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CRYPTOCURRENCY COMPETITION: AN EMPIRICAL TEST OF HAYEK'S VISION OF PRIVATE MONIES

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JEL Classification: B25, D40, E42, E50, E51, L11

Keywords: Cryptocurrencies, Currency competition, Network effects, Monopoly

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Cryptocurrency competition: An empirical test of Hayek's vision of private monies

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Abstract

We investigate monopolistic tendencies and the intensity of currency competition on the crypto market in the light of Hayek's "Denationalization of money". Interestingly, Hayek never considered that competition between private currencies could run on different functions of money, especially the function as a store of value and that as a means of exchange, which partly explains the differences in the set-up of private currencies that Hayek demanded and that of cryptocurrencies. Drawing on a large sample of 101 cryptocurrencies and a time frame from 2016 to 2022, we empirically examine the evolution and degree of competition on the crypto market, also taking changes in general crypto market structure into account. We find that competition is strong for unpegged cryptocurrencies that mostly compete as a speculative store of value. Competition is also strong for stablecoins when competing as a stable store of value. Competition is much less pronounced for the function as a means of exchange and network effects and monopolistic tendencies are more likely to be present on this sub-market.

Keywords: Hayek; Cryptocurrencies; Functions of Money; Currency Competition, Network Effects; Monopoly;
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1 Introduction

Almost half a century ago, Friedrich August von Hayek made the revolutionary proposal of a "denationalization of money". While there are historical examples of privately issued banknotes that were denominated in the national currency, Hayek envisaged something more radical. He propagated a competition of currencies, i.e. a competition of "*different kinds of money clearly distinguishable by different denominations among which the public could choose freely*" (Hayek, 1978, p. 27).

For decades, Hayek's proposal did not receive a lot of academic, political or economic attention. But with the creation of a whole cryptocurrency universe in the 2010s, currency competition has become real. Due to the long delay between Hayek's proposal and the spontaneous implementation of its vision, it is not surprising, that Hayek's name is rarely mentioned in the recent academic discussion on cryptocurrencies, exceptions being Brunnermeier, James, and Landau (2019), Fantacci (2019) and Sanz-Bas (2020).

It is regrettable that the spiritus rector of currency competition has been so much forgotten. On the one hand, this is a missed opportunity to test Hayek's hypotheses on monetary competition in a fascinating laboratory experiment, as it were. For another, many Bitcoin supporters in particular seem to overlook the fact that the market for cryptocurrencies is an increasingly competitive one, in which it is anything but certain that Bitcoin will be able to maintain its still strong position in the long run. Thus, with the exception of Gandal and Halaburda (2016) and Halaburda, Haeringer, Gans, and Gandal (2022), who do not refer to Hayek, the concept of currency competition has so far not received much attention in the academic papers on cryptocurrencies.

Our study addresses this deficit in the discussion of cryptocurrencies. We first work out how Hayek envisioned currency competition in concrete terms and what hypotheses he put forward for such a competitive process. This allows us to first identify differences and similarities between cryptocurrencies on the market today and Hayek's ideas. On this basis, we then conduct an extensive empirical investigation of the competitive processes in the cryptocurrency market. The cryptocurrency market is an ideal object of academic research as well-defined and high-quality data on prices and volumes over time are avail- able on a daily basis. We will use these data for a large number of cryptocurrencies thereby closing the analytical gap mentioned in the survey by Bariviera and Merediz-Solà (2020), according to which "*most past research was focused exclusively on bitcoin, or at most in the four or five most important cryptocurrencies.*"

Our study concludes that Hayek's hypotheses are only partially confirmed by reality. The most important finding of the reality test of Hayek's proposal is that competition between private currencies is possible in principle without the dominance of any single currency in the sense of a

natural monopoly. Thus, for the whole universe of cryptocurrencies one can exclude winner-take-it-all dynamics due to network-related reinforcement effects (Gandal & Halaburda, 2016). Instead, one can identify a stable co-existence of several cryptocurrencies and a market which is contestable, i.e. always open for successful new entrants. But beyond this fundamental agreement, there are clear divergences between Hayek's theory and the practice of currency competition.

- Whereas for Hayek the **stability of a currency** with respect to a specific bundle of goods or commodities was the decisive feature for the success of a private currency, unpegged cryptocurrencies are characterized by an almost excessive volatility compared to other financial assets.
- While for Hayek the **function of the means of payment** was central to currency competition, the unpegged cryptocurrencies are primarily in demand as a **speculative store of value**.
- There is greater congruence with Hayek in the case of **stablecoins**, which have met with a strong increase in investor interest in the recent past. But stablecoins target a stable exchange rate to the U.S. dollar and are thus just as exposed to the loss of purchasing power as the latter. And while the three major stablecoins are in demand as a stable store of value, there is one stablecoin (Tether) that dominates as a means of payment. Thus, the tendency toward a natural monopoly seems to prevail for this function of money, which, in this context, calls the concept of currency competition into question.

2 Hayek's proposal

Hayek presented his proposal in 1976 under the impression of relatively high inflation rates prevailing in the western world after the first oil crisis. In his view, the government monopoly over money was the main reason for the resurgence of inflation since the mid-1960s.

> "*It* [the monetary system at the time of Hayek's writing], *has the defects of all monopolies: one must use their product even if it is unsatisfactory, and, above all, it prevents the discovery of better methods of satisfying a need for which a monopolist has no incentive*" (Hayek, 1978, p. 27-28)

Thus, the main motivation for Hayek's proposal was the belief that private currency competition would force the issuers of money to keep their currencies **stable in terms of their purchasing power**.

> "*Neither a general increase nor a general decrease of prices appears to be possible in normal circumstances so long as several issuers of different currencies are allowed freely to compete without the interference of government.*" (Hayek, 1978, p. 95)

Hayek (1978, p. 46) described the **institutional features** of his concept as follows:

- "*I would announce the issue of non-interest bearing certificates or notes, and the readiness to open current cheque accounts, in terms of a unit with a distinct registered trade name such as 'ducat'.*
- *The only legal obligation I would assume would be to redeem these notes and deposits on demand with, at the option of the holder, either 5 Swiss francs or 5 D-marks or 2 dollars per ducat.*
- *This redemption value would however be intended only as a floor below which the value of the unit could not fall because I would announce at the same time my intention* [...] *to keep their (precisely defined) purchasing power as nearly as possible constant.*
- [...] *it seems neither necessary nor desirable that the issuing bank legally commits itself to maintain the value of its unit.*"

It is important to note that Hayek's proposal differs from 'free banking' models, as he did not envisage competition between monies of the same currency denomination, but a competition between monies that are **denominated in different currency units** (Fantacci, 2019).

Hayek was not very clear about the **convertibility** of private monies into national monies. While he speaks of a "*legal obligation*" (Hayek, 1978, p. 111) to convert private monies at a fixed rate into national currencies at least in the beginning, he also argues that convertibility is not decisive for his concept.

> "*Convertibility is a safeguard necessary to impose upon a monopolist, but unnecessary with competing suppliers who cannot maintain themselves in the business unless they provide money at least as advantageous to the user as anybody else.*"(Hayek, 1978, p. 111)

As far the **dynamics of private currency competition** are concerned, it seemed "*fairly certain*" to Hayek (1978, p. 52) that

a) "*a money generally expected to preserve its purchasing power approximately constant would be in continuous demand so long as the people were free to use it,*
b) *with such a continuing demand depending on success in keeping the value of the currency constant one could trust the issuing banks to make every effort to achieve this better than would any monopolist who runs no risk by depreciating his money,*
c) *the issuing institution could achieve this result by regulating the quantity of its issue, and*
d) *such a regulation of the quantity of each currency would constitute the best of all practicable methods of regulating the quantity of media of exchange for all possible purposes.*"

As a consequence, Hayek expected that private monies would gradually drive the national monies out of business:

> "*The appearance and increasing use of the new currencies would, of course, decrease the demand for the existing national ones and, unless their volume was rapidly reduced, would lead to their depreciation. This is the process by which the unreliable currencies would gradually all be eliminated.*" (Hayek, 1978, p. 53)

Astonishingly, Hayek did not consider the risk that due to **network effects** (Sanz Bas, 2020) the competition between private issuers could lead to a private monopoly:

> "*I trust the banks would be wise enough not to desire even a distant approach to a monopoly position, but to limit the volume of their business may become one of their most delicate problems.*" (Hayek, 1978, p. 94)

This is even more surprising as Hayek focused on the **medium of exchange** function as the main field of currency competition:

> "*There are four kinds of uses of money that would chiefly affect the choice among available kinds of currency: its use, first, for cash purchases of commodities and services, second, for holding reserves for future needs, third, in contracts for deferred payments, and, finally, as a unit of account, especially in keeping books. To treat these uses as different 'functions' of money is common but not really expedient. They are in effect simply consequences of the basic function of money as a medium of exchange, and will only in exceptional conditions, such as a rapid depreciation of the medium of exchange, come to be separated from it.*" (Hayek, 1978, p. 67)

Hayek dismisses the problems of **information and transactions costs** that are associated with the parallel use of several means of payment:

> "*Shopkeepers, on the other hand, so long as they know they can instantaneously exchange any currency at a known rate of exchange against any other, would be only too willing to accept any currency at an appropriate price*" (Hayek, 1978, p. 67)

Accordingly, Hayek did not consider the possibility that the processes of currency competition could be differ between the functions of means of payment and the area of store of values. This point was raised Bofinger (1985) who argued that such a differentiation between the different functions of money is crucial for the understanding of currency competition. In his view, competition in the means of exchange function would lead to a natural monopoly, while competition among financial assets in the store of value function could lead to stable coexistence of several or many competitors.

3 Cryptocurrencies and the Hayek proposal: differences and similarities

While the universe of cryptocurrencies comes close to Hayek's vision of a competition of private currencies "distinguishable by different denominations" (Hayek, 1978, p. 21), there are nevertheless not only similarities but also differences between Hayek's monies and cryptocurrencies. They concern above all the specific features of such financial assets and the behavior of the suppliers.

3.1 The money flower: a taxonomy for different forms of money

A useful approach for highlighting the specific features of Hayek's private money on the one hand and of cryptocurrencies, on the other hand, is the so-called money flower which was developed by Bech and Garratt (2017). It allows a **taxonomy of different forms of "monies"** by combining four different constituent elements.[1]

- Privately issued money versus money issued by the government
- Peer-to-peer exchange versus a centralized accounting mechanism
- Physical money versus digital money
- Convertible money versus inconvertible money.

The specific fields in the money flower can be attributed to the existing forms of money as follows:

- **Cash**: public, peer-to-peer, physical and inconvertible
- **Traditional bank deposits**: private, centralized accounting, digital, and convertible
- **Central bank reserves and central bank digital currency (CBDC)**: public, centralized accounting, digital and inconvertible
- **Classical cryptocurrencies (unpegged cryptocurrencies)**: private, peer-to-peer (distributed ledger), digital and inconvertible.

  Because of their inconvertibility, unpegged cryptocurrencies constitute a completely new asset class. While cash and central bank reserves in fiat currency system are by definition inconvertible, all private financial assets typically include a legal claim against the issuer (dividend payments and ownership rights in the case of shares, interest payments and redemption payments in the case of bonds, rights to purchase or to sell a financial asset at a

[1] Our money flower differs from the money flower developed by Bech and Garratt as it uses the element "convertible money versus unconvertible money". Bech and Garratt instead use the element "generally accessible versus not generally accessible".

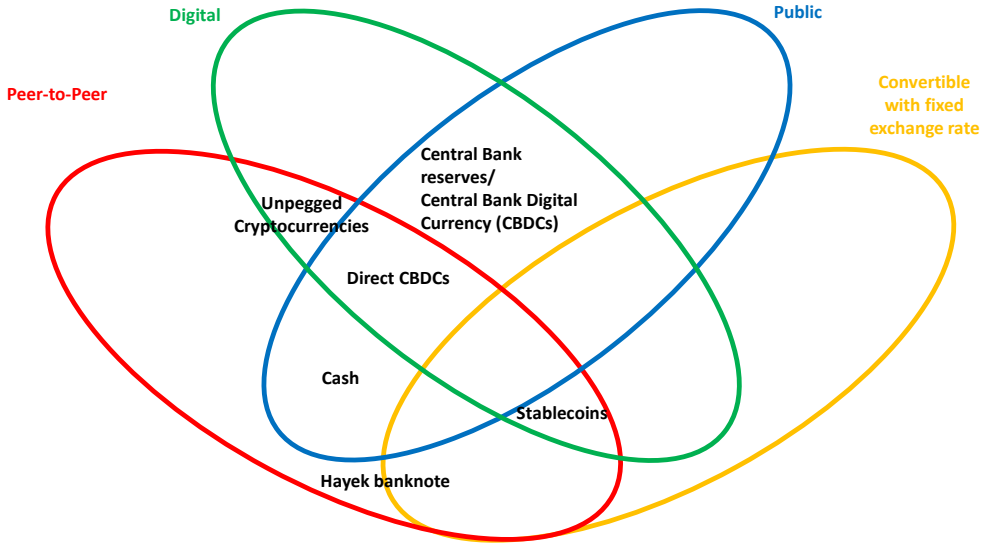

Figure 1: The money flower (based on Bech and Garratt (2017), own adjustments)

predetermined price in the case of derivatives). This is different with unpegged cryptocurrencies like Bitcoin which do not offer any legal right to the owner of such a financial asset. We therefore also speak of "unpegged cryptocurrencies".

- **Stablecoins (pegged cryptocurrencies)**: private, peer-to-peer, digital and convertible.

  Stablecoins are also a new asset class, as they are private, peer-to-peer, digital currencies with a fixed exchange rate (even if the legal status of convertibility can be questionable). Their convertibility also separates them from unpegged cryptocurrencies, even though stablecoins are usually regarded as cryptocurrencies. At the moment, the three largest stablecoins are Tether, USD Coin and Binance USD.

While the **monies of Hayek's currency competition** are private, one must differentiate between Hayek banknotes (physical and peer-to-peer) and Hayek bank accounts (digital and central accounting mechanism). The classification in convertible and inconvertible is difficult, as Hayek, as already mentioned, makes different statements about this important feature of a financial asset.

- If one assumes **convertibility** into national currencies, Hayek bank accounts are not so different form traditional bank accounts. Abstracting from the accounting mechanism, one could also compare them with stablecoins. The specific advantage of a Hayek bank account is the additional promise to keep the purchasing power stable so that they offer a hedge against the inflation risk. But this raises the fundamental question how a Hayek bank could be profitable if it offers the hedge for free.

- If one assumes for this reason that the Hayek bank provides **no legal convertibility obligation**, Hayek money comes to close to unpegged cryptocurrencies, except for the accounting

mechanism.

3.2 The money supply process and the role of the issuers

The differences between Hayek's money, traditional money and cryptocurrencies can be also highlighted by looking at the **issuing process**.

- **Traditional bank deposits** are typically created when a bank provides a loan to its customer. This also applies to the creation of **central bank money (reserves)** which can be created by central bank refinancing loans to commercial banks. But central banks and commercial banks can also create money by purchasing foreign exchange or bonds.
- The creation of **stablecoins** can be compared with the creation of commercial bank or central bank money by purchasing foreign exchange.
- The creation of **unpegged cryptocurrencies** is completely different as they are "mined", i.e., created without a corresponding purchase of monies or a credit transaction. This process has some similarity with Milton Friedman's other theoretical concept of "helicopter money" where bank notes are distributed from the air to the population.

For the creation of private money, Hayek had the traditional forms of money creation in mind:

> "*The issuing bank will have two methods of altering the volume of its currency in circulation: it can sell or buy its currency against other currencies (or securities and possibly some commodities); and it can contract or expand its lending activities.*" (Hayek, 1978, p. 59)

The differences in the money supply process determine the role of the **issuing institutions**.

- In the case of commercial bank money, the issuing institution decides on a discretionary basis about the supply of its money, which is identical with its lending policy.
- In the case of stablecoins, the issuer must regulate the supply in order to maintain the promised exchange rate to the dollar.
- In the case of unpegged cryptocurrencies, the supply process is **determined by a fixed rule** so that issuers behave passively. In the case of Bitcoin, the issuer is not even know to the public.
  - **Bitcoin**'s maximum supply is limited to 21 million BTC in total. Bitcoin issuance is halved every 210,000 blocks, which is roughly every 4 years. On 9 July 2016, the block reward was cut to 12.5 Bitcoin per bloc and on 11 May 2020 to 6.25 Bitcoin. Thus, the final Bitcoin is not expected to be generated until the year 2140.

- The **Ethereum** platform has an unlimited supply but an **annual maximum supply** of 18 million ETH. Due to the annual absolute supply cap of coins, the growth rate is slightly decreasing in relative terms.
- **Dogecoin** started with a limited supply of 100 billion coins, with an additional 5 billion coins put into circulation every year thereafter. Although there is no theoretical supply limit, at this rate, the number of Dogecoins put into circulation will double in 20 years.
- About 1 billion **Ripple** were pre-mined at launch and have been released gradually into the market by its main investors. A smart contract controls the release of XRP. Ripple planned to release a maximum of 1 billion XRP tokens each month as governed by an in-built smart contract; the current circulation is over 50 billion. The Ripple network, although decentralized, is owned and operated by a private company with the same name
- The rate at which **Litecoins** are generated forms a geometric series and halves every four years until a predefined total amount of Litecoins is reached to protect Litecoin from inflation. The Litecoin network therefore also produces four times as many units as the Bitcoin network over the entire process, whereby the number of Litecoins converges to 84 million.

In Hayek's vision, the issuer would be in a similar position as a stablecoin issuer who must regulate the issuance to maintain the promised fixed rate vis-à-vis the US-Dollar. But instead of stabilizing the exchange rate vis-à-vis a national currency, a Hayek banker must actively manage the issuance with the aim of maintaining a **stable commodity value of a currency**:

> "*The basis of the daily decisions on its lending policy (and its sales and purchases of currencies on the currency exchange) would have to be the result of a constant calculation provided by a computer into which the latest information about commodity prices and rates of exchange would be constantly fed as it arrived.*" (Hayek, 1978, p. 60)

4 Related literature

In the last few years, a rich strand of literature on the crypto market has developed. Most of the research focusses only on the most prominent cryptocurrencies, even though more recent studies use a larger set of cryptocurrencies. The findings most relevant for our analysis are briefly summarized here.

Theoretical findings Sanches and Fernandez-Villaverde (2016) examine the connection between Hayek and the crypto market from a theoretical point of view by constructing a model of currency competition. Their finding is that a system of competing currencies has the potential to increase efficiency and also the stability of a monetary system. They also show that private currencies tend to fail to provide the adequate amount of money for the economy, leading to monetary frictions. It can also be shown in their model that there exist asymmetric equilibria in which one dominant currency drives all competitors out of the market even though it can not be determined which currency will succeed.

Schilling and Uhlig (2019) provide a theoretical model for the monetary consequences of competition between Bitcoin and the USD and the evolution of Bitcoin prices. However, the model assumes that both BTC and USD can be used equally well for purchases which is vital for the competitive dynamics of the model but is not in line with reality.

Brunnermeier et al. (2019) make reference to Hayek and his concept of currency competition. They argue that in Hayek's sense, currencies would primarily compete as stores of value while cryptocurrencies can compete on all three functions of money. They also argue that 'full currency competition' demands competition on all functions of money, especially that of the unit of account, while 'reduced currency competition' only focuses on the function as a medium of exchange. They see an 'unbundling of the roles of money', i.e. the idea that low switching costs for digital forms of money allow for a specialization of digital moneys in one or more function of money. In their view, this can lead to increased competition between digital currencies along specialized dimensions. While this point is an important confirmation of our already established hypothesis, the analysis of Brunnermeier et al. (2019) is purely theoretical and does not examine actual competition between cryptocurrencies according to the functions of money.

Fantacci (2019) provides a close examination of Hayek's "Denationalization of Money" and its comparison to cryptocurrencies, namely Bitcoin, and the crypto market. The core ideas of Hayek's book are presented and subjected to critical evaluation. The author argues that Hayek does not provide convincing arguments that private currencies would not be subject to deflation and in that case be hoarded and not exchanged. Fantacci also briefly mentions currency competition but questions the possibility on the basis that cryptocurrencies do not represent liabilities for the issuers and therefore issuers of cryptocurrencies are not held responsible for the stability of value of their currency in the same way as they would be according to Hayek. While this analysis is valuable as a thorough study of Hayek's proposal, its scope is limited and purely theoretical. Also, currency competition on different functions of money is not taken into account.

Sanz Bas (2020) closely examines Hayek's "Denationalisation of Money" and compares unpegged cryptocurrencies and stablecoins to Hayek's idea of private money. He argues that unpegged cryptocurrencies (Bitcoin and altcoins) might be classified as digital assets that lack the monetary qualities Hayek saw as crucial for successful private currencies. The author also takes a close look at stablecoins and argues that while they come closer to Hayek's idea, they are at least currently only a bridge between fiat currencies and unpegged cryptocurrencies. While Sanz Bas (2020) addresses one of the key topics of our paper, the connection between Hayek's private currencies and cryptocurrencies, the focus is different. Sanz Bas asks whether unpegged cryptocurrencies and stablecoins are as Hayek imagined private currencies. We are more concerned with the question whether **competition** between cryptocurrencies is as Hayek envisioned it. Also, we examine how market dynamics are connected to different functions of money. The approach of Sanz Bas (2020) is based on intensive analysis of the relevant literature, whereas our analysis also takes into account the empirical realities of the crypto market.

Filip (2021) presents a multi-currency New Monetarist Model of cryptocurrency competition. Acknowledging the argument that strong network effects in the market for currencies protect government currencies and suppress private currencies, the paper shows that constant technological upgrades of cryptocurrencies due to competition may help to overcome this disadvantage. Also, cryptocurrencies can specialize on distinct needs of the public and provide additional services that are not available for government currencies.

Empirical studies Li and Wang (2017) examine determinants of the Bitcoin exchange rate and characteristics of Bitcoin as a financial asset. Their research, conducted in 2017, shows that it is important to examine different time periods. The first period, ranging from 2011 to 2013 reveals a different behaviour of the exchange rate between Bitcoin and the US-Dollar compared to the second period from 2013 to 2016. The early market shows stronger reactions to variables that capture public interest and technological impacts like the cost of mining. Hayes (2015) confirms the relationship between mining costs and cryptocurrency price. However, according to Li and Wang (2017), these technological factors become less relevant in the later stage of the market. The second period is also driven more by changes in economic fundamentals. In contrast to Yermack (2015) and Baur, Hong, and Lee (2018), who argue that Bitcoin is a highly speculative asset, the authors interpret this as a development where Bitcoin is evolving into a more sophisticated financial asset rather than a speculative object determined by waves of public interest.
White, Marinakis, Islam, and Walsh (2020) also discuss whether Bitcoin is more like an asset class or a currency and use in part similar methodological instruments as we do, such as correlation analysis and different time periods. However, their focus is more on Bitcoin vs. other assets like

gold and on the correlation between Bitcoin and regular currencies and not on a detailed analysis of the crypto market. They conclude that Bitcoin is most closely related to option indices and is distinctively different from currencies.

Corbet, Lucey, Urquhart, and Yarovaya (2018) provide a broad overview on the current state of research concerning the crypto market. Among many other topics, they take a look at intra-market dynamics finding that the sudden drop of Bitcoin price in January 2018 was accompanied by a shift in short-term correlations between Bitcoin and prominent Altcoins like Litecoin, IOTA and Bitcoin Cash. The authors see this as a sign of more informed investment decisions by crypto traders. Unfortunately, this result is not subject to further examination.

Bação, Duarte, Sebastião, and Redžepagić (2018) test the hypothesis of Bitcoin dominating the crypto market. Their analysis covers the top 5 cryptocurrencies in terms of market capitalization. While they use impulse responses and Geweke-feedback results for a sophisticated approach to assess the hypothesis, they only use price denominated in US-Dollars and not in Bitcoin which would have strengthened the intra-market perspective. The finding that Litecoin and not Bitcoin seems to be the transmission leader of the five cryptocurrencies is a surprising result that motivates further research on the dynamics of the crypto market in this paper.

Burnie (2018) analyses the connection between top ten cryptocurrencies between 2016 and 2018. Using correlation analysis, the author finds generally positive relationships between cryptocurrencies that are especially strong between cryptocurrencies that are forks. The exception is USDT, which shows no robust connection to the rest of cryptocurrencies under consideration. The study also finds strong correlations between cryptocurrencies with different set-up in terms of token creation, supply mechanism, etc., which hints at more complex underlying connections.

Aste (2019) examines the structure of the whole crypto market (1944 cryptocurrencies) during the first six months of 2018 using both sentiment and price analysis. He finds that interestingly minor low-capitalized cryptocurrencies play an important role in affecting both overall market sentiment and price development. Using a similar methodology, Francés, Grau-Carles, and Arellano (2018) also examine the structure of the crypto market. They analyse daily price data of 16 cryptocurrencies between July 2017 and January 2018.

Lahajnar and Rozanec (2020) examine correlations amongst ten major cryptocurrencies between 2017 and March 2020. They also use sub-periods according to general growth or decline of crypto market capitalization. The authors only look at prices denominated in USD and find moderate positive correlations between Bitcoin and the other cryptocurrencies when looking at the whole

period of their sample. They also find that correlations are relatively weaker during periods of overall market growth and stronger during times of market decline.

Stylianou, Spiegelberg, Herlihy, and Carter (2021) analyze the possible presence of network effects within the crypto market by examining the connection between valuation and user base of 6 prominent cryptocurrencies. They do not find a reliable connection between network effects and future valuation of cryptocurrencies. They do, however, find evidence for the presence of reverse network effects, i.e. a drop in valuation after a decrease in the user base. One of the most important findings is that according to their study, the crypto market is not characterized by winner-take-all mechanics and that the market is therefore not headed for a monopolistic or oligpolistic market structure.

Also closely connected is the study by Anisiuba et al. (2021) who study the prevalence of reinforcement or substitution effects in the crypto market for the global market and the emerging market economies of China, Russia and India. The authors use a sample of seven cryptocurrencies from August 2017 to November 2018. They find that Bitcoin and altcoins are on average positively correlated. They also find evidence from regression analysis that questions winner-takes-all dynamics for Bitcoin, which sees its position especially challenged by USDT.

Two of the papers most closely connected to the research question are the recent works by Gandal and Halaburda (2016) and Gandal, Gans, Haeringer, and Halaburda (2020) who also empirically access competition in the market for cryptocurrencies. However, they differ from our analysis as they do not specifically consider Hayek as the intellectual father of private currencies and as their analysis only covers the period until 2016 which does not include more recent developments in the crypto market. They do not find consistent evidence for winner-takes-all dynamics or tendencies of a natural monopoly for the first period of their sample but they see a reversing trend in the second period of the sample. Therefore, their analysis lays the ground for the analysis in this paper and provides a motivation for looking at the dynamics in different time periods separately.

To summarize:

- There are a number of findings in the literature that question the presence of network effects and winner-take-all mechanics in the crypto market.
- Some authors question that Bitcoin, or cryptocurrencies in general, can be defined as money. They do, however, base their assessment on the relative price behaviour of Bitcoin compared to other assets and not from a more theoretical perspective on the functions of money.
- Empirical studies tend to find positive correlations among cryptocurrencies, but there is also

evidence that there are changes to the pattern of relationships depending on overall market performance.

The vast majority of research analyses a very limited number of cryptocurrencies (usually less than 10), a relatively short time period (often a year or less), or suffers from a combination of both of this shortcomings. One of the contributions of this study will therefore be the large sample, both in terms of cryptocurrencies (>100) and time frame (2016-2022). In addition, we differentiate between unpegged cryptocurrencies and stablecoins and we also analyze the process of currency competition for the store of value and the means of payment function of money separately.

5 Empirical analysis of cryptocurrency competition

The dynamic developments in the cryptocurrency market offer an ideal opportunity to empirically test Hayek's central hypotheses. The first issue is the fundamental question of whether a market for private currencies is a competitive market, or whether there are tendencies toward a natural monopoly due to network effects that would call the concept of currency competition into question. Hayek was so animated by the idea of competition that he did not explicitly address this fundamental question.

For Hayek, moreover, there was no question that currencies with stable purchasing power would prevail in monetary competition, and he made no differentiation between the functions of store of value and means of payment.

Based on Hayek's hypothesis ideas, we want to analyze the market for cryptocurrencies from these two aspects in the following:

- Has this market proven to be a competitive one in recent years?
- What are the characteristics of the currencies that have proven to be particularly successful in this process, as evidenced by market capitalization?

In this analysis, we distinguish between the store of value function and the means of payment function, and between unpegged cryptocurrencies and stable coins.

The currency competition triggered by cryptocurrencies can be analyzed from different perspectives. From Hayek's perspective, it would be particularly interesting to see to what extent cryptocurrencies have succeeded in displacing liquid financial assets denominated in national currencies.

Here, the finding is relatively obvious. Despite their at times spectacular growth, the importance of cryptocurrencies is relatively limited. While the global broadly defined money supply amounted to USD 121 trillion in 2020, the market capitalization of cryptocurrencies was only around USD 1 trillion at last count (Figure 2). We therefore focus in the following on competition within the cryptocurrency market.

5.1 Measuring the intensity of competition

As a recent OECD study (OECD, 2021) makes clear, measuring the intensity of competition in markets is no simple undertaking. There are various methods for analyzing goods and services markets that can be applied, at least in part, to the market for private currencies. Available indicators can be distinguished according to whether they conceive of competition as a static or a dynamic concept.

Among the most important indicators based on the **static concept** are Concentration Ratios, which depict the market share of the leading suppliers, and the Hirschman-Herfindahl Index (HHI). We additionally examine correlations between USD prices of cryptocurrencies as an indicator of cryptocurrency substitutability from an investor perspective. We complement this analysis with a cointegration analysis.

Dynamic indicators primarily include rank stability measures. They examine how long individual providers can remain among the 10 or 20 most successful companies. We perform these analyses for the entire cryptocurrency market. In addition, we look separately at the markets for unpegged cryptocurrencies and for stablecoins, which have been able to attract enormous demand, especially since mid-2021.

5.1.1 Differentiation between boom, bust and stagnation phases

To gain a better insight into the competitive dynamics, we distinguish between the boom, bust and stagnation phases in the empirical analysis. We derive these from the changes in the market capitalization of the entire market.

Since 2009, when the first Bitcoin was created, the crypto market has received an impressive growth, especially since 2020. The market capitalization has reached a peak of 2.8 trillion USD in November 2022 and has since then declined to 1 trillion USD (Figure 2).

Figure 2: Total market capitalization of cryptocurrencies in US-Dollars (Source: coinmarketcap.com)

Based on these developments, we can identify several distinct periods:[2]

- 1^{st} period from January 2017 to December 2017 with the peak of the first boom,
- 2^{nd} period from January 2018 to December 2018 with the subsequent bust of the market,
- 3^{rd} period from January 2019 to October 2020 with a stagnation of the market capitalization,
- 4^{th} period October 2020 to May 2021 with the second boom in the market, which was far larger than the first boom,
- 5^{th} period from May 2021 to July 2021 with a short market slump,
- 6^{th} period from August 2021 to November 2021 with another strong boom, and
- 7^{th} period from December 2021 to February 2022 which is another bust period.
- 8^{th} period from February 2022 to April 2022 which is a short period of recovery.
- 9^{th} period from April 2022 until the end of our sample in September 2022, which was another bust period.

As we want to focus and boom and bust periods, we do not include the period before January 2017 into our analysis where Bitcoin had dominated the market (see Figure 6).

5.1.2 Static analysis

Concentration ratios A common measure of market concentration are concentration ratios (CR) (OECD, 2021, p. 11). Concentration ratios are an intuitive measure showing the market share of the top n firms in a market. The ratio is 1 if the top N firms make up the entire market and approaches zero for an infinite number of firms with equal market share of which only a fraction are part of

[2]The first two periods match the first two periods of Lahajnar and Rozanec (2020, p. 70) while period 3 and 4 of Lahajnar and Rozanec (2020) are part of period 3 in this study. The sample of Lahajnar and Rozanec (2020) ends in March 2020 and does therefore not include the large growth of the crypto market starting in October 2020. Looking back, the minor local peak of June 2019 as identified by Lahajnar and Rozanec (2020) is part of a period of stagnation.

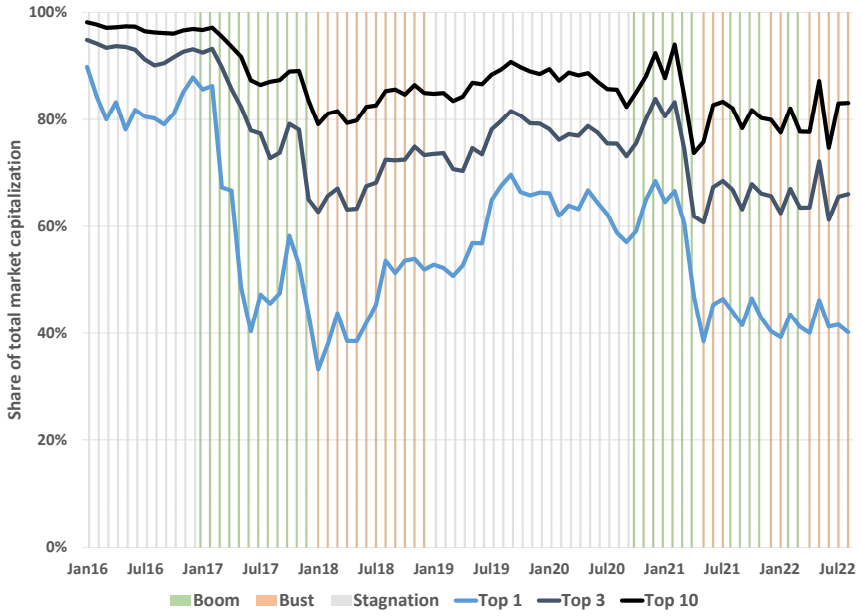

Figure 3: Concentration ratios of the whole crypto market (Source: coinmarketcap.com, own calculations)

N. Common values for N are C3, C5 and C10, which relate to the top 3, top 5 and top 10 firms respectively (OECD, 2021, p. 11). Concentration ratios only distinguish between the top N firms and the rest of market participants. It it is therefore advisable to compare different values of N to get a nuanced picture of market concentration.

To apply CR to the crypto market, we use C1, C3 and C10 which amounts to the top 1, top 3 and top 10 cryptocurrencies according to market capitalization. While the top 1 and top 3 of cryptocurrencies remain unchanged for most of the time, the composition of the top 20 is subject to frequent change. Market shares are calculated by dividing the combined market capitalization of the respective cryptocurrencies by total crypto market capitalization according to coinmarketcap.com. The result for the whole crypto market are presented in Figure 3.

Initially, concentration in the crypto market was very high. In early 2016, top 10 cryptocurrencies accounted for more than 95% of total crypto market capitalization and the top cryptocurrency, Bitcoin, for more than 90% of total market capitalization. During the first boom, CR's dropped significantly but rose again during the subsequent bust and especially during the period of stagnation from early 2019 until mid of 2020. Interestingly, CR's remained high during the second boom period in late 2020/early 2021 but fell dramatically during the turbulent phase of boom and bust cycles afterwards.

Figure 4 shows the concentration ratios of the crypto market but excludes stablecoins, i.e. only

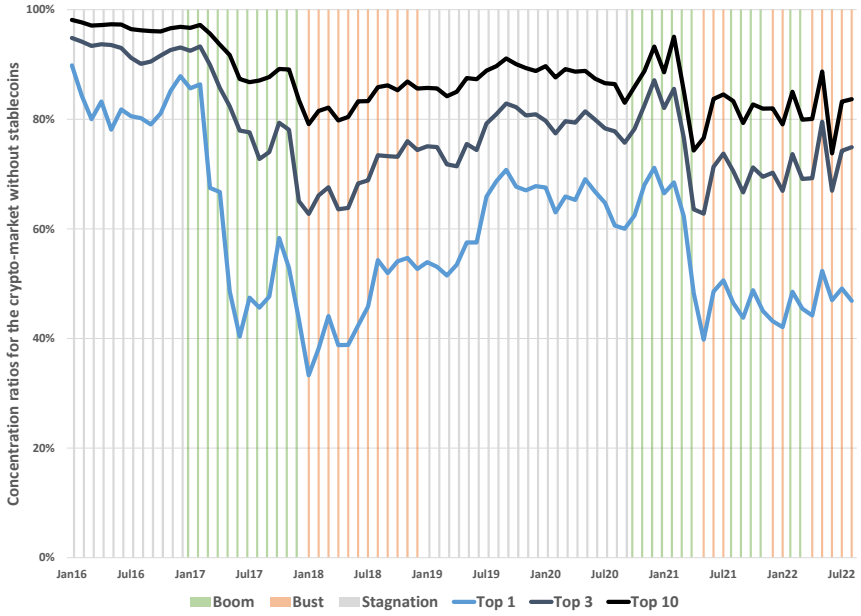

Figure 4: Concentration ratios of the crypto market excluding stablecoins (Source: coinmarketcap.com, own calculations)

shows the concentration of the market for unpegged cryptocurrencies.It can be seen that the general development of market concentration is the same when looking only at unpegged cryptocurrencies. However, market concentration is higher as important competitors to unpegged cryptocurrencies are now missing.

Figure 5 shows the concentration of the market for stablecoins. It is much higher than the concentration in the market for unpegged cryptocurrencies. The market is dominated by Tether which nevertheless has lost significant market shares to USD Coin and Binance USD and controls a similar share of the market as Bitcoin in the market for unpegged cryptocurrencies. However, compared to the market for unpegged cryptocurrencies, the top 3 stablecoins have a greater market share than the top 10 of unpegged currencies.

The Herfindahl index In the public discussion, the market for cryptocurrencies is often equated with Bitcoin, without taking into account the competition with other providers. The intensity of competition in other markets is usually described with the Herfindal-Index and the Lerner-Index. For the calculation of the Lerner Index prices and marginal costs are required. This makes it inappropriate for the analysis of crypto markets where no information on marginal costs is available.

Thus, we concentrate on the Herfindahl index (sometimes also called the Herfindahl-Hirschman Index). This index is a measure designed to capture the concentration of market power within a certain market (Rhoades, 1993, p.188). It can be calculated in the following way:

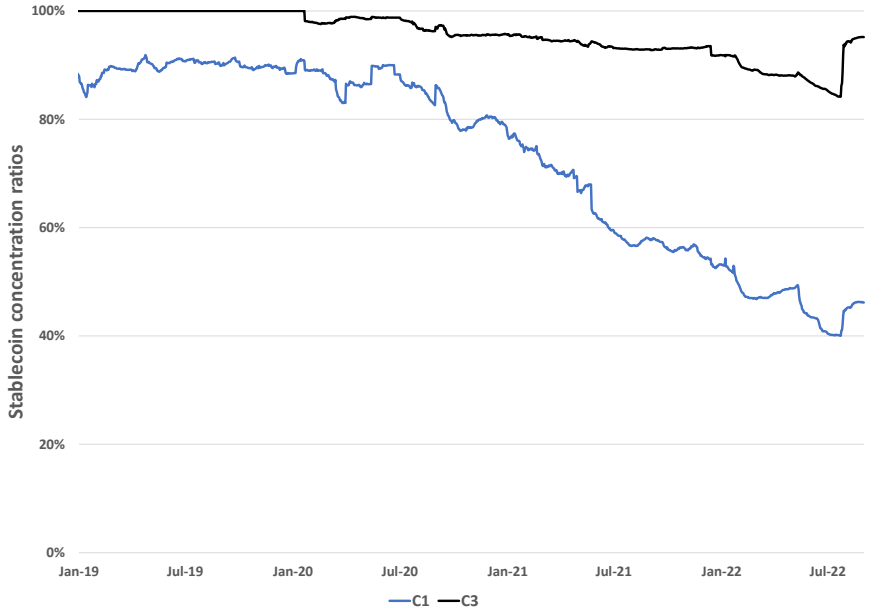

Figure 5: Concentration ratios of the market for stablecoins (Source: coinmarketcap.com, own calculations)

$$HHI = \sum_{i=1}^{n} (MS_i)^2, \tag{1}$$

where MS_i denotes the market share of each firm i in the corresponding market. The maximum value the HHI can reach is 10.000 which indicates that there is one firm with 100 percent market share while all the other firms have no market share. Therefore, the smaller the HHI, the more competition there is within the certain market.

Using the HHI, we can calculate the concentration within the crypto market. We use monthly data on 101 of the largest cryptocurrencies in terms of market capitalization as provided by coinmarketcap.com. We analyze the period from January 1^{st} 2016 to August 31^{th} 2022. This period captures the most dynamic part of the crypto-story up to now. Market shares are calculated within this group which made up more than 90 percent of all crypto market capitalization during the period in question.

In January 2016, with a value close to 8000, the index shows a very high degree of concentration within the market. This changed fundamentally in early 2017 with an abrupt decline. After a short reversal, the index reached a historical low of less than 2000 in January 2018. Since then, the degree of concentration increased again reaching values fluctuating around 4000. After another decline, the index has moved around 2000 since spring 2021.

Thus, since 2016 the structure of the crypto market has changed fundamentally. Especially in the first boom period, new competitors were able to penetrate the market. As Figure 3 shows, Bitcoin, which had held a market share of 90 percent in January 2016, has lost its dominant role. The strongly declining market share of Bitcoin since 2016 is also reflected in the data for the market shares of the Top 3 and the Top 20.

The change in the market structure since 2016 could perhaps be attributed to the search of investors for alternative currencies when the Bitcoin price had been rising dramatically for the first time. While Bitcoin could recover some of its dominance in the subsequent bust and stagnation periods, after another decline in early 2021 its market share is around 40 percent.

The horizontal merger guidelines of the U.S. Department of Justice and the Federal Trade Commission (Department of Justice, 2010, p. 19) generally classify markets into three types:

- Unconcentrated Markets: HHI below 1500
- Moderately Concentrated Markets: HHI between 1500 and 2500
- Highly Concentrated Markets: HHI above 2500

Thus, with a current HHI of around 2000, the market for cryptocurrencies can be considered as "moderately concentrated". The market for unpegged cryptocurrencies, which excludes stablecoins, is more concentrated and is oscillating between what is above classified as a "moderately concentrated market" and a "highly concentrated market".

A similar trend as in the market for unpegged cryptocurrencies can be observed in the market for stablecoins which in the beginning was even more concentrated than the unpegged crypto market. The total dominance of Tether ended in 2018. Since then, the market has become increasingly fragmented but its Herfindahl index is at a level of around 4000 which indicates a highly concentrated market (compare section 5.1.2).

Correlation analysis Another way to analyze the competition in the cryptocurrency market is to look at the correlations of the USD prices of each currency. Here, we assume that a high intensity of competition is reflected in high positive correlations. The more investors switching from traditional assets to the crypto market view the individual currencies as substitutes, the higher the correlation of their USD prices.

Our whole sample includes all cryptocurrencies that were in the Top 20 in terms of market capitalization at some point in time during the period from January 1^{st} 2016 to August 31^{th} 2022. This

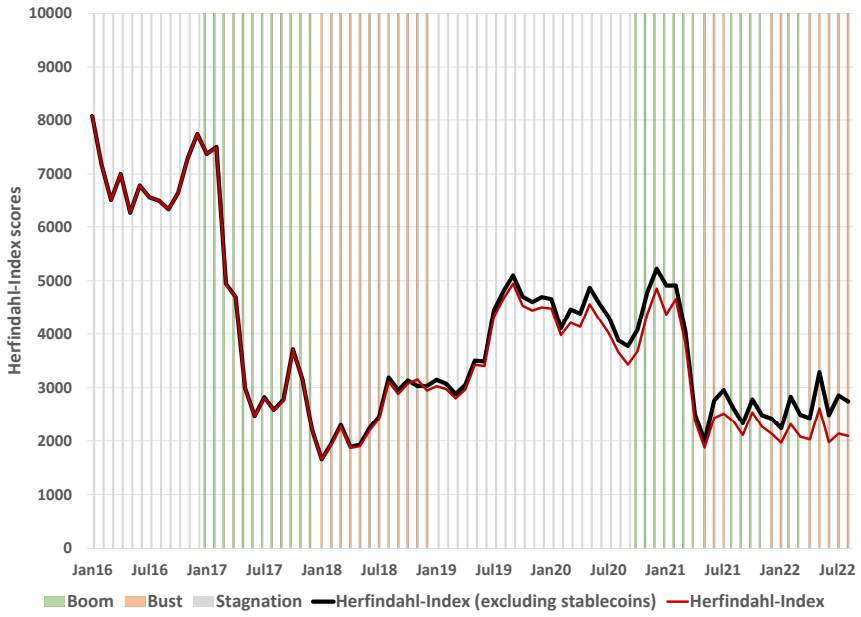

Figure 6: Herfindahl index of the crypto market (Source: coinmarketcap.com, own calculations)

Figure 7: Herfindahl index of the market for stablecoins (Source: coinmarketcap.com, own calculations)

amounts to 101 distinct currencies. A sample of 101 currencies means that there are $\frac{n(n-1)}{2} = 5050$ pairs that can be tested for correlation.

We find strongly positive correlations and only very few negative correlations between currency pairs. In Figure 8 red colorization indicates positive correlations, blue colorization indicates negative correlations, white indicates no correlation (the latter can also be the case if a cryptocurrency is no longer traded).

In order to interpret the results correctly, an example with a reduced number of currencies might help to illustrate the dynamics. Consider three currencies A, B and C. Prices of currencies B and C are denominated in units of currency A. If both currency B and C appreciate relative to currency A, correlations would be positive. If both B and C depreciate relative to currency A, correlations would also be positive. If B appreciates relative to A and C depreciates relative to A (or vice versa), correlations would be negative. If B appreciates relative to A while C remains constant relative to A, there would be no correlation[3]:

Table 1: Example of correlations

	B appr. rel. to A	B depr. rel. to A	B const. rel. to A
C appr. rel. to A	pos. corr.	neg. corr.	no corr.
C depr. rel. to A	neg. corr.	pos. corr.	no corr.
C const. rel. to A	no corr.	no corr.	no corr.

Therefore, the correlations presented in Figure 8 imply that investors who switch from USD (or other national currencies) into cryptocurrencies and vice versa regard most unpegged cryptocurrencies as substitutes. This finding supports the results of the Herfindahl index which shows a relatively high degree of competition in this market.

To get a more nuanced impression of market competition, the sample is split up into nine subsamples that are chosen according to the overall crypto market dynamics as seen in Figure 2.

Table 2: Correlations of cryptocurrency USD prices in boom, bust and stagnation

Boom periods	Corr.	Bust periods	Corr.	Stagnation	Corr.	Whole period
1	0.53	2	0.71	3	0.34	
4	0.76	5	0.71			
6	0.29	7	0.69			
8	0.53	9	0.79			
Average	0.53		0.73		0.34	0.42

The correlations of the USD prices for the nine subgroups in the boom periods, the bust periods

[3]Technically, a constant time series would of course result in zero variance and the resulting variance would thus be undefined, but if we consider a 'relatively' constant time series, the correlation would defined but close to zero.

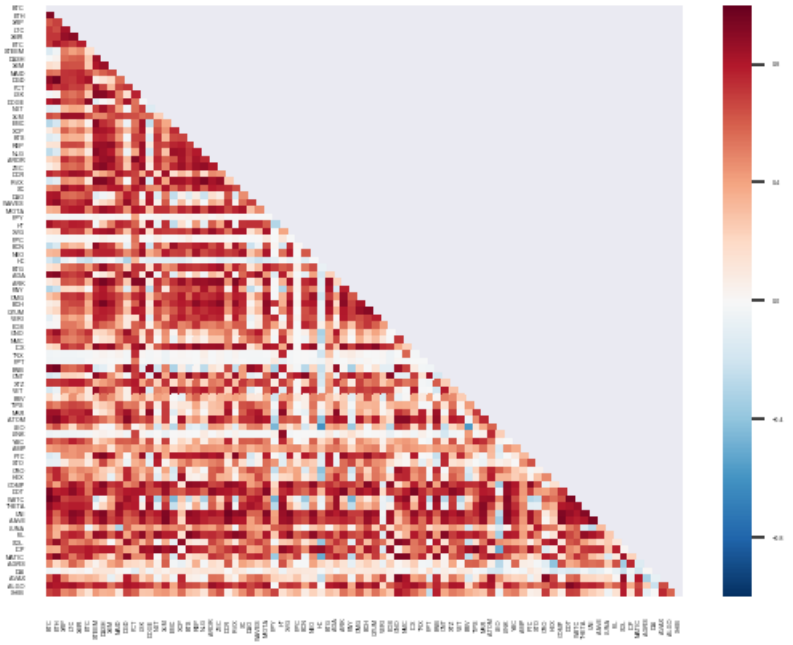

Figure 8: Correlations of selected cryptocurrencies denominated in USD

and the stagnation period are presented in Table 2. Heatmaps for the correlations in each period and also for prices in BTC are presented in the Appendix. For the whole period, they show a positive correlation. While the correlation it Is relatively weak in the stagnation period (0.34), it is more pronounced in the periods with strong overall market movements. In the boom periods, the average correlation is 0.53, in the bust periods it is 0.73. For the whole period, it is difficult to identify a trend in these correlations.

From the perspective of currency competition, the positive correlations indicate that investors who switch from USD (or other national currencies) into cryptocurrencies and vice versa regard

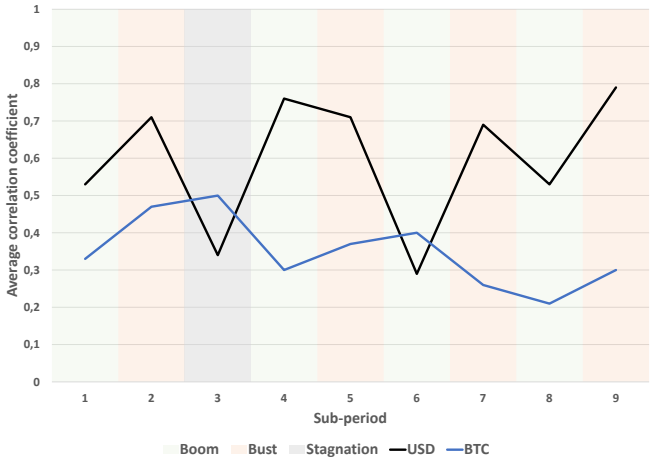

Figure 9: Average correlations for sub-periods in BTC and USD

most unpegged cryptocurrencies as substitutes. As apparent from our analysis, investors consider cryptocurrencies even more as substitutes in bust periods than in boom periods. Our findings support the results of the Herfindahl index which shows a relatively high degree of competition in this market. In stagnation periods which are characterized by a constant market capitalization, investors seem to differentiate more between cryptocurrencies which shows in a relatively low overall correlation coefficient (0.34 for stagnant periods, compared to 0.53 for boom periods and 0.73 for bust periods). This is again in line with Concentration Ratios (Figure 3) and the Herfindahl index which rose by about 2000 points during the period of stagnation (Figure 6), indicating increasing market concentration.

Our results confirm the analysis by Lahajnar and Rozanec (2020) which ended in October 2020. The authors analyzed bilateral currency pairs and also found weaker correlations for bull periods than for bear periods.

Cointegration Analysis As a next step, we check which price time series of the cryptocurrencies are cointegrated. Cointegration testing provides for a measure that tells us whether time series follow a common trend. A common dynamic in price development, i.e. cointegration, could again be interpreted as an argument that investors consider cryptocurrencies as substitutes. Correlations can be spurious, as many examples have shown. One way to overcome the problem that is imposed by the possibility of unit roots in the relevant time series is to look at the long-term relationship of two time series, which can be done by testing for cointegration. In that way, cointegration analysis is a check of our correlation analysis with more advanced techniques. For the cointegration test to make sense, we first need to check whether each series is stationary by testing for a unit root process in the series. This is done by using the standard approach of a Dickey-Fuller test in its augmented form [4]. The sample consists of daily data of the cryptocurrencies that were in the top 20 of cryptocurrencies for at least one month during the period in question (see above). The time series are available via the API of CryptoCompare[5] which was accessed using Python. Seven of the cryptocurrencies had to be omitted from the analysis as the data was not available[6]. Both the Augmented Dickey-Fuller test and the cointegration test are conducted using the statsmodels package for Python. The result of the Augmented Dickey-Fuller test provides a mixed picture. For about half of the cryptocurrencies we cannot reject the hypothesis of the presence of a unit root in the series.

The standard two-step Engle-Granger cointegration test is implemented, again using the statsmod-

[4] This standard approach will not be discussed here, for further information please refer to Hamilton (2003)
[5] See https://min-api.cryptocompare.com/documentation
[6] The omitted cryptocurrencies are BCC, VASH, ADCN, 999, AGRS, TAGZ5 and ACA.

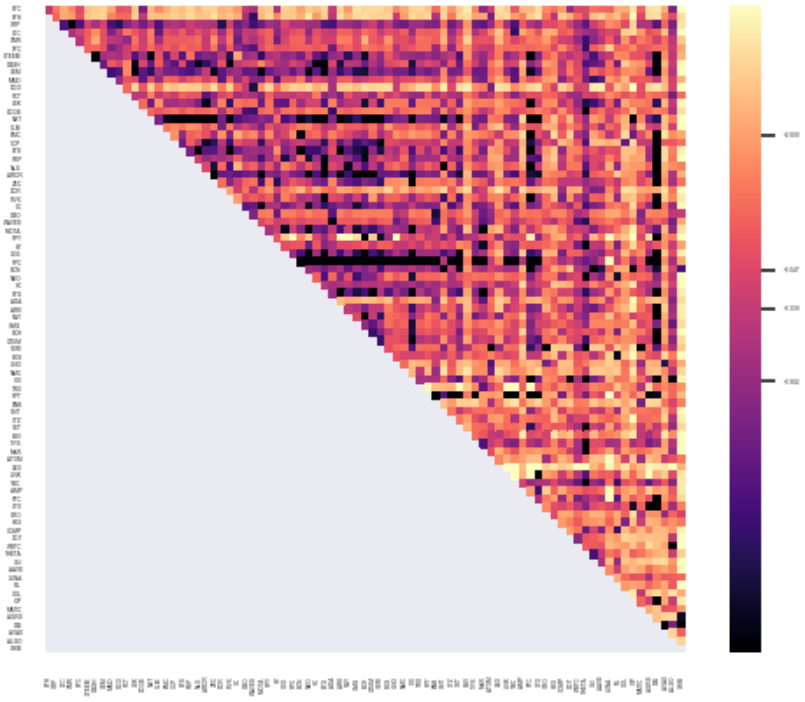

Figure 10: t-statistics of Engle-Granger cointegration tests for selected cryptocurrencies denominated in USD

els package for python. As the method is designed for univariate equations, each pair of cryptocurrencies is tested separately for cointegration where the null hypothesis is that there is no cointegration while the alternative hypothesis is that there is a cointegrating relationship between the pair of cryptocurrencies tested. Figure 10 shows the t-statistics of the Engle-Granger cointegration test, the critical values can be obtained from the index. Average t-statistics both for prices in USD can also be obtained from Table 3. The results show that there is a co-moving component as we can on average reject the null hypothesis for the whole sample, which would again be a confirmation of the hypothesis that cryptocurrencies are seen as substitutes by investors. There is however no clear pattern when we look at the overall picture of of cointegrating relationships within the crypto market. Instead, some currencies show strong co-movements while others show none at conventional significance levels. Interestingly, there are some currencies that seem to be in a strong relationship with many other cryptocurrencies while others seem to move on their own. Further research could tell us more as to why these currencies show such strong dependencies while the overall picture shows little co-movements.

Again, the test is repeated with a decomposed sample that is split up in nine periods as in section 5.1.2. The main result here is that for the average t-statistics of the sub-periods, we can not reject the null hypothesis of no cointegrating relationship. Without exceptions, the t-statistics are slightly closer to a conventional significance level during bust periods than during boom periods. This

result was also found when looking at correlations.

Table 3: Average t-statistics of Engle-Granger cointegration tests [7]

Boom periods	E-G	Bust periods	E-G	Stagnation	E-G	Whole period
1	-1.82	2	-2.91	3	-2.26	
4	-2.28	5	-2.77			
6	-2.39	7	-2.74			
8	-2.08	9	-2.69			
Average	-2.14		-2.78		-2.26	-3.44**

Overall, the empirical analysis indicates a high degree of competition for the unpegged currencies and a relatively high concentration for stablecoins. Competition within the market seems to have increased after overall market capitalization began to rise. The Herfindahl index fell from a very high score to one that is now lower than in most industries. When looking at correlations and cointegration, cryptocurrencies show strong dependencies when looking at the whole sample which would be an indication that cryptocurrencies are seen as substitutes and thus be an argument in favor of competition. The connection is, however, less strong during the recent sub-periods of growth. In general, both the results from cointegration and correlation analysis suggest that the price movements of cryptocurrencies show a stronger connection during bust periods.

5.1.3 Dynamic analysis

One drawback of static analysis is that it does not reveal the extent to which new entrants succeed in entering the market, displacing existing entrants in the process. This aspect, which is important for the competitive process, can be identified using the methods of dynamic analysis.

Rank analysis Figure 11 provides a different perspective on crypto market competition, which might seem confusing at a first glance. The figure tracks the rank of each of the top 20 currencies in terms of market capitalization from January from 2016 until to May 2022.

The figure shows an impressive dynamic in the market for cryptocurrencies. Many currencies could stay in the top 20 only for a very short period of time and very few were able to stay in the top 20 for the whole period under consideration. Over time, a clear change in the pattern can be observed. While there the first years were characterized by rather chaotic movements, the dust seems to have settled somewhat between 2018 and 2020, only to become chaotic again afterwards.

[7] Critical values for 1% (***), 5% (**) and 10% (*) significance levels are -3.99, -3.39 and -3.08 respectively.

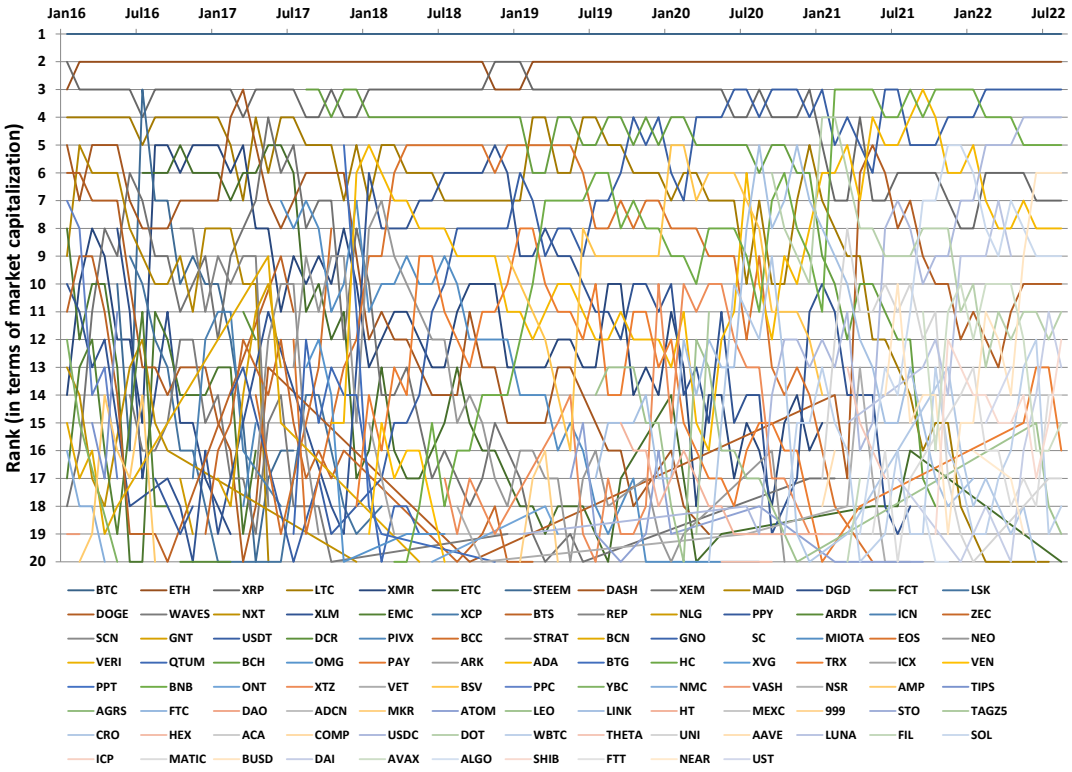

Figure 11: Rank of top currencies by market capitalization (Source: coinmarketcap.com, own calculations)

A more common measure of market competition is the analysis of **rank persistence** (OECD, 2021). Figure 12 shows the dynamic evolution of both the top 10 and the top 20 cryptocurrencies by market capitalization. The lines present the number of cryptocurrencies in the top 10/top 20 that have already been in the top 10/top 20 the month before and one year before. The lower the number, the more new entrants into the market and thus the more competitive the market (analogous for the top 20). Especially during the first and second boom period there was a relatively large number of new cryptocurrencies entering the top 10/20, while during stagnant period between 2019 and late 2020 there were relatively little newcomers into the top tier of cryptocurrencies. This result not only matches Figure 11, but also the results from the previous static analysis.

Overall, one can say, that, with the exception of the stagnation period, it is relatively easy to stay for one month in the top10/top 20. But for the one-year period, only about 50% of the currencies were able to keep their position in the top10/top 20 group. This is again an indication that the crypto currency market is characterized by rather high degree of market entries and exits which speaks for a high degree of competition.

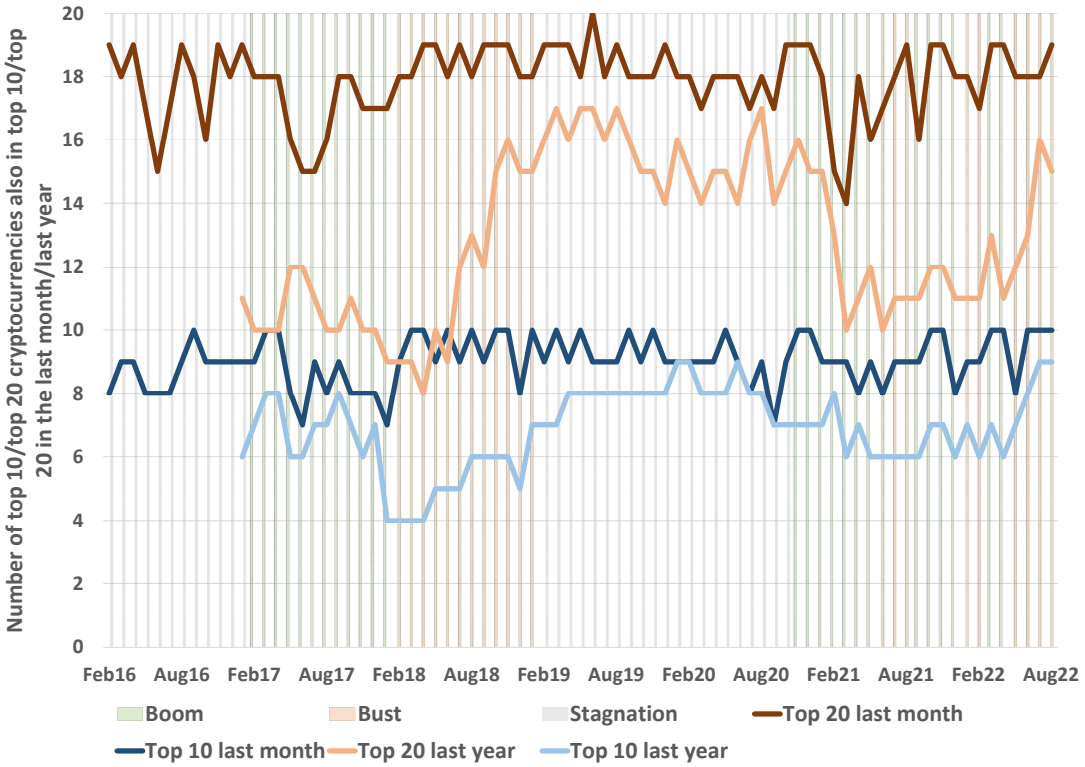

Figure 12: Rank persistence measured by amount of top currencies already in top ranks in the previous month (Source: coinmarketcap.com, own calculations)

Metric of top currencies In order to further investigate the dynamism of competition within the crypto market, we use a different measure the success of a cryptocurrency over the whole sample period. Success is in this case quantified by minimizing the average of the rank held by a certain currency as shown by the following formula:

$$S_i = \frac{\sum_{t=0}^{T} r_{i,t}}{T} \tag{2}$$

where S_i is the score of cryptocurrency i, $r_{i,t}$ is the rank of cryptocurrency i in period t and T is the number of periods cryptocurrency i spent in the top 20 of cryptocurrencies by market capitalization. Ranks are calculated using monthly snapshot data from coinmarketcap.com. The top 20 cryptocurrencies in terms of smallest score value and an overall number of periods spent in the top 20 in terms of market capitalization are presented in Table 4. Those currencies that have been in the top 20 longer than the average are printed in bold letters.

Table 4 again shows the dynamism of the crypto market. A large number of the cryptocurrencies presented here have been traded on markets prior to December 2015, the start of our sample.

[8]Retrieved on August 28^{th} 2022

Table 4: Top 20 Cryptocurrencies according to score (Source: coinmarketcap.com, own calculations)

Rank (Score)	**Name**	**Score**	**Start data availability**	**Periods in top 20**	**Curr. Rank**[8] (market cap.)
1	**Bitcoin**	1.00	01.01.2016	80	1
2	**Ethereum**	2.05	01.01.2016	80	2
3	**Ripple**	3.95	01.01.2016	80	7
4	DAO	5.00	17.05.2016	1	150
5	**Bitcoin Cash**	5.92	01.08.2017	51	29
6	**Tether**	6.83	01.01.2016	60	3
7	**Litecoin**	7.46	01.01.2016	76	21
8	**Binance Coin**	8.18	27.06.2017	54	5
9	**Cardano**	8.83	05.10.2017	59	8
10	**EOS**	8.88	29.06.2017	43	36
11	**Polkadot**	9.00	20.08.2020	24	11
12	**MaidSafe Coin**	9.00	01.01.2016	17	243
13	Storeum	9.00	25.07.2019	1	2683
14	Internet Computer	9.00	10.05.2021	1	33
15	**Bitcoin SV**	9.35	15.11.2018	26	48
16	**Solana**	9.53	11.04.2020	17	9
17	**USD Coin**	10.00	09.10.2018	27	4
18	Augur	10.25	01.01.2016	8	271
19	**Dash**	10.41	01.01.2016	49	73
20	Terra	10.7	28.07.2019	9	229

However, there are also numerous new entrants especially in 2017 and even in 2021. Even though they have entered the market at a significantly later stage, they were able to not only compete with cryptocurrencies already in the market, but to also outperform them in some cases. It is also interesting to compare the rank of the most successful currencies over time to their current rank in terms of market capitalization. While some cryptocurrencies have a lower current rank compared to the rank calculated by their score, some that have been very successful for short or medium periods of time have vanished from the market as in the case of Storeum or have become irrelevant as in the case of DAO, Augur and MaidSafe Coin (the latter of which has been in the top 20 for a almost a quarter of the time of our sample). This shows a high degree of competition. Of the 20 currencies that were the most succesfful during the whole period, more than 10 are no longer among the present top 10.

A similar picture is obtained by Table 5 which reverses the order by presenting the current top 20 in terms on market capitalization. Only 9 of the current top 20 were among the Top 20 according to the score for the whole period.

Summary statistics are presented in Table 6. During the observed window of 80 months the median of time within the top 20 in terms of market capitalization was 6.5 months while the average was more than double this time span. It is interesting that even the most successful cryptocurrencies so far, which are the cryptocurrencies in our sample, mostly spend less than half a year among the top

[9]Retrieved on August 28^{th} 2022

Table 5: Top 20 Cryptocurrencies according to present[9] market capitalization (Source: coinmarketcap.com, own calculations)

Rank (market cap)	**Name**	**Score**	**Start data availability**	**Periods in top 20**	**Rank** (score)
1	Bitcoin	1.00	01.01.2016	80	1
2	Ethereum	2.05	01.01.2016	80	2
3	Tether	6.83	01.01.2016	60	6
4	USD Coin	10.00	09.10.2018	27	17
5	Binance Coin	8.18	27.06.2017	54	8
6	Binance USD	12.00	05.09.2019	15	26
7	Ripple	3.95	01.01.2016	80	3
8	Cardano	8.83	05.10.2017	59	9
9	Solana	9.53	11.04.2020	17	16
10	Dogecoin	11.22	01.01.2016	21	20
11	Polkadot	9.00	20.08.2020	13	9
12	Dai	16.44	01.11.2019	9	66
13	Polygon	16.31	29.04.2019	13	64
14	Shiba Inu	14.55	01.08.2020	11	47
15	TRON	13.49	26.09.2017	43	33
16	Avalanche	12.42	21.09.2020	12	29
17	UNUS SED LEO	15.78	20.05.2019	18	57
18	Wrapped Bitcoin	16.59	31.01.2019	22	69
19	Uniswap	13.53	17.09.2020	15	34
20	Ethereum Classic	13.30	23.07.2016	46	32

ranks before they get replaced by other currencies. The difference between average and median periods in the top 20 also shows that there are some very successful currencies that manage to stay in the top 20 for a longer period of time while the majority of currencies only gets to enjoy a short-lived period of success leading to a skewed distribution.

Table 6: Summary statistics of rank analysis

Number of Cryptocurrencies	101
Number of Periods	80
Average score	14.78
Median score	15.42
Average of periods per currency	13.86
Median of periods per currency	6.50

5.1.4 Results of competition analysis

In sum, static and dynamic analysis come to a relatively similar picture. The **static analysis** shows that concentration of market power, measured by market capitalization, has decreased significantly since 2016 when it was a highly concentrated market. With a value around 2000 the crypto market can now be considered a moderately concentrated market according to the classification of the Department of Justice (2010, p. 19). It is noteworthy, that the concentration of market power increased during the period of stagnation (2019-2020) and dropped again during the second boom

of the crypto market in late 2020. The evolution of concentration has been relatively symmetric on the market for unpegged cryptocurrencies showing in the fact that increases and decreases of concentration show for top 1, top 3 and top 20 cryptocurrencies in a similar way. In contrast, the market for stablecoins is more concentrated and the decrease in market share of the top 1 stablecoin does not translate to a similar decrease in the market share of the top 3.

Further examination of correlations and Engle-Granger cointegration provides evidence in favor of strong competition in a confirmation of the hypothesis that cryptocurrencies are generally seen as substitutes rather than complements. When looking at sub-periods defined by boom-bust cycles of the crypto market, we see that connections between cryptocurrencies are generally stronger in periods of strong overall market movements and weaker during periods of stagnation. While investors seem to regard cryptocurrencies more as substitutes during booms than during stagnant periods, the connection between cryptocurrencies is strongest during bust periods.

Rank analysis also indicates that the market for unpegged cryptocurrencies is competitive as there is a high turnover among the top10/top 20 competitors. It also shows that the market is more dynamic during boom-bust periods. Both during boom and bust periods we see a large number of top 10/top 20 cryptocurrencies that were not among the top currencies in the last month or the last year. During the stagnant period, the composition of the top cryptocurrencies was very stable. The second boom/bust cycle starting in late 2020 appears to be slightly more stable in terms of the composition of top currencies compared to the first boom/bust cycle.

We then use an *ad hoc* metric to find the most successful cryptocurrencies for the span of our sample. We find that the most successful cryptocurrencies are very heterogeneous both in their characteristics and the entry to the market. Some of the most successful currencies have been created very early, but there are also a significant number of successful currencies that have entered the market only very recently. On the other hand, currencies that were successful in the early stages of the market have factually been forced to exit the market, even if some still technically exist.

Overall we argue that competition is high for the market of unpegged currencies. A range of methods showed the dynamism of the market, especially during booms and busts. The market for unpegged cryptocurrencies has evolved from a very concentrated one towards a moderately concentrated one. In contrast, the market for stablecoins is still very concentrated and not showing promising signs of a decrease in concentration. This is especially interesting, as the set-up of stablecoins is much closer to that of the private currencies that Hayek had in mind. This bifurcation of markets for cryptocurrencies with very different degrees of competition will now be examined further, but it has already become clear that opposing patterns of competition on the two markets

argue in favour of a critical distinction between the two types of digital assets.

5.2 What are the features of successful cryptocurrencies?

The difference in the degree of concentration in the market for unpegged cryptocurrencies and for stablecoins is a main result of the competition analysis of the previous section. We will now examine the key determinants of these two markets more closely. By recurring to Hayek, we will argue that these two markets rely on two different functions of money: the market for unpegged cryptocurrencies is driven mainly by the function of a safe store of value and the means of payment function.

5.2.1 Store of value: Volatility versus valuation

When we look at the crypto market from the perspective of the function of crypto-money as a store of value, we see a bifurcation of this market: the market for unpegged cryptocurrencies rewards high volatility as this allows for speculative returns. The market for stablecoins rewards stability as the focus lies on a stable store of value. To measure success as a store of value, we use market capitalization as an indicator. USD prices of unpegged cryptocurrencies and stablecoins allow to compare volatility both relative to other cryptocurrencies and conventional currencies and assets.

High volatility assets One of the key differences between Hayek's proposal and unpegged cryptocurrencies is the role of suppliers. While Hayek expected an active quantity regulation by the issuers to guarantee stability of value (see section 2), the issue of unpegged cryptocurrencies is determined by a rule which means that the issuers behave passively.

The result of this passive behavior is an excessive volatility of unpegged cryptocurrencies (Figure 13), with **daily** changes in valuation of more than 150%. The high degree of volatility also becomes obvious if one compares the volatility of Bitcoin with the volatility of Gold and of the Dow Jones index (Figure 14).

Thus, while Hayek expected that the stability in terms of purchasing power would be the decisive factor in private currency competition, the attractiveness of unpegged cryptocurrencies is in fact at least weakly positively correlated with the volatility of such assets. The currencies with the highest market capitalization are also the currencies with relatively high volatility (Figure 15). In stark contrast to Hayek's idea, volatility of cryptocurrencies is therefore far more excessive than that of regular public currencies and comparable assets.

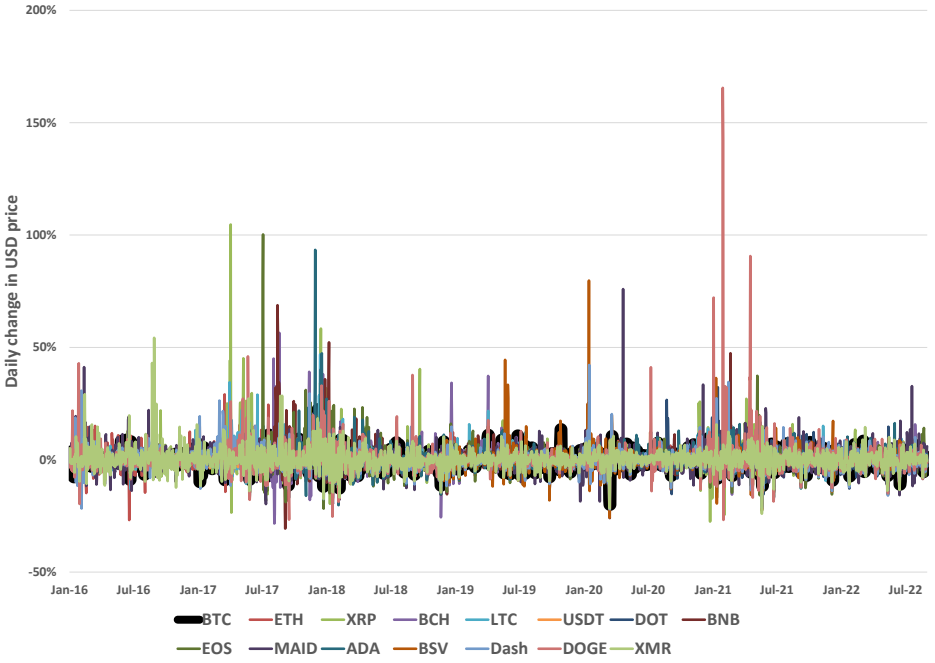

Figure 13: Daily change of selected cryptocurrencies (Source: coinmarketcap.com, own calculations)

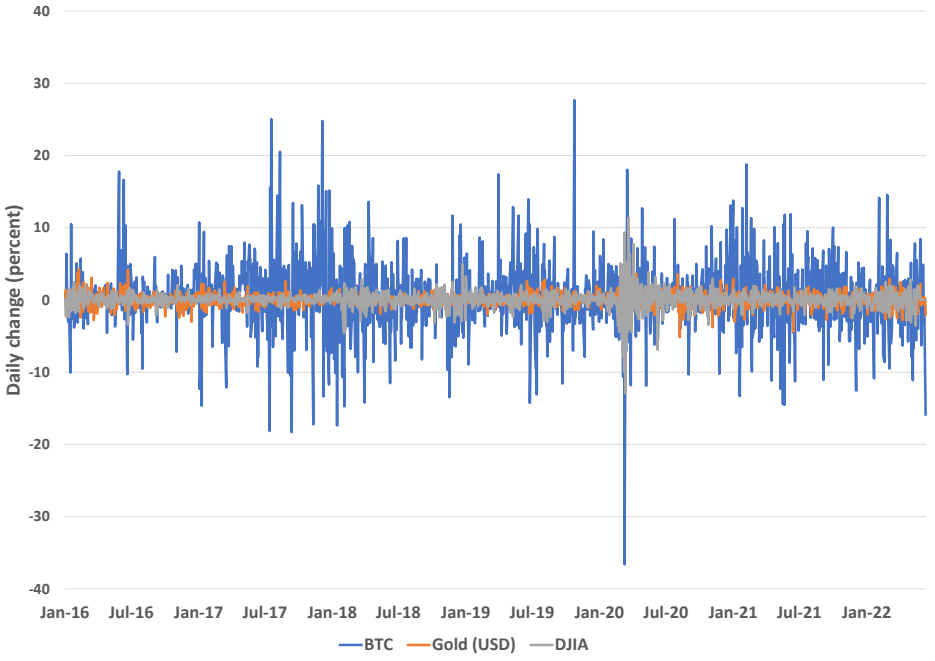

Figure 14: Daily change of Bitcoin, Gold price in USD and Dow Jones Industrial Average (DJIA) (Sources: FRED, World Gold Council, coinmarketcap.com, own calculations)

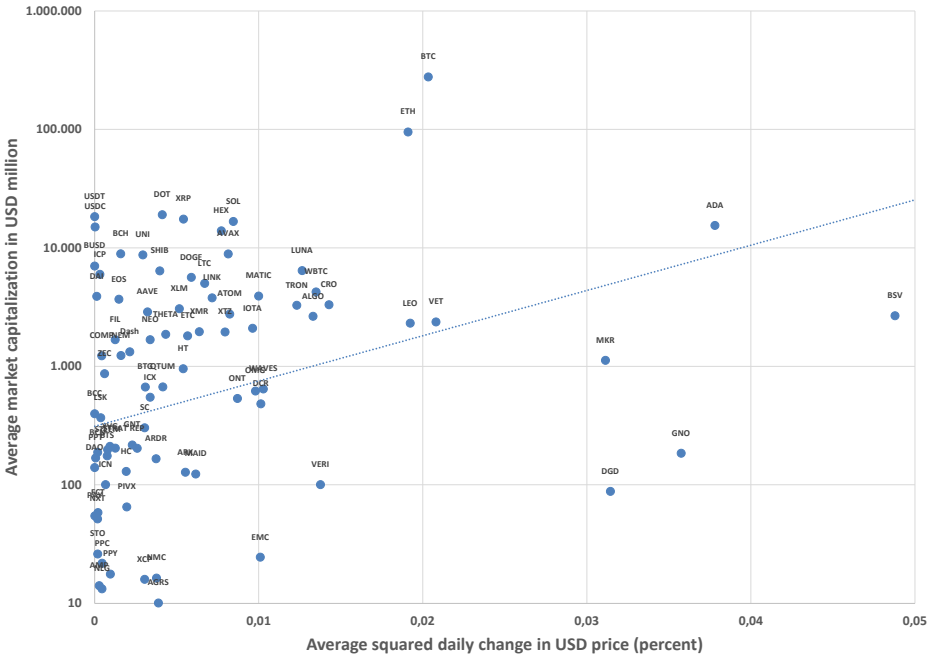

Figure 15: Valuation to Volatility of selected cryptocurrencies (Source: coinmarketcap.com, own calculations)

Stablecoins On the other hand, the growing attractiveness of stablecoins shows that there is also an interest in very stable cryptocurrencies. In fact, the most widely used stablecoins, which are all pegged to the US-Dollar, have been able so far to avoid fluctuations of their USD price, even in very turbulent market periods (Figure 17).

Hayek noted that active quantity regulation by suppliers of private currencies is required to avoid both inflationary and deflationary tendencies (see section 2). However, as has been shown above, Hayek's main concern (that led him to his proposal of competing private currencies in the first place) were the inflationary dynamics of classical fiat currencies during the 1970s. Therefore, Hayek proposed that private currencies should have a floor value, set by a fixed conversion rate to selected regular fiat currencies. This floor conversion rate would not have to be legally binding according, but rather a tool to generate trust for the private currency. Owing to competition, private currencies would be forced to keep the value of their currencies stable, in order to generate demand for them. Thus, private currencies might have a floor conversion rate to regular currencies, but would rise in relative value as regular currencies lose value due to inflation.

While the inflation argument has not been at the core of the stablecoins, it might receive more attention in the light of the recent rise in inflation rates. Nevertheless, the market for stablecoins has been very dynamic in recent times and stablecoins have not always been able to live up to their promised stability, as Figure 17 shows. It is also interesting to see that divergence from USD parity

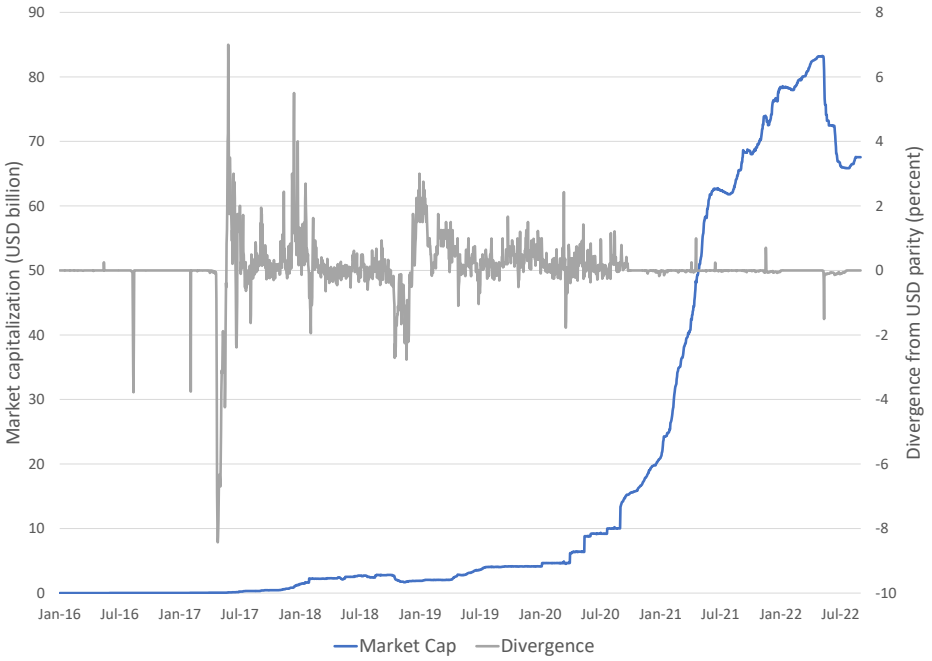

Figure 16: Market capitalization and divergence from USD parity for USDT (Source: coinmarketcap.com, own calculations)

has been relatively symmetric, which is in contrast to Hayek's idea of a floor value which would allow for relative appreciation of private currencies against the underlying fiat currency, but not for a drop below the set floor value. Obviously, issuers still face problems defending their peg, as Figure 16 shows. The issuers of Tether had to use more than 10 billion USD in funds to stop the decoupling of Tether from USD parity at a divergence of less than 2% from parity in May 2022.

[10]We include UST to show the effect of a permanent decoupling from USD parity. Please note that some divergences go beyond the scale of 10% divergence from parity.

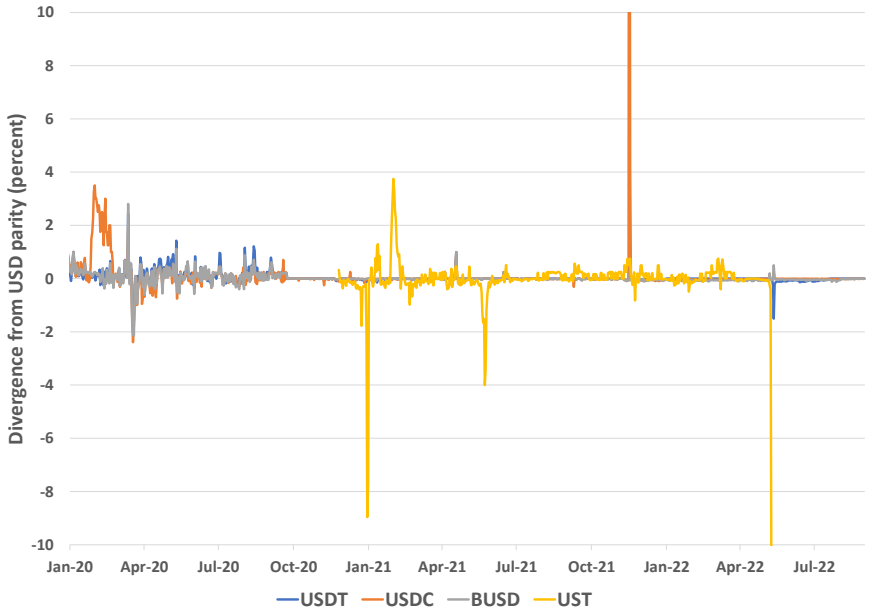

Figure 17: Divergence from USD parity of the three largest stable coins and UST[10] (Source: cryptocompare.com, own calculations)

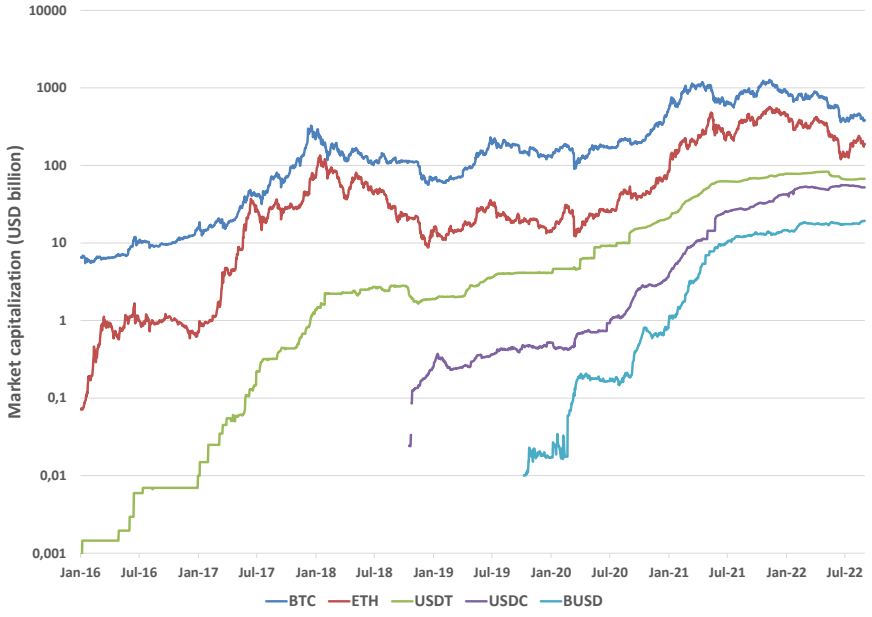

Figure 18: Market capitalization of the two largest unpegged cryptocurrencies and the three largest stablecoins, log scale (Source: coinmarketcap.com, own calculations)

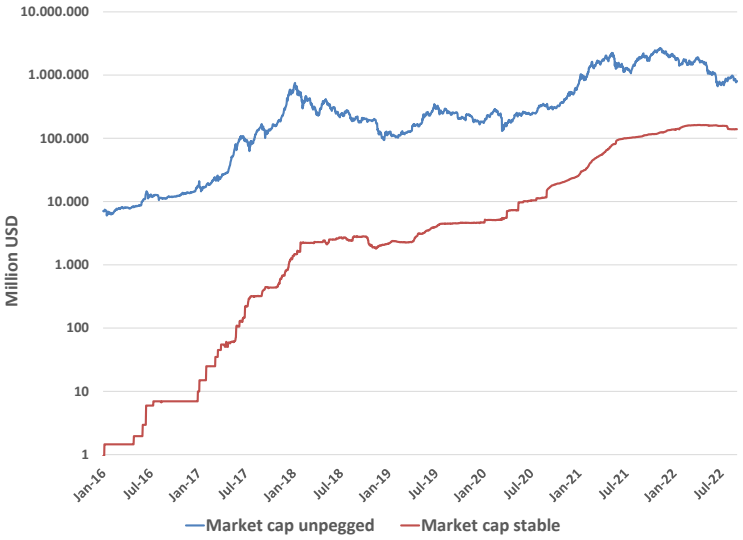

Figure 19: Total market capitalization of unpegged cryptocurrencies and stablecoins in US-Dollars (Source: coinmarketcap.com, own calculations)

Figure 19, Figure 18 and Figure 20 show that there has been a massive increase in the supply of stablecoins since mid 2020, most of which can be attributed to the increase of supply of Tether, the most prominent stablecoin. However, as presented in the shares of the stablecoin market in Figure 21, Tether is losing market dominance, especially to USD Coin and also Binance USD, which are issued by two of the largest markets for cryptocurrencies, Coinbase and Binance respectively. One of the reasons for the relative decline of Tether dominance might be justified concerns regarding the volume and the location of Tether's US-Dollar reserves and its reluctance to allow for third party audits.[11] However, due to the extraordinary structure of the crypto market, some analysts think that Tether can be successful in the short to medium term even though it does not have trustworthy reputation.[12]

The five most successful stable coins so far in terms of market capitalization can be found in Table 7. It can be seen that all of the most successful stable coins are pegged to the US-Dollar[13], a statement that would still be true if we would look at the top ten instead of the top five.
It has to be emphasized that the most successful stablecoins so far also do not meet the criteria that Hayek demanded from private currencies. The most relevant stablecoins all simply mirror existing public currencies, usually the USD, and are therefore subject to the exact same inflation

[11]The Commodity Futures Trading Commission has stated in 2021 that Tether's claim that it had 1 USD in reserve for each Tether issued was "wildly misleading", see eg. https://www.bloomberg.com/news/features/2021-10-07/crypto-mystery-where-s-the-69-billion-backing-the-stablecoin-tether or https://fortune.com/2021/10/15/tether-crypto-stablecoin-fined-reserves/

[12]https://research.aimultiple.com/tether/

[13]USD Coin, Binance USD and Terra USD already tell this by their name, Tether has the following statement on its website: "*Every Tether token is also 1-to-1 pegged to the dollar, so 1 USDT Token is always valued by Tether at 1 USD.*" (tether.to), and Dai has a similar statement in its whitepaper: *Currently, Dai has a target price of 1USD (1 Dai = 1 USD)* (https://makerdao.com/en/whitepaperdai-as-a-medium-of-exchange)

[14]Retrieved on August 31^{th} 2022

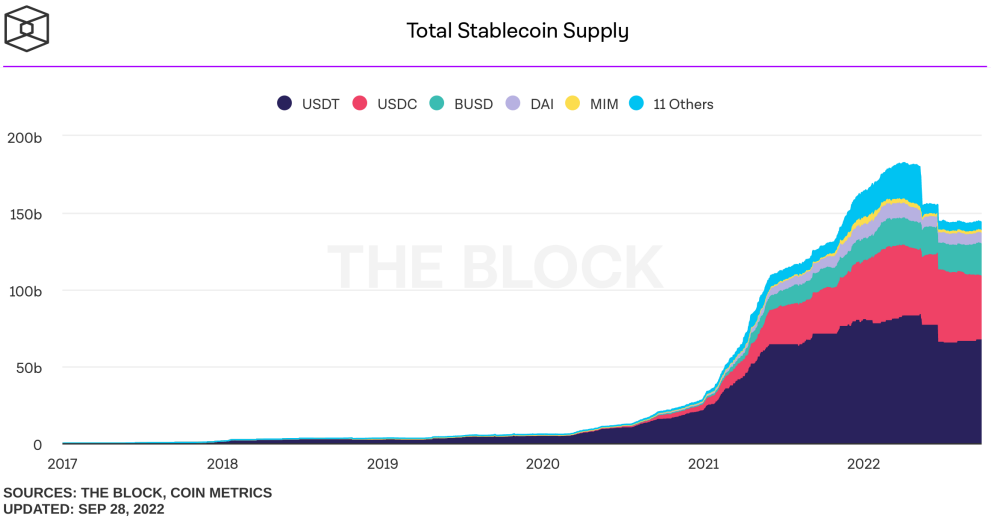

Figure 20: Total stablecoin supply (Source: theblockcrypto.com)

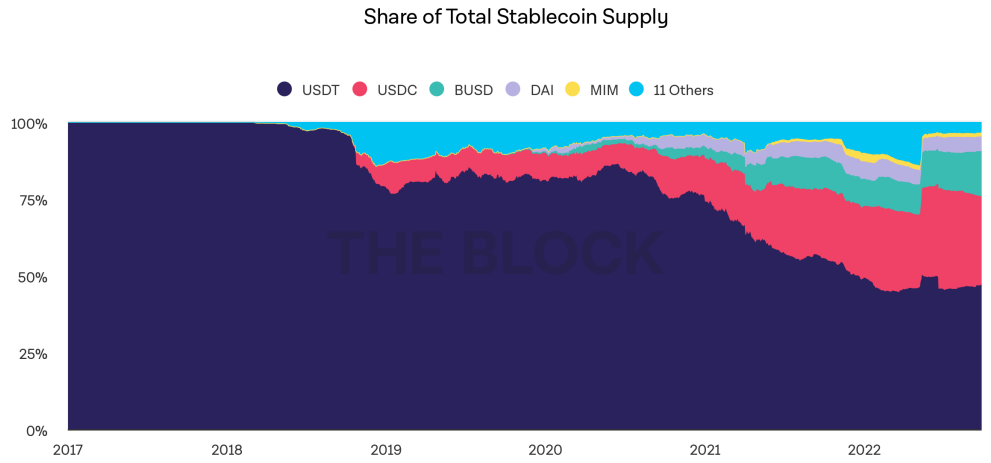

Figure 21: Share of total stablecoin supply (Source: theblockcrypto.com)

Cryptocurrency	Market capitalization[14]	Price in USD	Pegged to
Tether	67,550,878,447 $	1.00	US-Dollar
USD Coin	52,361,614,842 $	1.00	US-Dollar
Binance USD	19,311,789,101 $	1.00	US-Dollar
Dai	6,971,155,000 $	0.99	US-Dollar
TrueUSD	1,076,655,370 $	0.99	US-Dollar
Bitcoin	383,710,102,295 $	20,017.48	

Table 7: Top 5 stable coins in terms of market capitalization (Source: coinmarketcap.com)

rates as these currencies. The main point of Hayek's proposal, that private currency competition would lead to currencies that are **more stable** in value than national currencies is still not met by cryptocurrencies.

5.2.2 Means of payment: Network effects?

The dominant role of stablecoins as stable media of exchange is reflected in their high daily trading volumes. With a strong increase in the market capitalization of stablecoins since 2020, their trading volumes have exceeded the trading volumes of Bitcoin and Ethereum (Figure 22). The figure compares the quarterly average of daily trading volume of the two most important unpegged cryptocurrencies with the corresponding trading volume of the largest stablecoin, USD Tether (USDT), and its competitors. For comparison, the figure also shows the quarterly average of the daily trading volume of the Standard & Poor's 500 Index.

It can be seen that Tether's trading volume was already larger than that of Bitcoin in the third quarter of 2019. Periodically, the trading volumes of stablecoins even surpass the trading volume of the S&P 500. Figure 22 also shows the increasing share of stablecoin trading volume taken by Tether's rivals, namely Binance USD (BUSD) and USD Coin (USDC). These developments indicate tendencies towards a natural monopoly as far the means of payment function is concerned. This contradicts Hayek's expectation that under currency competition a coexistence of stable "monies" in the means of payment would emerge.

Figure 23 also shows a different ranking than that by market capitalization in table 7. Even though the composition of the top 5 currencies is similar, Tether is dwarfing Bitcoin in terms of trading volume. We can also see that there is basically a duopoly for unpegged cryptocurrencies when it comes to transactions. Despite their volatility, Bitcoin and Ethereum are dominating transactions. In the case of stablecoins we observe a quasi-monopoly of Tether that one could also translate to the overall crypto market. This is also reflected in Figure 24 where we can see that the most traded currency pairs among cryptocurrencies consist of of only four currencies. The most traded currency pair is that of the most important unpegged cryptocurrency and the most important stablecoin.

While Tether is still clearly leading the market, USD Coin and Binance USD have some advantages for future competition. Both can be perceived as being more trustworthy, as both have monthly audits by respected third parties which assess their holdings of fiat money, which is in both cases US-Dollars. Also, both are connected to some of the largest crypto exchanges which provides a good connection to the crypto market and the cryptocurrency community. In contrast, Tether lacks the transparency and the reputation of USDC and BUSD but nevertheless dominates the market

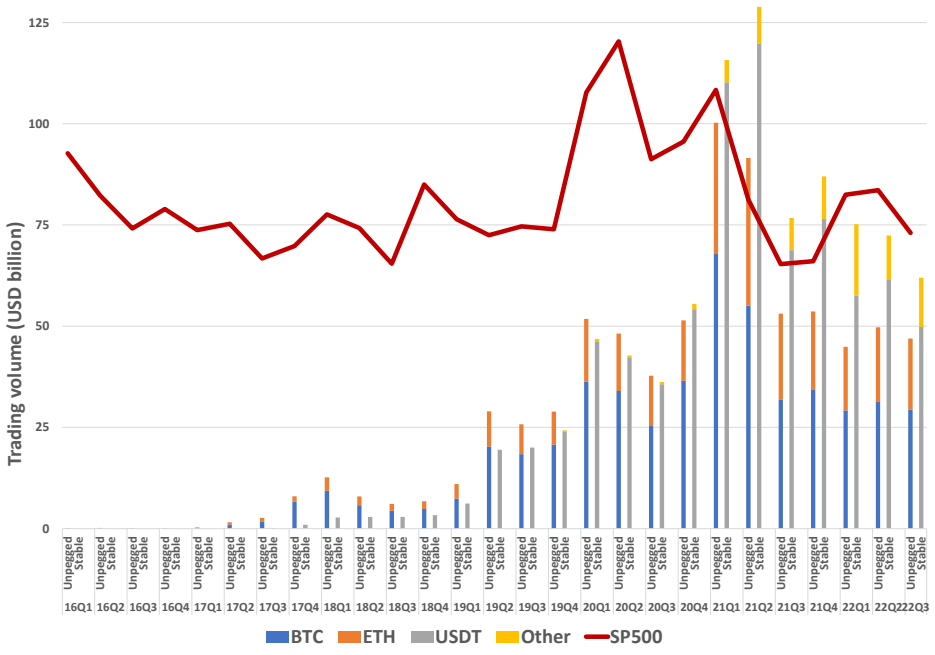

Figure 22: Quarterly average of daily trading volume of unpegged cryptocurrencies and stablecoins compared to S&P 500 trading volume (Sources: coinmarketcap.com, Yahoo Finance, own calculations)

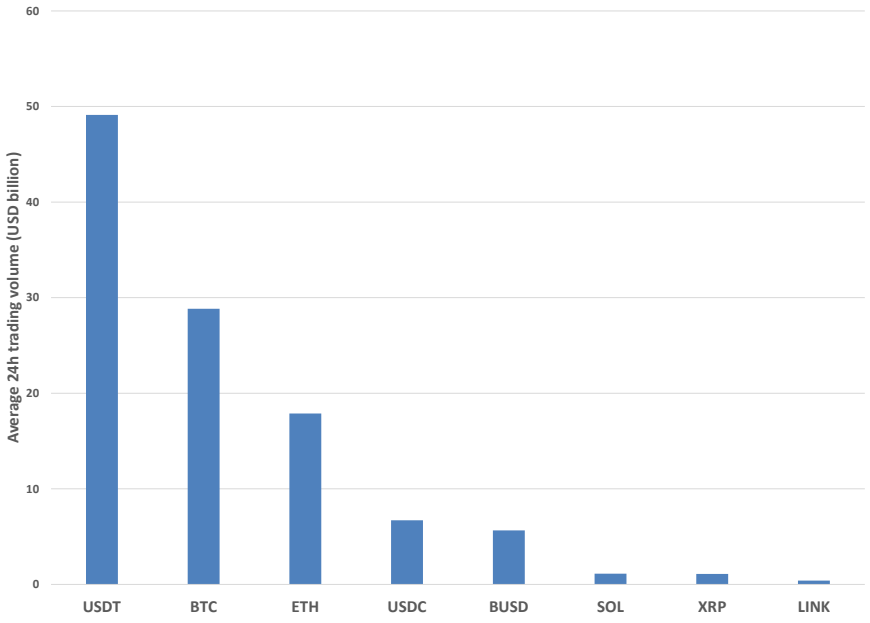

Figure 23: Monthly average of daily trading volume of the ten most traded cryptocurrencies in August 2022 (Source: coinmarketcap.com, own calculations)

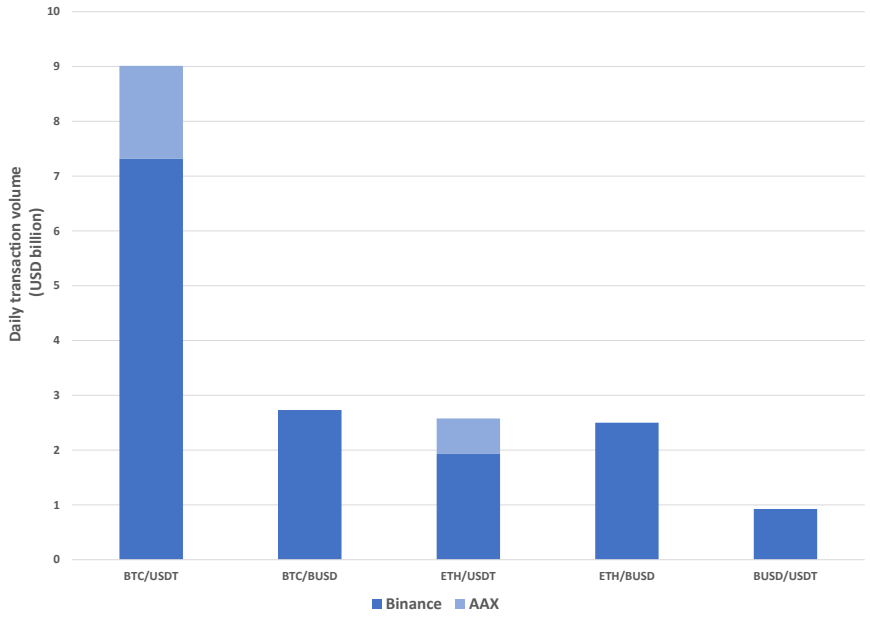

Figure 24: Daily trading volume of the most traded currency pairs among cryptocurrencies (Source: coinranking.com, own calculations)

for stablecoins.

One of the key drivers behind Tether's leading position in terms of trading volume in the whole market for cryptocurrencies - not just stablecoins - might be its function as a gateway towards unbanked exchanges. These are cryptocurrency exchanges without access to the regular and regulated banking system which can therefore not provide trading pairs between conventional fiat currencies and cryptocurrencies. Thus, these numerous exchanges rely on banked exchanges, where users of cryptocurrencies can exchange fiat currencies for cryptocurrencies, which the users can then transfer to the unbanked exchanges, which often attract customers by offering services and bonuses that banked exchanges do not. The vehicle currency for both the movement of value from banked to unbanked exchanges and trade on unbanked exchanges are often stablecoins as they reduce the risk of value losses which is significant regarding the short-term volatility of e.g. Bitcoin.[15]

The importance of stablecoins for the functioning of crypto markets can be inferred from Figure 23, which shows the trading volumes of the most traded cryptocurrencies. Even though Tether has less then on tenth of Bitcoin's market capitalization, its trading volume is more than double of that of Bitcoin. The other two stablecoins within our sample, USD Coin and Binance USD, are also amongst the most frequently traded cryptocurrencies, even though they do not appear in the most successful currencies according to our long-term metric. This shows the large demand for a

[15]https://crypto-anonymous-2021.medium.com/the-bit-short-inside-cryptos-doomsday-machine-f8dcf78a64d3

medium of exchange that is reliable in terms of value.

Another interesting observation from Figure 23 is that while USDC has around two thirds of Tethers market cap, it only has around 4 percent of its daily trading volume. This disproportion is less pronounced for BUSD, which has around 20% of Tethers market capitalization but around 8% of its daily trading volume again according to coinmarketcap. So while Tether is the stablecoin and also cryptocurrency most widely used for transactions, BUSD and USDC appear to more of a stable store of value, which is especially true for the latter.

When we look at the most successful cryptocurrencies in terms of a means of exchange, we find that competition is much less pronounced and market power stronger than in the case of a store of value. Tether dominates all transactions and it remains to be seen if it will be challenged by its rival stablecoins USDC and BUSD in the future. Of the unpegged cryptocurrencies only Bitcoin and Ethereum are actually used for transactions to a relevant degree. The different structure of transactions compared to market capitalization also emphasizes the importance of distinguishing between the two functions of money when looking at competition between cryptocurrencies. We can see that competition for a medium of exchange is much more prone to leading to a natural monopoly than competing as a store of value.

Hayek was partially right, when he pointed out that stability in value is of crucial importance for private currencies. Tether has kept its value tied to the USD so far and has thereby managed to become the most important cryptocurrency when it comes to transactions. On the other hand, Tether is tied to the USD and will therefore copy all inflationary dynamics of the USD. Also, Bitcoin is still the second most traded cryptocurrency and it is further from stability of value than Hayek could ever have had imagined.

5.2.3 Summary of results

When we look at the qualities of the most successful cryptocurrencies, we see that despite Hayek's idea of private currencies that are stable in value, price volatility appears to be in fact a favorable feature for investors when they look for a speculative store of value. This search for volatility in turn reduces the tendency towards market concentration and a natural monopoly as price movements are often relatively larger for smaller cryptocurrencies with a low price, creating a competitive advantage. We also see that the major stablecoin, Tether, is challenged by its main rivals who catch up in terms of market capitalization. This is an indicator that competition also takes place on the field as a stable store of value.

In contrast, the tendency towards a natural monopoly seems to much more pronounced when looking at the function of money as a medium of exchange. For transactions, the crypto market is extremely reliant on Tether and even the share of other major stablecoins is still relatively small.

Competition on the crypto market therefore seems to be dependent on the function of money. While competition works well for the function as a (speculative) store of value, it is limited for stable stores of value and there is a tendency towards a monopoly for the function as a medium of exchange.

6 Conclusion

In Hayek's vision of currency competition, the main function of money was the means of payment function which he regarded as closely tied to the store of value function. He did not consider that these two functions could be separated and that competition could take place along both of these dimensions. The early cryptocurrencies (unpegged cryptocurrencies), however, did not focus at all on stability of value relative to national currencies. Instead of actively managing the quantity of their currency in circulation, as Hayek demanded, issuers of cryptocurrencies usually set their supply independently of demand, thus creating large volatility in the price of their currency which is exacerbated by speculation. With the emergence of stablecoins, a type of cryptocurrency was created that was closer to Hayek's vision. Suppliers of stablecoins have to keep track of demand of their currency in order to manage their supply accordingly and keep their peg. However, in contrast to Hayek's proposal, stablecoins are not more stable in value than national currencies but in the best case only as stable the underlying national currency which is so far the USD.

Hayek also did not consider possible network effects that would undermine competition and lead to winner-take-all effects. We argue that these network effects are more likely to be in place for the function as a medium of exchange, not so much for the function as a (speculative) store of value. This hypothesis is also present in the literature, where several contributions also question the presence of network effects in the crypto market. There is, however, a lack of research that connects Hayek's ideas, a differentiation of the crypto market by the functions of money and the empirical evaluation of the degree of competition between cryptocurrencies.

We close this gap by first evaluating the intensity of competition on the crypto market over time. By using concentration ratios, Herfindahl indices, correlation analysis and cointegration, we find that the concentration of market power has decreased significantly since 2016. We also find that

competition increased during times of strong overall market dynamics, i.e. booms and busts. In contrast, during the long period of stagnant market capitalization (2019-2021), competition decreased and market concentration rose again. When looking at correlations, we find that cryptocurrencies are more likely to be seen as substitutes during boom periods than during periods of stagnation. The strongest connection between cryptocurrencies exists during bust periods. We therefore expect that strong downward price movements of a leading cryptocurrency will also have a strong negative impact on overall crypto market capitalization, at least in the short term.

Further analysis of dynamic indicators shows that the crypto market is subject to frequent change. Over the course of the last 6 years, more than 100 cryptocurrencies have been in the top 20 in terms of market capitalization at some point in time. However, even for these cryptocurrencies, that can be considered the most successful ones, the median of the time spent among the top 20 was only 6 months.

This high degree of competition and the decrease of market concentration does not translate to the market for stablecoins. Concentration of market power is still much larger for stablecoins and the leading currency, Tether, clearly dominates the market. We regard this as evidence that we can distinguish different sub-markets for cryptocurrencies that follow different dynamics.

We find that in stark contrast to Hayek's vision the market for unpegged cryptocurrencies values price volatility as this allows for speculative gains. This effect however encourages competition and counters network effects. On the other hand, demand for a stable store of value has been one of the driving forces behind the emergence of stablecoins. The catching-up in terms of market capitalization of Tether's main rivals, USD Coin and Binance USD, shows that competition is also possible on this sub-market. When turning from the function of money as a store of value towards that as a medium of exchange, we see a very different picture. Transactions are completely dominated by Tether with no signs of change. We argue that network effects are much more present on the market for media of exchange than on the market for stores of value. Competition on the crypto market therefore seems to be dependent on the function of money. While competition works well for the function as a (speculative) store of value, there is a tendency towards a monopoly for the function as a medium of exchange.

Overall, the evidence shows that the crypto market is still very young and dynamic and shares some characteristics close to Hayek's idea of private currencies even though it uses a technology completely beyond imagination at the time Hayek wrote his book in 1978. Ironically, the main argument by Hayek - that competition would lead to currencies more stable in value, to less inflation - is missed by cryptocurrencies. Hayek might have been right insofar as competition

currently seems to outweigh network effects but he focused on the wrong function of money. At the moment, it is not the medium of exchange that is the dominant function but the (speculative) store of value. Most adopters of cryptocurrencies seem to value volatility over stability of value. However, even over the relatively short time span that cryptocurrencies have been in existence, they have evolved significantly. In an extremely dynamic market that is almost entirely based on technology, first mover advantages vanish quickly and top positions will always be contested. Demand for stable currencies, stablecoins, is rising, which might lead to at least a sub-market where Hayek's vision is fulfilled. Again it is ironic that that these stablecoins are only stable relative to the USD, while Hayek's main argument for the competition of private currencies was to establish currencies that would be independent from the inflationary dynamics of major currencies, especially the USD. In the end, we have to see, if Kindleberger is correct when he states that *"[...] any system with one money that proves to be not completely satisfactory in all uses, the market will create additional money or moneys to suit its needs."*(Kindleberger, 1990, p. 55)

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Statements and Declarations

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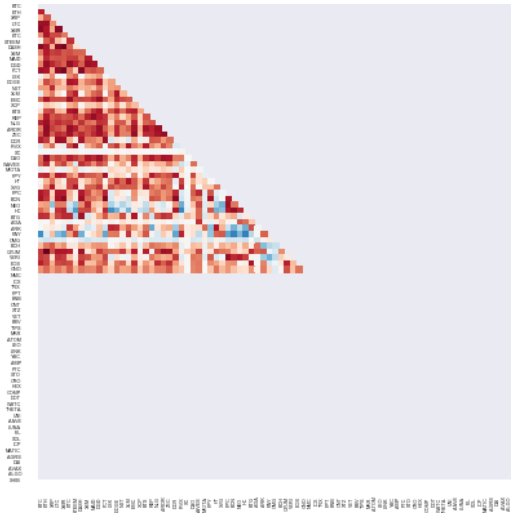
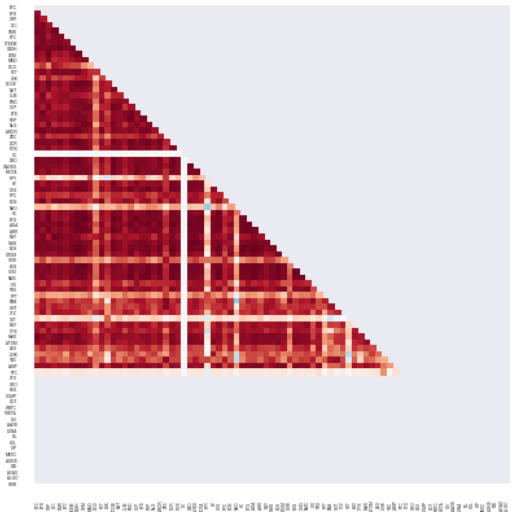
The authors have no relevant financial or non-financial interests to disclose.

All authors contributed to the study conception and design. All authors read and approved the final manuscript.

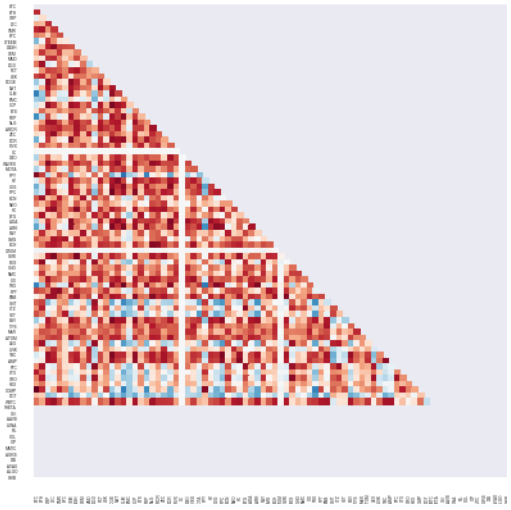
Appendix



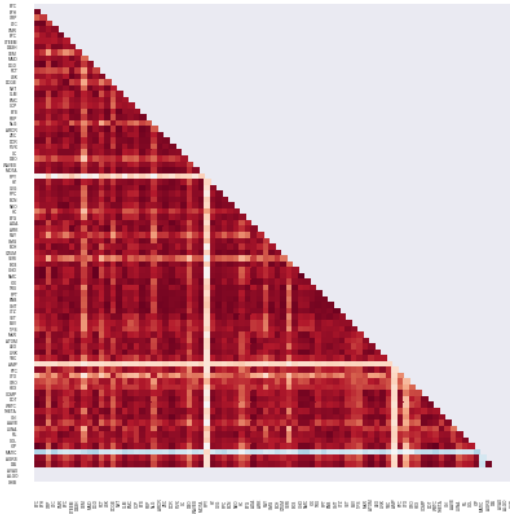
(a) Jan 17 to Dec 17, USD



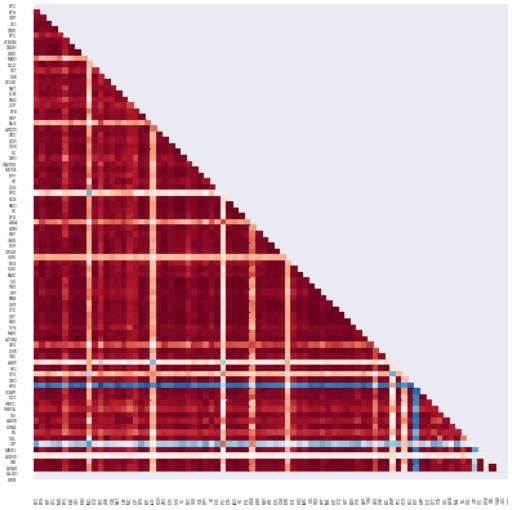
(b) Jan 18 to Dec 18, USD



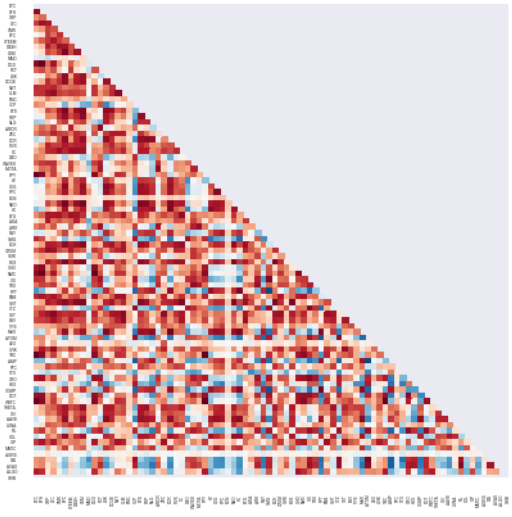
(c) Jan 19 to Oct 20, USD



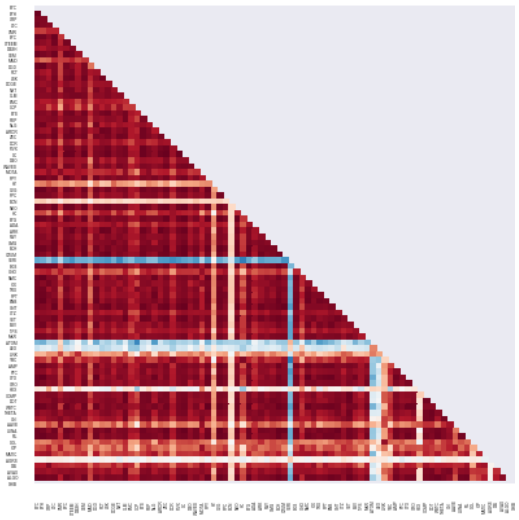
(d) Oct 20 to May 21, USD



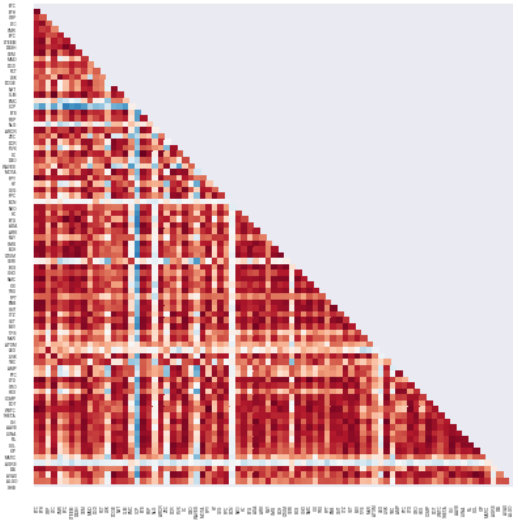
(e) May 21 to Jul 21, USD



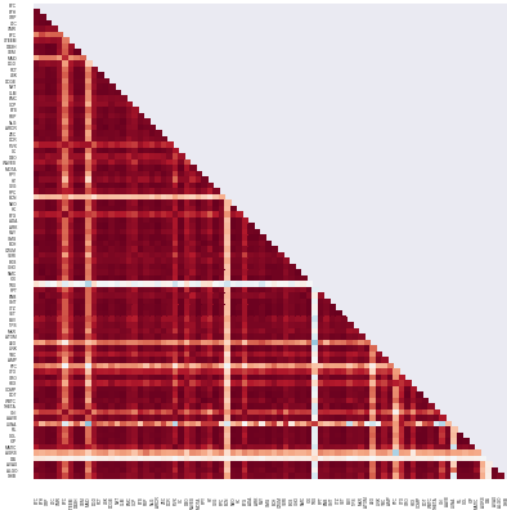
(f) Aug 21 to Nov 21, USD



(g) Dec 21 to Feb 22, USD



(h) Feb 22 to Apr 22, USD



(i) Apr 22 to August 22, USD

Figure 25: Correlations for selected time periods in USD

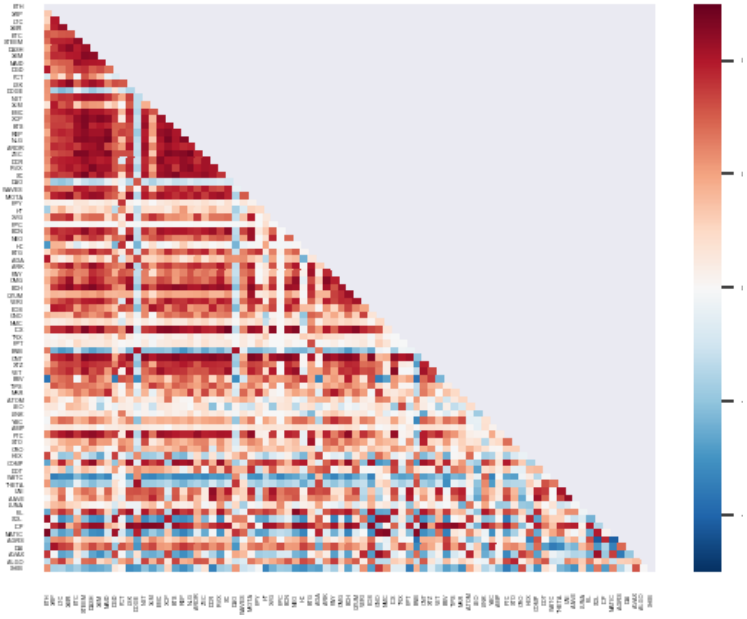
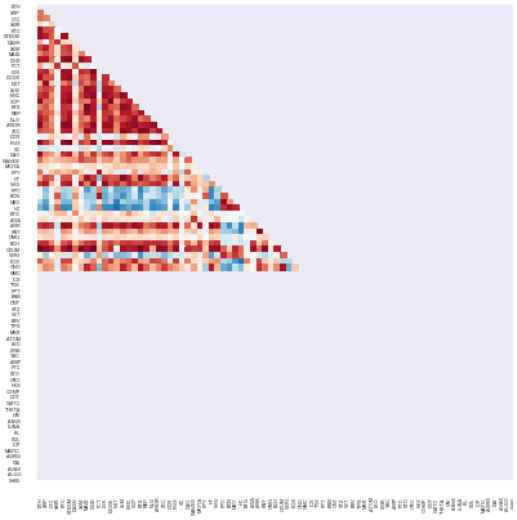
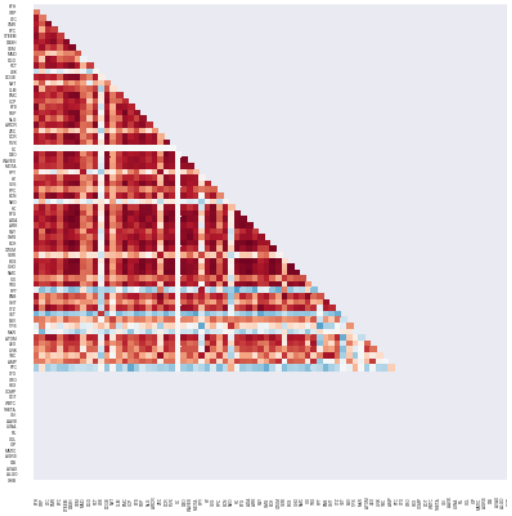


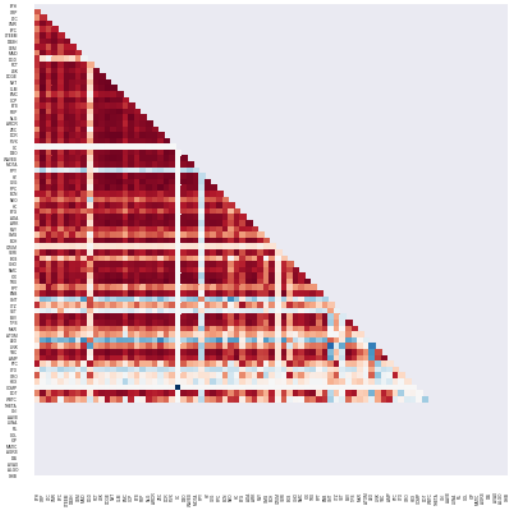
Figure 26: Correlations of selected cryptocurrencies denominated in BTC



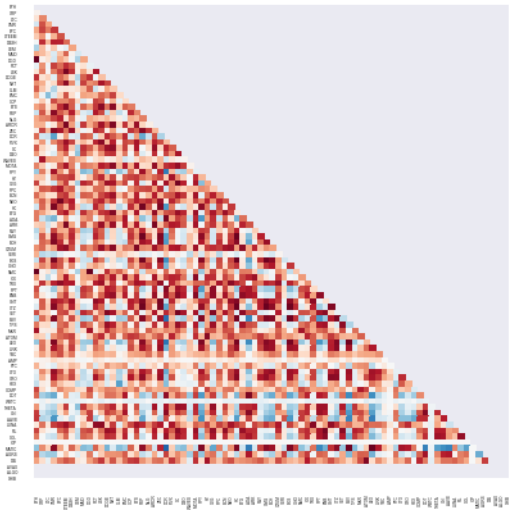
(a) Jan 17 to Dec 17, BTC



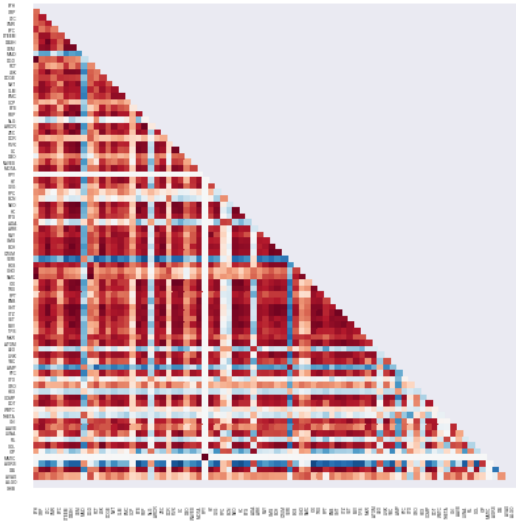
(b) Jan 18 to Dec 18, BTC



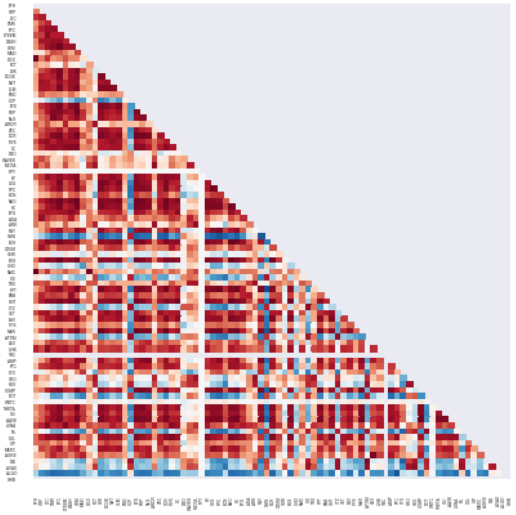
(c) Jan 19 to Oct 20, BTC



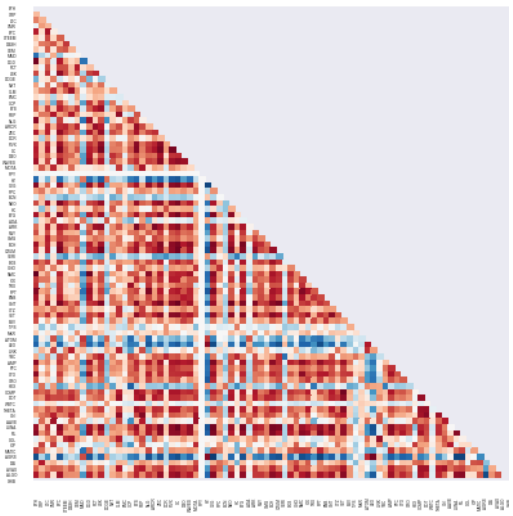
(d) Oct 20 to Mar 21, BTC



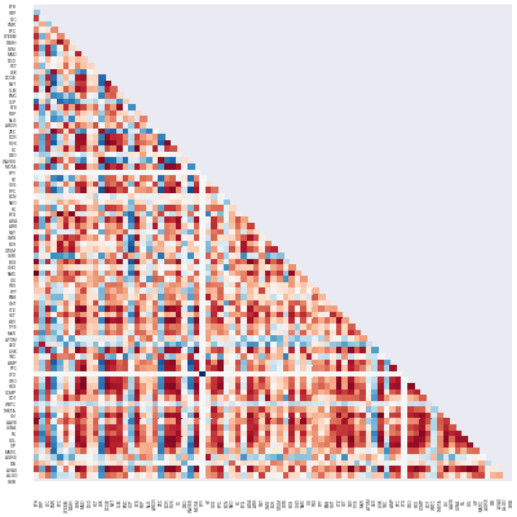
(e) Apr 21 to Jul 21, BTC



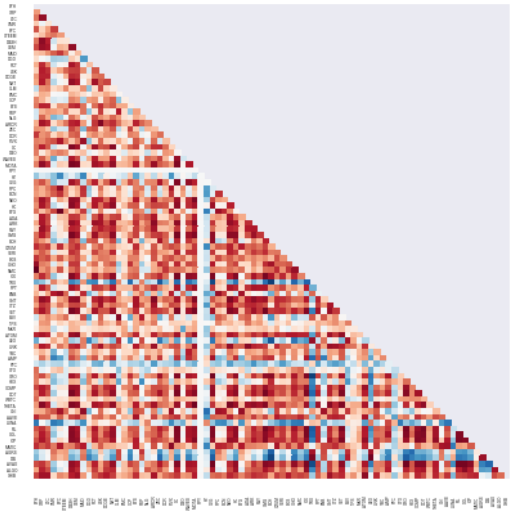
(f) Aug 21 to Oct 21, BTC



(g) Oct 21 to Feb 22, BTC



(h) Feb 22 to Apr 22, BTC



(i) Apr 22 to May 22, BTC

Figure 27: Correlations for selected time periods in BTC