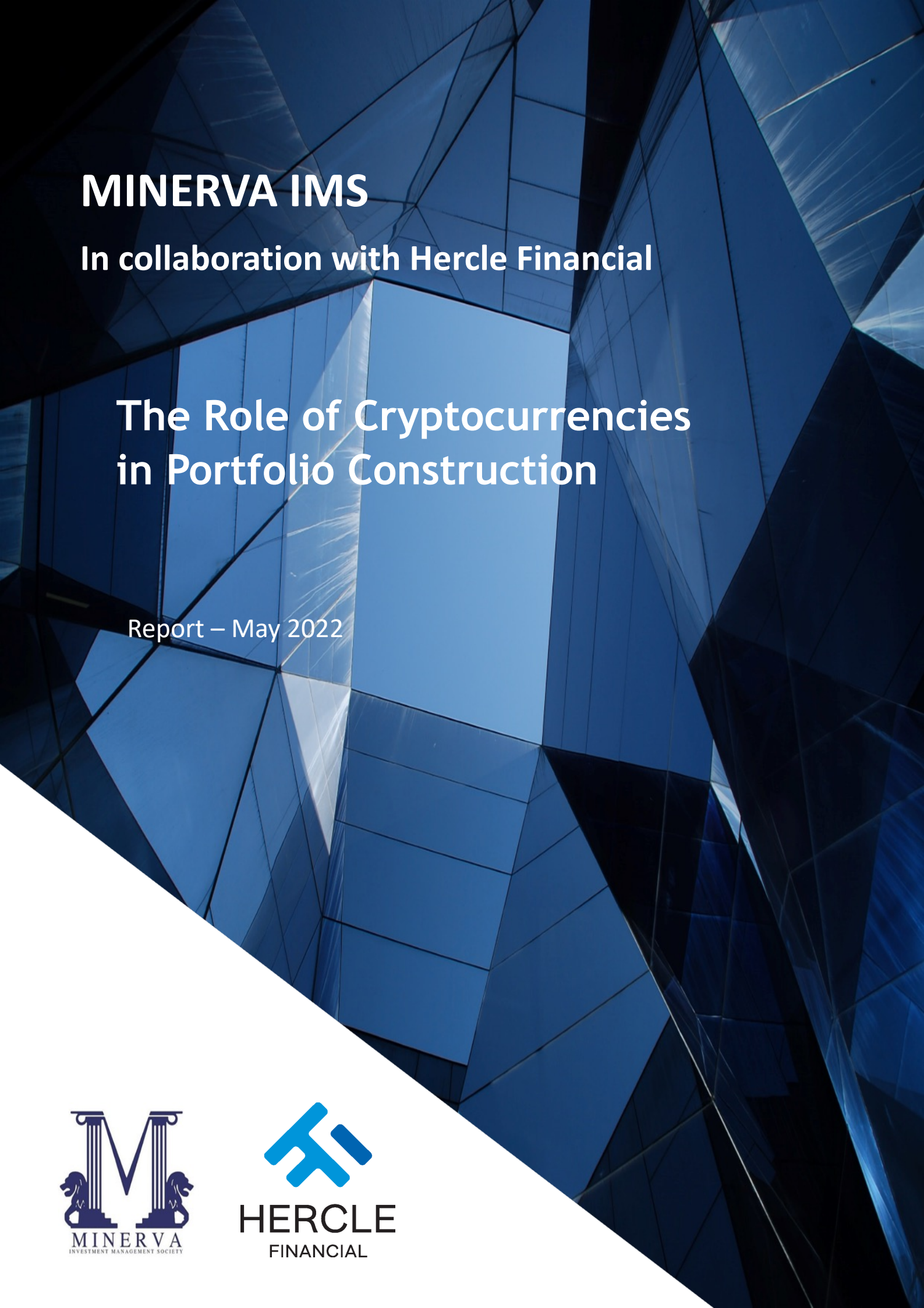

MINERVA IMS

In collaboration with Hercle Financial

The Role of Cryptocurrencies in Portfolio Construction

Report – May 2022

MINERVA
INVESTMENT MANAGEMENT SOCIETY

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MIMS – The Role of Cryptocurrencies in Portfolio Construction

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Abstract

The aim of this report is to **assess the performance of the two most popular cryptocurrencies**, **Bitcoin and Ethereum**, **when included in some traditional asset allocation strategies**. The time span we considered is from March 2017 to March 2022. After providing a brief introduction to the cryptocurrency environment and the choice of the financial instruments used in the analysis, the work describes the chosen **allocation strategies** (exogenous weights, risk parity, multi-asset allocation and factor-style investing) and the methodology in order to construct the relative portfolios. For each allocation strategy, we built at least two portfolios: one **without positions in cryptos and another one including them**. The weights, when not decided exogenously or according to a pre-determined criterion, have been chosen by means of a **Markowitz mean-variance optimization model**. Generally, the inputs have been estimated considering a 2-year time window. When crypto data were lacking, we assumed perfect forecasting. A detailed performance analysis has been performed by looking mainly at three indicators: the **Sharpe Ratio**, the **Sortino Ratio** and the **Omega Ratio**. Finally, we performed VaR models and backtesting in order to evaluate the potential losses of the portfolios we constructed. The results show that **portfolios with cryptocurrencies do not present a significant increase in the three ratios, except for risk-parity portfolio**. This is consistent with the main downside of cryptocurrencies i.e. their substantial volatility. As so, in order to benefit from further portfolio diversification coming from cryptocurrencies, an **investor must control for the volatility** of such an asset which is exactly the **rationale behind the risk-parity strategy**. Such an approach allows the investor to be exposed to the possibly larger returns of cryptocurrencies, while being protected from their harmful downturns during risk-off periods such as the current one. When the extra volatility is not dealt with, as in the case of the traditional 60/40 portfolios, there is no evidence of diversification benefits coming from the inclusion of cryptocurrencies in a portfolio.

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Snapshot of the Cryptocurrencies' World

In the recent years, **cryptocurrencies have engrossed the markets**, with **Bitcoin** holding the crown as **the best performing asset annually since 2019**. However, the **recent performances** of crypto assets **go against this fact**, and we are fully aware of that. The aim of this report is to compare the **impact of** including **cryptocurrencies** in a diverse set of popular portfolios. Our analysis focuses on a five-year timeline spanning the period from March 2017 to March 2022. Generally, the weights of the portfolios are estimated on a rolling basis using the past two-year weekly performance of the assets. The optimization is applied on structures that include a basic well-known **60/40 portfolio**, a risk-parity portfolio, a **multi-asset portfolio** and finally a **factor-style portfolio**, whose factors have been chosen as identified by E. Fama and K. French.

Overview of cryptocurrencies

Cryptocurrencies form a **new digital asset class**, where the verification of the transactions does not rely on traditional financial institutions, but it is decentralized (**distributed-ledger technology**). Transactions are recorded with cryptographic techniques, involving hash functions, on a public ledger/database known as blockchain, where information regarding the ownership, exchange and mining of coins is stored.

The total **market capitalization** of cryptocurrencies fluctuates currently around **$2 trillions**, having hit $3 trillions in November 2021. This makes them almost 1% of global financial assets. As of April 24, Bitcoin fluctuates around a market capitalization of $755 billion, while Ethereum ranks second with a market cap of approximately $354 billion.

Cryptocurrency	Market Cap	Volume
Bitcoin	$755,020,546,397	$16,275,441,734
Ethereum	$354,451,682,349	$8,295,717,486
Tether	$83,140,870,229	$37,207,732,644
BNB	$65,703,989,151	$1,182,716,719
USD Coin	$49,911,075,141	$2,407,006,113

Source: CoinMarketCap, retrieved 24 April 2022

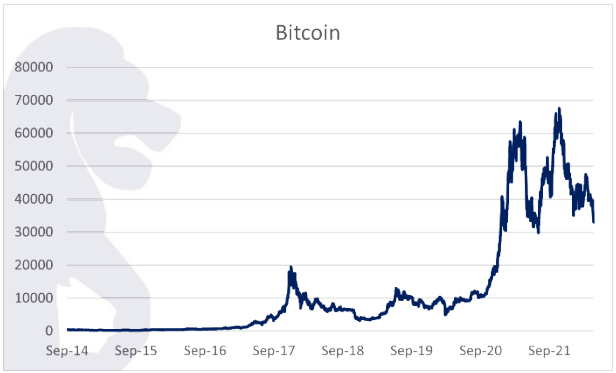
Bitcoin

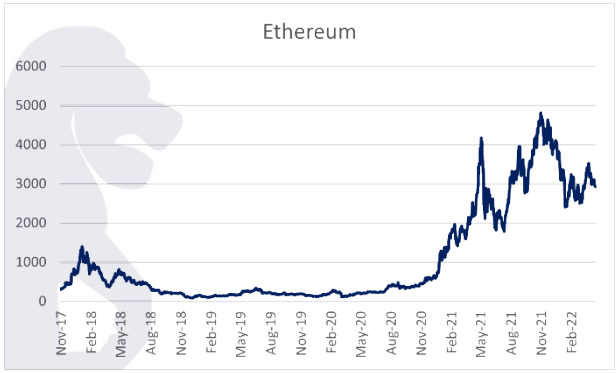
Bitcoin was launched in 2008 as a peer-to-peer payment open-source software where cash transactions were recorded on the blockchain. The "**Genesis Block**" that contained the first 50 bitcoins was first mined in 2009 by the obscure founder **Satoshi Nakamoto**. The rest is history.

Almost 19 million bitcoins have already been mined today, with the **maximum limit** being set at 21 million. This scarcity has often led to parallels with gold, a traditional hedge against inflation. At the same time, its price fluctuations have also sparked references to **tulip-fever** and South-Sea bubble.

Ethereum

In contrast to Bitcoin, the **Ethereum** blockchain, launched in 2015, also allows the execution of "**smart contracts**", enabling users to run immutable and permanent applications on it. This allows to perform more complex financial transactions, such as purchasing **NFTs** (non-fungible tokens) with ether, the native currency of the Ethereum blockchain. Moreover, Ethereum does not have a prespecified limit for coins issued, unlike Bitcoin.





Source: Yahoo Finance, retrieved 24 April 2022

Emerging proof-of-stake cryptocurrencies

However, the crypto market is also populated by several **emerging cryptocurrencies**. For instance, **Avalanche**, released in September 2020, is currently trading at around 59$ with a return of approximately 1160% since its launch, having skyrocketed to 134$ in November 2021. **Cardano**, currently trading at 0.78$, was launched in September 2017, boasts a 2341.1% return, hitting its all-time high of 2.97$ in March 2021.

Cardano and Avalanche stand out against cryptos like Bitcoin and Ethereum thanks to their **proof-of-stake protocol** for the verification of transactions, as opposed to **proof-of-work**. In proof-of-work protocols, miners use energy and computer power to solve cryptographic hash puzzles that verify blocks of transactions.

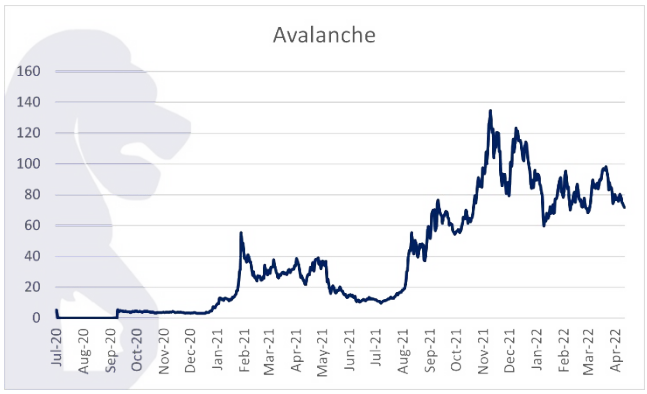
Cryptocurrency	Market Cap
Cardano	$26,174,925,810
Avalanche	$15,780,594,226
Solana	$29,331,639,178
Dogecoin	$17,460,544,659

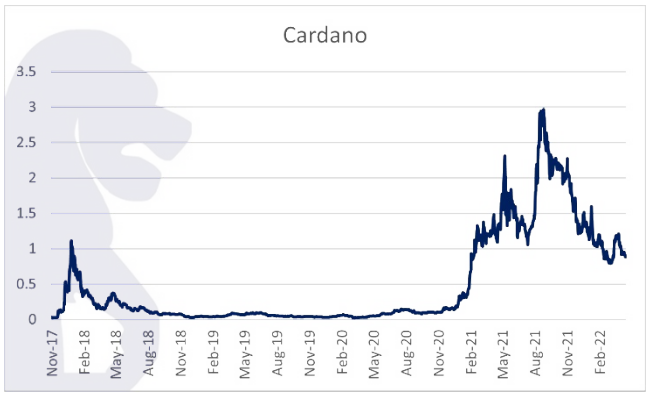
If the network of nodes performs a successful audit on the block, it is added to the chain. Since it is extremely unlikely that anyone will be able to control at least half of the crypto's hash rate (i.e., computing power of all the miners) and the node of networks, a proof-of-work protocol provides robust protection against nefarious miners.

Instead, the proof-of-stake protocol used in Cardano allows block creators to add a block to the ledger based on the number of tokens they hold. Thus, financial resources determine instead the **validation power of new blocks**.

In parallel to the proof-of-work protocol, this would mean that a **nefarious validator** should also hold at least half of coins circulating and the nodes of the network. While this is still challenging for cryptos like Cardano or Avalanche, requiring financial resources as opposed to mining hardware presents a lower barrier to entry compared to a proof-of-work protocol and might encourage validators with big pockets to hoard coins in order to access rewards.

At the same time, cryptos like Cardano present a more energy-efficient and accessible alternative to proof-of-work-based cryptos, like Bitcoin or Ethereum. This scalability achieved through greater energy efficiencies has prompted also **DeFi** (**decentralized finance**) blockchains, where smart contracts and NFT minting are executed, to shift towards proof-of-stake protocols (like ETH2).





Source: Yahoo Finance, retrieved 24 April 2022

Solana and the proof-of-history protocol

Launched in April 2020, **Solana** has been typically poised as a challenger to Ethereum, given that it also has smart contract capabilities for DeFi applications. Its popularity has been especially boosted since the launch of **Solanart**, one of the biggest **NFT marketplaces** on the Solana blockchain. While on the 11th of April 2020, the coin was trading for round $0.78, based on latest prices, it has reached $88, representing an over 10,000% historical return.

It has captured attention for its speed and scalability, with transactions having an average cost of $0.00025. It has attracted over $300 million in funding from investors such as venture capital firm Andreesen Horowitz, principal trading firm Alameda Research and Europe's largest and longest standing digital asset investment firm, CoinShares.

The element that differentiates Solana is the employment of a **proof-of-history protocol**. While in cryptos like Ethereum, time is derived from external programs that produce a "median" timestamp, a proof-of-history protocol saves timestamps into the blockchain itself, using a verifiable delay function. This allows for fast sequencing validators, meaning that the nodes (or computers) have a clear order of when blocks are mined to save them on the blockchain, and use this as a validation method.

Solana's technological innovations allow it to process a block in 400 milliseconds, compared to Ethereum's 10 seconds and Bitcoin's 10 minutes block time. Running smart contracts on the lower-level programming language RUST as opposed to a virtual machine, which occurs in Bitcoin and Ethereum, allows for more powerful processing as well.

Liquidity

In our last paper in collaboration with Hercle Financial, the **liquidity of cryptocurrencies**, and specifically Bitcoin, was discussed citing the **bid-ask spread** as a factor that contributes to the coin's volatility and lower liquidity, given the immediate costs for selling or buying a security.

The resilience of Bitcoin was calculated, which refers to the speed by which the bid-ask spread reverts to its long-term average following a spike. A resilience of 1 reflects a very quick adjustment, while a resilience of 0 implies that there is no return to the long-term average. Bitcoin's resilience was estimated at 0.042, pointing to a **low resilience**, which however has been strongly impacted by the outbreak of COVID-19 in March 2020 and discouraging economic data released in the beginning of 2021 regarding spiking inflation.

Cryptocurrency infiltration: attracting both institutional and corporate investors

Cryptocurrencies have also gained attention from institutional and corporate investors. This section provides some examples that occurred over the past years relating to the topic.

Since the end of 2021, **Paypal** has launched the service of crypto wallets, enabling consumers to gradually buy and use crypto (Bitcoin, Ethereum, Litecoin, and Bitcoin Cash) for their 29 million merchants worldwide. With Paypal, the wallet owner holds only the public key for the crypto, while Paypal is in possession of the private key, prohibiting transfer of ownership.

Block, a financial services and payments company co-founded by Twitter's Jack Dorsey, is also moving towards facilitating crypto mining and increasing vertical integration for the mining process through custom silicon production and design.

Grayscale, a subsidiary of the venture capital firm Digital Currency Group, caught the spotlight when it requested approval from the SEC to convert its $30 billion Bitcoin Trust into a bitcoin spot ETF. The firm holds over 654,000 bitcoins, or over 3% of total Bitcoin supply. As the European crypto market becomes increasingly competitive, with 73 exchange traded products worth $7 billion having been already approved, Grayscale has also expressed its intentions of joining the competition.

In the corporate world, **MicroStrategy Inc** is the biggest publicly-traded owner of Bitcoin, holding over 125,000 coins, about 2.5 times more than the second biggest contender, Tesla. Its crypto-investments, in fact, exceed its current market cap of about $3.9 billion, with its crypto holdings being valued at just under $5 billion.

Fueled by its CEO's tumultuous relationship with cryptocurrencies, on the other hand, **Tesla** made a purchase of $1.5bn in Bitcoin in the first quarter of 2021, without any similar ventures having followed. Based on the company's earnings filings, its digital asset holdings stand at around $1.96 billion as of the first quarter of 2022. While Elon Musk had initially tweeted that Tesla would start accepting Bitcoin as payment from clients, the CEO later renounced this position, citing the environmental impact of crypto-mining as a deterrent.

On the institutional side, **Fidelity Investments**, one of the biggest asset managers, with $ 4 trillion assets under its control, is also one of the biggest 401(k) plan providers in the US. The asset management firm has recently proposed launching a 401 (k) plan with bitcoin and other digital assets, likely no more than 20% in contribution, planning to offer it to 23,000 employees.

Cryptocurrenices and Public Institutions. Mentions to the future EU regulatory framework and central bank digital currencies (CBDCs).

The world of cryptocurrencies is also arousing a lot of interest from a **regulatory** and **monetary policy** point of view.

The **European Commission**, in September 2020, published a draft regulation on the markets in crypto assets (**MiCAR**), which will probably come into force in 2024. The objective of MiCAR is to standardize within the European Union the rules applicable to those who issue or provide services in relation to crypto assets, making them subject to authorization, requirements and supervision. This decision will place the European Union at the forefront worldwide.

As far as monetary policy is concerned, many **central banks**, especially in emerging countries, are considering the adoption of **digital currencies** and sometimes their pilot projects are at an advanced stage of development (e.g., China). Few countries have decided to directly adopt some cryptocurrencies as **legal tender** (e.g., El Salvador). Without diving into the countless technical and conceptual details that differentiate a cryptocurrency from a CBDC, the interest of central banks in distributed-ledger technologies is relevant. Considering the European context, also the ECB showed interest in the issuance of a CBDC. As a matter of fact, along with opinions on the topic expressed by the ECB President Christine Lagarde and some ECB Executive Board Members, a public consultation regarding a **digital euro** was run from October 2020 to January 2021.

Data Selection and Analysis

In order to construct our portfolios, we decided to employ the following **financial assets**:

- the **2Y T-Bill** as risk-free rate;
- **SPDR S&P 500 ETF Trust** (SPY), an ETF tracking the US equity S&P500 index;
- **iShares 20+ Year Treasury Bond ETF** (TLT.O), an ETF for US long-term government bonds;
- **iShares S&P GSCI Commodity-Indexed Trust** (GSG), an ETF for exposure to commodities;
- the exchange rates of **Bitcoin** and **Ethereum** against the US dollar (BTC and ETH);
- the **Fama&French five-factor model portfolios**, so as to capture also strategies that involve factor-style investing.

Because the rationale for including BTC and ETH should be already clear, we now provide a quick view on the other assets used to perform the analysis.

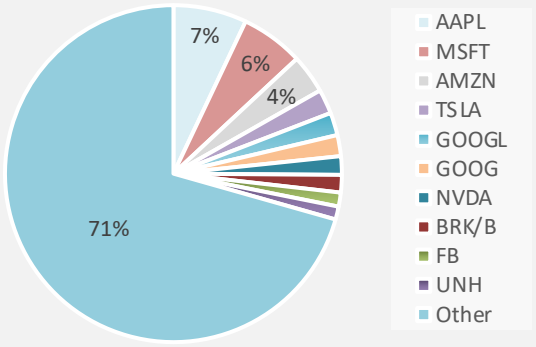
2Y US Treasury Bill

As a **risk-free benchmark**, we decided to use the 2Y US Treasury Bill, motivated by the fact that we performed a short-medium term analysis. We considered treasury bills under 2 years to be too heavily influenced by supply and demand dynamics, while the 10-year ones would have been too long term with respect to the framework taken into consideration.

SPDR S&P 500 ETF Trust – SPY

The SPY fund tracks the **S&P500 index**, which contains 500 securities chosen by the S&P's index committee – and not the 500 largest by market cap – to represent the US large-cap space. It seeks to achieve its investment objective by holding a portfolio of the common stocks that are included in the index, with the weight of each stock substantially corresponding to the weight of such stock in the index.

The index includes many of the largest **tech companies**, with the top ten holdings accounting as of March 2022 for 29% of the total value and the first five being in order: Apple, Microsoft, Amazon, Tesla and Google.



iShares 20+ Year Treasury Bond ETF – TLT.O

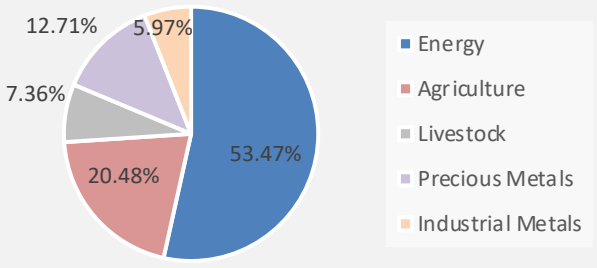
As a proxy for the **bond market**, we opted for the iShares 20+ Year Treasury Bond ETF. TLT.O seeks to track the investment results of an index composed of US Treasury bonds with remaining maturities greater than **twenty years**, capturing the tail of the Treasury yield curve. As a result, it is very sensitive to long-term interest-rate movements. With 34 bonds in total, more than half of the total value is composed by the first ten.

Fama&French Factor Portfolios

We downloaded from French's online data library the returns of five portfolios mimicking the five factors included in the **Fama&French Model**. In particular, they try to capture from observable characteristics some proxies for other risk sources other than market risk premium (i.e., size, value, profitability and investment).
The five portfolios are: (i) the **market risk premium**, essentially investing in the market; (ii) **SMB**, a long-short portfolio built to capture the fact that smaller companies tend to outperform larger ones in the long term; (iii) **HML**, a long-short portfolio linked to the idea that value stocks outperform growth ones in the long term; (iv) **RMW**, a long-short portfolio which invests in companies having robust operating profitability and sells those with weaker margins; (v) **CMA**, a long-short portfolio applying the same logic as before but with respect to conservative and aggressive investment.

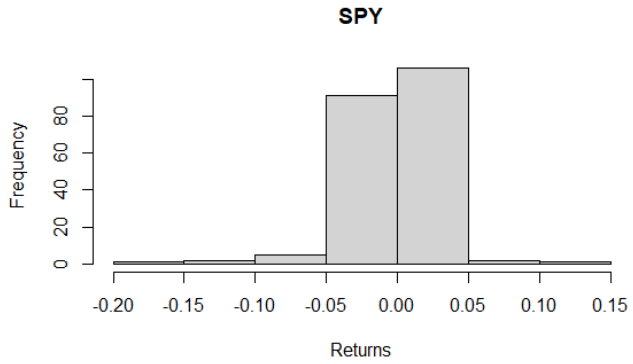
iShares S&P GSCI Commodity-Indexed Trust – GSG

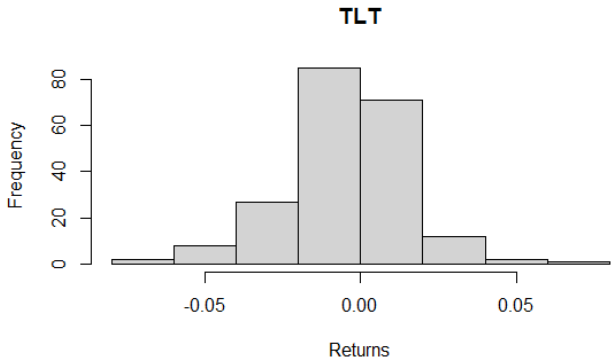
The GSG tracks the S&P GSCI Total Return Index, which is a **benchmark commodities index** that is tied to the performance of the global commodities market. It is made up of 24 exchange-traded futures contracts that cover physical commodities covering five sectors: energy (including **crude oil**, refined oil products, **natural gas**), industrial metals (**aluminum**, zinc, nickel, copper), precious metals (**gold**, **silver**, platinum), agriculture (**coffee**, sugar, cotton), and **livestock** (hogs, cattle).

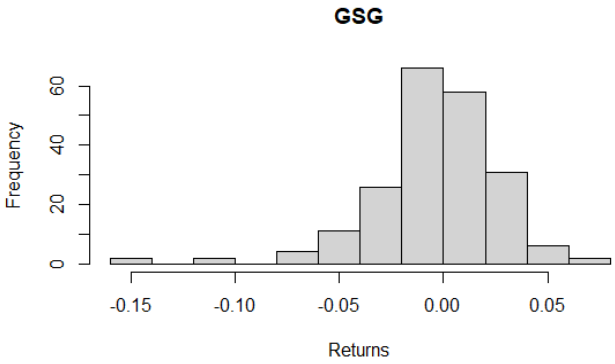


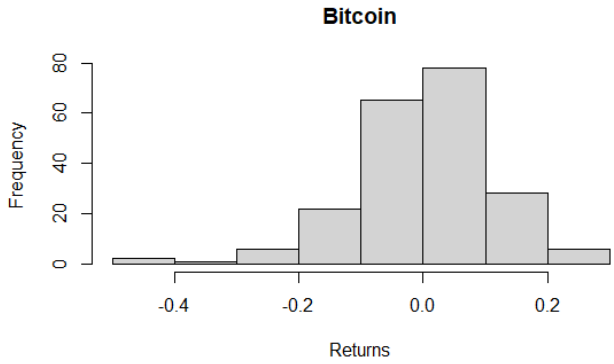
Excluding 2017 because of the **lack of ETH data** retrieved from Refinitiv (this issue is addressed with greater detail in the Portfolio Construction and Performance section), this section will focus on the **data analysis** that was performed on the assets of the different portfolios, specifically on their weekly log returns **from March 2018 to March 2022**. Focusing on log returns allows us to use their time-additive property and the fact that they are unbounded. The table below collects the main key statistics of these assets. The statistics and histograms for the Fama&French portfolios are not reported for the sake of conciseness. Moreover, some comments concerning important events happened on some subperiods are drawn. The 2-year time length of subperiods is set because input data for portfolio optimization use the same time window for forecasting.

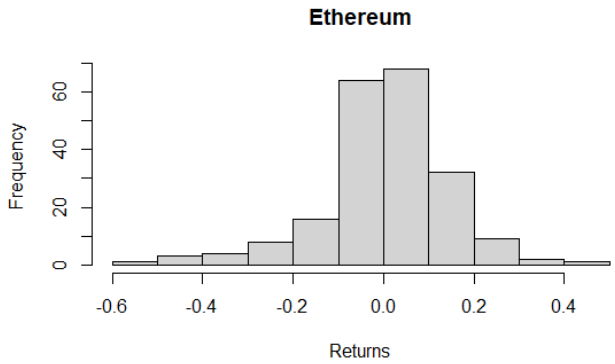
Asset	Mean	STDDEV	Median	Trimmed	Mad	Min	Max	Range	Skew	Kurtosis
SPY	0.30%	2.81%	1.00%	0.48%	1.00%	-16.00%	11.00%	27.00%	-1.33	11.33
TLT.O	0.03%	1.97%	0.00%	0.09%	1.00%	-8.00%	7.00%	15.00%	-0.37	5.07
GSG	0.10%	3.09%	0.00%	0.31%	2.00%	-15.00%	7.00%	22.00%	-1.34	7.63
BTC	0.65%	10.85%	1.00%	1.16%	6.00%	-46.00%	25.00%	71.00%	-0.83	5.22
ETH	0.52%	13.89%	1.00%	1.25%	7.00%	-53.00%	43.00%	96.00%	-0.62	4.95











Macroeconomic context in 2018-2019

The S&P GSCI ETF has been traditionally more than 50% exposed to the energy industry. The **geopolitical tensions** throughout 2018 had not particularly favored oil prices. During the fourth quarter of 2018, the recovery of oil prices following the 2014-16 crash, was halted. **Sanctions** were imposed on Iran, the third largest OPEC producer in May 2018, which was later followed by the abandonment of supply restriction agreement from Russia and OPEC producers. **Saudi Arabia** started increasing supply, while momentum trading and a shift towards gas futures was observed towards the end of the year. A raging **US-China trade war** in combination with rate hikes and geopolitical tensions also culminated in a downward trajectory of equity, especially tech stocks, towards the end of 2018.

The table reports the same **key statistics** for the subperiod **2018-2019**.

Asset	Mean	STDDEV	Median	Trimmed	Mad	Min	Max	Range	Skew	Kurtosis
SPY	0.19%	2.35%	1.00%	0.43%	1.00%	-12.00%	5.00%	17.00%	-1.90	9.99
TLT.O	0.23%	1.79%	0.00%	0.25%	1.00%	-7.00%	5.00%	12.00%	-0.51	5.33
GSG	-0.16%	2.41%	0.00%	0.00%	1.00%	-10.00%	5.00%	15.00%	-0.92	5.05
BTC	-0.11%	10.53%	0.00%	0.12%	5.00%	-41.00%	23.00%	64.00%	-0.57	4.47
ETH	-1.34%	13.97%	1.00%	-0.69%	6.00%	-42.00%	43.00%	85.00%	-0.31	4.26

Macroeconomic context in 2019-2020

In 2019, the **stock market rallied**, gaining over 28%. This was a combination of **looser monetary policy**, with the Fed lowering rates between 1.5% and 1.75% and promising to keep them stable throughout 2020. A lower starting point in the beginning of 2019 combined with a strong performance in tech stocks also drove the SPY higher, with semiconductor companies seeing one of the biggest returns.

Moreover, while sanctions were threatened, but in the end repealed from the US to Chinese imports, the Brexit negotiations seemed to settle towards the end of the year, easing slightly political tensions.

Energy prices, and oil in particular, remained relatively depressed throughout 2019. The expansion of renewables market share led to a smaller boost in demand. This fact, combined with increased US production, counteracted tariffs and supply reductions from OPEC countries.

The table reports the usual **key statistics** for the subperiod **2019-2020**.

Asset	Mean	STDDEV	Median	Trimmed	Mad	Min	Max	Range	Skew	Kurtosis
SPY	0.31%	3.35%	1.00%	0.48%	1.00%	-16.00%	11.00%	27.00%	-1.29	10.33
TLT.O	0.13%	2.37%	0.00%	0.19%	1.00%	-8.00%	7.00%	15.00%	-0.36	4.41
GSG	-0.11%	3.62%	0.00%	0.19%	2.00%	-15.00%	7.00%	22.00%	-1.47	7.07
BTC	2.49%	10.00%	1.00%	2.74%	5.00%	-46.00%	25.00%	71.00%	-0.93	7.39
ETH	2.18%	12.35%	2.00%	2.67%	5.00%	-47.00%	36.00%	83.00%	-0.65	5.63

Macroeconomic context in 2020-2021

In the beginning of 2020, the demand shock arising from the **COVID-19 pandemic** was exacerbated from Russia and Saudi Arabia's oil price war, resulting in fall in prices that, combined with lack of storage facilities, even pushed May 2020 WTI futures to around -$37 a barrel in April. This series of events between 2018-2020 resulted in an average negative weekly return for the GSCI ETF of -16%.

Returning to stocks, despite a 34% fall of the S&P 500 in spring of 2020, the index made a gain of around 14% that year, as Congress passed a $2.2 trillion stimulus package and the Fed kept steady their quantitative easing measures. The **Nasdaq** was pushed to an **all-time high** in June, as tech stocks were favored from lockdown measures, remote working and learning.

This was also the year of the cryptos, with Bitcoin making a return of more than 300% and Ethereum of more than 450% in 2020. While new incoming retail investors entered the crypto trading picture, 2020 was also the year in which a big shift was noticed from institutional investors and corporations in embracing cryptocurrencies.

Fears of currency debasement and crippling **inflation** from trillions of dollars of stimulus in combination with cryptocurrencies' scarcity and promising decentralized finance potential spurred analysts into considering it a safe-haven asset.

Asset	Mean	STDDEV	Median	Trimmed	Mad	Min	Max	Range	Skew	Kurtosis
SPY	0.41%	3.21%	1.00%	0.52%	1.00%	-16.00%	11.00%	27.00%	-1.09	10.59
TLT.O	-0.16%	2.13%	0.00%	-0.11%	1.00%	-8.00%	7.00%	15.00%	-0.21	4.81
GSG	0.36%	3.64%	1.00%	0.67%	2.00%	-15.00%	7.00%	22.00%	-1.51	7.36
BTC	1.41%	11.15%	1.50%	2.14%	5.50%	-46.00%	25.00%	71.00%	-1.09	6.00
ETH	2.38%	13.62%	3.00%	2.98%	7.50%	-53.00%	36.00%	89.00%	-0.98	6.22

The **all-sample correlation** may be quite misleading. As a matter if fact, by looking at the first table, there seems to be a slightly negative correlation between Bitcoin and the S&P500. On the other hand, Ethereum shows a slightly positive correlation with equity during the same time span. However, if we look only at the last two years, the correlation between Bitcoin and the S&P500 changed sign, turning into positive territory.

2018-2022 Correlation matrix	SPY	TLT	GSG	Bitcoin	Ethereum
SPY	1.0000	-0.2598	0.5293	-0.0614	0.2534
TLT	-0.2598	1.0000	-0.3093	-0.0249	-0.0292
GSG	0.5293	-0.3093	1.0000	-0.0657	0.2397
Bitcoin	-0.0614	-0.0249	-0.0657	1.0000	0.0706
Ethereum	0.2534	-0.0292	0.2397	0.0706	1.0000

Normality (Jarque-Bera Test)

Finally, we tested whether the distributions of returns for each asset could be approximated with a **Normal distribution**. This step, which may be seen as a pure theoretical exercise, is relevant in order to understand whether Gaussian approximations are reliable for data description purposes. To achieve this objective, we performed a **Jarque-Bera test** for each asset. The rejection of the null hypothesis of such test essentially means that there is enough evidence that data come from a distribution that is not Gaussian, hence mean and variance alone do not provide a good description of the shape of the related distribution. As seen in the table, the Jarque-Bera test is rejected for each traditional confidence level, meaning that **all assets have a non-Normal distribution**. More in detail, the deviation from normality is attributable mainly to the fourth moment (**kurtosis**) in excess of 3. All the distributions are hence **leptokurtic** or heavy-tailed distributions (i.e., they show more extreme tail events than a Normal with same mean and variance). For the sake of completeness, the **skewness** of all the assets is negative, even though the deviation from 0 (i.e., the skewness of a Gaussian distribution) is less marked.

Jarque-Bera Test	p-value	Null Hypothesis
SPY	<2.2E-16	Rejected
TLT.O	8.245E-10	Rejected
GSG	<2.2E-16	Rejected
BTC	3.109E-15	Rejected
ETH	8.246E-11	Rejected

Portfolio Construction

This section deals with the **description**, **construction and performance measurement of some portfolios** built according to standard asset allocation rules and optimization methods. For all the examined portfolios, we simulated the evolution of a $10,000 investment on the last week of February 2017. An **annual rebalancing** was implemented at the start of each subsequent period, also for strategies having weights exogenously set. This has been done to avoid the criticism that **transaction costs** of continuous rebalancing would be unaffordable and totally unrealistic. Therefore, all the strategies are buy-and-hold for one year. Because of the lack of Refinitiv ETH data before November 2017, we decided to assume **perfect forecasting** for the first two years for all the assets (i.e., weights based on the **Markowitz's optimization method** are based on the future **realized variance-covariance matrices**) and to keep as liquidity the amount allocated to ETH from March to November 2017. **Short selling was allowed**. However, since Markowitz's mean-variance optimization algorithm has the tendency to return extreme weights, whenever the **tangency portfolio** presented irrational short positions, the choice fell on the **minimum variance portfolio**. From a theoretical standpoint, this is suboptimal as it does not maximize the Sharpe ratio. Nonetheless, the tangency portfolio maximizes the Sharpe ratio only if the expected returns and variance-covariance matrix used as inputs are effectively realized, which is challenging in reality but effectively realized in the only two years in which we assumed perfect forecasting. This fact allowed us also to check the performance when all the assumption of the Markowitz's model were satisfied. Different comparisons in terms of portfolio value and risk-adjusted indicators will be carried out between basic and crypto portfolios.

60/40 Basic Portfolio

Classic portfolio where we invest only in two assets: **stocks** (SPY) **and bonds** (TLT.O) in a 60/40 ratio. During the year, the proportion inevitably changes as the performance of the two assets is never exactly the same. Therefore, to maintain the desired ratio during the 5-year time span, every year the portfolio is rebalanced so that the target **60/40 ratio is preserved at the rebalancing dates**. Since we already know the desired weights of the two assets, there is no need for an optimization method for this portfolio. However, the resulting portfolio is much more correlated with the equity component than with the bond one. As far as performance is concerned, the portfolio **grew to $15,500** within our 5-year time span (9.2% yearly on average), mainly thanks to the noticeable growth in stock valuations in recent years, especially with regards to the technology sector.

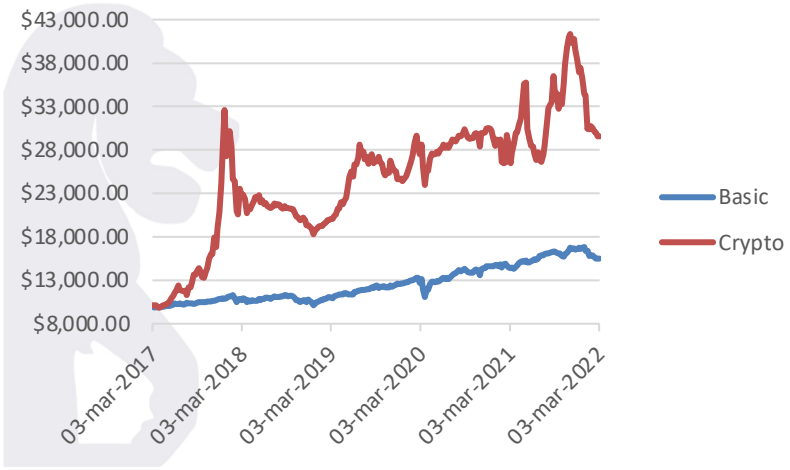
60/40 Crypto Portfolio

The portfolio is composed by the previous **60/40 portfolio** with the **addition of two cryptocurrencies**: **Bitcoin** (BTC) and **Ethereum** (ETH). The weights are not fixed (as they were in our previous portfolio), so we used an optimization methodology to determine them. We opted for the **Markowitz optimization model**, that allows us to find the **efficient frontier**. After its estimation, we found the **tangency portfolio** (which corresponds to the tangency point between the efficient frontier and the line that passes through the risk-free rate) and the appropriate annual weights for all the assets. It is important to mention that for the first three years the weights given to the cryptocurrencies were very high (more than 20% of the total portfolio value). This allocation resulted in a double effect: a great contribution to returns and higher volatility.

When comparing these two portfolios, the difference in performance is evident: cryptocurrencies have experienced an unprecedented growth in the past several years, leading to the 60/40 crypto portfolio being worth almost **$30,000 at the beginning of 2022** (with a stunning average yearly growth of 24.6%) compared to the $15,500 of the basic 60/40 portfolio.

Basic	SPY	TLT.O
2017	60%	40%
2018	60%	40%
2019	60%	40%
2020	60%	40%
2021	60%	40%

Crypto	60/40	BTC	ETH
2017	77.32%	11.86%	10.82%
2018	77.32%	11.86%	10.82%
2019	77.32%	11.86%	10.82%
2020	100%	3.51%	-3.56%
2021	44.36%	34.30%	21.33%



Risk Parity Basic Portfolio

Risk Parity is an investment strategy that focuses on the allocation of risk across the portfolio where there is not a fixed proportion of different investment classes (such as the 60/40 portfolio). Risk parity means that the weights of the different assets are optimized so that **each asset contributes equally to the total risk** (volatility) of the portfolio.

The combination of this methodology with the attempt to choose non-correlated asset classes has huge benefits with respect to the risk-hedging of a stock market downturn. In our case, we first constructed a basic risk parity portfolio with only SPY and TLT.O. In this case, the exposure to equity is less than the 60% allocation of our previous portfolios. Its reduction determined a higher exposure to the bond market, which in turn contributed to the reduction of the portfolio's total risk and volatility. Compared to its 60/40 counterpart, the **risk parity portfolio performed slightly worse** ending its 5-year span at $14.500 (with an average yearly growth of 7.7%). These results are reasonable since the 2017-2022 interval has witnessed a very bullish stock market, which rewarded portfolios with a higher exposure to that asset class.

Risk Parity Crypto Portfolio

In this portfolio we added BTC and ETH to the 'risk parity' method. The **allocation in cryptocurrencies is very low** (between 3% and 9%) since a reduced exposure still meets a substantial level of risk contribution. **The risk parity crypto portfolio outperformed its basic counterpart**: its final value is $33,000 (with a remarkable average yearly growth of 27%). This result is not surprising: as was mentioned before, the crypto market has experienced an extremely fast growth. Hence, despite the investment of a small fraction of the initial capital in this asset class, the returns were enormous. Asset allocation rules that **control for the risk contribution** of the crypto assets seem to bring advantages to the portfolio, also in terms of risk-adjusted performance indicators (see below). This suggests that strategies which allocate a small arbitrary portion of cryptocurrencies may improve the results of the portfolio with a **pre-determined and acceptable risk**, bearing a bit of additional volatility but limiting the nominal losses due to crypto assets.

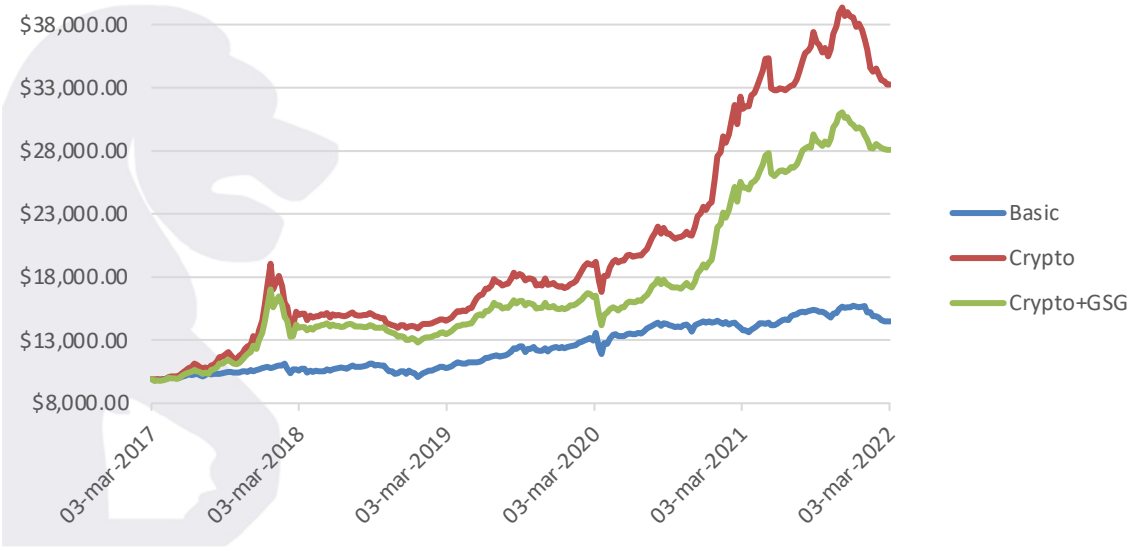
Risk Parity Crypto + GSG Portfolio

In addition to the aforementioned risk parity strategies, we tried to add a **commodity index** (GSG) to the mix. As previously mentioned, the aim of the risk parity strategy is to build a portfolio that is not as susceptible to market downturns by investing in asset classes that are not strongly positively correlated. Thus, we believed that commodities could be a coherent addition to the calculations. The commodity market is well known for its counter-cyclicality (i.e., when the security market is bullish, the commodity one is bearish and vice versa). Looking at the performance, **the value of the portfolio** at the end of the 5-year period **is $28,000** (with an average yearly growth of 23%), slightly lower than the one without GSG.

Basic	SPY	TLT.O
2017	51.60%	48.40%
2018	53.63%	46.37%
2019	40.56%	59.44%
2020	42.83%	57.17%
2021	40.69%	59.31%

Crypto	SPY	TLT.O	BTC	ETH
2017	29.40%	62.17%	4.66%	3.77%
2018	29.40%	62.17%	4.66%	3.77%
2019	29.40%	62.17%	4.66%	3.77%
2020	35.96%	53.41%	5.80%	4.82%
2021	29.22%	54.59%	8.89%	7.30%

Crypto + GSG	SPY	TLT.O	GSG	BTC	ETH
2017	20.50%	52.19%	20.42%	3.57%	3.32%
2018	20.50%	52.19%	20.42%	3.57%	3.32%
2019	20.50%	52.19%	20.42%	3.57%	3.32%
2020	22.91%	46.88%	21.90%	4.23%	4.08%
2021	19.17%	48.63%	19.61%	6.59%	6.00%



Multi Asset Basic Portfolio

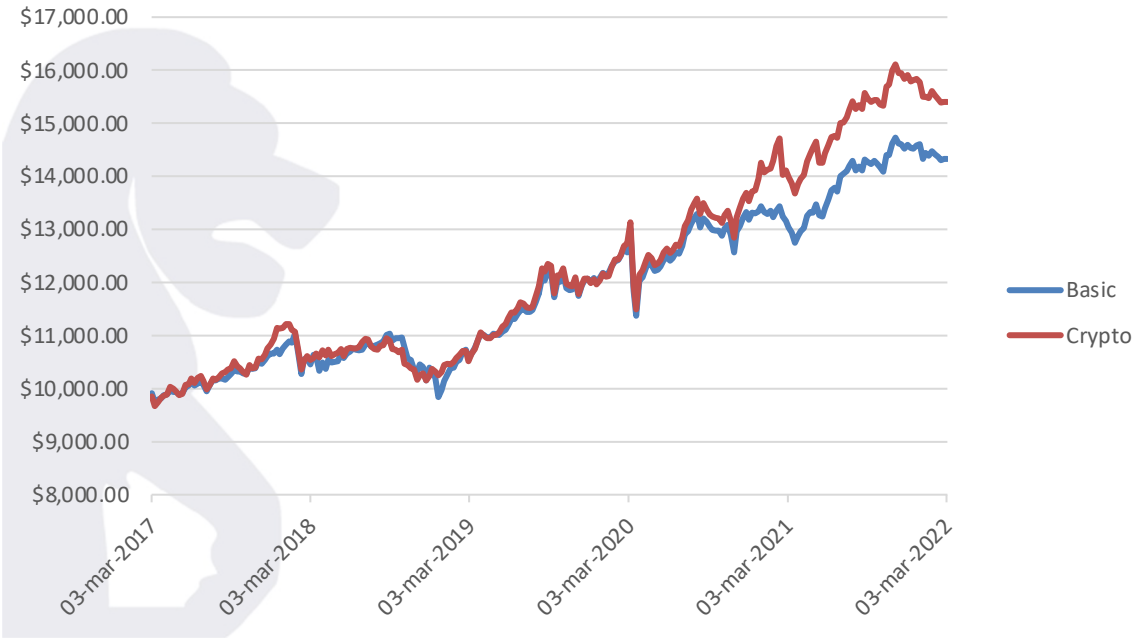
This is portfolio is made of three assets: the ETF replicating the S&P500 **stock** index (SPY), a **bond** exposure (TLT.O) and the **commodity** ETF (GSG). The allocation was determined through the **Markowitz's optimization model**. From the efficient frontier we picked the weights corresponding to the **minimum variance portfolio** (i.e., the portfolio on the minimum variance frontier that has the absolute lowest variance) and allocated them to the respective asset classes. The actual allocation consisted half of the total capital to be invested in bonds, closely followed by stocks. With respect to commodities, they remained in the 10/15% range for the whole period. This is by far the safest portfolio. Indeed, it is well diversified and made up for two thirds by bonds and commodities (not very volatile assets, at least historically). This is also confirmed by the returns: the portfolio had the **worst performance** (**except for the following Factor Crypto Portfolio**), as it ended at a value of just over **$14,000** (with an average yearly growth slightly below 7%). As there is 'no such thing as a free lunch', this was to be expected. In other words, there is always a trade-off between risk and return.

Multi Asset Crypto Portfolio

BTC and ETH were added to the multi-asset portfolio along with re-optimization and relative selection of the minimum variance portfolio. The amount invested in bonds has increased to about 70%, while some of the investment in equity switched to cryptocurrencies. Again, since we picked the least volatile portfolio out of all the ones on the efficient frontier, the **amount invested in highly risky assets** (i.e., cryptos) **is practically negligible** (almost always <1% of the portfolio). This is evident in our results: the **difference in performance with the multi-asset basic portfolio is minimal** (this portfolio ended at a value of **$15,500**, with an average yearly growth of 9.2%). We can conclude that our addition of cryptocurrencies increased the returns of our portfolio as expected, but as the amount of capital invested in them was so low (we chose to use the minimum variance portfolio), it did not make a significant difference.

Basic	SPY	TLT.O	GSG
2017	38.40%	47.12%	14.48%
2018	49.56%	39.20%	11.24%
2019	26.71%	62.23%	11.05%
2020	27.84%	55.46%	16.71%
2021	19.12%	60.34%	20.53

Crypto	SPY	TLT.O	GSG	BTC	ETH
2017	17.37%	68.54%	13.14%	0.37%	0.58%
2018	17.37%	68.54%	13.14%	0.37%	0.58%
2019	17.37%	68.54%	13.14%	0.37%	0.58%
2020	26.63%	54.74%	18.02%	-0.64%	1.25%
2021	17.79%	59.95%	20.09%	0.63%	1.54%



Multi Factor Basic Portfolio

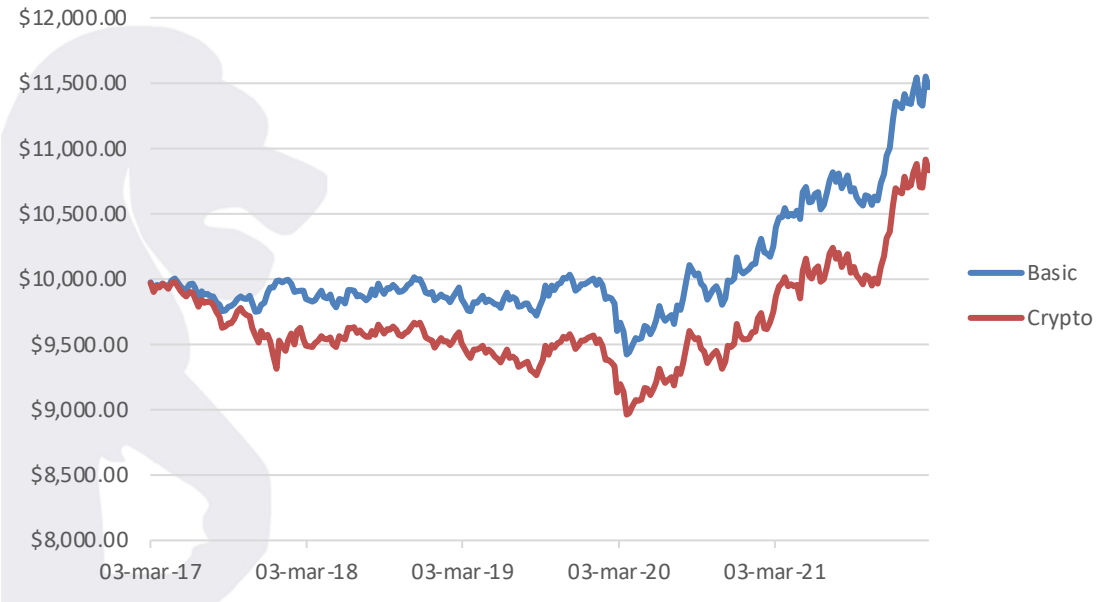
The portfolio is based on the **Fama&French five-factor model**, an asset pricing model that expands on the CAPM by adding more risk factors. These risk factors had been considered by the authors to provide a more thorough tool to **non-diversifiable risk exposure**, and not being limited to the market risk. However, their factor identification has led not only to a more granular description of the risks underlying a security but also to different asset allocation strategies being maximally exposed to a determined factor. After downloading the data from French's data library, we **manually converted daily data into weekly data** to align the data structure to the other ones and perform the **Markowitz's optimization**. We opted for including all the factors in our optimization, even though the results pointed towards short positions which are quite substantial.

Basic	MKT-RF	SML	HML	RMW	CMA
2017	8.39%	16.46%	-0.87%	39.57%	36.45%
2018	9.05%	11.21%	-2.72%	45.00%	37.46%
2019	10.22%	14.11%	-3.87%	39.81%	39.73%
2020	8.25%	16.98%	-13.93%	32.24%	56.45%
2021	3.33%%	-21.87%	-21.87%	42.71%	50.39%

Multi Factor Crypto Portfolio

The same process has been done including the cryptos in the pool of available assets. As the table containing the weights testifies, **the contribution of crypto assets is limited**, practically irrelevant. Also, the results of **the two portfolios are very poor in terms of returns**.

Crypto	MKT-RF	SML	HML	RMW	CMA	BTC	ETH
2017	10.04%	16.72%	-1.43%	35.14%	39.97%	-0.37%	-0.07%
2018	10.04%	16.72%	-1.43%	35.14%	39.97%	-0.37%	-0.07%
2019	10.04%	16.72%	-1.43%	35.14%	39.97%	-0.37%	-0.07%
2020	8.25%	17.14%	-14.28%	33.00%	56.10%	0.33%	-0.20%
2021	3.33%%	26.21%	-22.43%	43.02%	50.35%	0.63%	-0.66%



Performace Evaluation

For our analysis three main ratios have been calculated for all the portfolios: **Sharpe Ratio**, **Sortino Ratio** and **Omega Ratio**. All three indicators measure **risk-adjusted performance** in different ways. The calculations were carried out on **log returns** and for an annual sample consisting of weekly returns to have a larger sample starting from March 2017. The sample is then **rolled over by one quarter** until it meets March 2022.

The well-known **Sharpe Ratio** consists of the difference between expected returns and risk-free rate for the same time frame divided by the standard deviation of the returns. Thus, it shall measure the **performance in excess of the risk-free rate** and adjusted for the volatility. The higher the Sharpe ratio, the better.

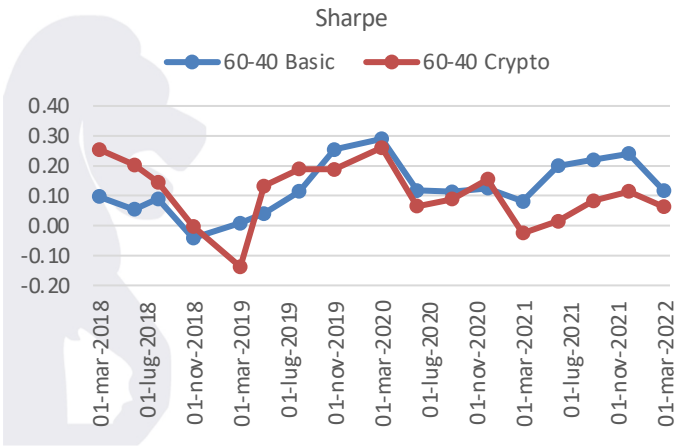
The **Sortino Ratio** is a modified version of the Sharpe ratio in which the denominator corresponds to a "**downside deviation**", which is practically a standard deviation calculated on those returns that were negative as we set a benchmark of 0% rather than the risk-free rate. It should capture the deviation of those negative instances that could represent negative volatility. Again, the higher the ratio, the better.

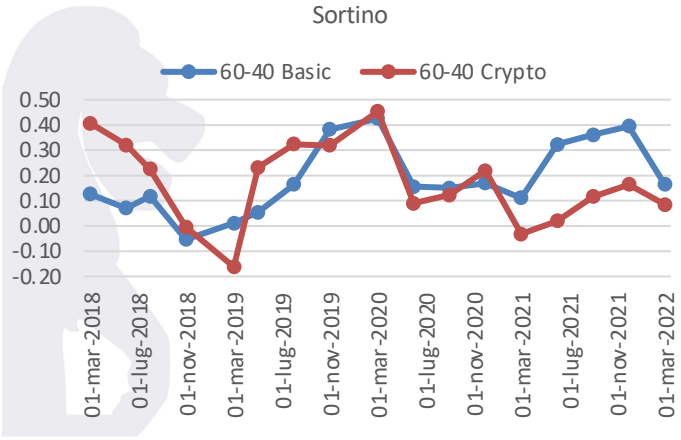
Finally, the **Omega Ratio** is slightly different from its two aforementioned companions. It consists of a ratio between the sum of those returns that **outperformed the benchmark** and the sum of those returns that underperformed it. It should represent a proportion of "wins to losses". Once again, the higher the better.

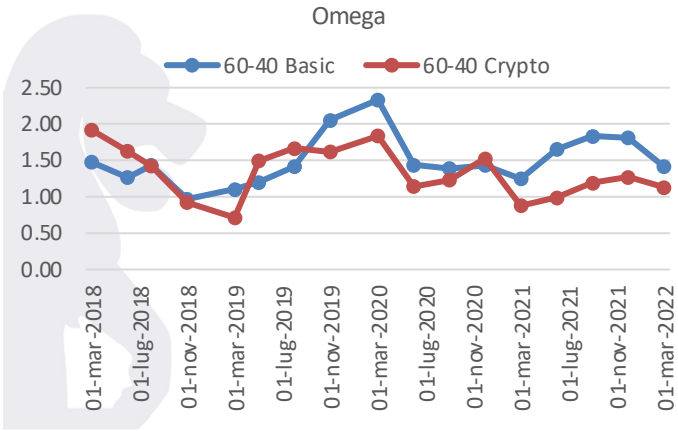
60/40 Portfolios

The first thing that we should point out is that the Sharpe and Sortino ratios are fairly similar between Basic and Crypto because of a presumable **absence of tail events**.

With respect to a cross-portfolio comparison, **cryptocurrencies do not seem to bring any clear additional value to the portfolio**. Crypto portfolios seem to behave better in the first part of the sample, while risk-adjusted indictors are worse in the last part of the sample. Moreover, from an Omega ratio perspective, it seems that the cumulative gains as a fraction of losses decrease.

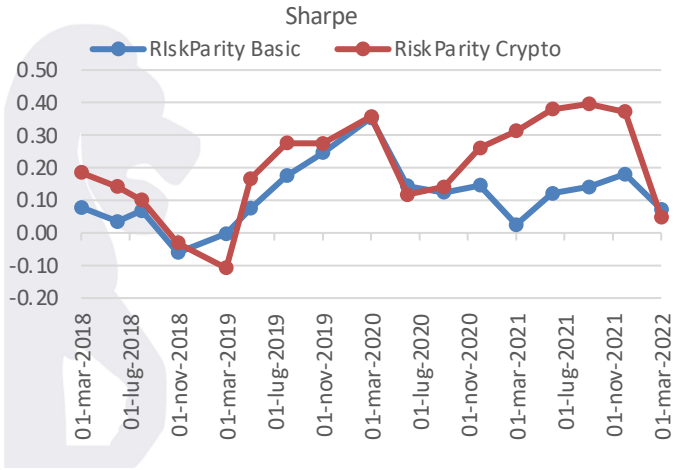


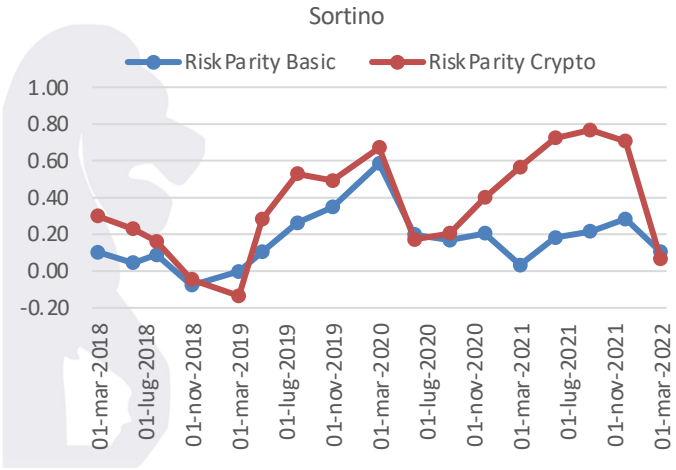


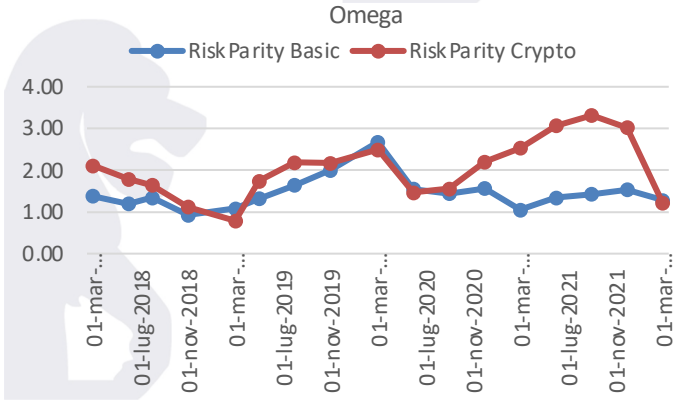


Risk Parity Portfolios

A **completely different picture** arises from the **Risk Parity ratios**. The cryptocurrency portfolio brings **better risk adjusted performance on every front**. This is probably due to the construction of the portfolio itself. All the asset classes are optimized based on their contribution to risk, which is far easier to estimate than expected returns, and as a consequence **all the benefits of crypto assets' higher returns are extracted with reasonable risk exposure**. Moreover, the difference between Sortino and Sharpe ratio is quite remarkable. The related graphs are reported in the next page. This results in being by far the best asset allocation we analyzed, also because it directly **controls for the risk exposure** in the allocation process.



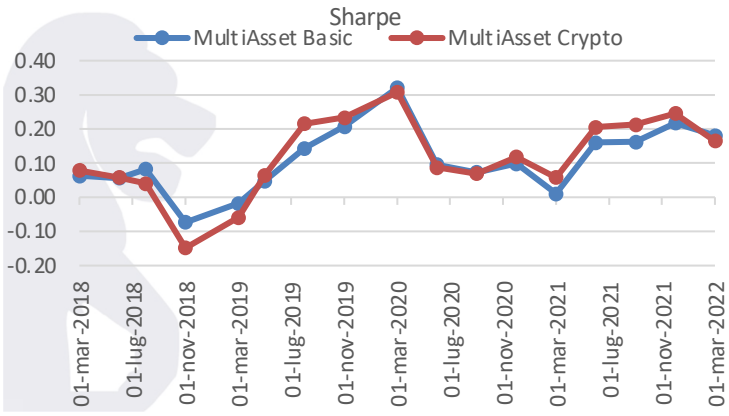


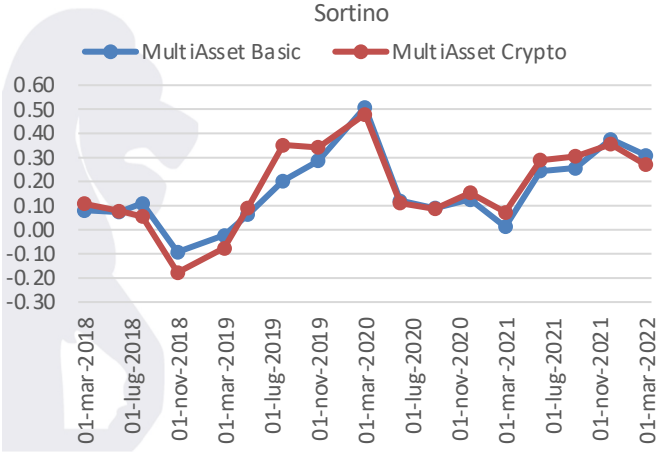


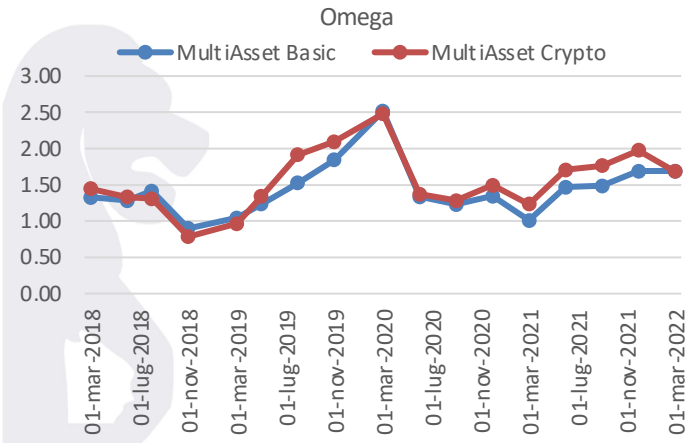
Multi Asset Portfolios

A **slight difference** arises in the Sortino ratio for multi-asset crypto due to **higher volatility of the portfolio in negative scenarios**.

With the great exception of the data referring to November 2018, the rest of the dataset seems to suggest an equal if not better Sharpe ratio achieved by the crypto portfolio. The **general similarity** is due to the incredibly small amount of cryptos in the portfolios, which however seems to have contributed to better indicators due to their bull market. In terms of Omega ratio, crypto also beats its basic counterpart, even if **the difference is almost negligible**.

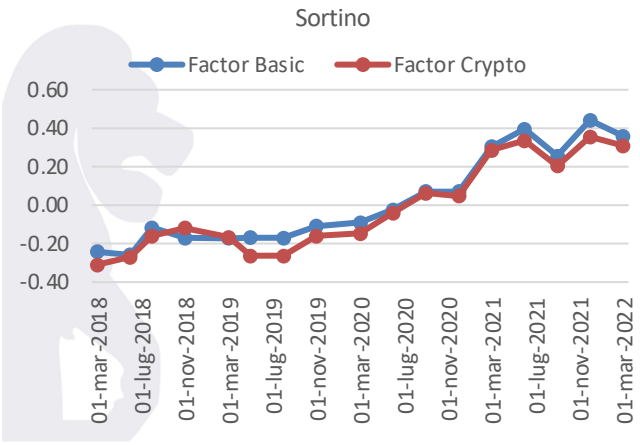


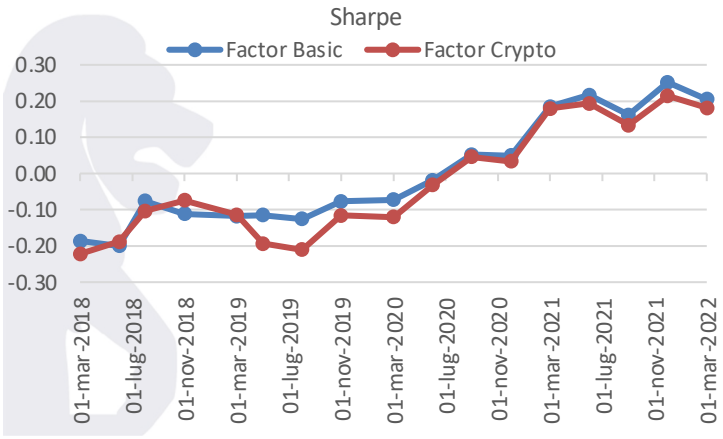


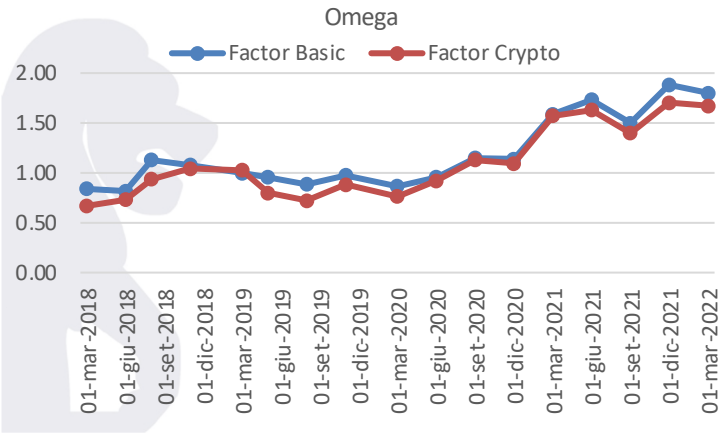


Multi Factor Portfolios

Finally, with respect to multi-factor portfolios, the addition of cryptocurrencies to the portfolio **did not generate any additional risk-adjusted value**, as it can be easily noticed by looking the almost null difference between the indicators. This is also due to the relative **poorer performance** of the factor crypto portfolio against its basic counterpart.





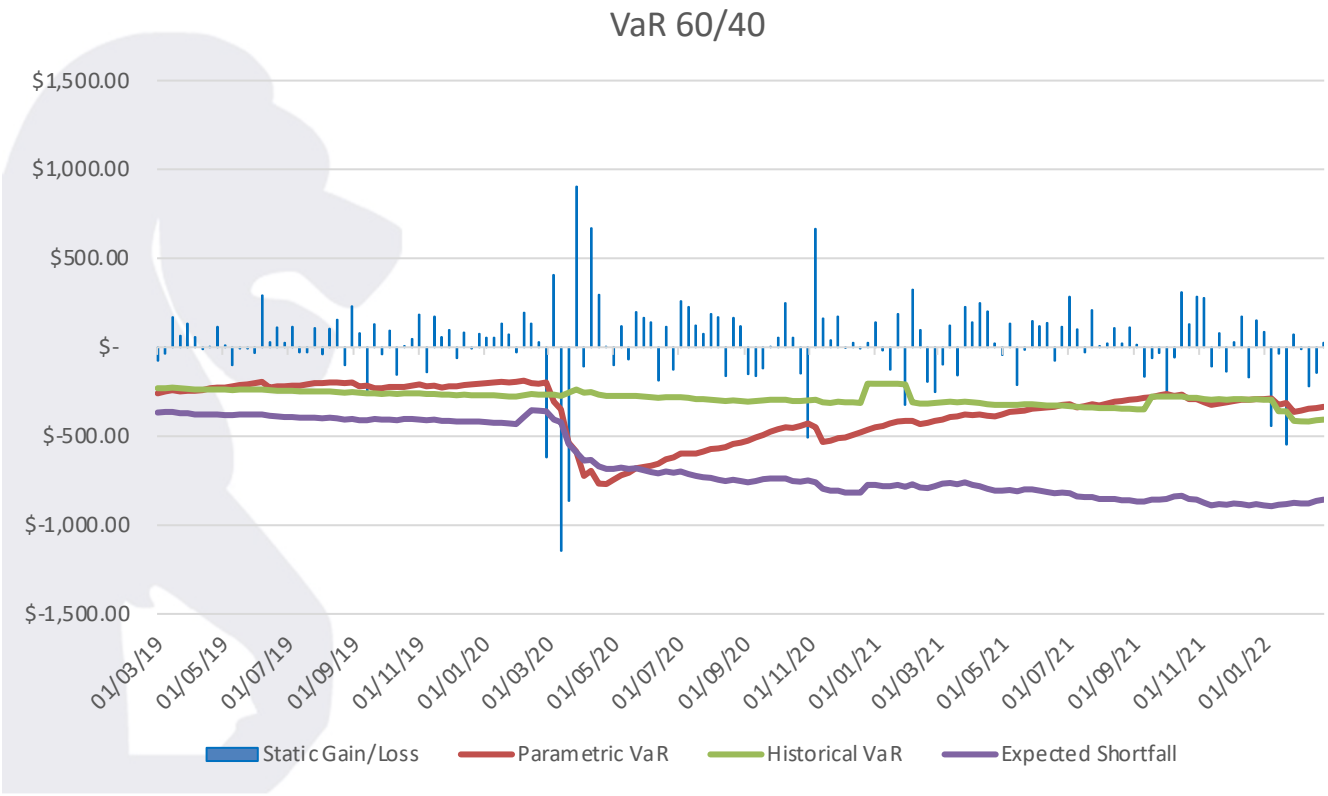


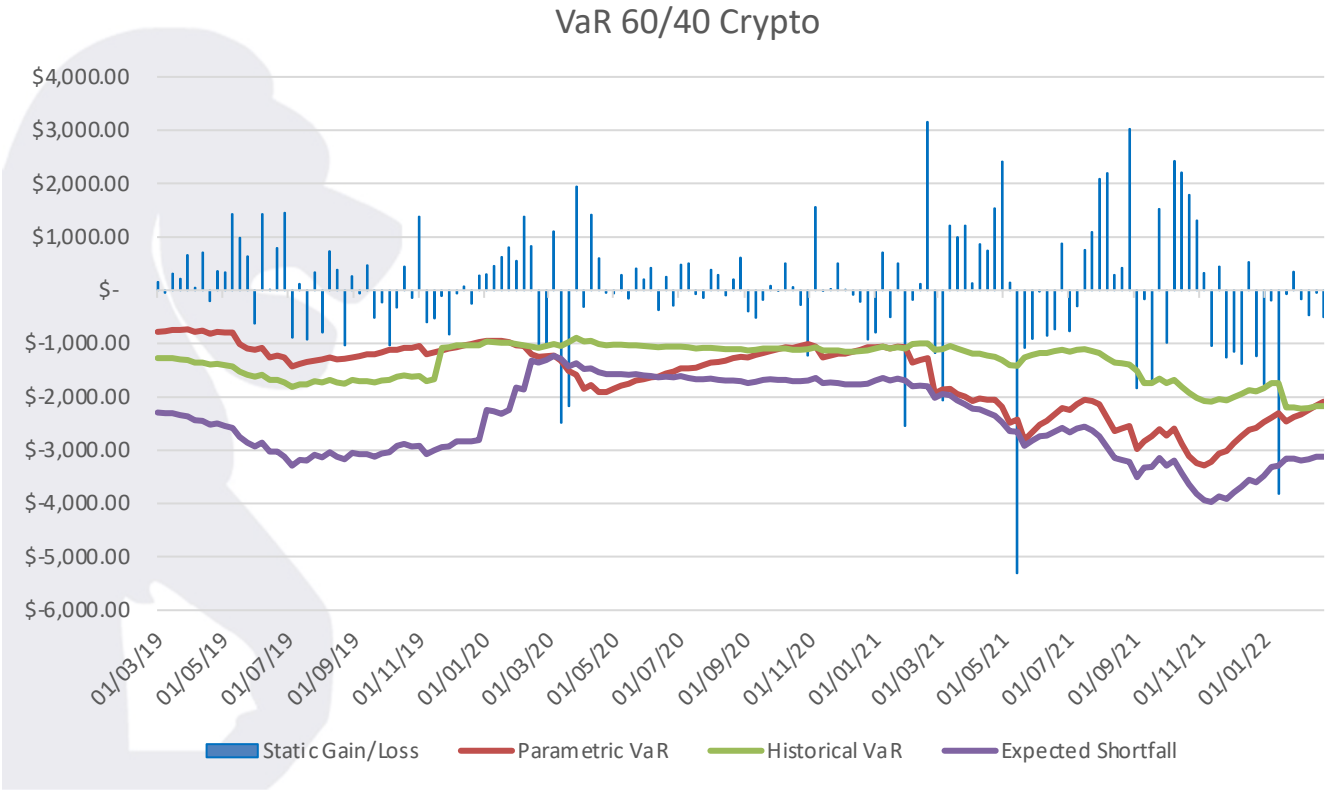
VaR and Backtesting

Finally, we performed a **VaR model** and **backtesting analysis**. In particular, for each portfolio we computed the time series of its Value at Risk in two different ways: (i) using the **parametric approach** (i.e., assuming the returns' distribution to be **Normal**); and (ii) using the **historical approach** (i.e., extracting the **corresponding quantile from the historical distribution**, implicitly assuming **stationarity** over time). Furthermore, also the **expected shortfall** time series, also known as conditional Value at Risk, time series has been calculated starting from the historical VaR. It represents the expected loss over time when the VaR threshold is violated. We chose a standard **95% confidence interval** and a **2-year time horizon** (104 weeks) as input for forecasting. This was done in order to allow a better definition of the tails of the empirical historical distribution, even if it may have resulted in a less reactive VaR. As far as the parametric VaR is concerned, we assumed a prudential expected return equal to zero and we estimated the **volatility** on a **rolling basis through the EWMA method**, namely by giving higher weights to more recent observations. This results in a more smoothed volatility, avoiding the problem which scholars know as "**echo effect**". The **lambda** used for the smoothing procedure was set to **0.94**. In order to assess the validity of our models, we tested them with means of the **Kupiec and Christoffersen tests** (also jointly). The former one compares the empirical violation frequency with the theoretical value, whereas the latter evaluates the time distribution of such violations. A good VaR model should pass both tests. The difference in the VaR absolute values is not an indicator, since it depends on the different growth path that different portfolios have had.

60/40 Portfolios

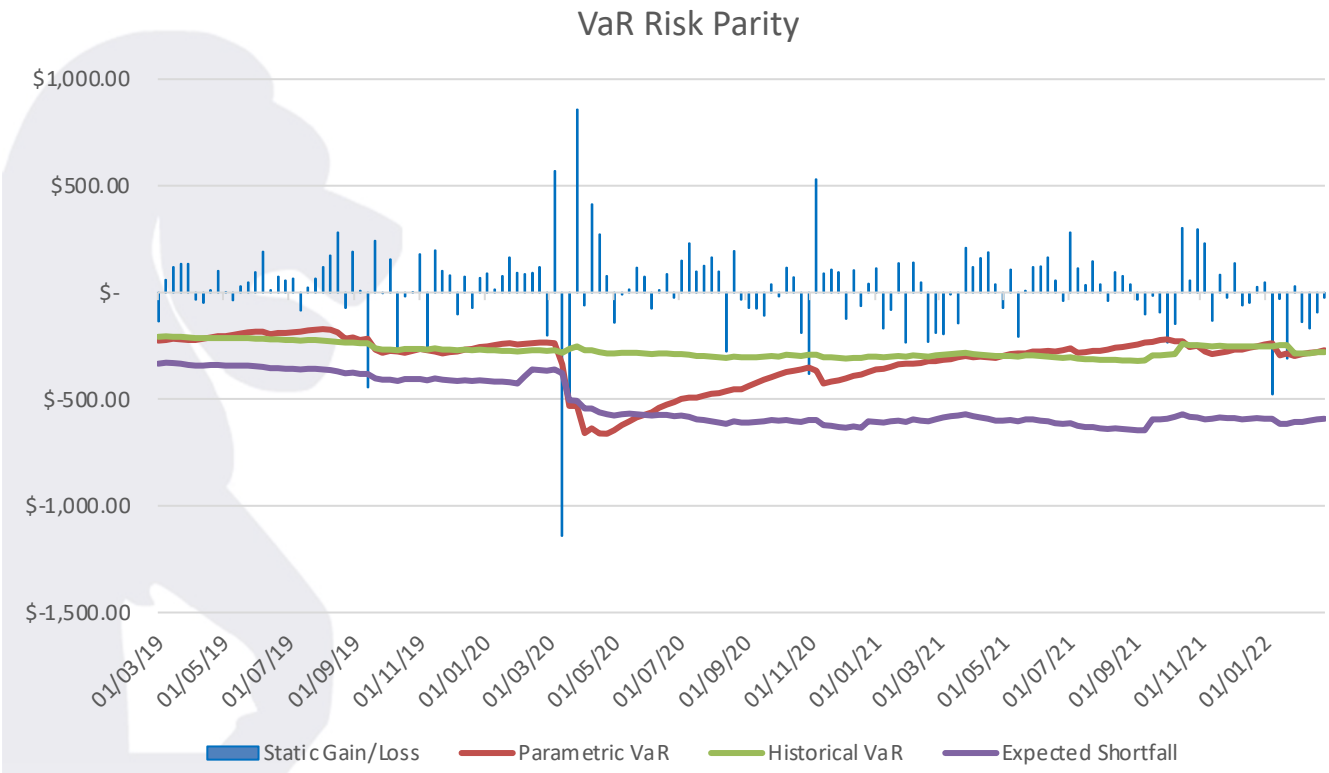
The 60/40 portfolio shows **smaller mean and volatility** with respect to its crypto counterparty. However, the kurtosis of the crypto portfolio is closer to 3 than that of the basic 60/40. We saw before that the comparison through risk-adjusted ratios **does not clearly identify an improvement in the performance**. When it comes to VaR models, both the models estimated using our input parameters perform well. The **Kupiec and Christoffersen tests are passed** in both the two cases. It is worth noting that, even though there is not enough statistical evidence that the empirical frequency differs from the theoretical value, the maximum deviation occurs when performing the historical VaR for the crypto portfolio (7.01%). **The number of violations is in line with the theoretical one for the basic version, but they are more clustered during the COVID-19 outbreak**.

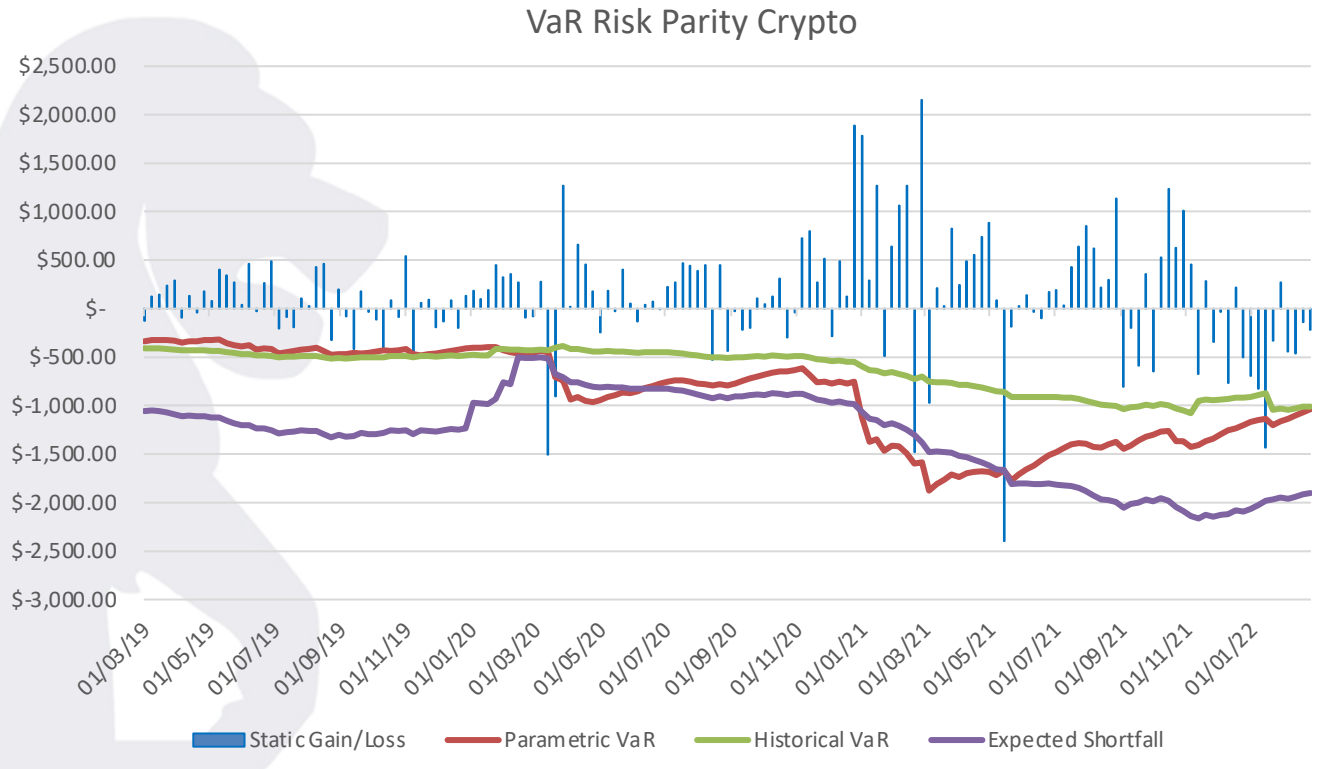


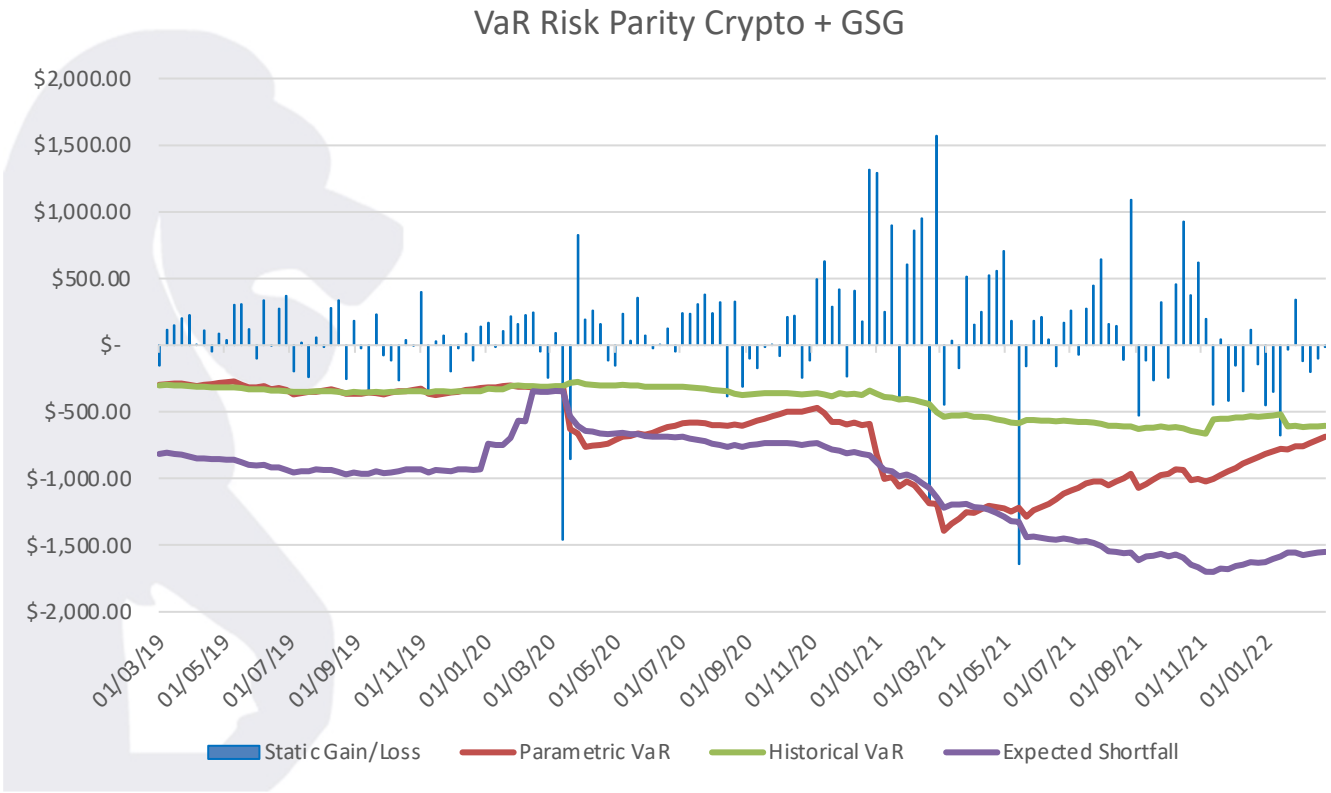


Risk Parity Portfolios

Looking at the two risk parity portfolios, **the model still behaves well**. The **Christoffersen test could not be performed** for the parametric VaR of the basic version because no observations fell into the bucket of two subsequent violations. **The number of violation is a bit lower than 5%, although compatible with the theoretical one**. The number of violations ranges from 5 to 7 out of 157 VaR computed. Considering also the **crypto + GSG variant**, **results do not change**. Furthermore, the expected shortfall model seems to predict in satisfactory manner the empirical drawdowns.

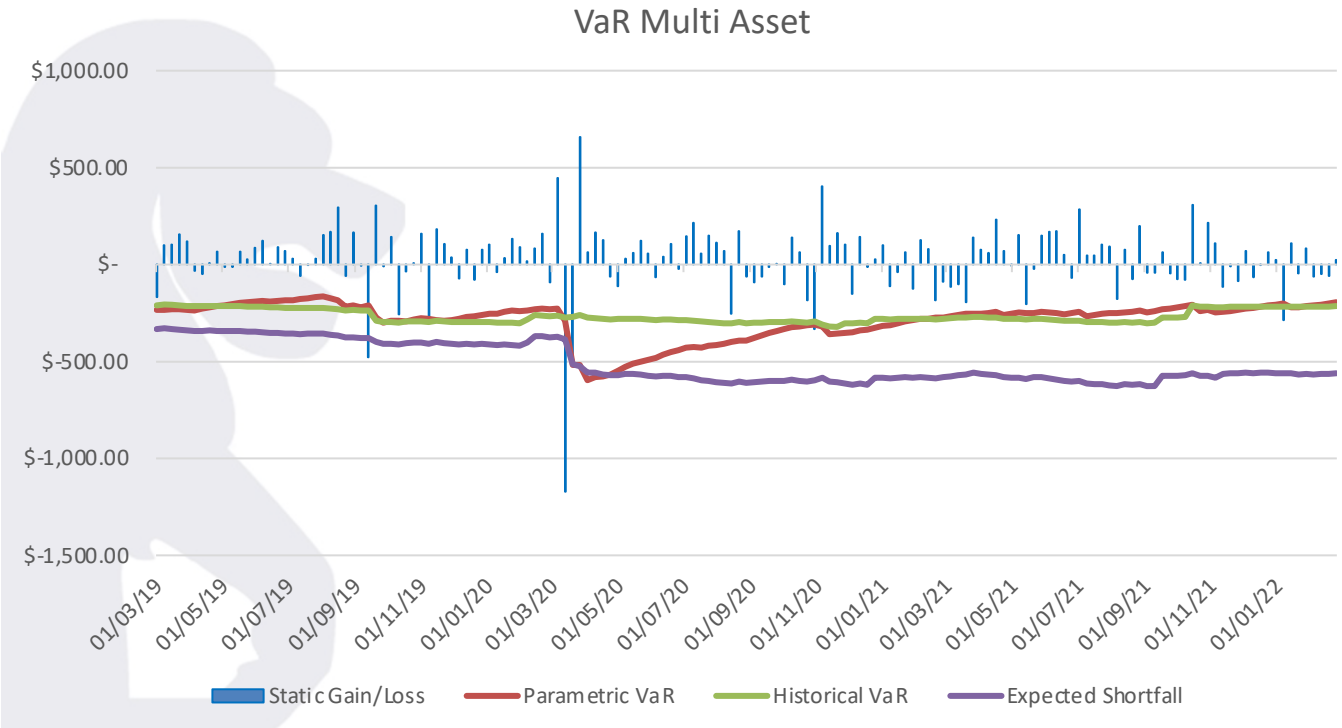


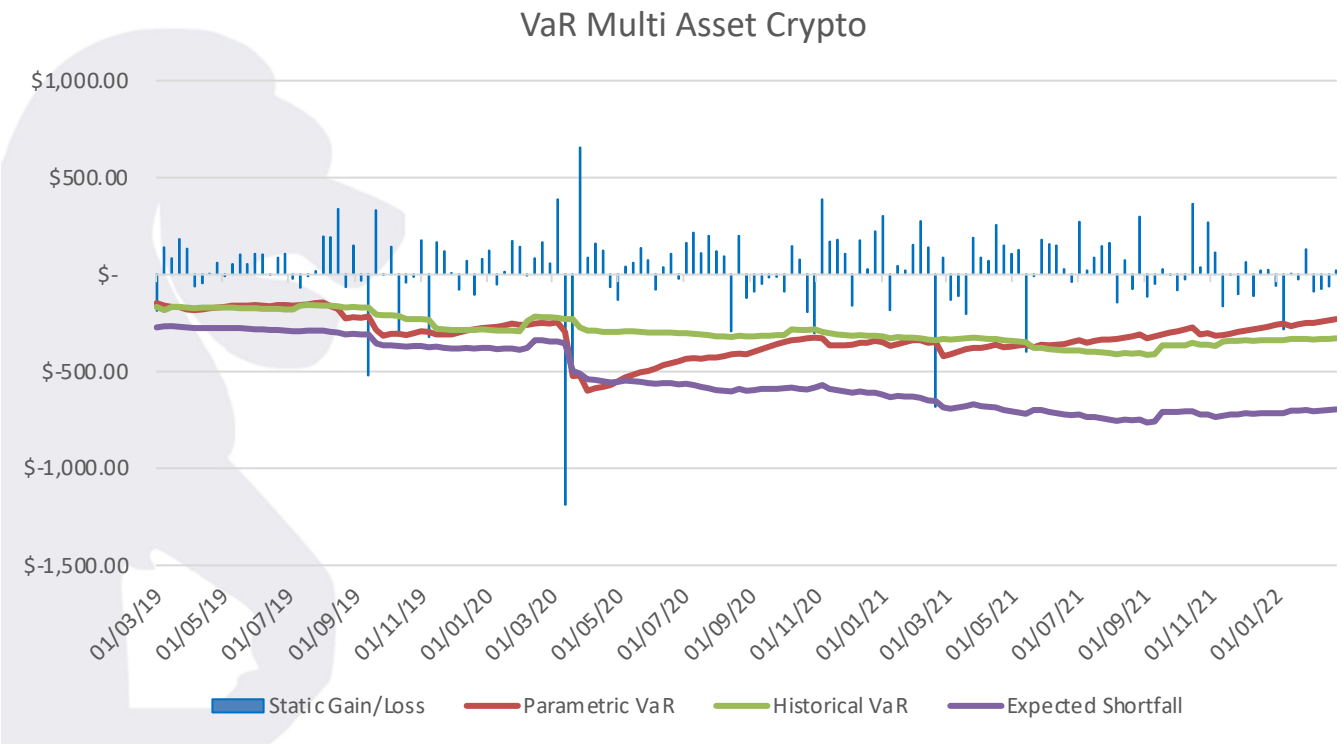




Multi Asset Portfolios

Similar conclusion may be drawn for the two multi-asset portfolios. The **Christoffersen test cannot be performed** for the parametric VaR of both portfolios due to the lack of observations in the bucket of subsequent violations. Furthermore, the absolute number of violations is higher for the crypto portfolio than its basic counterpart, but all of them are **compatible with the theoretical one** according the Kupiec test. This fact is a strong evidence that, considering the joint test, historical VaR computed using the inputs we described at the beginning of this section constitute **reliable models also when cryptocurrencies are added to portfolios**. The addition of such volatile assets does not result in a necessary change in the input parameters. **A 2-year time horizon for forecasts' estimation seems to be able to deliver satisfactory results.**





We decided **not to report the graphs for the VaR model of the two multi-factor portfolios** since they have been rejected by the joint test essentially due to the high number of violations compared to the theoretical limit, alongside they did not perform well in terms of value. This could be seen as another possible hint to the fact that **a 2-year time span for the forecasts was not a good choice for this type of portfolio**.

Conclusions

Cryptocurrencies have grown incredibly in the last few years, following the enthusiasm for the new technology, and therefore **deserve further analysis on their contribution to portfolio performances** when added in the asset allocation process. The present analysis shows that **their contribution to portfolio risk-adjusted performance is unclear or irrelevant when considering basic strategies** like the classic 60/40 or a multi-asset strategy with weights obtained through mean-variance optimization. Instead, when the **asset allocation process controls for their volatility** (i.e., **risk parity portfolios**), the results are more interesting, as they seem to be able to grant both a **higher performance in terms of nominal portfolio value and risk-adjusted performance ratios**. The economic explanation for these findings may be that cryptocurrencies are dumped during times of market stress in favor of safer asset with a longer track record of protection in times of crises erasing their diversification function in a portfolio. However, the higher expected return of cryptocurrencies may justify their presence in a portfolio when it is built considering the volatility of the assets it is comprised of since such an allocation would mitigate the potential risk of cryptocurrencies while providing exposure to their higher expected returns. As an example, lately the **correlation of cryptocurrencies with the Nasdaq index** has significantly increased showing the preference of investors for high-quality assets when there in uncertainty. Therefore, a conservative asset allocation towards cryptocurrencies would have limited the losses stemming from this part of the portfolio while keeping proving some exposure to this asset class which may deliver higher returns once some of the present uncertainty in the market (coming from inflation, monetary tightening and the Russian invasion of Ukraine) eases out. Some other possible explanations of the findings may be: (i) the **difficulty to estimate the expected values** of such newborn assets and thus the optimal weights through Markowitz's algorithm; (ii) their **extreme volatility**; or (iii) **wrong choice of the forecasting window** (2 years). In addition, it should be noted that the **lack of fundamentals** does not allow a judgement on their undervaluation or overvaluation, thus not leaving room for other criteria in determining whether to overweight or underweight such assets. However, **further research on the topic**, with particular regards to relationships between cryptocurrencies and the macroeconomic context **should allow for further conclusions**, as it would help to shed light on how to manage the strategic positioning on these financial assets for example during weaker phases of the economic cycle.