# An Investor's Guide to Crypto

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This version: June 1, 2022

**ABSTRACT**

We provide practical insights for investors seeking exposure to the growing cryptocurrency space. Today, crypto is much more than just bitcoin, which historically dominated the space but accounted for just a 21% share of total crypto trading volume in 2021. We discuss a wide variety of tokens, highlighting both their functionality and their investment properties. We critically compare popular valuation methods. We contrast buy-and-hold investing with more active styles. We only deem return data from 2017 representative, but the use of intraday data boosts statistical power. Underlying crypto performance has been notoriously volatile, but volatility-targeting methods are effective at controlling risk, and trend-following strategies have performed well. Crypto assets display a low correlation with traditional risky assets in normal times, but the correlation also rises in the left tail of these risky assets. Finally, we detail important custody and regulatory considerations for institutional investors.

Keywords: *Crypto, currency, bitcoin, ether, gold, custody, NFTs, inflation hedge, stablecoins, DeFi.*

JEL codes: C58, E42, E51, G10, G11, G12, G21, G23, G24, K24, K42, L86, O31.

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## Introduction

In 2018, it was relatively easy for asset managers to ignore the cryptocurrency space. Bitcoin had crashed, losing over 80% of its value, and the new ecosystem was littered with failed initial coin offerings. It all looked like a fad. Today, the space is harder to ignore.

As of May 2022, the capitalization of cryptocurrencies is over $1.3 trillion, approximately half the value of all U.S. notes and coins in circulation (Exhibit 1). The goal of our paper is to provide an investor's perspective on how to approach the space, given its newfound prominence.

**Exhibit 1: Asset Class Value and Money as of February 2022**

This figure shows the outstanding notional in trillions of U.S. dollars of traditional asset classes and cryptocurrencies. Data are collated from the following sources. Bonds – International Capital Market Association (ICMA), USD equivalent notional outstanding. Equity – MSCI, total free-floating market capitalization (sourced from Bloomberg). Private Markets – McKinsey annual private markets review 2021. Gold and Silver – United States Geological Survey (USGS) based on 244k and 1.7m metric tons discovered and current prices (gold at $1,898 per oz and silver at $24 per oz). Crypto – CoinMarketCap. Conventional FX – central banks as appropriate (Fed, ECB, BoJ and BoE). We convert to USD using exchange rates as at end February 2022. These data are as of 28 February 2022, apart from the crypto category which is updated to 19th May 2022.

| Asset Class | Size ($trn) |
|---|---|
| **Bonds** | **129.0** |
| *… Government* | *88.0* |
| *… Corporate* | *41.0* |
| **Equity** | ***88.0*** |
| *… Developed* | *66.0* |
| *… Emerging* | *22.0* |
| **Private Markets** | **6.5** |
| *… PE & VC* | *3.8* |
| *… Private Debt* | *0.9* |
| *… Real Estate* | *1.0* |
| *… Infrastructure* | *0.8* |
| **Gold** | **16.0** |
| **Silver** | **1.5** |

| Asset Class | Size ($trn) |
|---|---|
| **Crypto** | **1.3** |
| *… Bitcoin* | *0.6* |
| *… Ether* | *0.2* |
| **USD M2** | **22.0** |
| *… Notes & Coins* | *2.2* |
| **EUR M2** | **16.4** |
| *… Notes & Coins* | *2.1* |
| **JPY M2** | **9.6** |
| *… Notes & Coins* | *1.0* |
| **GBP M2** | **3.9** |
| *… Notes & Coins* | *0.1* |

The starting point for any investment is to understand what you are investing in. While bitcoin gets the most media attention, it represents less than half of the value in this new space of cryptoassets. Indeed, there is considerable diversity in the functionality of blockchains and price drivers of cryptocurrencies. In contrast to bitcoin, ethereum supports so-called smart contracts and features token development standards[2] that help create and deploy projects and tokens on top of their blockchain.[3] These tokens can enable specific functionality, such as payment for providing data storage or representing ownership of digital art via NFTs (non-fungible tokens). There are also tokens that are linked to decentralized exchanges as well as savings and lending protocols. There is in addition a growing market for stablecoins – tokens linked to a hard currency such as the U.S. dollar. The space is increasingly diverse.[4]

[2] For example, ERC-20 is the standard interface for fungible (interchangeable) tokens, like voting tokens, staking tokens or virtual currencies such as ether and bitcoin. ERC-721 is a standard interface for non-fungible tokens, like a deed for artwork or a song. There are many other standards such as ERC-777 and ERC-1155. See https://ethereum.org/en/developers/docs/standards/tokens/

[3] The Bitcoin and Ethereum blockchains are known as Layer 1 blockchains. There are many other Layer 1 chains such as Solana and Algorand.

[4] There are many subcategories within the cryptospace including: 1) Layer 1 coins (e.g., bitcoin, ether); 2) DeFi (UniSwap, Compound, Maker Dao, dYdX); 3) NFTs (OpenSea, LooksRare); 4) Gaming (Sky Mavis); 5) Metaverse (Decentraland,

There are many different ways for an investor to get exposure to crypto. Perhaps the most straightforward is through futures contracts or other securities such as exchange-traded funds (ETFs). Investors can also invest with a crypto-oriented venture capital (VC) fund and pay the fees associated with the VC investment. It is also possible to buy the physical coins. Further, investors can deploy collateralized stablecoins[5] to centralized protocols and earn a return for supplying liquidity – somewhat analogous to a fixed income investment.

We begin by examining the various approaches that are used to value cryptocurrencies. None of these methods, such as 'bitcoin is the new gold', is satisfactory. However, it is important for investors to be familiar with these arguments as well as their weaknesses.

Our paper attempts to navigate this complex space and we offer a number of insights that could be useful for those seeking exposure. We also detail some myths. For example, it is a fact that cryptocurrencies like bitcoin are very volatile. However, investors do not need to bear that volatility. Mixing a portfolio of cash and crypto can deliver equity-like volatility in a risk-managed portfolio. Surprisingly, our empirical results show that the cash-crypto portfolio with equity-like volatility has fewer downside tail events and much lower volatility of volatility than the S&P 500 portfolio over our short historical sample.

We then empirically examine the return characteristics of various cryptocurrencies.[6] While many of these cryptos should be theoretically independent of monetary policy and stock-market sentiment, they are not. Further, cryptocurrencies tend to move together, which limits the diversification potential. Indeed, we show that the correlations of cryptos and equity have sharply increased over recent years as many speculators have entered the market seeking 'risk on' assets.

Our paper then provides an analysis of active strategies. We analyze both volatility-scaled portfolio returns and various trend-following strategies. While the sample is relatively short in years, we are able to examine higher-frequency data, and so still have a meaningful number of data points on which to base our empirical analysis.

We also address important considerations of custody and regulation for institutional investors. If you buy a physical cryptocurrency, your ownership is defined by your private key. If you lose your private key, you lose your assets. There is no password-recovery mechanism. There are a number of companies that now specialize in custody. Finally, many investors are bound by anti-money-laundering and 'know your customer' (AML/KYC) regulations. While cryptocurrencies are traded on hundreds of both centralized and decentralized exchanges, investors need to choose trading venues that have robust AML/KYC foundations.

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Sandbox); 6) Layer 2 (Starkware, Optimism); 7) Privacy (Keep, Aztec); 8) Institutional services (Coinbase Pro, Fireblocks); 9) Financial services (Blockfi, MoonPay, Bitgo, Circle); 10) Infrastructure (Blockstream, Chainlink, Consensys); 11) Trading and exchange (FTX, Coinbase, Binance); 12) Data and analytics (Chainalysis, Dune Analytics, Messari); 13) Mining includes mining companies (TeraWulf, Hive), hardware (Bitmain, Bitfury) and lending (Genesis, NYDIG); 14) Web3 (Skynet, Helium, Protocol Labs); 15) Social networks (DeSo); 16) R&D (OpenZeppelin, Shard Labs), 17) Browser/wallets (Argent, Opera); 18) Security (Gauntlet, Forta); 19) Identity (Spruce); and 20) Cross-chain bridges (Wormhole). There are more including DAO/Governance and the Creator Economy (includes decentralized music and video).

[5] Collateralized stablecoins do not include algorithmic stablecoins. Collateralized stablecoins include fiat collateralized such as USDC and USDT and crypto over-collateralized such as DAI, RAI and FEI. In contrast, algorithmic stablecoins rely on a dynamic money supply rule to help maintain their peg. As for any under-collateralized asset, algorithmic stablecoins are risky and subject to bank runs.

[6] This analysis excludes transaction costs which we discuss later.

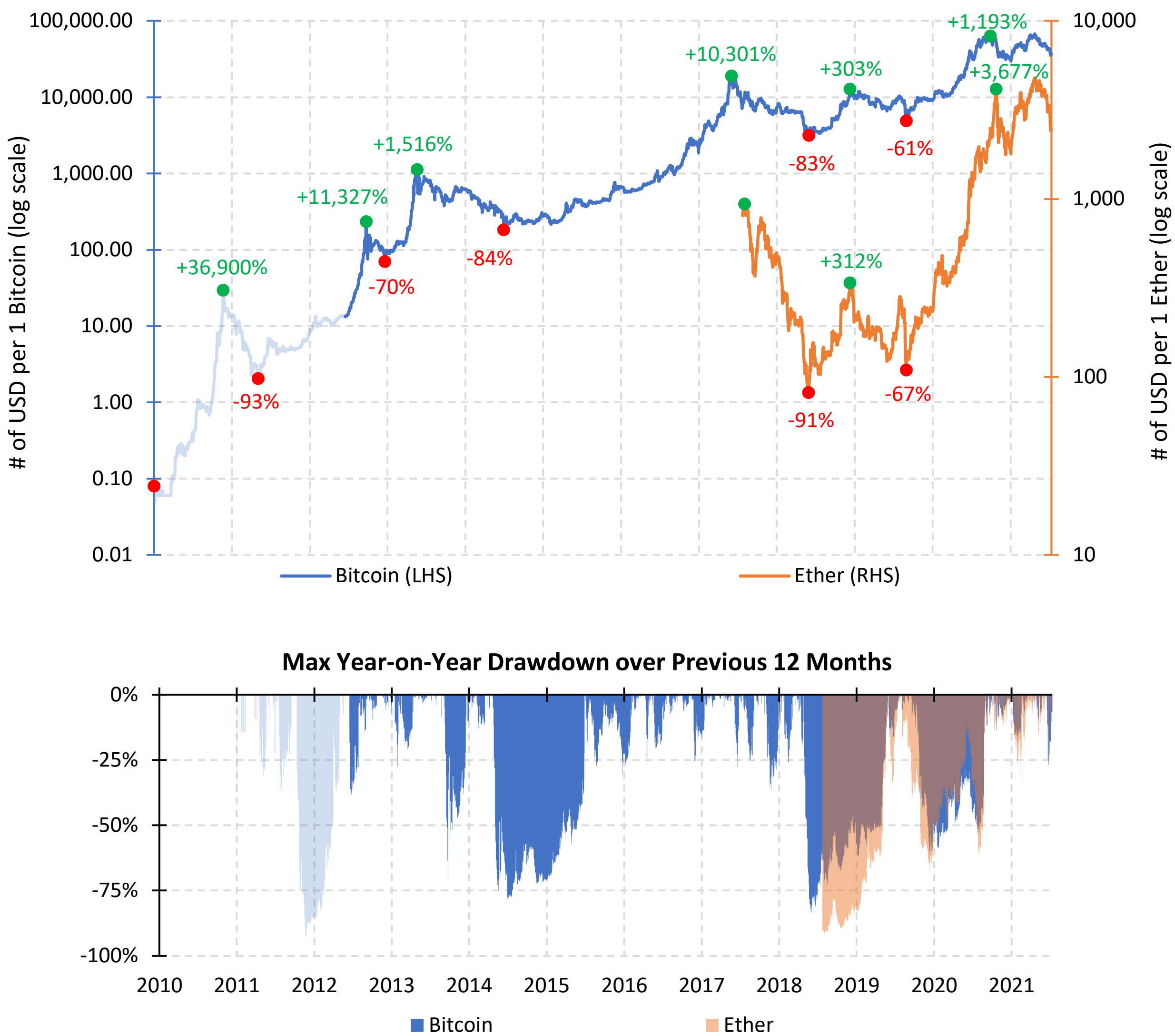
## The Investible Universe

The two most popular cryptocurrencies are bitcoin and ether, both of which have exhibited extremely high historical volatility. Any investor entering this space without a risk-management overlay needs to be prepared for large drawdowns.

In Exhibit 2 we show the price history of bitcoin and ether, from 2010 and 2018 respectively. In the top panel, we distinguish between bull and bear markets. In the bottom panel, we show maximum year-on-year drawdowns over trailing 12-month periods. We mentioned the 83% drawdown in bitcoin in 2018. However, there are five episodes in the past 12 years with drawdowns greater than 60%. Ether has an even shorter history but similarly has experienced extreme drawdowns. In the overlapping recent period, the bitcoin and ether drawdowns are highly correlated.

**Exhibit 2: Bitcoin and Ether Drawdowns**

The top panel shows the value in USD of one bitcoin (on the left-hand vertical axis) and one ether (on the right-hand vertical axis). Bitcoin data prior to 2013 are colored light blue to denote that the early data are less reliable. We denote optical peaks and troughs in both cryptocurrencies as green and red circles respectively. At each of these points we give the percent appreciation/depreciation since the most recent trough/peak. The bottom panel shows, at each point in time, the maximum 12-month drawdown over the previous 12 months. Similar to the top panel, we shade the pre-2013 bitcoin data light blue. The data are from Bloomberg – which collates quotes from the 15 and 12 major exchanges for bitcoin and ether respectively – and run from July 2010 to January 2022.



Are cryptocurrencies a bubble? A bubble is a persistent deviation from fundamental value. In this space (and as we will discuss later), it is difficult to define fundamental value. However, there is one distinguishing characteristic between the price behavior of cryptocurrencies and the classic historical bubbles: crypto drawdowns have been (so far) followed by recoveries.

Exhibit 3 shows six historical episodes that have been popularly labeled bubbles. Four of these episodes have never regained their boom-phase peak, while the other two took well over a decade to do it. In contrast, over the short history of crypto, the recovery is often very rapid. Some caution needs to be exercised in using the term bubble. We should not confuse bubbles with volatility.

**Exhibit 3: Historic Financial Market Bubbles**

The table shows summary statistics for six of the most notable financial market bubbles. The first column gives the name of the bubble, and its dates in parentheses. The following columns detail (respectively) the length of the boom, the maximum multiple attained, the length of the bust, the size of the bust and the length of time it took for an investor who had invested at the peak to recover their investment. We define the start of the bubble as the lowest point in the 10 years prior to the peak. We define the trough as the lowest point in the ten years following the peak. Data are collated from various sources. For 'Tulipmania' we use prices as listed in van der Veen (2012). For the Mississippi Company we use Buchan (2018). For the South Sea Company we use data collated by Yale School of Management. We proxy the 'U.S. Roaring 20s' with total returns from U.S. equities, from Professor Robert Shiller's online database. For '1980s Japan' we use the total return of rolling short-end Topix futures, using data from the Man AHL database. Finally, for 'DotCom' we take the total return from the MSCI World Information Technology index.

| Bubble | Start to Peak *(months)* | Max Multiple of Start | Peak to Trough *(months)* | % Decline from Peak | Recovery Time *(years)* |
|---|---|---|---|---|---|
| Tulipmania (1634 - 39) | 5 | 40x | 5 | -93% | Never |
| Mississippi (1718-20) | 17 | 37x | 11 | -64% | Never |
| South Sea (1719-20) | 11 | 8x | 5 | -81% | Never |
| US Roaring 20s (1921-32) | 99 | 7x | 33 | -82% | 13 |
| 1980s Japan (1982-92) | 87 | 6x | 31 | -59% | Never[1] |
| DotCom (1995-02) | 62 | 8x | 30 | -81% | 16 |

1. Even in total return terms Japanese equities remain a little over 20% below their 1989 peak

The diversity of the functionality of blockchains and their cryptocurrencies is detailed in Exhibit 4. We divide the space into six different categories. In the first category are cryptos that are only useful for transactional purposes. These include the first-mover bitcoin as well as other currencies such as Ripple's XRP and Stellar lumens. We also provide volume statistics from one of the leading U.S. exchanges, Coinbase. Note that these currencies are traded on hundreds of exchanges and we are sampling only one prominent exchange. We also provide annualized volatility, maximum drawdowns and a Sharpe ratio.[7] Given the size of the maximum drawdowns, caution should be exercised in looking at the Sharpe ratio which measures the return premium per unit of volatility risk. It is obvious that the risk of these cryptocurrencies goes beyond standard deviation.

[7] All statistics are based on log returns. However, the same patterns are evident in arithmetic returns.

The second category covers native coins of blockchains that allow for smart contracting. This allows users to send crypto not just to other users but to algorithms enabling functionality like decentralized exchange (a user trading with an algorithm). This group is dominated by ethereum but also includes some ethereum competitors such as Solana, Avalanche, and Algorand. We also include the increasingly important cross-chain technologies such as Polygon. Finally, Chainlink represents a technology called 'oracles' which allows smart contracts to draw data from outside their native blockchains (such as price feeds from exchanges).

Decentralized exchange is the third category of functionality. Popular exchanges such as Coinbase and Binance are centralized and act similarly to traditional broker/exchanges. To invest in Coinbase, you would buy their stock which is listed on NASDAQ. Decentralized exchanges (DEXs) are smart contracts that allow for algorithmic trading. An investor can send currency X to the automated market maker and receive currency Y. Further, the algorithm operates 24/7, is completely transparent, and does not care if you are a buyer or a seller. In addition to using DEXs for trading, investors also have the option of providing liquidity to a DEX and earning rewards based on transaction fees and platform rewards. Popular DEXs are Uniswap, PancakeSwap and, SushiSwap.

The leading lending and borrowing platforms, Aave and Compound, make up the fourth category. Their respective governance tokens, AAVE and COMP, reside on the Ethereum blockchain (known as ERC-20 tokens). There are other tokens that are associated with these platforms. For example, Compound also issues equity tokens known as 'c' tokens.

Web3 is an initiative that allows users to interact in a peer-to-peer way and easily pay or be paid using the technology of decentralized finance. For example, in Web3 there are no usernames and passwords. You have a wallet (such as the decentralized application MetaMask) with some cryptocurrency in it. You 'connect wallet' and you are ready to go. In Web3, data are interoperable, decentralized and controlled by individual users rather than centralized companies. For example, Web3 does not use traditional payment channels like bank credit cards. Web3 also enables the so-called metaverse as well as gaming platforms.

The fifth category provides a sample of cryptocurrencies in this diverse space. Filecoin is used in Web3 for decentralized file storage. Decentraland is a leading metaverse platform. Axie Infinity is a leading gaming platform. In this category, we could include leading NFT marketplace OpenSea if it had a token. NFTs are an increasingly popular way to tokenize unique objects from art to gaming objects. Emerging applications include ticketing and even fashion.

Our final category is labeled 'meme' and a leading example is Dogecoin. These should be included in the first category (transactional currencies) but they are mainly used by speculators. While it is obvious that speculators participate in all of these currencies, most of the currencies have specific use cases.

One important category, stablecoins, is omitted. Stablecoins, particularly those backed by traditional fiat currency (issued by government decree of "fiat"), are not supposed to appreciate in value. As such, metrics like Sharpe ratios have little meaning. However, investors may consider an allocation to collateralized stablecoins to earn rewards for providing funds to a liquidity pool. Investors can earn interest as well as other rewards for being a liquidity provider. This is somewhat analogous to fixed income investing in traditional asset allocation.

**Exhibit 4: Different Cryptocurrencies Considered**

The table covers the 22 cryptocurrencies considered in Section 1, which are all traded on Coinbase. We split the universe into six groups based on the coin type. We report the start date of data at Coinbase, the latest volume share as a percentage of total USD volume (excluding stablecoins), the annualized Sharpe ratio, the annualized volatility and the maximum drawdown. The performance statistics are based on daily excess returns, where the price data are taken from the Coinbase API. The excess returns are relative to funding rate which is the secured overnight financing rate (SOFR), a U.S. dollar-denominated reference interest rate. The returns and volume data start from when each coin began trading on Coinbase, and end on 26 January 2022.

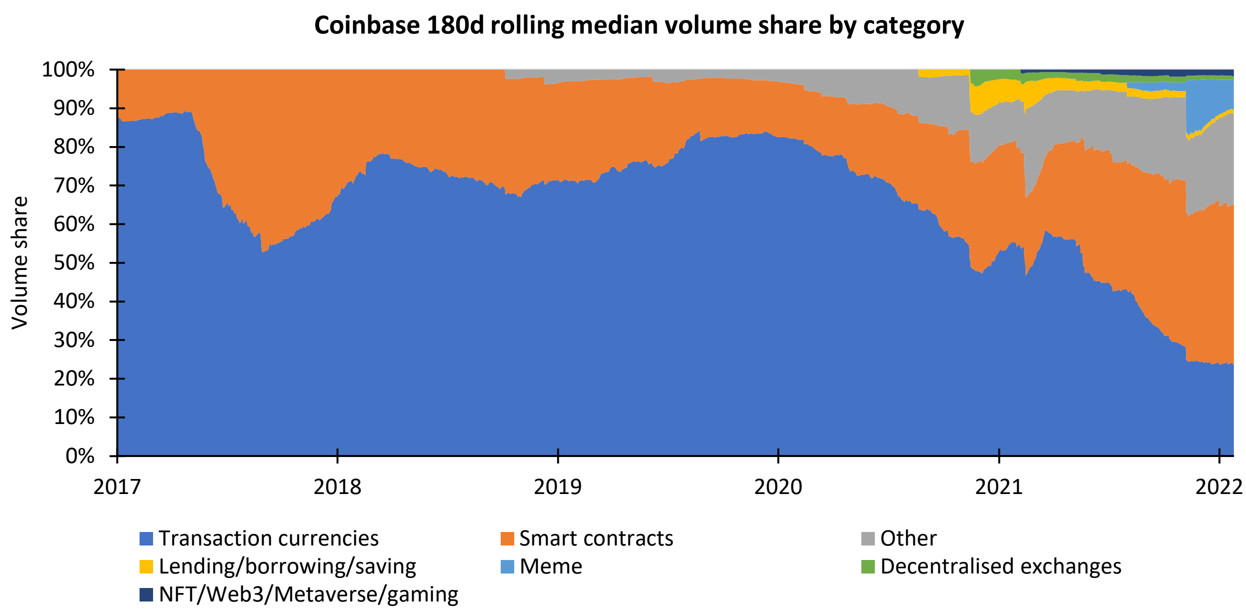
| Blockchain Functionality/Coin | Start date | 2021 volume on Coinbase | Sharpe | Ann. Vol | Max. DD |
|---|---|---|---|---|---|
| **Transaction currencies** | | | | | |
| Bitcoin (BTC) | 20/07/2015 | 20.50% | 0.98 | 73.5% | -83.5% |
| Litecoin (LTC) | 17/08/2016 | 1.65% | 0.53 | 114.2% | -93.6% |
| Bitcoin Cash (BCH) | 20/12/2017 | 0.49% | -0.49 | 122.0% | -97.9% |
| Stellar Lumens (XLM) | 14/03/2019 | 1.28% | 0.19 | 111.9% | -77.0% |
| Ripple[8] (XRP) | 26/02/2019 | N/A | -0.02 | 99.9% | -70.6% |
| **Smart contracts** | | | | | |
| Ethereum (ETH) | 18/05/2016 | 19.37% | 0.84 | 105.9% | -93.9% |
| Solana (SOL) | 17/06/2021 | 7.78% | 1.15 | 122.0% | -63.2% |
| Algorand (ALGO) | 15/08/2019 | 1.38% | 0.08 | 131.9% | -82.1% |
| Avalanche (AVAX) | 30/09/2021 | 2.66% | 0.05 | 115.8% | -53.4% |
| Cardano (ADA) | 18/03/2021 | 4.98% | -0.16 | 113.3% | -64.8% |
| Polygon (MATIC) | 11/03/2021 | 2.91% | 0.83 | 173.0% | -71.8% |
| Chainlink (LINK) | 27/06/2019 | 2.43% | 0.56 | 126.5% | -73.7% |
| **Decentralized exchanges** | | | | | |
| Uniswap (UNI) | 17/09/2020 | 0.59% | 0.45 | 146.7% | -75.4% |
| SushiSwap (SUSHI) | 11/03/2021 | 0.46% | -1.02 | 152.7% | -79.5% |
| **Lending, borrowing, and savings** | | | | | |
| Aave (AAVE) | 15/12/2020 | 0.43% | 0.34 | 141.7% | -75.8% |
| Compound (COMP) | 23/06/2020 | 0.27% | -0.29 | 132.8% | -85.4% |
| yearn.finance (YFI) | 15/09/2020 | 0.29% | -0.18 | 147.4% | -76.3% |
| **NFT/Web3/Metaverse/Gaming platforms** | | | | | |
| Filecoin (FIL) | 09/12/2020 | 0.76% | -0.31 | 146.3% | -90.5% |
| Decentraland (MANA) | 20/04/2021 | 0.69% | 0.26 | 196.9% | -72.1% |
| Axie Infinity (AXS) | 12/08/2021 | 0.36% | -0.40 | 139.9% | -68.3% |
| **Meme coins** | | | | | |
| Dogecoin (DOGE) | 03/06/2021 | 1.97% | -1.37 | 112.9% | -65.8% |
| Shiba Inu (SHIB) | 09/09/2021 | 5.61% | -0.65 | 392.9% | -88.6% |

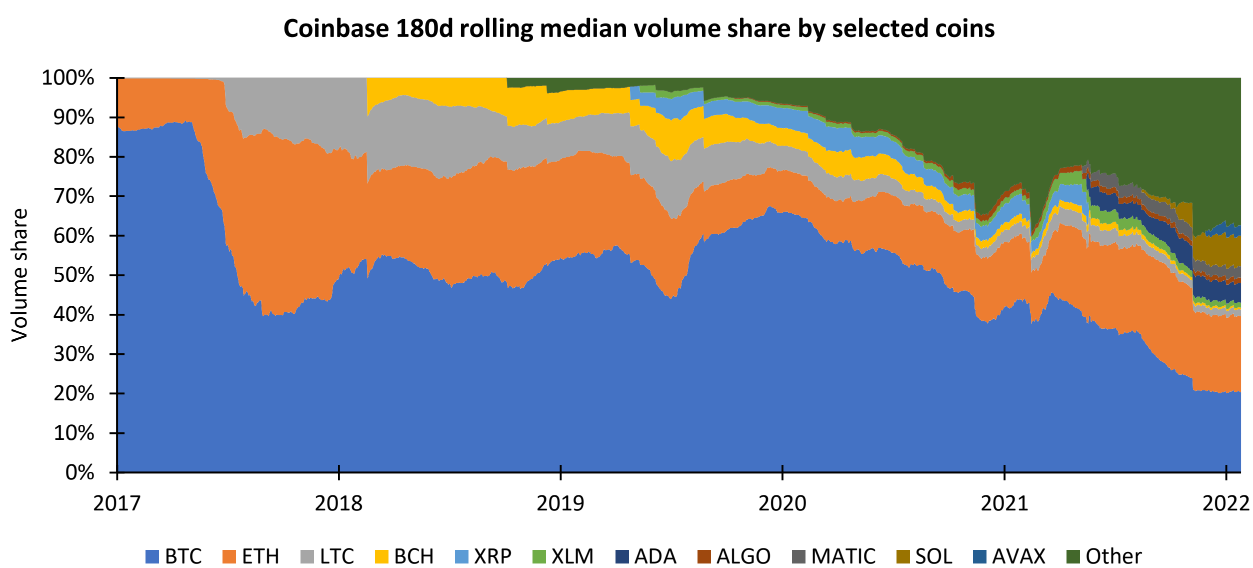
Exhibit 5 shows how this space has evolved over the past five years. In 2017, 90% of all trading volume on Coinbase was bitcoin (see bottom panel). Today it is 21%, as the smart-contracting platforms have gained a greater share of the volume.[9] Indeed, notice that the lending and borrowing, the NFTs, and decentralized exchange categories all use smart contracting. That is, an NFT is just a type of smart contract (called an ERC-721). The smart-contracting platforms account for roughly 70% of all volume. This is an important observation for an investor who thinks that she will get exposure to crypto by purchasing bitcoin alone.

[8] Ripple's XRP stopped trading on Coinbase on 2021/01/19, so all data are up until this date.
[9] This is a relative statement. The smart-contracting platform volumes have increased faster than the bitcoin volume.

**Exhibit 5: Volume Share For Different Cryptocurrencies Over Time**

The figure shows the rolling 180-day median volume share by category (top panel) and for selected major coins (bottom panel), using data from the coin/USD pairs available on the Coinbase API as of 25 January 25 2022, excluding stablecoins. The coin categories are defined as in Exhibit 4, with the "Other" category including all coins not mentioned in Exhibit 4. The data start in 2017.



## The Challenges of Valuing Cryptocurrencies

### *Economic Mechanism*

The U.S. dollar, while uncollateralized since August 1971, has value for three reasons. First, the dollar is legal tender in the U.S. Second, U.S. taxes are paid in U.S. dollars. Third, if taxes are not paid, taxpayers can be incarcerated. More generally, the U.S. dollar is the reserve currency of the world. As with any fiat currency, it has value because people believe the currency has value. If the confidence in the currency's value erodes, it will depreciate. In extreme cases, this can lead to citizens seeking alternatives to their national fiat.

Why does a cryptocurrency like bitcoin have value? It is not legal tender in the U.S. It is extremely volatile – approximately 40 times more volatile than the U.S. dollar compared to a basket of other G-10 currencies. Transactions are slow and expensive. There is substantial regulatory risk. That said, bitcoin has appreciated spectacularly since its launch.

There are a number of hypotheses that attempt to explain its valuation. Given that bitcoin does not pay any dividends, the simplest explanation is that people buy bitcoin because they believe it will rise in value. However, it is unlikely that this expectation is sustainable in the long term. Indeed, buying a permanent non-dividend-paying asset solely because you believe the price will go up leads some to compare it to a Ponzi scheme. On the other hand, it is also possible that the cryptocurrency network produces something valuable (such as fast, secure, or cheap transactions) that are valued by the network participants.

To make the problem even more complicated, the diversity of cryptocurrencies means that different models are potentially needed for different cryptocurrencies. Of course, the simplest model is that of a collateralized token. For example, a token that represents one share of some stock (that is traded on a regular exchange) is just the value of the stock. However, for a currency like bitcoin, the task is much more challenging.[10]

We examine some popular approaches to valuing cryptocurrencies such as bitcoin.[11] None of these approaches are satisfactory. However, it is important to understand why.

### *Metcalfe's 'Law'*

If a cryptocurrency is seen as a new form of fiat network, then one simple way to ascertain a valuation is to observe how many participants the given token contains. This is often referred to as Metcalfe's Law, the heuristic attributed to Robert Metcalfe that a telecommunications network's value will be proportional to the square of the number of connected users of the system. This hypothesis has been discussed and criticized in relation to cryptocurrencies by Erb (2021) among others.

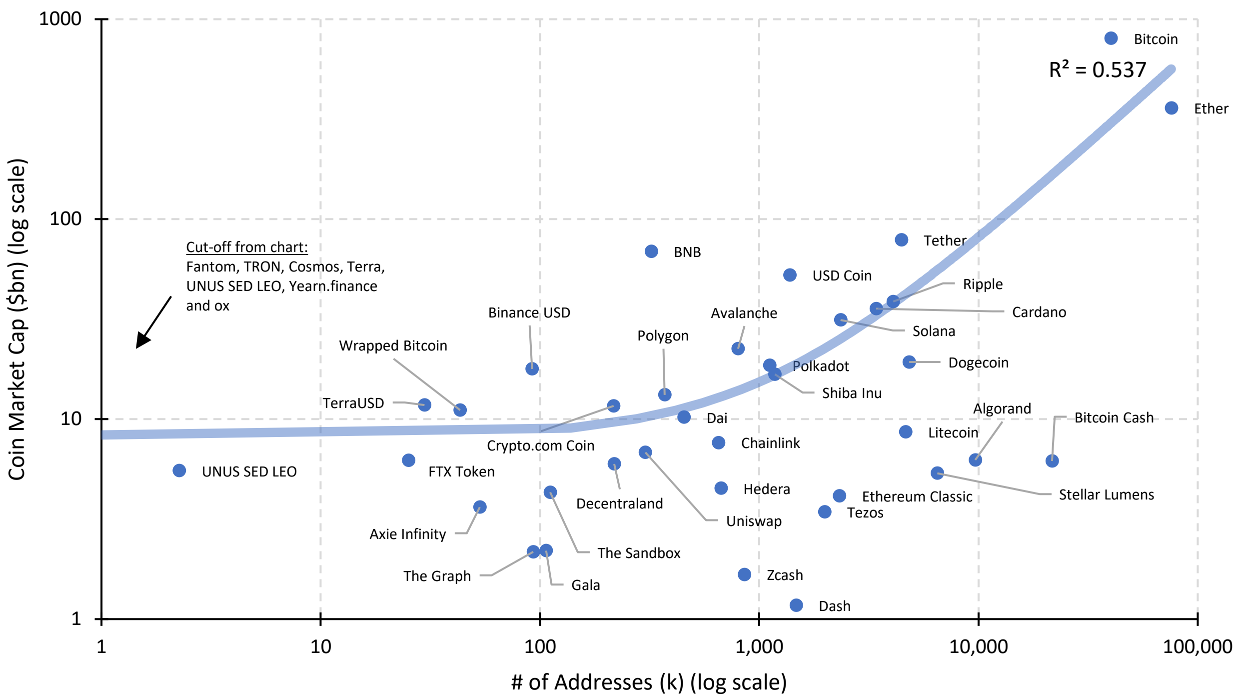
[10] Cong, Li and Wang (2020) present a model where value is related to transactional demand. Biais et al. (2022) show the value of bitcoin depends on transactional benefits, which depends on price expectations.
[11] Burniske and Tatar (2018) and Bernardi and Bertelli (2021) discuss value drivers for bitcoin, while Liu, Tsyvinski, and Wu (2021) study cross-sectional value based on the change of new addresses.

Exhibit 6 shows the relation between market capitalization and the number of addresses. The regression fit appears impressive, with a 54% $R^2$. However, the high correlation is driven by two data points, bitcoin and ether. If we remove those two points, the $R^2$ vanishes. Furthermore, bitcoin users routinely create new addresses for each transaction. As such, the number of addresses is overstated (Makarov and Schoar, 2022). While this heuristic might be useful for valuing platforms like Google and Meta, it is not obviously useful for the diverse set of cryptocurrencies.[12]

Overall, it makes sense that increased network size positively contributes to the valuation of the network. It may even be the case that the value of a network is in proportion to the square of the network size. However, the proportionality coefficient is unknown and likely varies across different use cases. With the unknown coefficient, we are left with the conclusion that network size is a good but insufficient variable in explaining cryptocurrency valuation.

**Exhibit 6: Metcalfe's Law: Is Market Capitalization Related to Addresses?**

We take the cryptocurrencies shown in Exhibit 4 as well as the top 50 tokens by market cap not already included. For each we plot the market cap against the total number of addresses. Where no data exist for the latter, the token is excluded. This leaves us with a sample of 42. We cut off the axes at 1,000 addresses and $1bn market cap for legibility. This excludes seven tokens from the graph but the linear regression is modelled on all 42. Data from Coinmarketcap.com, Messari and Crypto.com, and is collated as at 17 February 2022. The curve represents the fit from the linear regression (on log scale). If bitcoin and ether are excluded, the $R^2$=0.003.

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[12] There are many ways to present Metcalfe's Law. An alternative is to focus on a single cryptocurrency, such as bitcoin, and sample number of addresses vs. value throughout history. The same type of graph can be produced for a single currency.

### ***Bitcoin as Digital Gold***

Historically, gold has frequently been its own financial network, sitting on top of – and in many cases behind – conventional national currencies. Given its limited industrial use (indeed 70% is used for artistic purposes, most notably jewelry), its value has come from its optionality of being accepted across most national currency networks. For bitcoin specifically, leading proponents suggest that it might usurp some of this functionality, the so-called 'digital gold' argument – see, for instance, Winklevoss (2020). In contrast to most other tokens, bitcoin has a hard stop at 21 million units, potentially analogous to the 244,000 metric tons of gold that represents the estimated hard stop on the yellow metal (at least until extraterrestrial deposits are found).[13]

It should be stated at the outset that this line of reasoning is based on a logical fallacy: it all follows from the supposition that bitcoin is the 'new gold' which, until more time has elapsed to confirm this, is supposed rather than evidenced. Nevertheless, it is a commonly held belief within the cryptocurrency community and it is therefore important for asset allocators to be familiar with the parameters of the debate.

The point that gold is itself a token, rather than something inherently valuable, was first made formally in Cantillon (1755). Cantillon points out that when gold first became the prime standard of coinage in Greece, around the fifth century BC, there were numerous alternatives – such as iron or copper – which could be, and sometimes were, chosen as units of economic account. That the yellow metal rose to the top was, in Cantillon's view, due to it best satisfying five constraints: durability, divisibility, transportability, homogeneity and rarity.

It can be argued that bitcoin also satisfies these constraints and as such can act as a digital mirror of physical gold. Historically, total mined and unmined reserves have been priced so as to constitute about 3.4% of global wealth.[14] Global wealth today is $446trn[15] and thus the 'gold share' based on historical precedent should be a little over $15trn. By way of example, if we assume that this share should be split 90% physical (gold the metal) and 10% digital (bitcoin), that would imply valuations of $1,270 per ounce for gold (34% downside from the current price of $1,912 per ounce as at 29 April 2022) and $72,270 for bitcoin (86% upside from the current price of $38,900 as at 29 April 2022). It may be the case that other cryptocurrencies cannibalize further share from physical gold, or indeed that of bitcoin itself. For now, we think it is a fair assumption to limit this analysis to bitcoin. Of course, the key to valuation is the share. Is it 10%, 100% or 0%?

'Bitcoin as digital gold' illustrates an important point from the investor's perspective. That is that not having a position means you are underweight compared to the average investor. A final point to make is that 'bitcoin as digital gold' was never the original intention of the cryptocurrency's founder, as evinced in the founding white paper, see Nakamoto (2008).[16]

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[13] As estimated by the USGS, see here.
[14] We use global wealth figures from the Credit Suisse Global Wealth Databook 2021. Note that this reports up to end 2020 ($418trn). To estimate a figure for 2021 we take the 2020 figure and apply the average growth in wealth over the previous 20 years (7%). We use year-end gold prices per ounce from Bloomberg to calculate the average percent of global wealth from 2000 to end 2021.
[15] Data from the Credit Suisse Global Wealth Report 2021, per above.
[16] Appendix A provides additional analysis.

### *Value as a Multiple of Mining Cost*

If the gold analogue is correct, another way of looking at the value of bitcoin is as a multiple of its cost of mining, and comparing that with other assets that require a process of prospecting. There are similarities between mining bitcoin and extraction of commodities such as gold, copper or oil. Each requires considerable outlay for an uncertain but binary outcome. Exhibit 7 shows the operating cost of mining one bitcoin token, relative to its price, and compares this with gold (per ounce), copper (per pound) and oil (per barrel), respectively bellwethers of the precious, industrial and energy commodity complexes.

Exhibit 7 shows that, for traditional commodities, this ratio tends to be stable, both across years and across the complex. In 11 years, none of oil, gold or copper fall below 0.9x, or rise above 2.3x.[17] This multiple may represent the equilibrium level of utility that global society derives from the material. Given its relative novelty, it is perhaps unsurprising that the market has yet to properly assess this ratio for bitcoin, at least with much stability. Indeed, the metric has oscillated between 4x and 220x.

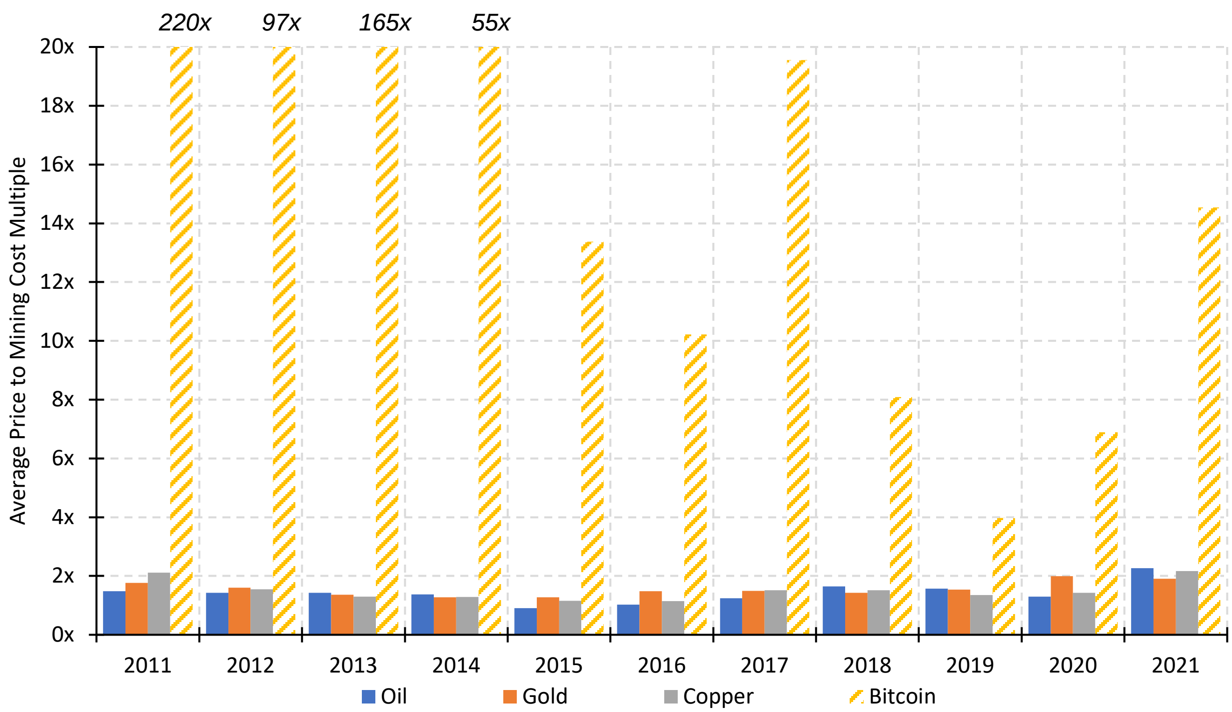
It is notable that since 2015 the bitcoin multiple has been more restrained, remaining below 20x. If the equilibrium were to settle around similar levels to the three traditional commodities (on average 1.5x through history), however, this would imply a significantly bearish outcome for bitcoin, with a current valuation of just over $11,450, based on current hash rates and electricity prices (roughly 70% below the price in April 2022).

There are two flaws with this model. First, a large part of the differential may be explained by differing capital intensities for different types of extraction. Second, we don't know anyone that currently uses multiples of mining costs to value commodities. Third, it is not possible to apply the model to proof-of-stake tokens. We give further detail in Appendix B.

[17] So for instance, in 2021 the average cost of copper was $4.24 per pound, which was 2.2x greater than the $2.17 it cost to dig up a pound of the metal, on average.

**Exhibit 7: Historic Price to Mining Cost Multiples**

The chart shows the average price to mining cost multiple, by calendar year, for gold, oil, copper and bitcoin. The calculation uses operating costs only (in other words excludes capital depreciation and financing costs). For bitcoin, we first use data from Küfeoğlu and Özkuran (2019) to calculate the energy efficiency of the most efficient mining equipment at each point in time. Next we use the number of terahashes per second (on a 7-day moving average basis) from https://www.blockchain.com/ to get the required power usage per day. We then follow the methodology of Song and Aste (2020) to translate this into a USD value based on the average energy intensity across oil and coal. This cost is spread over the number of bitcoin mined per day, also from blockchain.com. Bitcoin price data from Bloomberg, as per Exhibit 2. Cost of production for oil, gold and copper collated by Morgan Stanley. For oil we proxy the marginal barrel using US shale, the swing producer of the past decade. For gold and copper we use C1 cash cost, at the 90th percentile of the cost curve. The y-axis is cut off at 20x for legibility. These data are as of 31 January 2022.




## *Flow Versus Stock Analysis*

There is another popular story that relies on the ratio of new currency creation to the total stock of currency – the so-called flow vs. stock ratio (see, for example, Prasad, 2021). Appendix C presents analysis that shows that this ratio is very low for bitcoin and ether compared to leading fiat currencies. The idea is that if the value of the stock of cryptocurrencies to the flow becomes closer to the average of fiat currencies, then the value of bitcoin and ether could substantially appreciate.

This argument is problematic for a very simple reason. For bitcoin, the flow will eventually go to zero. This implies an infinite valuation.

### *Relative Value*

While it is difficult to establish absolute prices of cryptocurrencies, we might be able to say something about the relative value of the spot versus the futures/forward prices.

For fiat currency exchange rates, covered interest parity implies that the forward rate is determined by the interest rate differential between two countries and the current spot rate. Is it possible to apply the same logic to cryptocurrencies?

On 17 February 2022, the 12-month DeFi lending rate for bitcoin is 6.2%[18] and the USD 12-month LIBOR is 1.3%[19] implying a spread of 5.9%. Given a bitcoin spot rate of $42,340[20], we would expect the one-year forward price of bitcoin to be $44,388. However, the exchange-traded bitcoin futures one year out recently traded at $47,183, suggesting the token was a little under 6% overvalued.

There are plenty of caveats with this type of analysis. For example, the DeFi lending rates do not generally guarantee the rate for 12 months. DeFi lending is more akin to floating-rate lending. More importantly, this type of analysis does not tell us anything about the fundamental value of bitcoin or any other cryptocurrency. Instead, it reflects possible discrepancies between spot and forward pricing. The forward price could be overpriced, the spot price could be underpriced, but both the forward and spot may be over or underpriced on an absolute basis.

## Performance and Risk of Cryptocurrencies

In this section, we analyze the risk and return properties of cryptocurrencies. We start with an analysis of the volatility and other risk properties of bitcoin and ether, for which we have the longest data available. Next, we explore the trend characteristics of these two cryptocurrencies. And finally, we look at the correlation between a larger group of cryptocurrencies.

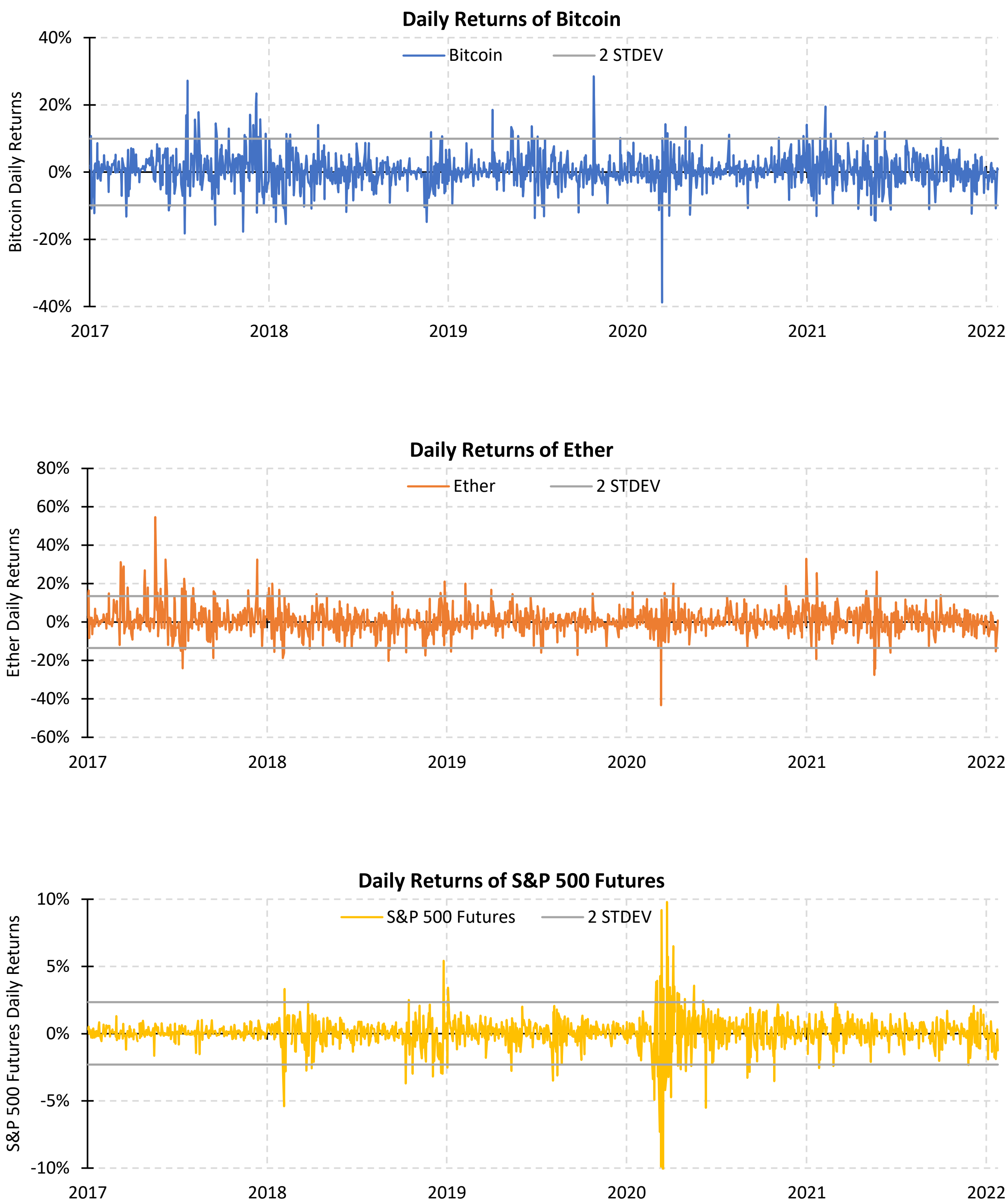
### *How Non-normal are Cryptocurrency Returns?*

The top panel of Exhibit 8 shows that the daily returns of bitcoin frequently are around plus or minus 10%. The standard deviation of daily returns is 4.9% over the full 2017-2022 sample period, or around 80% on an annualized basis.[21] The picture is similar for ether, see the middle panel of Exhibit 8.

[18] See https://defirate.com/lend/ (accessed 17 February 2022)
[19] From Bloomberg (accessed 17 February 2022)
[20] *Ibid*.
[21] We annualize by multiplying with the square root of 261, approximately the number of weekdays in a year. While cryptocurrencies trade 24-7, we sample only Monday-Friday to compare to other assets.

**Exhibit 8: Bitcoin and Ether Versus the S&P 500 Daily Returns**

This figure shows daily returns for bitcoin (top panel), ether (middle panel) and the S&P 500 equity index (bottom panel). Each panel also has plotted alongside two horizontal dashed lines representing plus and minus two times the standard deviation of daily returns, computed over the full sample. To allow for easy comparison, we only use weekday returns, and so for bitcoin and ether price moves over the weekend are included in the Monday return. The data run from January 2017 to 25 January 2022.



The daily returns to a stock-index investment are more muted and rarely reach plus or minus 10%; see the bottom panel of Exhibit 8 for the S&P 500 daily returns, with a full-sample daily return volatility of 1.2%, or 19% on an annualized basis.

However, the high volatility of an asset can be managed. Volatility can be reduced by investing, say, a quarter of the capital in the asset and keeping the rest of the capital in cash. This way, the return volatility on the total capital available is just a quarter that of the asset itself. And indeed, a quarter investment in bitcoin has been about as volatile as a full investment in the S&P 500.

What would be more concerning is if cryptocurrencies displayed more non-normal returns, by experiencing larger tail returns relative to what one may expect given the volatility level.[22] In other words, by having a high degree of negative skewness or excess kurtosis. It turns out that over the 2017 to 2022 time period, bitcoin and ether have experienced relatively few tail events, compared to the S&P 500 index. This is visible in Exhibit 8, by noting the greater incidence of standard deviation moves bigger than three for the S&P 500 index (shown as observations falling outside the solid grey lines).[23] Particularly during the Covid-19 equity selloff in 2020 Q1, the S&P 500 index experienced much bigger price swings than usual, while bitcoin continued to be about as volatile as it had been before.

### *The Persistence of Volatility and Volatility-scaled Returns*

Asset returns typically display persistent volatility, as documented for a wide range of assets by Harvey et al. (2018). Bitcoin and ether also display persistence in their volatility, as illustrated in the right panel of Exhibit 9.[24] Here we sort five-day periods based on the standard deviation of five-minute returns into quintiles, and then plot the average standard deviation of five-minute returns over the subsequent five days for each of the quintiles. High volatility over the previous five days tends to be followed by high volatility over the next five days. For the left panel of Exhibit 9 we again sort by volatility quintile, but then plot the average return (rather than volatility) over the subsequent five days for each quintile. Similar to the findings of Harvey et al. (2018), higher volatility does not reliably predict higher subsequent returns.

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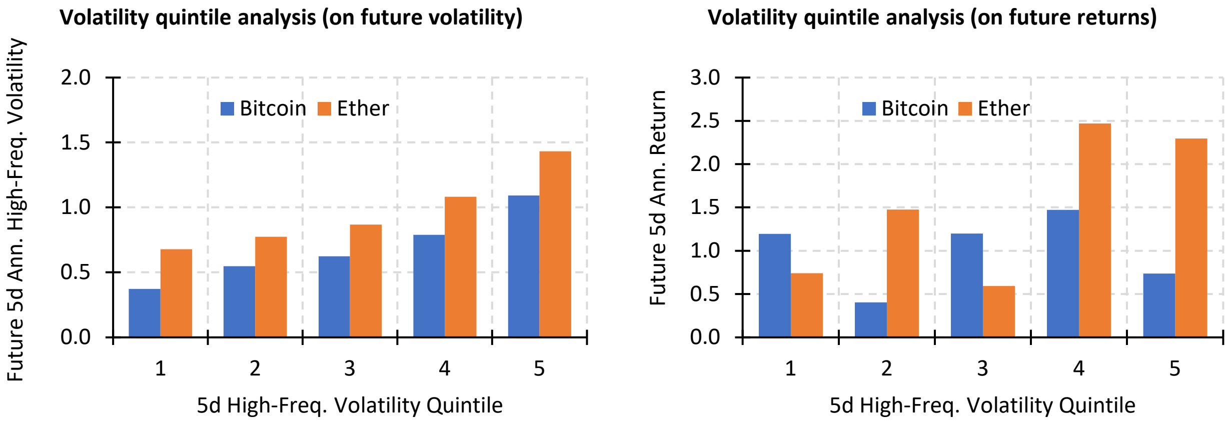
[22] Härdle, Harvey and Reule (2020) provide a statistical analysis of cryptocurrencies, gold and the S&P 500, including normality tests.

[23] There are 84 and 70 breaches of the two standard deviation band for bitcoin and ether over the time period respectively and 58 for S&P 500. However, for the three standard deviation band, the S&P has 21 breaches vs. 16 and 18 for bitcoin and ether. While these differences are not statistically significant, the point is that volatility scaled crypto positions do not have higher tail risk than a comparable position in the S&P 500 in our sample.

[24] Zhang et al. (2018) also document volatility clustering in cryptocurrency returns.

**Exhibit 9: Illustration of the Persistence of Volatility**

We look at the persistence of volatility by sorting five-day volatility into quintiles and looking at the average subsequent five-day volatility and return. All data for each coin are from the Coinbase trading start date until 26 January 2022. In this section we only consider bitcoin and ether since they have the longest data history (5+ years).




The persistence of volatility is an important property to be aware of, as one can counter the effect by scaling the size of one's investment by the current volatility level. In Exhibit 10, we follow the method of Harvey et al. (2018) to illustrate the impact of volatility targeting on bitcoin, ether, and S&P 500 investments.[25] Here we use returns in excess of the funding rate. To facilitate comparison, we apply a further scaling to the full returns stream, so that all series realize 10% full-sample annualized volatility.

We show results for both a fast (five-day) and slow (180-day) volatility estimate, as well as an average of the two. We consider both daily returns and hourly returns based on intraday data.

The Sharpe ratio of an investment in bitcoin is typically modestly higher when volatility scaling is applied whereas scaling has little effect on ether.[26] There is, however, an important additional advantage of volatility scaling: that returns are more stable in the sense that the annualized one-year rolling volatility of 21-day return volatility (or "vol-of-vol" statistic) is substantially reduced, as can be seen in the second-last column of Exhibit 10. The maximum drawdowns (last column) are also modestly reduced for bitcoin.

[25] Volatility is measured using squared returns (i.e., assuming zero mean), exponentially weighted.
[26] The volatility managed strategies as well as the trend strategies in the next section do not incorporate transaction costs. From our live trading experience, transactions costs are very modest, around one basis point for a position with 10% annualized volatility that turns over once a year. Part of the reason transactions costs are very modest is that the high volatility of crypto means one only needs a partial investment to get a 10% annualized volatility exposure

**Exhibit 10: Performance of Buy-and-hold Crypto vs. Volatility-scaled Crypto**

The exhibit shows various statistics for the excess returns on investments in bitcoin (top panel), ether (middle panel) and the S&P 500 index (bottom panel). We consider both constant sized (unscaled) positions, and positions that are inversely proportional to a volatility estimate using daily or five-minute intraday data. To facilitate comparison, all return series are ex-post vol-scaled to 10% annualized volatility. Volatility is measured using squared returns (i.e., assuming zero mean) and uses exponentially decaying weights. Vol-scaling is done by dividing return at time t by volatility estimate in time t-2 (and multiplied by target vol). The Sharpe and vol-of-vol statistics are calculated using overlapping monthly (21-day) returns. The vol-of-vol statistic is the standard deviation of annualized one-year rolling vol of the returns. The exposure and turnover are calculated using daily exposure values. The turnover is the mean absolute daily exposure change, annualized and divided by twice the mean exposure. The data for bitcoin and ether are from each coin's Coinbase trading start date until 26 January 2022, and the data for the S&P 500 index are from 22 July 2015 (the same start date as bitcoin).

| | Sharpe | Mean Notional Exposure | Turnover Notional Exposure | Vol of Vol | Max Drawdown |
|---|---|---|---|---|---|
| | | | **Bitcoin** | | |
| **Constant sizing/Unscaled** | 1.26 | 13.6% | 0.00 | 2.7% | -19.0% |
| *HF Volatility* | | | | | |
| **Vol-scaled (Avg(5d, 180d))** | 1.38 | 14.6% | 3.08 | 1.3% | -17.1% |
| **Vol-scaled (5d)** | 1.33 | 15.0% | 6.71 | 2.0% | -18.8% |
| **Vol-scaled (180d)** | 1.39 | 13.5% | 0.30 | 2.1% | -16.1% |
| *Daily Volatility* | | | | | |
| **Vol-scaled (Avg(5d, 180d))** | 1.32 | 14.4% | 4.49 | 1.5% | -17.4% |
| **Vol-scaled (5d)** | 1.21 | 14.9% | 9.90 | 1.7% | -19.5% |
| **Vol-scaled (180d)** | 1.38 | 13.5% | 0.37 | 2.2% | -16.2% |
| | | | **Ether** | | |
| **Constant sizing/Unscaled** | 1.11 | 9.5% | 0.00 | 2.0% | -20.1% |
| *HF Volatility* | | | | | |
| **Vol-scaled (Avg(5d, 180d))** | 1.14 | 10.2% | 2.79 | 1.1% | -21.1% |
| **Vol-scaled (5d)** | 1.06 | 10.5% | 5.91 | 1.5% | -23.9% |
| **Vol-scaled (180d)** | 1.17 | 9.7% | 0.25 | 1.1% | -18.3% |
| *Daily Volatility* | | | | | |
| **Vol-scaled (Avg(5d, 180d))** | 1.08 | 10.0% | 4.37 | 1.2% | -21.0% |
| **Vol-scaled (5d)** | 0.98 | 10.1% | 9.48 | 1.6% | -23.7% |
| **Vol-scaled (180d)** | 1.15 | 9.6% | 0.32 | 1.2% | -18.6% |
| | | | **S&P 500** | | |
| **Constant sizing/Unscaled** | 0.99 | 56.1% | 0.00 | 4.6% | -20.4% |
| *HF Volatility* | | | | | |
| **Vol-scaled (Avg(5d, 180d))** | 1.06 | 77.9% | 2.75 | 3.0% | -16.1% |
| **Vol-scaled (5d)** | 1.13 | 86.6% | 6.14 | 2.0% | -14.3% |
| **Vol-scaled (180d)** | 0.84 | 62.0% | 0.28 | 4.1% | -19.6% |
| *Daily Volatility* | | | | | |
| **Vol-scaled (Avg(5d, 180d))** | 0.97 | 79.2% | 3.85 | 3.0% | -17.1% |
| **Vol-scaled (5d)** | 0.91 | 84.3% | 9.27 | 2.0% | -14.6% |
| **Vol-scaled (180d)** | 0.83 | 63.3% | 0.36 | 4.1% | -19.5% |

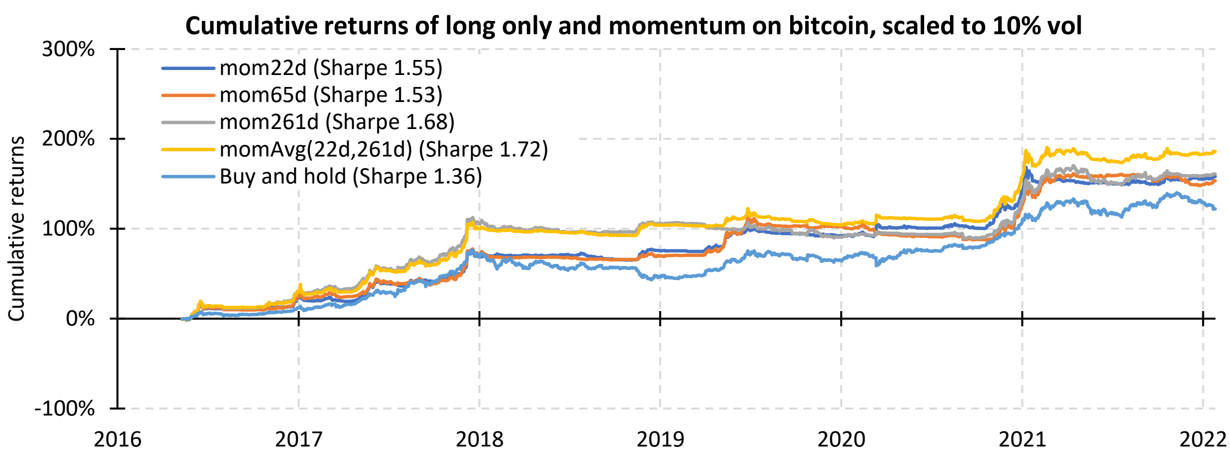
### *Trend-following Strategies for Cryptocurrencies*

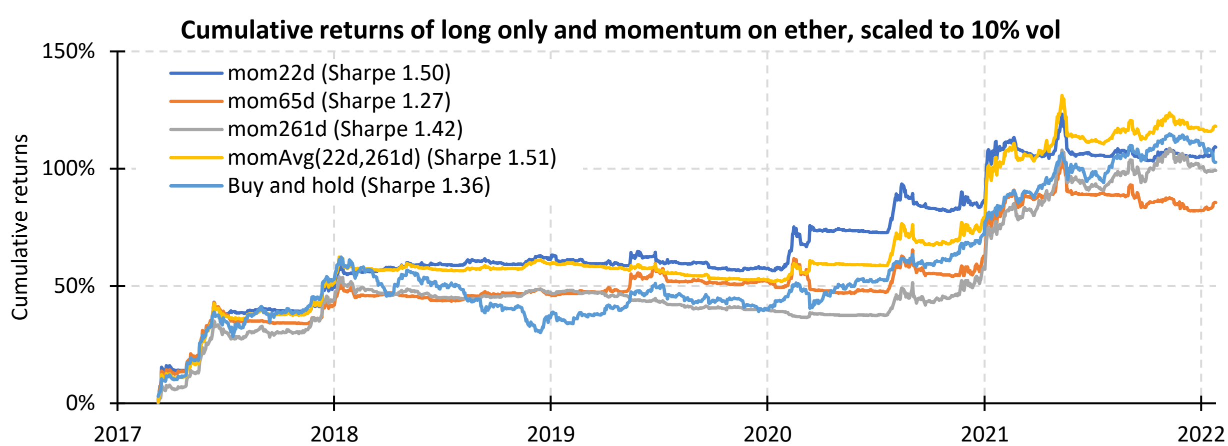
Macro assets, such as equity indices, government bonds, currencies, and commodities, tend to display time-series momentum (or "trendiness") at the 1- to 12-month horizon. We follow the methodology of Harvey et al. (2019) to define 1-month (22-day), 3-month (65-day), and 12-month trend strategies.[27] In Exhibit 11, we show the results for bitcoin (top panel) and ether (bottom panel), alongside which - we show a constant investment in the coin. The trend strategy will have mostly been long both coins, as these markets have tended to trend upwards. However, it takes larger long positions when the trend is more strongly upwards, and does take short positions during the few time periods when the trend was negative.

The trend strategies have performed well over the (admittedly short) history available to us, and have mostly outperformed a constant investment in the coin itself (see the Sharpe ratio reported in the legends).

**Exhibit 11: Trend-following Crypto**

The exhibit shows the cumulative returns to various time series of momentum strategies applied to bitcoin (top panel) and ether (bottom panel), as well as a buy-and-hold investment, all scaled to 10% ex-post volatility to facilitate comparison. The data run from 10 May 2016 to 26 January 2022 for bitcoin and from 10 March 2017 to 26 January 2022 for ether.



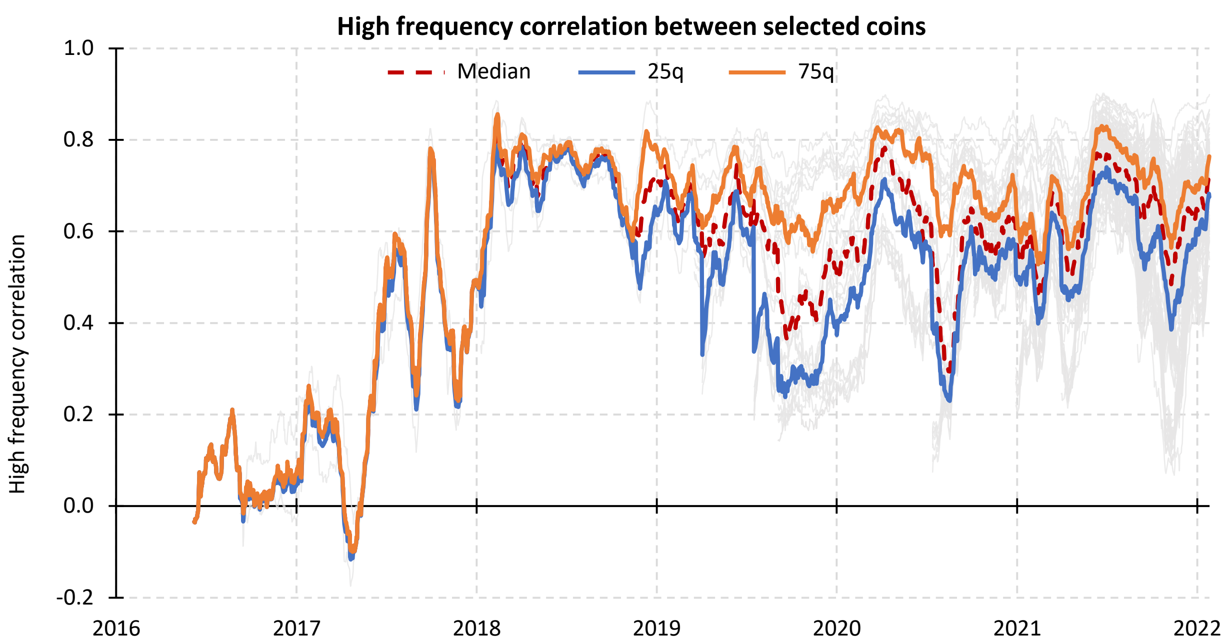

[27] Rozario, Holt, West, and Ng (2000), Liu and Tsyvinski (2021), Liu, Tsyvinski, and Wu (2022) document a momentum effect in cryptocurrencies as well.

### *Correlation Between Different Cryptocurrencies*

In Exhibit 12, we show the rolling 20-day correlation between pairs of coins listed in Exhibit 3. To increase the statistical power, we again make use of intraday data. We compute the 15-minute return correlation for each day, and average over the rolling 20-day window. We note that cryptocurrencies display around a 0.4 to 0.8 pairwise correlation from 2018 onwards. That means a modest amount of diversification across coins can be achieved.[28] Indeed, given that many of these cryptocurrencies power blockchains with much different functionality, the high degree of cross-correlation is likely the result of the role of many speculators treating almost all assets in this space as "risk on" assets. We present evidence later that the correlation with non-crypto risk assets has increased through time.

**Exhibit 12: Correlation Between Coins**

We calculate daily intraday correlations between all pairs of the coins listed in Exhibit 3 using 15-minute non-overlapping returns, and then plot the 20-day moving averages (grey lines). In addition, we superpose the 25th, 50th (median) and 75th percentile of the various pairwise correlations at each point in time. The data start from when each coin began trading on Coinbase, and end on 26 January 2022.




## The Role of Cryptocurrencies in a Broader Portfolio

We now turn our attention to the role cryptocurrencies can play in a broader portfolio. We first look at the correlation between bitcoin and various static and dynamic (factor) investments. Next, we analyze the correlation between bitcoin and the S&P 500, using intraday data to obtain more statistical power to detect any change over time in this correlation.

[28] Yi, Xu, and Wang (2018) find return and volatility spillover effects from more prominent cryptos, like bitcoin, into other cryptos.

### *Correlation of Bitcoin to Other Assets*

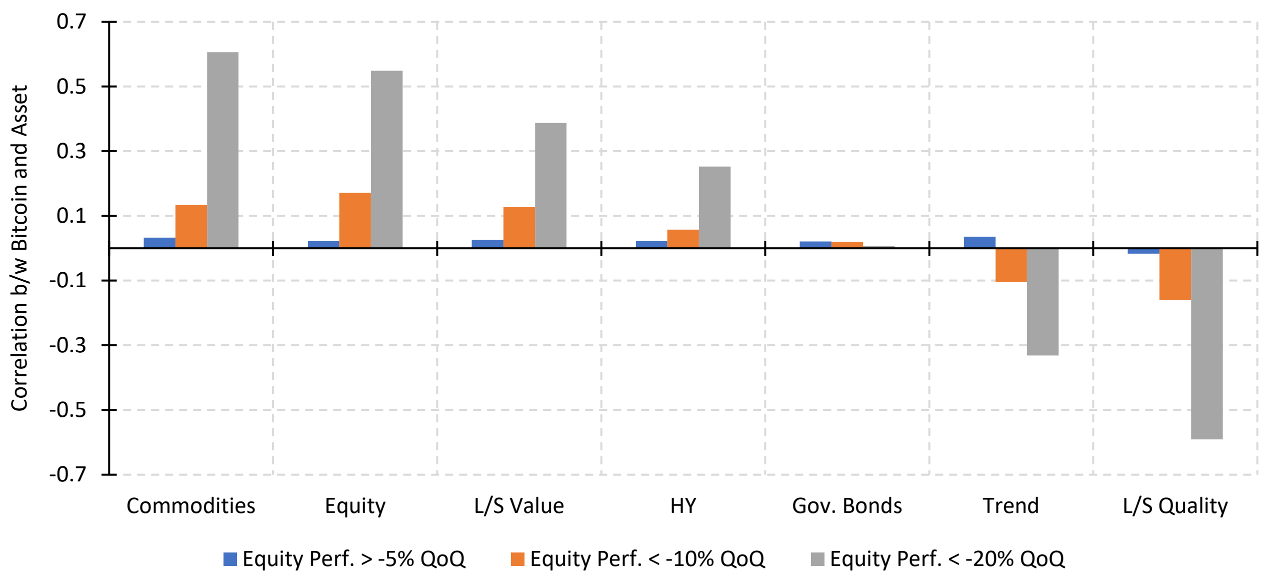
In Exhibit 13, we note that in normal times bitcoin has limited correlation to other assets often used as multi-asset portfolio building blocks. Indeed, on average, when equities are not in drawdown (which we define here as falling 5% or more over rolling quarters) the average correlation between bitcoin and the seven assets in our sample set is just 0.02.

However, as we move further into the left tail of the return distribution, the correlation with some of the naturally riskier assets rises dramatically. Heightened correlations during volatile periods are documented in the equity markets by Forbes and Rigobon (2002). In particular, we find that the correlation between bitcoin and a broad commodity basket moves from 0.03 in normal times, to 0.61 when equities are drawing down 20% or more over the quarter. Similarly, the correlation with equities themselves rises from 0.02 to 0.55. This suggests that multi-asset investors should have a degree of caution when allocating to cryptocurrencies; while there does seem to be a considerable diversification benefit to traditional betas when markets are tranquil, in drawdowns this advantage becomes more fragile.[29]

Exhibit 13 also suggests that Trend and L/S Quality Equities are good complements to a cryptocurrency allocation in a risk-off environment. The latter in particular sees correlation to bitcoin falling from virtually zero, to -0.59.

**Exhibit 13: Correlation to Other Asset Classes**

We calculate correlations between bitcoin and a number of multi-asset portfolio building blocks. Assets proxied as follows: Equity = MSCI World Local FX TR, Gov. Bonds = Bloomberg Barclays Global Agg Treasuries TR, Commodities = Bloomberg Commodity Index TR, Value and Quality strategies constructed by Goldman Sachs based on equal weight to U.S. and Europe, HY = Bloomberg Barclays USD HY Corporate TR, Trend = Man AHL global trend proxy. Three regimes defined according to QoQ performance of MSCI World. The data are daily from July 2010 to October 2021.



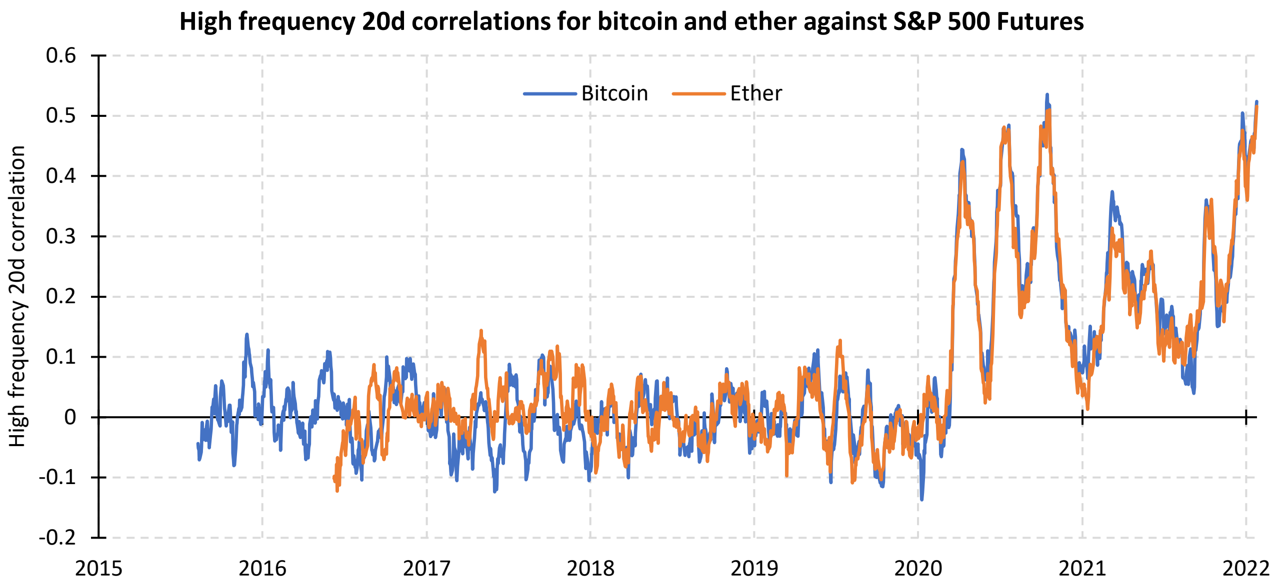

[29] Chuen, Guo, and Wang (2017), Borri (2019), and Petukhina (2021) find a low correlation between cryptocurrencies and other asset classes, while Iyer (2022) shows that cryptocurrencies and equities have become more interconnected over time, consistent with our empirical result.

### *Correlation of Bitcoin to the S&P 500 Index Over Time*

In Exhibit 14, we use 15-minute returns for each day to calculate a daily intraday correlation estimate between bitcoin/ether and the S&P 500 index and average this daily estimate over a rolling 20-day window. We see a clear regime change beginning March 2020, at which point the bitcoin/ether correlations to the S&P 500 went up notably. The results are very similar for other equity indices like the NASDAQ and EURO STOXX futures (not shown here). We do not find evidence that bitcoin or ether have started to correlate more to U.S. Treasury bonds or gold over time (not reported here either).

**Exhibit 14: Correlation to Equities Through Time**

We calculate intraday correlations between bitcoin/ether and S&P 500 futures using 15-minute non-overlapping returns between 0900-1400 Chicago time, and then smooth using a 20-day moving average. The data are from each coin's Coinbase trading start date until 26 January 2022.




## Adding Crypto to a Portfolio: Custodial and Regulatory Issues

We next discuss how to safely buy, hold, and sell cryptocurrencies.

There are many securities that retail investors have difficulty investing in, or are even prohibited from holding. For example, initial public offerings may be restricted to certain investors, or funds may have a prohibitively high minimum investment amount. For cryptocurrencies, however, retail investors have easy access, and it is professional asset managers that face substantial hurdles.

The reasons are perhaps twofold: individuals may be more willing to tolerate non-standard asset custody and institutions are obliged to perform AML and KYC checks on counterparties that some crypto service providers will be unable to satisfy.

Asset custody of cryptocurrencies is different from custody of other financial assets: coins themselves are not custodied (their location is identified on a blockchain). Instead, custody secures the private keys which enable the coins to be moved ('spent').

Custody broadly falls into two categories: self-custody and third-party custody.

At the most basic level self-custody is not dissimilar to storing a password, except in this case password loss may result in millions of dollars of asset loss because there is no password recovery mechanism. For example, spare a thought for Stefan Thomas, who famously had two more guesses (out of a total of 10) at a password before his multi-hundred-million-dollar stash of bitcoin became inaccessible forever.[30] Any asset manager taking this route should be aware of the risks involved.

First, assigning key safeguarding to one individual may leave the assets inaccessible if the individual dies or departs without revealing the key. The assets (not to mention the individuals) may also be put at risk if coercion is applied to the key holder(s). Any building holding the keys is at risk of intrusion – both physical and cyber.

Even if a building can withstand intrusion there is the additional risk of equipment failure, whether due to natural device failure (e.g. a hard-disk crash) or an external event such as a fire.

Finally, even if key storage is robust, it is important that user roles are satisfactorily segregated. For example, if a single individual can both whitelist a (third-party) address as well as authorize coin transfers, then that individual is able to steal the investor's assets.

Third-party custody does not change the problem, but rather delegates it to a business whose sole concern is these issues. They will likely employ a variety of defenses.

A common technique is to split coin holdings between 'hot wallets' (where keys are accessible on networked devices) and 'cold wallets' (where keys are held on devices physically disconnected from the internet). The increased safety of the latter typically comes at a cost of slower access to keys and therefore assets. In the event of loss, there may be an insurance tower covering some or all of the losses. This may be backed by a combination of custodian capital and specialist insurance. Such insurance is unlikely to cover investor instructions which appear correct but are actually fake. To counter this, there may be protocols for identifying valid customer instructions (and potentially identifying when instructions are being issued under duress).

Dependence and exposure to single individuals may be managed by employing specific key-management processes such as multisignature protocols requiring 'k of n' signatures to approve access, sharding to split keys across multiple locations, and HSMs – Hardware Security Modules that securely perform cryptographic functions.

While centralized custody runs somewhat counter to the ideals of a decentralized currency, it likely offers the greatest protection for large balances, has a similar 'look and feel' to custody of other assets, and may even be mandatory for certain regulated institutions.

Navigating a path through crypto while adhering to KYC/AML obligations can be challenging.

At one extreme, there is no hope of 'knowing your customer' when transacting on a permissionless decentralized exchange, so for some institutions this execution venue has to be ruled out. However, investing in the governance token of the decentralized exchange is not ruled out.

[30] https://www.nytimes.com/2021/01/12/technology/bitcoin-passwords-wallets-fortunes.html

Whether a centralized exchange is acceptable will depend upon the investors and the exchange. It is not just a matter of whether clients are identified and screened, but also whether any coins brought on to the exchange are screened against originating from sanctioned countries, sanctioned individuals, or having otherwise nefarious origins. For this, exchanges often use the services of specialist blockchain analysis services such as Chainalysis and Elliptic.

In order for such an analysis to be possible, a specific blockchain must not be deliberately obfuscating the origins of coins (i.e., their passage between addresses). This is one of the reasons why, for example, some of the larger service providers do not support Monero and Zcash, which have specific privacy features.

## Conclusions

There are five facts that summarize the current state of crypto investing. First, for years, crypto was not viewed as a serious investment or asset class. Indeed, Satoshi Nakamoto's seminal 2008 paper did not refer to 'digital gold'; bitcoin is cast as a transactional mechanism. In recent times, the space has blossomed into a very diverse set of assets and has started to move away from niche towards mainstream. Second, crypto volatility is very high. That said, it is relatively straightforward to achieve a lower volatility by mixing with cash, and we demonstrate that a risk-managed portfolio that mixes crypto with cash to achieve equity-like volatility has fewer left-tail events than equities over the limited sample. We also find that volatility persists in crypto assets as it does in other assets, and we demonstrate that trend-following strategies mostly outperform buy-and-hold strategies, judged by Sharpe ratios. Third, while the correlation with other traditional risky assets such as equities is low in normal times, the correlation rises to quite high levels in the left tail of these traditional risky assets. Fourth, there are practical considerations for institutional investors such as custody that need to be considered. Finally, given this is a new space, there are many unknowns such as the decisions that regulators will make over the next few years.

Along these same themes, what are the possible future paths for this space? It is quite possible that crypto continues on its path to becoming mainstream. Indeed, institutional adoption may increase as a result of the attractiveness of diversification. Further, tokenization has the potential to create new types of liquid investments such as digital art and music that further diversify investor portfolios. As longer-term institutional investors enter this space and provide liquidity, it is possible that the volatility of some of the cryptocurrencies moderates to levels displayed by commodities or currencies – but, of course, this depends on the particular cryptocurrency. If volatility moderates, the correlation with other asset classes may increase but one would reasonably expect cryptoassets to still provide some degree of diversification. Finally, while regulation is a risk factor, we find it to be unlikely that regulators will eliminate all cryptos.

One final thought. While your portfolio might have zero direct investment in crypto (leaving aside crypto-related securities in equity indices), that does not mean you have zero exposure. Indeed, you may have negative beta. That is, some of the names you are invested in might be challenged by some of the startups in the crypto space.

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## Appendix A: Gold, Bitcoin and Inflation

Neville, Draaisma, Funnell, Harvey and van Hemert (2021) found that, in historic inflation surge regimes over the past century, gold has delivered on average a 13% real annualized return – though this average is strongly influenced by the surge in gold prices in 1979 and 1980. In the current inflation regime – which began in March 2021 – gold's real performance has been 3% (as at end March 2022). One possible explanation for this historic discrepancy is that the yellow metal is starting to be disrupted by bitcoin. There may, however, be other reasons. As pointed out by Erb and Harvey (2012), while gold may be a robust inflation hedge over the very long term, in specific instances it is unreliable, and therefore it may be unwise to read too much into any single episode.

As discussed, there is a key flaw with the 'bitcoin as digital gold' model in that it assumes that gold and bitcoin are physical/digital twins, that is, the assumption ensures the result. While there are indeed similarities, as already discussed, there are also differences. Most of all, it may be observed that the hard stop on gold is much 'harder' than that of bitcoin. The 21 million coin limit is amendable with the support of 50% or more of the mining computing power.[31] There are many reasons why this would be difficult to attain – most notably the fact that it seems unlikely the system would vote for something that had the potential to erode its source of value – but it would not be impossible.[32] It would be impossible to program additional physical gold, even with all the hashing power in the world.

One qualification is that certain extractive technological leaps forward could make eye-wateringly vast additional gold supplies available. For instance, one geologist has estimated that there could be as much as 20 million tons of gold in the world's oceans, both dissolved within the seawater, as well as underneath the seabed.[33] Currently both sources remain economically unviable to exploit. Perhaps an even more outlandish source is the gold contained in extraterrestrial objects, as already alluded to. In 2020 Nasa began preliminary work to send a probe to 16 Psyche, an asteroid between Mars and Jupiter, containing enough gold, platinum, iron and nickel to be worth $15.8 quadrillion, at current prices.[34] Such advances are likely decades, if not centuries, away, but we highlight to illustrate that the hard stop on gold supply may perhaps not always be as established as it is today.

[31] The computing power is known as 'hashing power.' Currently this is running at around 190 million terahashes per second (one terahash = one trillion hashes), where hashes refer to a cryptographic hashing function known as SHA-256.
[32] And may become more likely over time. At the point at which we reach, or get close to, the 21 million limit, the block reward will approach zero. In order for miners to continue to be incentivized, either miners will need to leave the pool, transaction fees may have to rise or new coins will have to be minted.
[33] See https://www.forbes.com/sites/trevornace/2017/09/15/771-trillion-worth-gold-hidden-ocean/
[34] See https://www.bbc.co.uk/newsround/51858259 and http://www.asterank.com/

## Appendix B: Analysis of Mining

As alluded to in the main text, the multiple of mining cost model has two significant flaws. First, while it is too complex to make an accurate comparison between the capital intensity of bitcoin mining relative to conventional commodity extraction, it is likely that the former requires less fixed investment. An Antminer S19 Pro (currently the most powerful specialist bitcoin mining equipment on the market) retails for around $12,000. While the big farms will utilize many hundreds at once, it is unlikely to match the capital expenditures of the big commodity houses.

To illustrate this argument more fully, consider that the Antminer S19 Pro has a hashrate of 110 terahashes per second. Currently the entire bitcoin network is performing around 200 million terahashes per second. Thereby we may deduce that even if the entire network was running on the most efficient hardware possible, it would imply some 1.8 million units, costing just under $21bn. The useful economic life of these machines is around two years, and we can thus surmise that the annual capex cost of bitcoin mining is around $11bn. By comparison, if we take the Solactive Global Copper Miners Index as a benchmark, over the past 12 months its 39 members have between them made $31bn of capital expenditures. The comparison is not perfect, as many of these companies will have business lines other than copper extraction, but it does illustrate a potential explanation for the discrepancy in the mining cost multiple between bitcoin and 'other' commodities.

Second, while the model can be useful for computationally intensive tokens like bitcoin, it completely disintegrates with proof-of-stake consensus protocol. With the latter protocol increasingly dominant – ether is currently transitioning that way, for instance – the method may find itself limited to a smaller subset of tokens.

## Appendix C: Stock Versus Flow

For many of its advocates bitcoin and other cryptocurrencies derive their value from the fact that the creation of new units follows clear and pre-defined rules, rather than conventional tender which is printed at the unpredictable whim of centralized authorities. Indeed Satoshi Nakamoto – bitcoin's 0pseudonymous founder – alluded to this, embedding in the genesis bitcoin block the words "The Times 03/Jan/2009 Chancellor on the brink of second bailout for banks", widely seen as a condemnation of an unstructured operation of monetary policy that their new currency aimed to remedy.

While not a valuation method per se, according to this analysis we would expect to see flow-to-stock ratios[35] running at a healthy discount to those of centralized currencies. While this analysis could be applied to many different coins, we limit ourselves here to bitcoin and ether, given that their mining numbers are the most readily available. In Exhibit C we present this metric for both, alongside the four most heavily traded national units of exchange, being USD, JPY, EUR and GBP.

[35] We define this as the ratio of the amount of new currency issued in any given month, relative to the stock of currency in circulation at the beginning of that month. See note to Exhibit 8 for further detail.

Here we see both the bitcoin and ether ratios falling well below all the comparators from the middle of 2020. It is not shown here, but it is also notable that the volatility of bitcoin's ratio has greatly decreased. Indeed, this has fallen to 0.3% annualized as at the end of 2021, half the level of the euro and the yen, its closest competitors in this regard. Continuing to be a unit of exchange whose volume increases at a slower rate, and with greater predictability (as proxied by a lower volatility of new supply), will be an important input into the cryptocurrency value proposition and is therefore important to monitor.

While interesting to monitor, we find this analysis to be weak and self-serving. In particular for bitcoin, once the flow goes to zero, which currently is by definition guaranteed, the value will in theory become infinite. It is interesting, however, as an illustration of the cryptocurrency competitive advantage relative to traditional currencies, assuming continued central-bank largesse, as already discussed, but it should not be relied upon to give a quantitative definition of value.

**Exhibit B: Historic Flow-to-stock Ratios**

The chart shows the average flow-to-stock ratio, on a monthly periodicity, with a one-year lookback. For USD we use M2, for EUR and JPY M3, and for GBP M4; we find these measures to be roughly equivalent in their stipulations. For bitcoin we take the number of units in circulation on a monthly basis from blockchain.com. Otherwise data are all from Bloomberg.