest negative returns and standard deviations. Including NFTs in this type of portfolio encourages the deterioration of both these metrics even further. Interestingly, RiskRet portfolios have larger annualised return in Group 1, almost the same return with NFT Index and lesser return with Group 2. In our opinion, the results differ for two reasons. First, the Group 1 covers the successful 2021 period thus, affecting the ultimate outcome. Second, the price estimated for NFT Index are more robust, since derived from a larger sample of sales, meaning that this result may the closer to real case than for Group 2. Overall, only the NFT Index could slightly improve/not deteriorate the annualised returns across all five types of portfolios, but nonetheless they remained negative.

Given all that, we the hypothesis of a better performance of portfolios with NFTs included has to be rejected.

Portfolio Statistics for BTC+ETH vs BTC+ETH+NFTs 21

	Minimum	Median	Arithmetic Mean	Maximum	Variance	Stdev	Skewness	Kurtosis	Annualized Return	Annualized Std Dev
EW.portfolio.with.NFT	−0.079	−0.007	0.000	0.2832	0.0011	0.0333	2.2582	11.6544	−0.2059	0.5294
Pure.portfolio.with.NFT	−0.079	−0.007	−0.001	0.2239	0.0010	0.0309	1.7487	6.8395	−0.3771	0.4907
MinVar.portfolio.with.NFT	−0.052	−0.001	−0.002	0.0562	0.0002	0.0144	0.0501	1.2344	−0.3289	0.2285
MaxR.portfolio.with.NFT	−0.163	−0.011	−0.004	0.8269	0.0064	0.0802	3.2889	23.2170	−0.8315	1.2732
RiskReturn.NFT.portfolio.with.NFT	−0.077	−0.001	0.000	0.1153	0.0004	0.0192	0.6916	3.9125	−0.0077	0.3041
EW.portfolio	−0.070	0.000	0.000	0.0602	0.0003	0.0162	−0.3048	1.5016	0.0348	0.2571
Pure.portfolio	−0.070	0.000	0.000	0.0451	0.0002	0.0156	−0.5511	1.3017	−0.1055	0.2474
MinVar.portfolio	−0.062	−0.001	−0.001	0.0585	0.0002	0.0142	−0.3289	1.5668	−0.1867	0.2255
MaxR.portfolio	−0.079	0.000	−0.001	0.0600	0.0003	0.0169	−0.4813	1.7208	−0.2464	0.2680
RiskReturn.portfolio	−0.078	0.000	−0.001	0.0594	0.0002	0.0154	−0.4768	2.3934	−0.1645	0.2445

Table 6: Portfolio Statistics for BTC+ETH vs BTC+ETH+NFTS 21

Portfolio Statistics for BTC+ETH vs BTC+ETH+NFTs in 2022

	Minimum	Median	Arithmetic Mean	Maximum	Variance	Stdev	Skewness	Kurtosis	Annualized Return	Annualized Std Dev
EW.portfolio.with.NFT.Index	−0.054	−0.004	−0.002	0.1337	0.0007	0.0260	1.9694	7.1843	−0.4373	0.4123
Pure.portfolio.with.NFT.Index	−0.054	−0.004	−0.002	0.1337	0.0007	0.0265	1.9805	7.0370	−0.3669	0.4214
MinVar.portfolio.with.NFT.Index	−0.052	−0.002	−0.002	0.0300	0.0002	0.0126	−0.7125	2.1545	−0.4622	0.2000
MaxR.portfolio.with.NFT.Index	−0.117	−0.004	−0.001	0.4255	0.0036	0.0596	3.5777	20.9311	−0.5135	0.9460
RiskReturn.NFT.portfolio.with.NFT.Index	−0.054	−0.002	−0.002	0.0280	0.0002	0.0128	−0.7480	1.9910	−0.4823	0.2032
EW.portfolio	−0.061	−0.002	−0.003	0.0451	0.0002	0.0147	−0.6184	1.8324	−0.5379	0.2335
Pure.portfolio	−0.061	−0.002	−0.002	0.0451	0.0002	0.0147	−0.6565	2.0067	−0.4485	0.2340
MinVar.portfolio	−0.055	−0.002	−0.002	0.0293	0.0002	0.0125	−0.8124	2.6274	−0.4686	0.1982
MaxR.portfolio	−0.069	−0.002	−0.003	0.0264	0.0002	0.0146	−0.8623	1.7875	−0.5316	0.2324
RiskReturn.portfolio	−0.055	−0.002	−0.002	0.0293	0.0002	0.0126	−0.8104	2.5083	−0.4699	0.1999
EW.portfolio.with.NFT	−0.068	−0.009	−0.006	0.1459	0.0006	0.0247	1.2840	4.8736	−0.7758	0.3919
Pure.portfolio.with.NFT	−0.068	−0.009	−0.005	0.1459	0.0006	0.0252	1.3207	4.8890	−0.7656	0.3995
MinVar.portfolio.with.NFT	−0.048	−0.003	−0.002	0.0467	0.0002	0.0144	−0.0012	1.4725	−0.4863	0.2282
MaxR.portfolio.with.NFT	−0.164	−0.022	−0.023	0.3906	0.0044	0.0660	1.5029	7.0095	−0.9982	1.0471
RiskReturn.NFT.portfolio.with.NFT	−0.060	−0.003	−0.005	0.0337	0.0003	0.0161	−0.8453	1.5910	−0.7045	0.2555

Table 7: Portfolio Statistics for BTC+ETH VS BTC+ETH+NFTS in 2022

Discussion of the results

Regardless of the NFTs being included in all random optimised portfolios, their presence negatively influences the performance of crypto portfolios as of the end of 2022. From the list of optimisation approaches used in the thesis, we could not identify any that could be favourable in the case of a mixed assets portfolio. The mean-variance method, which is usually considered optimal and is commonly used for portfolios with traditional assets, did not perform well either. Therefore, we can say that as of December 2022, NFTs do not hedge Bitcoin and Ether portfolios for bear market losses regardless of the asset allocation approach chosen. In line with previous studies, we detected some diversifying potential in NFTs for cryptocurrency portfolios that was limited to 2021. Consequently, there could be implied that NFTs start to behave more uniformly with the crypto market dynamics responding to the external shocks. The earlier studies of NFTs that denote NFTs as being responsive mostly to internal shocks rather than external ones must be reconsidered. The fear of recession across traditional and alternative markets that is present now shows to be translated to the NFTs too.

Limitations of the study

It is, however, important to acknowledge the limitations of our thesis. Considering the methodology chosen, we analyse the general tendencies in portfolio performance, hence there could exist particular cases of portfolios with NFTs that certainly outperform the ones without them. Detecting such portfolios, however, was not our research objective. Despite the use of exponential moving averages and treatment of outliers, the irregularities in the volatilities of NFTs may persist, thus our price estimates may not be robust enough. Furthermore, the sales history for NFTs is rather short compared to stocks or bonds and it subsequently affects the effectiveness of the portfolio optimisation procedures. Also, the different choices of assets for the base crypto portfolio may possibly influence some of the metrics. The study can be naturally extended to testing the inclusion of NFTs in portfolios of stocks or bonds. Since the volatility connectedness between NFTs and these assets proved to be lower than between NFTs and cryptocurrencies it may produce various alternative results.

Future of NFTs and Conclusion

In the last chapter of the thesis, we summarise the results of our study and reflect on the future of NFTs. Along the chapters, we could introduce the concept of non-fungible tokens and their ecosystem to the reader. Then, we performed qualitative and quantitative analyses on the matter. Besides the NFTs being included in all types of random portfolios in the thesis, they demonstrated no improvement in the performance of Bitcoin and Ethereum-based portfolios. The empirical results from the last chapters indicate that NFTs can no longer be considered an extremely profitable asset to make a quick "buck". The market panic caused by a number of events of the last year did influence the NFT price, hence the market of the non-fungible token can no longer be recognised as one independent from exogenous shocks. Were the NFTs a "hype"? Definitely yes, but we could demonstrate that it is rather something truly valuable wrapped in it. The future of NFTs as a financial asset is dubious from this point in time, but its perspectives as a technology persist. We have seen in the recent past how the 'digital' world has triumphed over the 'physical' with e-commerce and streaming services becoming more prevalent than their physical counterparts. NFTs, however, can still be next.

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Appendix

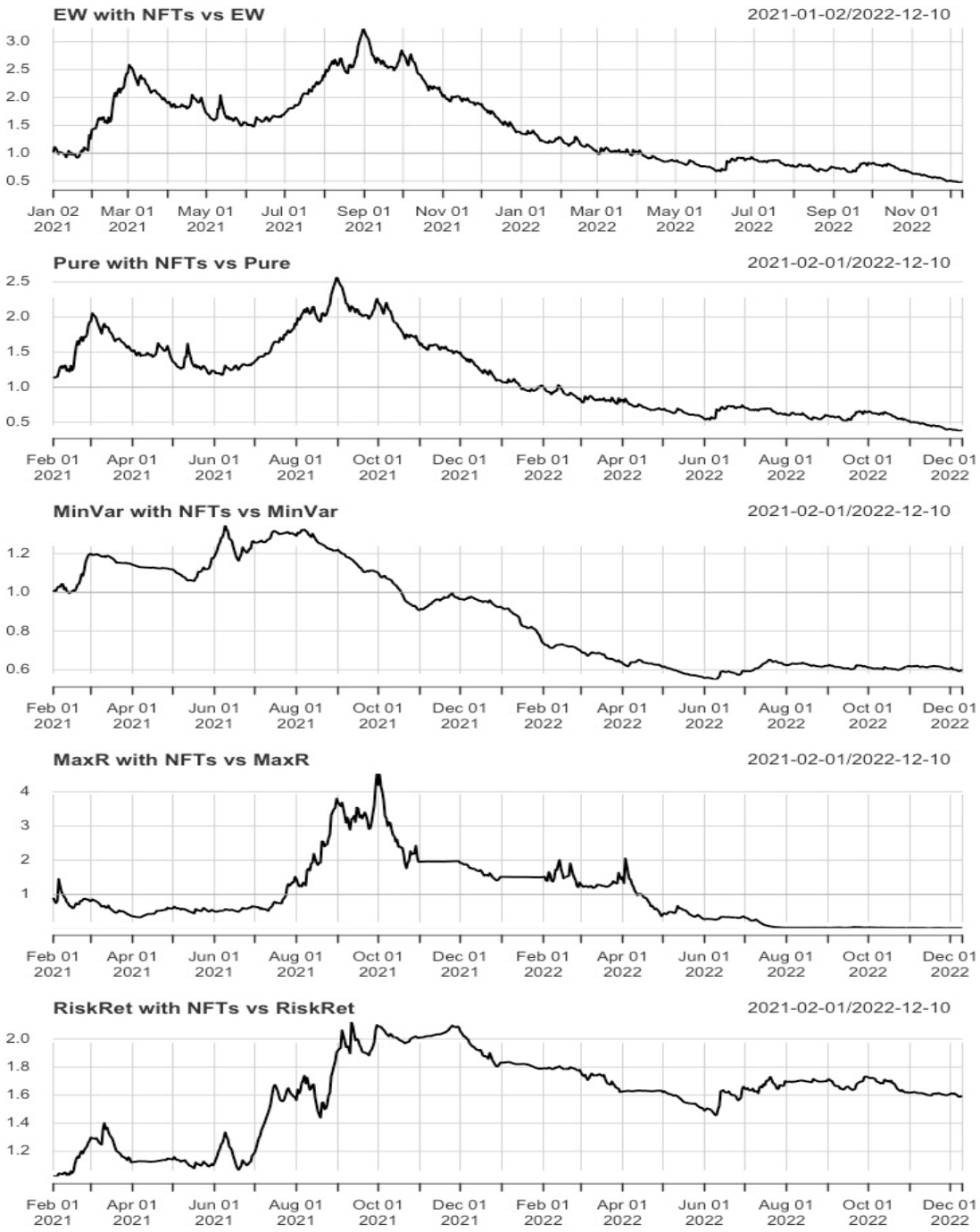
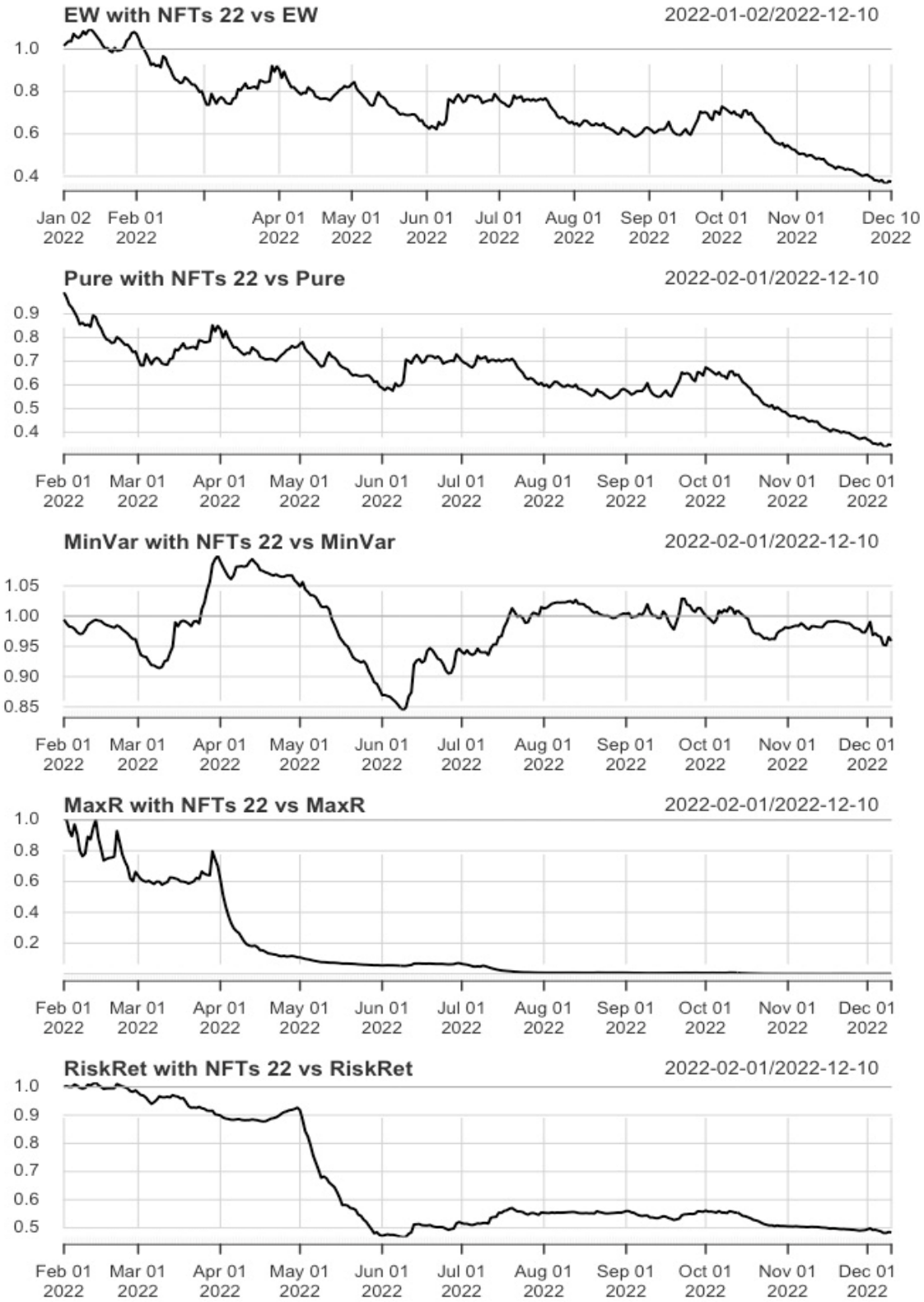


Figure 14


EW with NFTs 22 vs EW
2022-01-02/2022-12-10
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Jan 02 2022
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Sep 01 2022
Oct 01 2022
Nov 01 2022
Dec 10 2022
Pure with NFTs 22 vs Pure
2022-02-01/2022-12-10
0.9
0.8
0.7
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Feb 01 2022
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Sep 01 2022
Oct 01 2022
Nov 01 2022
Dec 01 2022
MinVar with NFTs 22 vs MinVar
2022-02-01/2022-12-10
1.05
1.00
0.95
0.90
0.85
Feb 01 2022
Mar 01 2022
Apr 01 2022
May 01 2022
Jun 01 2022
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Aug 01 2022
Sep 01 2022
Oct 01 2022
Nov 01 2022
Dec 01 2022
MaxR with NFTs 22 vs MaxR
2022-02-01/2022-12-10
1.0
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Nov 01 2022
Dec 01 2022
RiskRet with NFTs 22 vs RiskRet
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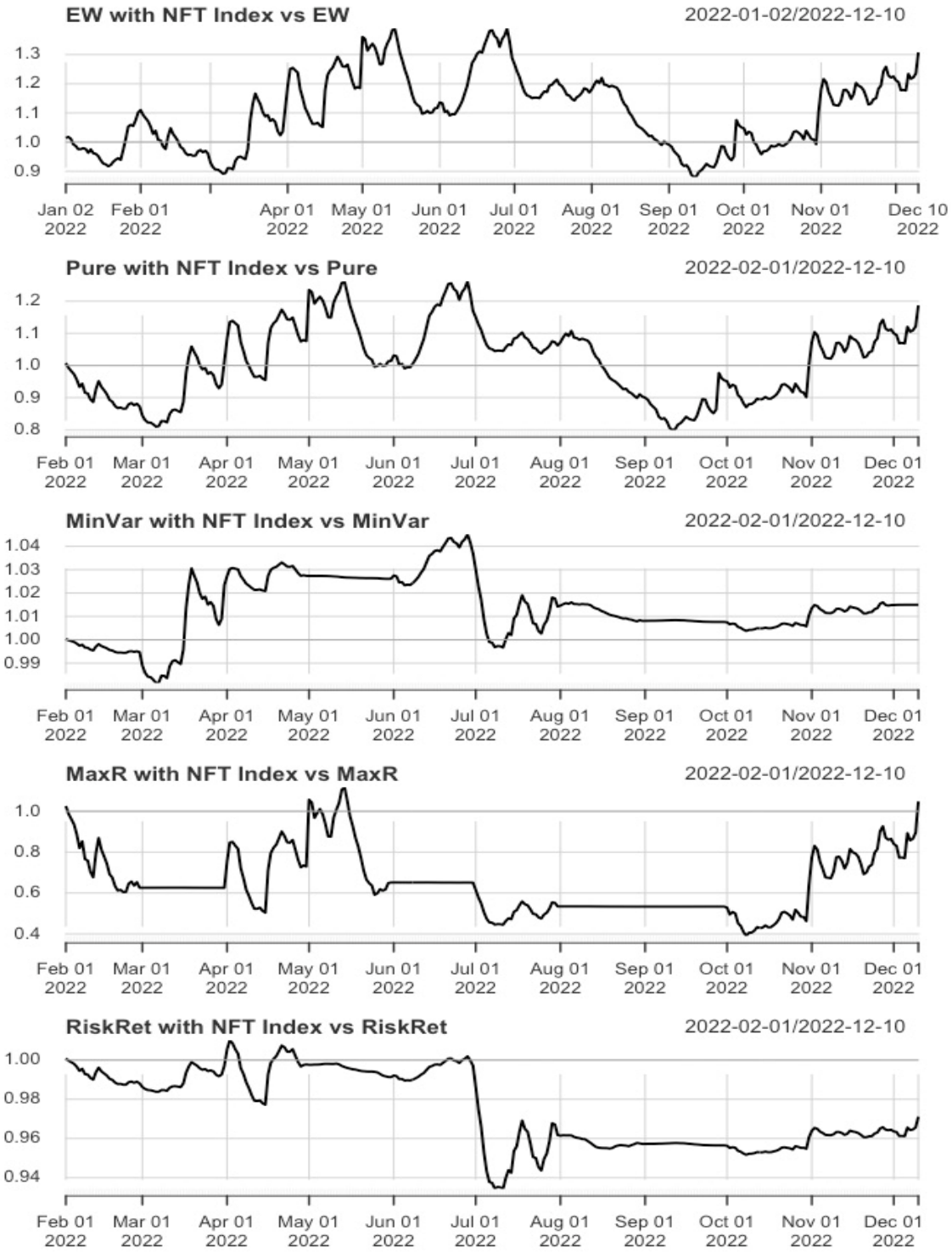
Figure 15


EW with NFT Index vs EW
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May 01 2022
Jun 01 2022
Jul 01 2022
Aug 01 2022
Sep 01 2022
Oct 01 2022
Nov 01 2022
Dec 10 2022
Pure with NFT Index vs Pure
2022-02-01/2022-12-10
1.2
1.1
1.0
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Feb 01 2022
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MinVar with NFT Index vs MinVar
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RiskRet with NFT Index vs RiskRet
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1.00
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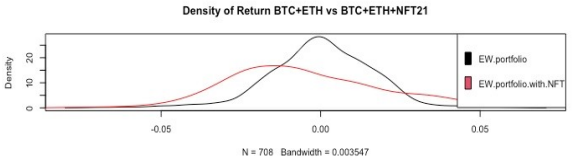
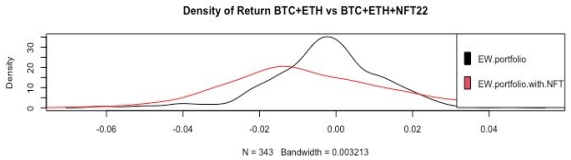
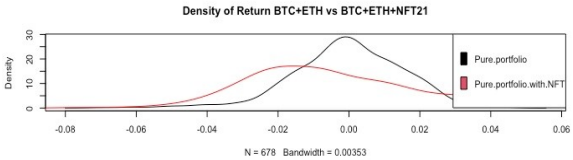
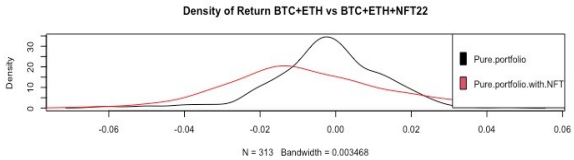
Figure 16

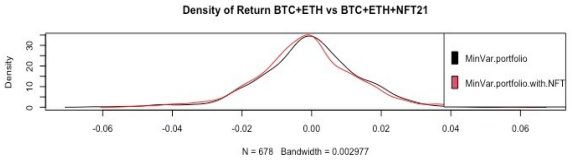
Figure 17

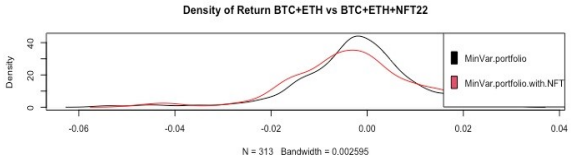


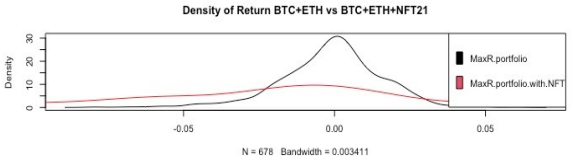


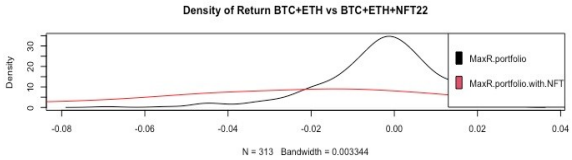


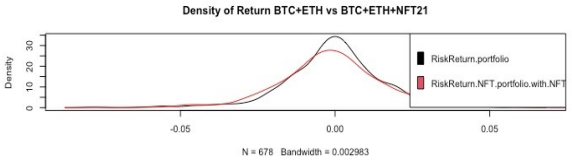












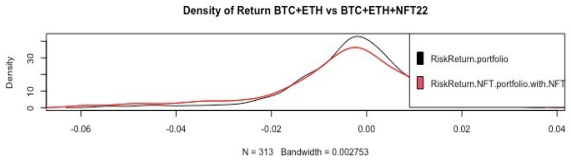


Figure 18

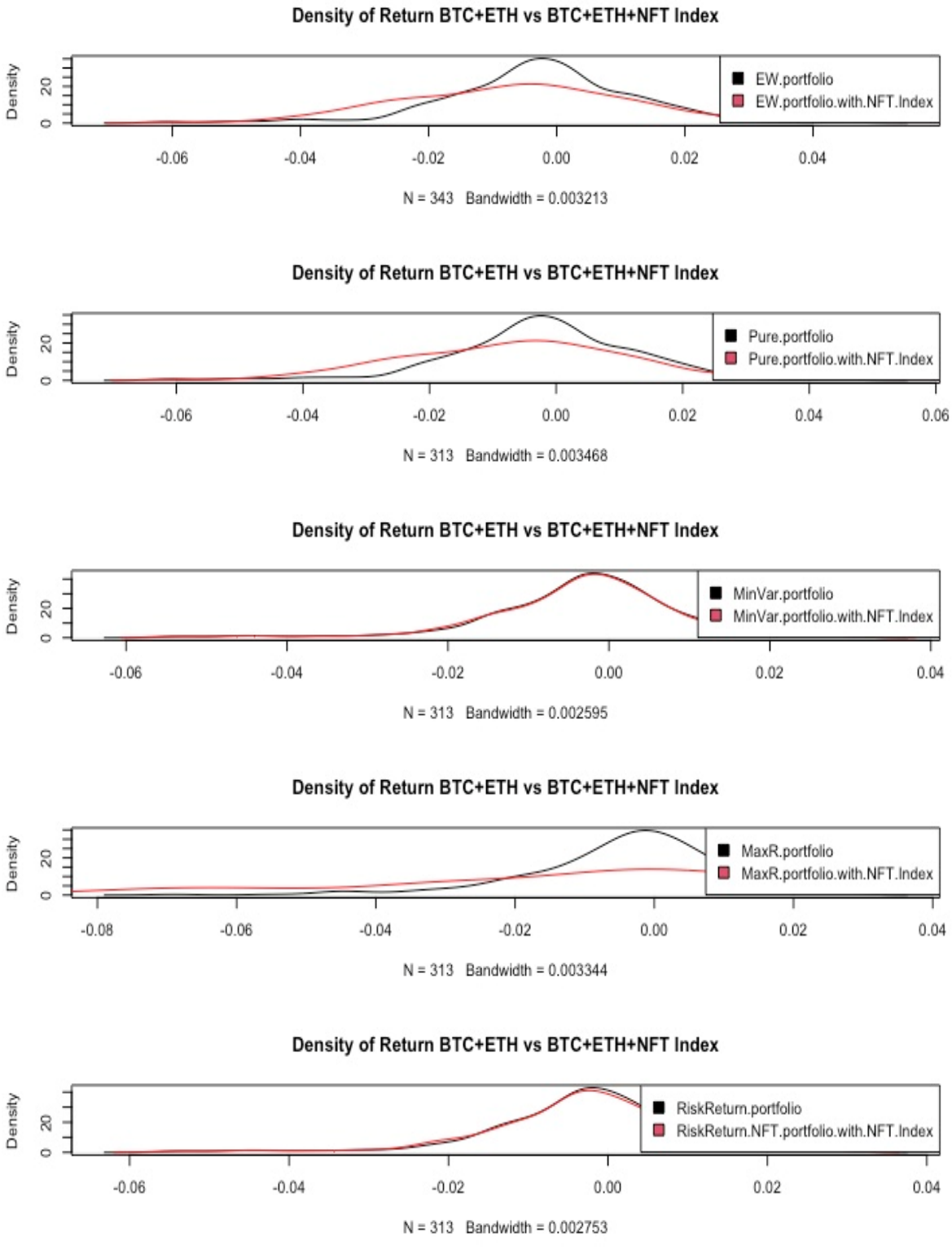

Density of Return BTC+ETH vs BTC+ETH+NFT Index
Density
EW.portfolio
EW.portfolio.with.NFT.Index
N = 343 Bandwidth = 0.003213
Density of Return BTC+ETH vs BTC+ETH+NFT Index
Density
Pure.portfolio
Pure.portfolio.with.NFT.Index
N = 313 Bandwidth = 0.003468
Density of Return BTC+ETH vs BTC+ETH+NFT Index
Density
MinVar.portfolio
MinVar.portfolio.with.NFT.Index
N = 313 Bandwidth = 0.002595
Density of Return BTC+ETH vs BTC+ETH+NFT Index
Density
MaxR.portfolio
MaxR.portfolio.with.NFT.Index
N = 313 Bandwidth = 0.003344
Density of Return BTC+ETH vs BTC+ETH+NFT Index
Density
RiskReturn.portfolio
RiskReturn.NFT.portfolio.with.NFT.Index
N = 313 Bandwidth = 0.002753

Figure 19