

# Cryptocurrency Market Dynamic Causality

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## Abstract

This study also finds speculation evidence when examining the causality centrality network of the cryptocurrency market. Studying the dependence structure among cryptocurrencies draws tremendous attention, but there is a paucity of research on that and almost focusing on leading cryptocurrencies defined by their market capitalization. Not only focusing on the relationship, our work also studies the dynamic causality in the cryptocurrency market from both return and liquidity perspectives. By employing a stable causality network, we present the directional causality among the cryptocurrencies and find that the leading cryptocurrencies are not the most influential players in the markets.

*Keywords:* Cryptocurrency, Causality, Network Analysis

*JEL:*

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## 1. Introduction

Cryptocurrencies draw broadening attention from both the media and investors because of their innovative features and attractive price fluctuation (Li et al., 2019). The cryptocurrency market reached \$2.5 trillion of market capitalization in May 2021, which had been \$750 billion in January 2021. The dominant market share of Bitcoin is being replaced by later cryptocurrency generations, including Ethereum, Litecoin, Monero, Dash, Ripple, Tether, Bitcoin Cash, EOS, and Tezo. These cryptocurrencies are considered as investment assets with the possibility to gain high returns but suffer extreme volatility Ji et al. (2018) by both individual investors and fund managers. However, understanding how cryptocurrencies interact with each other in terms of return and liquidity is surprisingly limited. Extending the literature on dynamic causality network structure in the cryptocurrency market is crucial for investors in terms of risk management and portfolio diversification, miners who consider the coins worth consuming the power to mine, and policy-makers in financial stability preservation.

Research on cryptocurrencies are attempting to explore in what extents they can act as financial assets Yermack (2015), Polasik et al. (2015)), Al-Yahyaee et al. (2018), Grobys and Sapkota (2019); Nadarajah and Chu (2017);Urquhart (2016); Zhang et al. (2018)) then investigate their price behaviors (Philippas et al. (2019); Sun et al. (2020), Cheah and Fry (2015), Corbet et al. (2018b) Bouri et al. (2019), Fry (2018)). The causality relationship is also another mainstream literature, but the existing research mainly focuses on the return and volatility interconnectedness surrounding Bitcoin and other dominants such as Ethereum and Ripple. In particular, Yi et al. (2018) measured a cyclic volatility connectedness among eight leading cryptocurrencies. Koutmos (2018) and Ji et al. (2018) extends their research to return and volatility spillover. We are motivated by the fact that the interaction is surprisingly different among cryptocurrencies. This is also debated in Ji et al. (2018) that Dash and Ethereum connectedness is weak via positive returns while Ethereum and Ripple exhibit very strong via negative returns. In the closest to our study research, Yavuz (2022) shows Granger causality among seven cryptocurrencies by investigating the causality and co-integration using Granger Causality and Johansen Cointegration tests. They also indicate that the bi-directional causality appears only between Binance and Ethereum relations.

This paper is to fulfill this gap by examining the integration and network structure of that attractive market. We employ the mechanism of stable causality networks to investigate the dynamic causality of forty market capitalization leading cryptocurrencies. By considering the time-varying Granger causality test proposed by (Hong, 2001), we attempt to visualize the representation of cryptocurrency markets as vertices and causality direction. It allows seizing the contagion and risk spillovers in cryptocurrency markets mentioned by (Luu Duc Huynh, 2019).

Our study differs from the existing literature in several ways. Firstly, comparing with the existing studies, we extend the cryptocurrency sample by using daily closing prices and volumes of forty leading cryptocurrencies abstracting for more than 80% market value. With such a sample, our results hence can imply the whole cryptocurrency market. Secondly, we apply a special causality network type called "stable causality networks" to discover the mechanism of transmitting risk within the cryptocurrency market. By using results from the DCC-MGARCH Hong process studying the dynamic correlation between the cryptocurrencies, the stable causality networks can provide reliable findings to the existing literature. This model also allows us to demonstrate the direction of each causality, which is notably critical to understand the interconnectedness structure of the cryptocurrency market. Finally, the present paper sheds light on the cryptocurrency liquidity network yet studied to our best knowledge. We are interested in the liquidity transmission among cryptocurrencies because of two reasons. First, the interrelationship evidence between cryptocurrency price volatility and liquidity has been explored in Corbet et al. (2022) during the COVID period. It raises a question about how cryptocurrency liquidity interacts in its own market. Second, liquidity contagion among them becomes much more crucial if liquidity provision can be considered as a determinant of cryptocurrency returns as debated by Bianchi et al. (2022). Indeed, we find evidence of dynamic shock transmission through their liquidity channel.

The paper is organized as follows. Section 2 gives a brief review of literature. We describe the sample data and the method to estimate return and liquidity at section 3. Section 4 presents the methodology. The results are discussed in section 5 and the conclusions are provided in section 6.

## 2. Literature Review

The cryptocurrency era arose from a new payment method using the cryptographic system to get confirmation among the parties and be decentralized. Satoshi Nakamoto is known as the person who created the first cryptocurrency in 2009, named Bitcoin. Cryptocurrencies are created from the mining process, in which the miners have to solve various complicated math puzzles and reward new crypto coins. In 2013, MasterCoin was created with a protocol based on Bitcoin. Similarly, in 2014, Ethereum first introduced the concept of smart contracts, in which transactions are only executed if a condition set is met. Afterward, a sequence of alternative cryptocurrencies integrated one or some nature different from Bitcoin, Ethereum, or following coins like Stellar Waves, Ripples, and Litecoin were born. Such coins concisely have some common characteristics of a decentralized network, immutability and anonymity. They increasingly attract investors' attention because of their distinct characteristics in comparison with conventional financial assets. First, the cryptocurrency market is non-stop, where the listed coins are traded 24/7. Second, they do not have intrinsic value. The primary determinant of cryptocurrency prices is the concept of "hash of current block" (Nakamoto and Bitcoin, 2008) estimated by their hash rate, mining possibilities, and unique random key generated in the currency process. Last but not least, different from conventional financial markets, the cryptocurrency market does not have a daily trading limit. Thus, their volatility can be surprisingly high as the prices can increase and decrease sharply.

Though those studies on cryptocurrencies appeared not long ago, many research papers were recorded to examine their characteristics and properties, especially Bitcoin. It exits a doubt whether Bitcoin and other cryptocurrencies are considered as monetary currency (Polasik et al. (2015), Yermack (2015)) and a hedging tool (Briere et al. (2015) and Dyhrberg (2016)) despite their high volatility, contagion and spillover risk (Gkillas and Katsiampa (2018), Corbet et al. (2018a), Brauneis and Mestel (2018), Huynh et al. (2018) and Borri (2019). Evidences of bubble presence in the cryptocurrency market are also studied at Cheah and Fry (2015), Corbet et al. (2018b), Bouri et al. (2019), Fry (2018).

Our study complements a strand of literature examining the interconnectedness among cryptocurrencies on which there are rather limited papers, according to our best knowledge. By using



the VAR model to investigate return and volatility connectedness in the cryptocurrency market, both Koutmos (2018), and Ji et al. (2019) provide evidence that Bitcoin plays a dominant and influential role among the top cryptocurrencies. The authors also highlight that market size does not heavily relate to the connectedness among the six leading cryptocurrencies. Yi et al. (2018) also underlines the cryptocurrency volatility connectedness estimated by the LASSOR-VAR model. Interestingly, the research indicates that cryptocurrencies are tightly interconnected, but smaller cryptocurrencies, like Madsafe Coins, surprisingly play an essential role in transmitting volatility spillovers.

Focusing on cross-correlation, there are even fewer studies. Francés et al. (2018), employs minimum spanning trees and hierarchical structure methodology to explore the cryptocurrency interdependencies and figures out that their price movements are highly correlated, and Ethereum stands in the middle of the sixteenth cryptocurrency graph. Utilizing the same method Stosic et al. (2018) otherwise argues that the cross-correlation is partially exhibited. Alternatively, Zikéba et al. (2019) analyzes VAR models with variables resulting from the minimum spanning trees method in two sub-periods to see the hierarchical causality clusters, which is most relevant to this paper. In addition, Moratis (2021) uses a rolling window Bayesian Vector Autoregressive Model to quantify market spillover effects and uncover pairwise directional shock transmission between cryptocurrencies. Most recently, Yavuz (2022) investigated the causality and co-integration among seven cryptocurrencies by combining Granger Causality and Johansen Cointegration tests. However, the authors provide only bi-directional causality evidence between Binance and Ethereum.

This article unfolds this literature by conducting a stable causal network model using the Granger Causality test results of forty leading market capitalization cryptocurrencies. The network-based model is considered as an efficient method to analyze the time series correlations (Marti et al., 2017), which could indicate each direction in the cryptocurrency causal network. Moreover, we also extend the model to study the return and liquidity causal networks which no study, to the best of our knowledge, takes into account when examining the spillover. The existing literature only focuses on how to measure cryptocurrency liquidity (Brauneis et al., 2021). The precise empirical method is described in the section 4.

### 3. Data

We collect historical data of forty cryptocurrencies from the website `coinmarketcap.com` whose data is sourced from aggregated cryptocurrency trading exchange platforms across the globe. The cryptocurrency selection is based on two criteria. First, they have a larger market capitalization recorded by `coinmarketcap.com` and second, their data can be matched in the longest period, which is finally determined as of January 1, 2018 - December 31, 2020 period (see Table 7 in the Appendix).

**Insert Figure 1 here.**

Employed data contains daily closing prices and daily trading volume data in US dollars (\$). As declared by `coinmarketcap.com` the volume data is calculated by multiplying the number of traded coins with the opening price on each day. Figure 1 shows the historical closing prices of the forty studied cryptocurrencies in the study period. Bitcoin has a price interval especially different with the minimum price of \$3,252.83 while all other cryptocurrency prices are minor than \$3,000.

With the aim of investigating the empirical causality network cryptocurrency market of both return and liquidity, we first measure return and liquidity time series as follows.

#### 3.1. Cryptocurrency return

We compute the return of each cryptocurrency  $i$  by measuring the natural logarithm of the ratio of two closing prices on day  $t$ ,  $R_{i,t}$ .

$$R_{i,t} = \ln\left(\frac{P_{i,t}}{P_{i,t-1}}\right) \quad (1)$$

**Insert Figure 2 here.**

**Insert Table 1 here.**

Table 1 shows the descriptive statistics of the return series. Except for Bitcoin and Binance, which experience a positive average return in the whole period of 2018-2020, other cryptocurrencies have either zero or negative returns. Revain's mean return is the lowest ( $-4\%$ ), while a large part of the sample (16 on 40 observed cryptocurrencies) has an average return of  $-1\%$ . Voyager token

is recorded as the highest standard deviation. Notably, there are two skewness style groups. The first group contains right-skewed cryptocurrencies, including Tether, Chainlink, Stellar, Dogecoin, Tron, Nem, Waves, 0x, LBRY Credits, Voyager Token, OMG Network, Enjin Coin, Decentraland, and Bitcoin Gold. The remaining cryptocurrencies skew to the left. However, the kurtosis values are above three, giving evidence of the leptokurtic distribution consistent with the Jarque-Bera test results. Lastly, all the series are stationary, as shown in the ADF test figures.

### 3.2. Cryptocurrency Liquidity

The aggregate daily trading volume (in USD) is also collected to measure the market liquidity of cryptocurrencies. Based on the robustness and simplicity, we employ Amihud’s illiquidity ratio (Amihud, 2002) to measure the liquidity among cryptocurrencies. The Amihud illiquidity ratio is calculated as below:

$$ILLIQ_t^i = \frac{|r_t^i|}{V_t^i} \quad (2)$$

Where  $r_t^i$  is the absolute return value on day  $t$  of cryptocurrency  $i$  and  $V_t^i$  is the daily volume of cryptocurrency  $i$  on day  $t$ . This ratio describes the relationship between the changes of each cryptocurrency on one dollar trading volume. As such, an asset having a higher Amihud illiquidity ratio is less liquid than the others.<sup>1</sup> Table 2 shows descriptive statistics of the Amihud Illiquidity series.

**Insert Table 2 here.**

On average, Maker is the most illiquid cryptocurrency as its illiquidity ratio is the highest (35.083). All cryptocurrency illiquidity figures are skewed to the right side, while their distributions have a leptokurtic style as their values are higher than three. The JB statistic test also gives the same results. Finally, the ADF test provides that all illiquidity series are stationary.

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<sup>1</sup>We multiply the illiquidity results by  $10^6$  as suggested by Amihud (2002).

## 4. Methodology

### 4.1. Time-varying Granger Causality

We employ Lu et al. (2014) time-varying causality approach to study the causal relationship between cryptocurrency returns and illiquidity ratios. Given that  $\{y_{i,t}\}, i = 1, 2$  and  $t = 1, \dots, T$  is stationary,  $y_{2,t}$  Granger-causes  $y_{1,t}$  in mean in condition of  $T_{t-1}$  if:

$$E(y_{1,t}|I_{1,t-1}) \neq E(y_{1,t}|I_{t-1}) \quad (3)$$

where  $T$  is the sample size and  $I_t = (I_{1,t}, I_{2,t})$  is the information set of time series  $\{y_{i,t}\}$  available at time  $t$ . The dynamic causality model of Lu et al. (2014) is considered as an extension of the Granger causality test studied by Hong (2001) which took into account the sample cross-correlation function (CCF) of the GARCH standardized residuals of two time series. The Lu et al. (2014) approach could access both mean and variance causality by proposing two types of time-varying Granger causality tests with two dynamic correlation estimators, namely the rolling Hong test and the dynamic conditional correlation multivariate GARCH (DCC-MGARCH) Hong test, respectively. In this study, we utilize the DCC-MGARCH Hong procedure due to its ability to test the dynamic correlation among cryptocurrencies. In addition, Lu et al. (2014)'s model enables us to detect both unidirectional and bidirectional causality directions; and capture the stylized facts of various types of time series, which might include asymmetry or fat tail, for instance.

The DCC-MGARCH model by Hong (2001) consists of two steps. First, we estimate the dynamic conditional correlation between two time series  $y_{i,t}, i = 1, 2$  by using the DCC-MGARCH(1,1) model. Let denote  $y_t = [y_{1,t}, y_{2,t}]'$  with lag  $j$ ,  $y_{i,t}$  is build as the following:

$$\begin{aligned} y_t(j) &| \sim N(0, D_{t,j} R_{t,j} D_{t,j}) \\ D_{t,j}^2 &= \text{diag}\{\omega_{i,j}\} + \text{diag}\{\kappa_{i,j}\} \circ y_{t-1}(j) y_{t-1}'(j) + \text{diag}\{\lambda_{i,j}\} \circ D_{t-1,j}^2 \\ u_{t,j} &= D_{t,j}^{-1} y_t(j) \\ Q_{t,j} &= S \circ (u' - A - B) + A \circ u_{t-1}(j) u_{t-1}'(j) + B \circ Q_{t-1,j} \\ R_{t,j} &= \text{diag}\{Q_{t,j}\}^{-1} Q_{t,j} \text{diag}\{Q_{t,j}\}^{-1} \end{aligned} \quad (4)$$

where  $D_{t,j}$  is a diagonal matrix of time varying standard deviation resulted from univariate GARCH

process,  $R_{t,j}$  is the conditional time-varying cross correlation matrix with lag  $j$ ,  $u_{t,j}$  is the matrix of standardized residuals of  $y_t(j)$ ;  $Q_{t,j}$  is the time-varying with lag  $j$  of standardized residuals and  $A$  and  $B$  are non-negative scalars satisfying  $A + B < 1$  to ensure that positive definiteness of  $Q_{t,j}$ .

The dynamic correlation estimator with lag  $j$  is formulated as:

$$\begin{aligned}\rho_{pq,t}(j) &= \bar{\rho}_{pq}(j) + \alpha_j(u_{p,t-1}u_{q,t-1-j} - \bar{\rho}_{pq}(j)) + \beta_j(\rho_{pq,t-1}(j) - \bar{\rho}_{pq}(j)) \\ t_{pq,t}(j) &= \frac{\rho_{pq,t}(j)}{\sqrt{\rho_{pp,t}(j)\rho_{qq,t}(j)}}\end{aligned}\tag{5}$$

Second, we incorporate the dynamic correlation estimator from the DCC-MGARCH model to the Hong (2001) causality test. We denote  $H_t(k)$  as the unidirectional DCC-MGARCH Hong test from  $y_{2,t}$  to  $y_{1,t}$ .

$$H_t(k) = \frac{T \sum_{j=1}^{T-1} k^2\left(\frac{j}{M}\right) r_{12,t}^2(j) - C_T(k)}{\sqrt{2D_T(k)}}\tag{6}$$

where  $k_x$  is the kernel function, and  $M$  is a positive integer.  $C_T(k)$  and  $D_T(k)$  are determined as follows:

$$\begin{aligned}C_T(k) &= \sum_{j=1}^{T-1} \left(1 - \frac{j}{T}\right) k^2\left(\frac{j}{M}\right) \\ D_T(k) &= \sum_{j=1}^{T-1} \left(1 - \frac{j}{T}\right) \left(1 - \frac{j+1}{T}\right) k^4\left(\frac{j}{M}\right)\end{aligned}\tag{7}$$

In this DCC-MGARCH Hong causality test, Lu et al. (2014) argued that no lagged dynamic correlation would be feasibly estimated. The non-uniform kernels and  $M$  in Hong (2001)'s choice has little impact on the test size, while the lagged dynamic correlation approaches zero when  $M$  increases. The Bartlett kernel is, therefore, a solution to be used in empirical studies:

$$k(z) = \begin{cases} 1 - z, & |z| < 1 \\ 0, & |z| \geq 1 \end{cases}$$

when  $j \geq M$ , the Bartlett kernel  $k\left(\frac{j}{M}\right) = 0$ . Let denote  $\Phi_t(k)$  as the standardized unidirectional DCC-MGARCH Hong test from  $y_{2,t}$  to  $y_{1,t}$ .  $\Phi_t(k)$  is estimated as follows:

$$\Phi_t(k) = \frac{T \sum_{j=1}^M r_{12,t}^2(j) - M}{\sqrt{2M}} \quad (8)$$

Under appropriate conditions, DCC-MGARCH Hong causality tests are asymptotical  $N(0,1)$  distributed, so we are able to make judgments from empirical studies <sup>2</sup>

#### 4.2. Causality-based stable networks

The integrated framework consists of two main parts. In the first step, we obtain the time-varying causalities among time series. The second step is to build their dynamic network  $N_t$ , including nodes (representing sample cryptocurrencies) connected by directed edges resulting from causality at time  $t$ .

At any given time  $t$ , the directed and unweighted network  $N_t$  evolves and involves at most  $k$  nodes from  $\{n_1, n_2, \dots, n_k\}$ . At time  $t$ , certain or all the nodes in the network may be connected to each other, following some  $t$ -dependent criteria. We denote  $e_{ij}$  as a directed edge connecting  $n_i$  to  $n_j$  and time  $t_1$  spans from  $t_1$  to  $t_m$  in the set  $\{t_1, t_2, \dots, t_m\}$  and  $e_{ij}$  appears  $s$  out of  $m$  times in the network.  $e_{ij}$  is called a  $p$ -stable directed edge (or connection) if  $0 < p \leq \frac{s}{m} \leq 1$ . Then a network  $\Gamma$  is called  $p$ -stable network of  $N_t$  if it comprises only  $p$ -stable directed connections of  $N_t$ . If  $p$  is relatively high, it is natural to argue that the network  $\Gamma$  reveals the transmission of rooted information or shock in the sample. In particular, if the  $p$  is chosen equal to 1, the constructed direct network would present the significant daily causalities during the sample spanning. This causality network given by  $p$ -stable ( $p = 1$ ) holds all time and is not affected if the sample is not stable or may contain turbulent times. In other words, any decisions based on this network studied above are independent of the instability risk.

#### 4.3. Network Centrality Analysis

Centrality estimation addresses the impact role of each member in the network from different perspectives, including in-out degree, in-out closeness, betweenness, PageRank, and hubs and

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<sup>2</sup>0.05 is taken as the significance level when dynamic causalities are detected.

authorities.

### In-degree

The number of edges incoming to  $i$  is considered as in-degree score  $c^{in(i)}$  whilst out-degree score  $c^{out(i)}$  is the number of edges outgoing from  $i$ .  $i$  and  $j$  are denoted to be two nodes in the observed network. If  $j$  is the successor of  $i$  we have an adjacency matrix  $A_{ij}$ .  $A_{ij}$  equal to either 1 or 0. In the following,  $c^{out(i)} = \sum_j A_{ij}$  and  $c^{in(i)} = \sum_j A'_{ij}$  in which  $A'$  is the transposed matrix of  $A$ . As such, the cryptocurrency with a higher in-degree score is likely more affected than the others, while a higher out-degree score means the cryptocurrency has greater influence on the others.

### In-Out closeness

In-closeness centrality of node  $i$  is to measure the (inverse) number of edges from other nodes  $j$  that can reach node  $i$  in the network, and in contrast, out-closeness centrality is the number of nodes  $j$  that node  $i$  can reach. The in-out closeness centrality is defined as:

$$c^{in(out)}(i) = \left( \frac{s_i^{in(out)}}{N-1} \right)^2 \frac{1}{\sum_{j=1}^N d^{in(out)}(i, j)} \quad (9)$$

where  $N$  is number of total nodes in the network,  $s_i^{in(out)}$  is the number of node that could reach (be reachable from)  $i$ , and  $d^{in(out)}(i, j)$  is the minimum geodetic path distance to (from) node  $i$  from (to) node  $j$ . In the empirical study, the cryptocurrency with the higher in-closeness score is properly affected faster by the crisis occurring in the network than the others. Differently, the higher out-closeness degree indicates that the cryptocurrency can spread its crisis quicker than the others in the network.

### Betweenness

The betweenness centrality measures the appearance frequency of a node  $i$  in on the shortest path between any other pairs of node  $(i, j)$  in the network. The betweenness centrality is estimated as:

$$c(i) = \sum_{j, k \neq i} \frac{N_{jk(i)}}{N_{jk}} \quad (10)$$

Where  $N_{jk(i)}$  is the shortest path passing through node  $i$  between  $j$  and  $k$ , including both incoming and outgoing directions, the cryptocurrency with a higher betweenness score is likely more vulnerable and influential in the network.

### PageRank

PageRank is a variant of eigenvector centrality that resulted from a random walk of the network. Let  $\mathbf{c}$  as the vector of PageRank scores, then  $\mathbf{c} = \alpha P\mathbf{c} + (1 - \alpha)I$ , where  $P_{ij} = \frac{A_{ij}}{k_j^{out}}$  is the transition matrix,  $A_{ij}$  is the adjacency matrix,  $k_j^{out}$  is the out-degree of node  $j$  and  $I$  is the identity. This score measures the probability that a crisis from node  $j$  can transmit to node  $i$ . As such, a cryptocurrency with a higher PageRank score is likely more vulnerable to any random shock occurring in the network.

### Hubs and authorities

Hub score estimates how well a cryptocurrency transmits information to others, and the authority score provides how well that cryptocurrency receives information from the others in the network. Let  $n$  is the number of nodes in the network,  $A_{ij}$  is the  $n \times n$  adjacency matrix,  $\mathbf{h}$  and  $\mathbf{a}$  is its  $1 \times n$  hub and authority score vectors respectively.  $\mathbf{h}$  and  $\mathbf{a}$  is initialized to identity, then  $\mathbf{a} = A'\mathbf{h}$  and  $\mathbf{h} = A\mathbf{a}$ .

## 5. Results

### 5.1. Causality network of cryptocurrency returns

The  $p - stable$  causality network of forty cryptocurrencies over the period of January 01, 2018 - December 31, 2020 are presented in Figure 3 and Table 3 gives their respective centrality scores. At first glance, the results show evidence of intimate integration among the cryptocurrency returns increasing substantially as  $p$  reaches 0.5.

**Insert Figure 3 here.**

**Insert Table 3 here.**

Interestingly, Dogecoin (DOGE) plays the most influential role in the return causality networks, featured by its highest out-degree and out-closeness scores. Additionally, its betweenness scores and hub centrality in all levels of  $p$  also show evidence of being the main shock transmitter in the network. This finding is in line with Zikéba et al. (2019) that Dogecoin is one of the two biggest hubs. The authors argue that Dogecoin's mining mechanism is preferable, with the Script



algorithm costing less than Bitcoin and other leading cryptocurrencies. In addition to Dogecoin, EOS also performs its central shock transmission in any crisis cases in the network, given its highest hub centrality scores in  $p = 0.8$  and  $p = 0.7$ .

Another important finding is that Chainlink (LINK) and Horizen (ZEN) are the top vulnerable currencies as they have high in-degree, in-closeness, and page-rank scores. In the meantime, Binance (BNB) surprisingly shows its vulnerability evidence through its highest preeminent authority rank at  $p = 1$  but is replaced by ChainlinkNK) and ICON (ICX) in  $p$  lower than 1.

Notably, Tether (USDT) is isolated in the return causality network at  $p = 1$  but information transmitters at lower  $p$  levels of 0.5 and 0.6. It may derive from that Tether is created as a stable coin mirroring the US dollar price. An amount of dollar is reserved equal to the amount of Tether in circulation to anchor its token to US dollars; hence its prices remain stable and are not affected by any shock. Besides that, OMG Network (OMG) and Decentraland (MANA) are also shown to be relative isolation from the cryptocurrency causality network at  $p = 1$

In contrast with Koutmos (2018) and Ji et al. (2019) but supporting for Yi et al. (2018), and Moratis (2021) recently, our study indicates that Bitcoin is neither a shock transmitter nor a receiver in the return causality networks of the cryptocurrency market. The central positions are now forwarded to other smaller-price cryptocurrencies.

## 5.2. Causality network of cryptocurrency liquidity

Turning to the liquidity perspective, the causality network structure and the centrality scores are presented in Figure 4 and Table 4 respectively. We can see the evidence that the liquidity of all cryptocurrencies densely interacted at all levels of  $p$ . The causality and centrality scores are almost homogeneous except for  $p = 1.0$  and  $p = 0.9$ .

**Insert Figure 4 here.**

**Insert Table 4 here.**

There are two causal liquidity groups in the board  $p = 1$ . Binance (BNB), LBRY Credits (LBC), Siacoin (SC), IOTA (MIOTA), and Voyager Token (VGX), are in one group, the so-called peripheral

group, and the other group, which consists of all remaining cryptocurrencies, the so-called central group. The peripheral group members have less interaction with other cryptocurrencies, whereas the central group members strongly interact with others.

In the center of this liquidity causal network, Chainlink (LINK), Kyber Network (KNC), Stellar (XLM), and Zcash (ZEC) are the most vulnerable cryptocurrencies with the highest in-degree and in-closeness scores. Stellar furthermore stands at the highest position in PageRank scores, and Chainlink ranks first in terms of authority. This finding of Chainlink is consistent with section 5.1. Besides that, Nano (NANO) and Decentraland (MANA) are shown as the most influential cryptocurrencies as they have the highest betweenness ranks. Nano is also the top liquidity shock transmitter as it holds the highest hub score.

### 5.3. Robustness

We shift the focus to the sub-period from 15/12/2019 to 31/12/2020 to observe the risk transmission among cryptocurrencies that may be affected by the COVID pandemic. The investigation can provide the robust analysis for the earlier results in Section 5.1 and 5.2. Figure 5 and 6 show the stable causality network of cryptocurrency returns and liquidity while Table 5 and 6 present their centrality scores.

In the return causality network, Horizen (ZEN) acts as a shock transmission catalyst given its top scores of in-degree, out-degree, out-closeness, betweenness, and hub centrality. In other words, Horizen (ZEN) plays a role both transmitter and receiver at level  $p$  of 1. Besides Horizen (ZEN), we can observe that Monera places at the first position of shock transmission in the network because of its out-degree and out-closeness highest scores, while Bitcoin and Bitcoin gold are the most fragile and vulnerable cryptocurrencies as they ranked first in in-closeness, PageRank, and authority scores at  $p = 1$ . We also find the shreds of evidence of uni-directional causality transmitter-receiver in the stable network, including Binance (BNB) - Revain (REV) and Digibyte (DGB) - OMG Network (OMG). It is also worth noting that Decentraland (MANA), DASH (DASH), LBRY Credits (LBC), Enjin Coin (ENJ), Stellar (XLM), Dogecoin (DOGE), IOTA (MIOTA), and Neo (NEO) are relatively isolated in  $p = 1$  causality network, and Zcash (ZEC) is in relative isolation in all broads of  $p$ . In addition to BTC, Digibyte is highly vulnerable at lower levels  $p$ .

Turning to the stable liquidity network, we observe the same results that Horizen (ZEN) is the most vulnerable member in the liquidity causality network as holding the highest in-degree, in-closeness, PageRank, and Authority scores. At the same time, Litecoin is the most influential in the network through its top out-degree, out-closeness, and Hub centrality scores.

#### 5.4. Discussion

Taken together, it is noteworthy to summarize the centrality simulation results in certain crucial points contributing implications for both investors and policy-makers. First, comparing return and liquidity stable networks, we can see that the liquidity causality among cryptocurrencies is more exuberant with heavy bi-direction pairs than their return network, confirmed in the whole period and sub-period sample. It means that the contagion of liquidity is stronger than the return in the cryptocurrency market. Argued by Bianchi et al. (2022) that the return from liquidity provision of cryptocurrency pair is more broadened if they are smaller, less liquid, and more volatile, the evidence of shock transmission among their liquidity is much more considered when making an investment decision. Second, in line with Bianchi et al. (2022), this study also provides pieces of evidence that the smaller cryptocurrencies play influential roles in causality networks of both returns and liquidity. In particular, Dogecoin (DOGE), Litecoin (LTC), Monero (XMR), and Nano (NANO) are the influence on the others, while Chainlink (LINK), Horizen (ZEN), and Bitcoin (BTC) are subject to high fragile and vulnerable in turmoil cases. This information transmission flows presents speculation evidence when the information is centralized surrounding the small cryptocurrencies instead of the most conventional cryptocurrencies such as Bitcoin and Ethereum. That may give an idea of policy design to mitigate risk transmission in the cryptocurrency market. Last, we observe more uni-direction causal pairs and isolated cryptocurrencies in the stable return network during the COVID-19 period. Compared with the previous period, the investment reluctance caused by the COVID-19 crisis made the investors more circumspect when choosing cryptocurrencies, so the “penny” cryptocurrencies were in isolation in the network. It again supports our argument of the speculative nature of cryptocurrencies (Grobys and Junttila, 2021).

## 6. Conclusion

The present paper investigates the dynamic integration and risk transmission cryptocurrency market by developing stable causality networks among the forty leading cryptocurrencies. With the sample market capitalization of a relative 80% total market capitalization on 31 December 2020, our results can give implications for the whole cryptocurrency market. Our study shows evidence of a rich causal interrelationship among both cryptocurrency return and liquidity. Especially, the liquidity interconnectedness is much tighter than returns. By integrating the causality direction, we noticeably find that smaller cryptocurrencies play the most influential roles in transmitting and receiving the shock. Bitcoin does not strongly interconnect with other cryptocurrencies in the whole period from both the return and liquidity points of view. But during COVID-19 time, Bitcoin was subject to vulnerability and fragility to the shocks in the stable return network. In addition, we further hypothesize the speculative characteristics of the cryptocurrency market because of not only the big causality influence of smaller cryptocurrencies but also the causality direction difference in the crisis period (2019 - 2020). It can be seen from the robust results that there are more isolated cryptocurrencies and one-way causality relationships than in the whole period. Over time, we observe heavy bi-direction causality in both return and liquidity stable networks.

Our study may support the investors in choosing cryptocurrencies as a hedging tool or portfolio diversification through the findings of the relative influence of one cryptocurrency on one another, especially the smaller ones. The miners may also benefit from our results by selecting the appropriate cryptocurrencies to avoid potential losses due to the causality effect in the market and save computing power. The policymakers may have more evidence of substantial spillover to initiate the policy that makes the cryptocurrency market approached closely to the conventional financial markets, limit risk transmission and make the cryptocurrency market more resilient and efficient.

## Figures

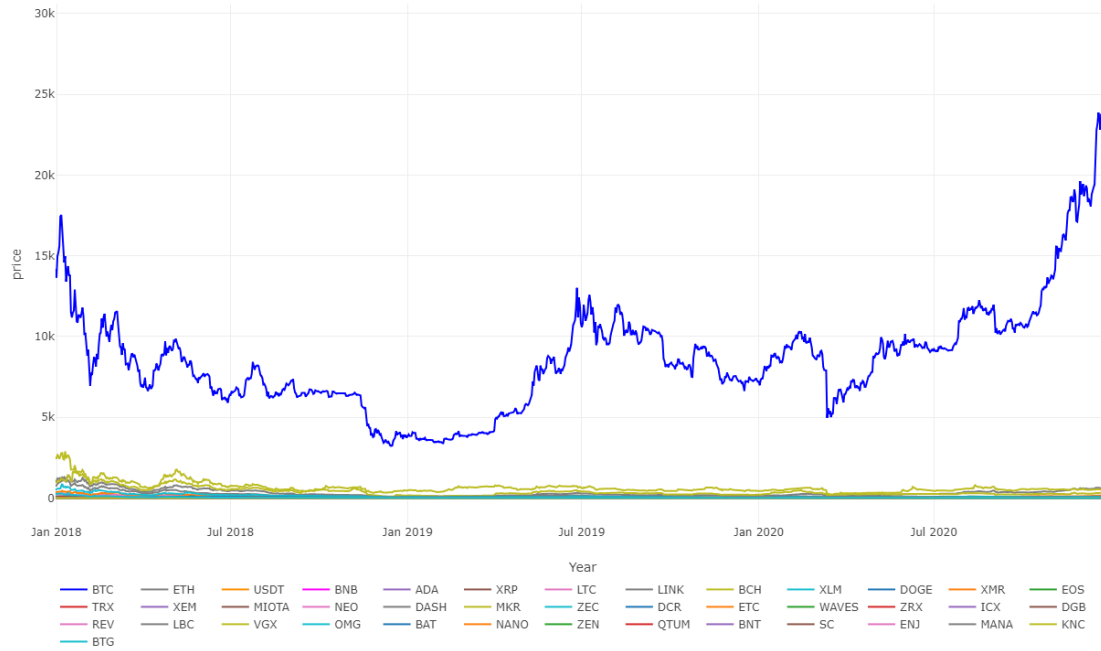


Figure 1: Cryptocurrency closing prices from January 2018 to December 2020

*The full name of each cryptocurrency are shown in table 7.*

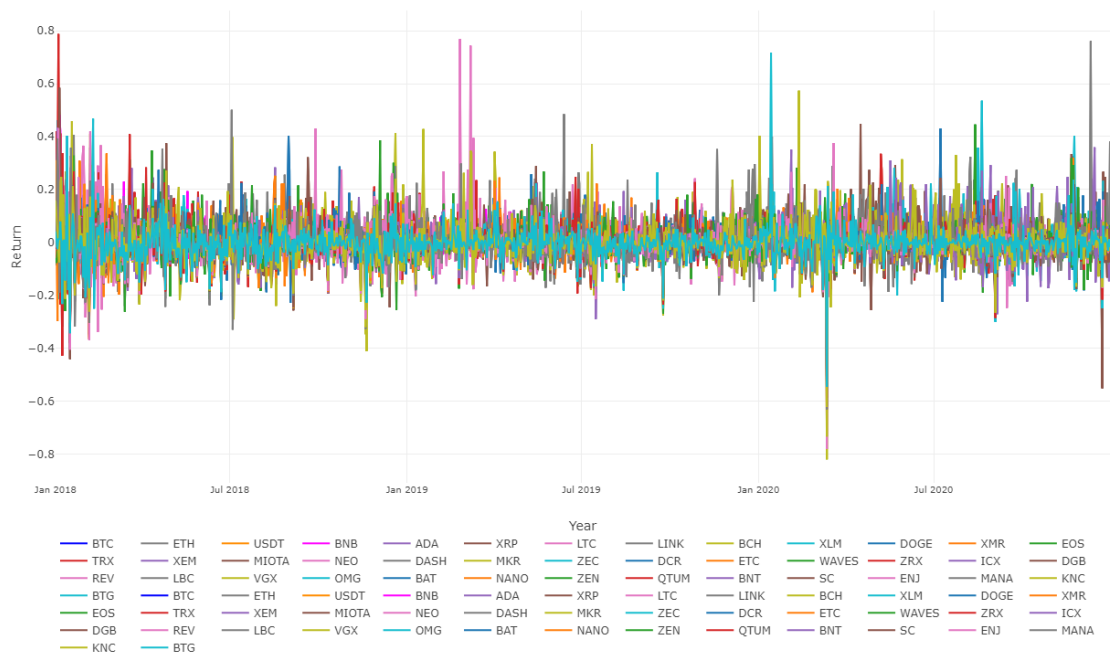
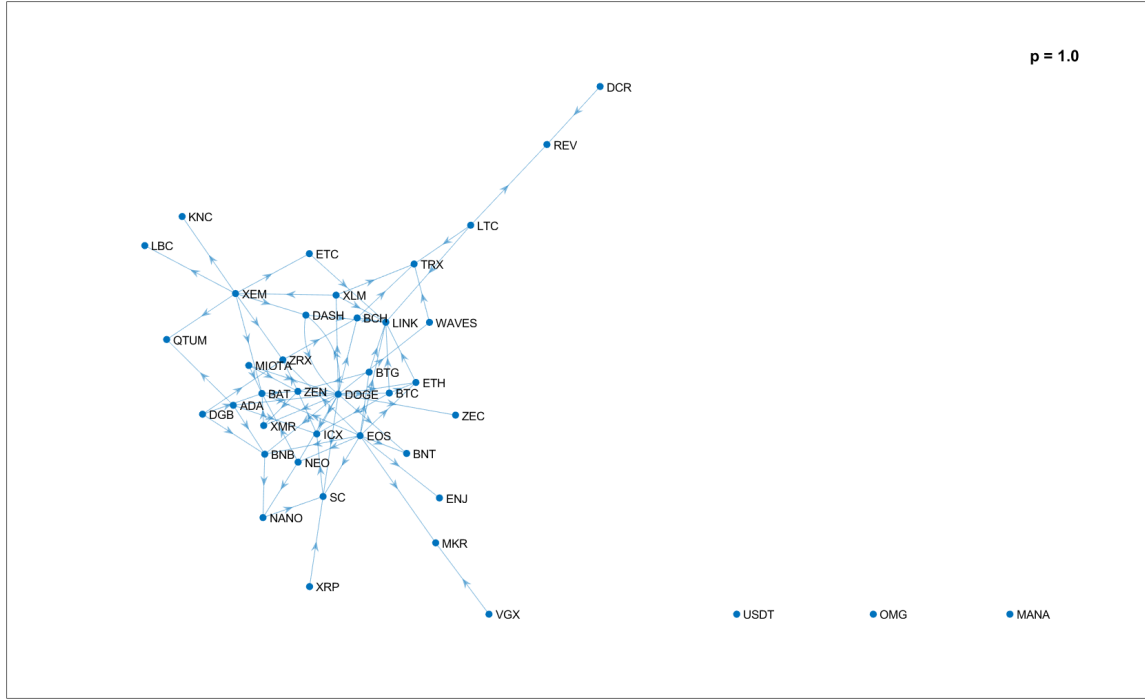
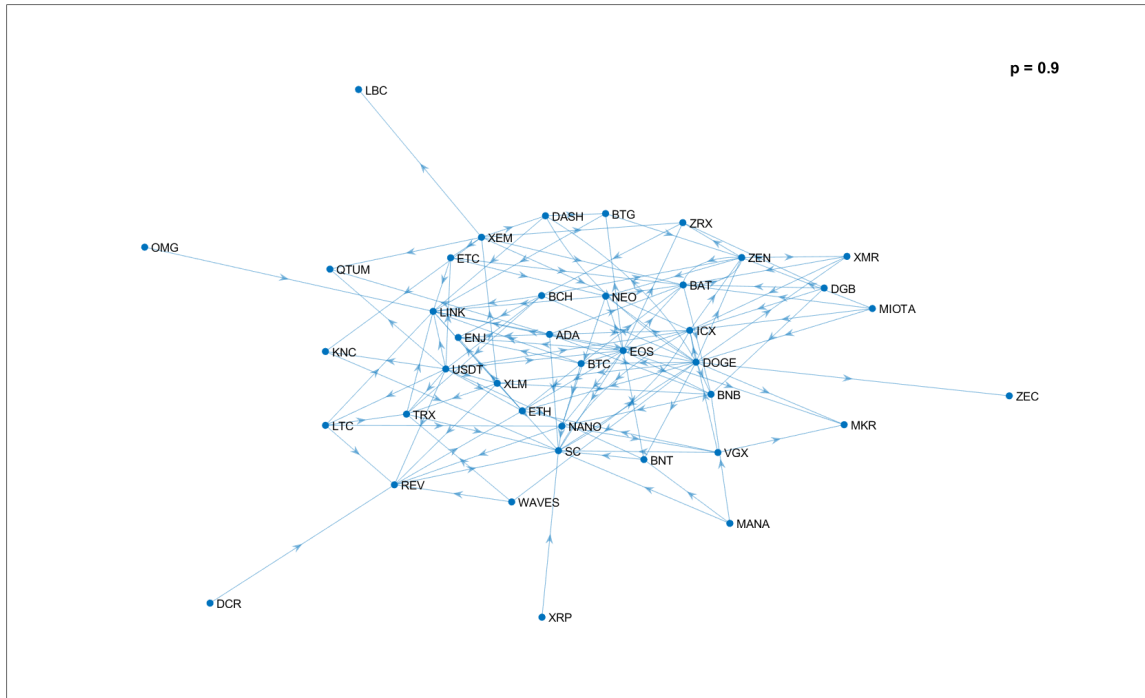


Figure 2: Cryptocurrency return from January 2018 to December 2020

*The full name of each cryptocurrency are shown in Table 7.*



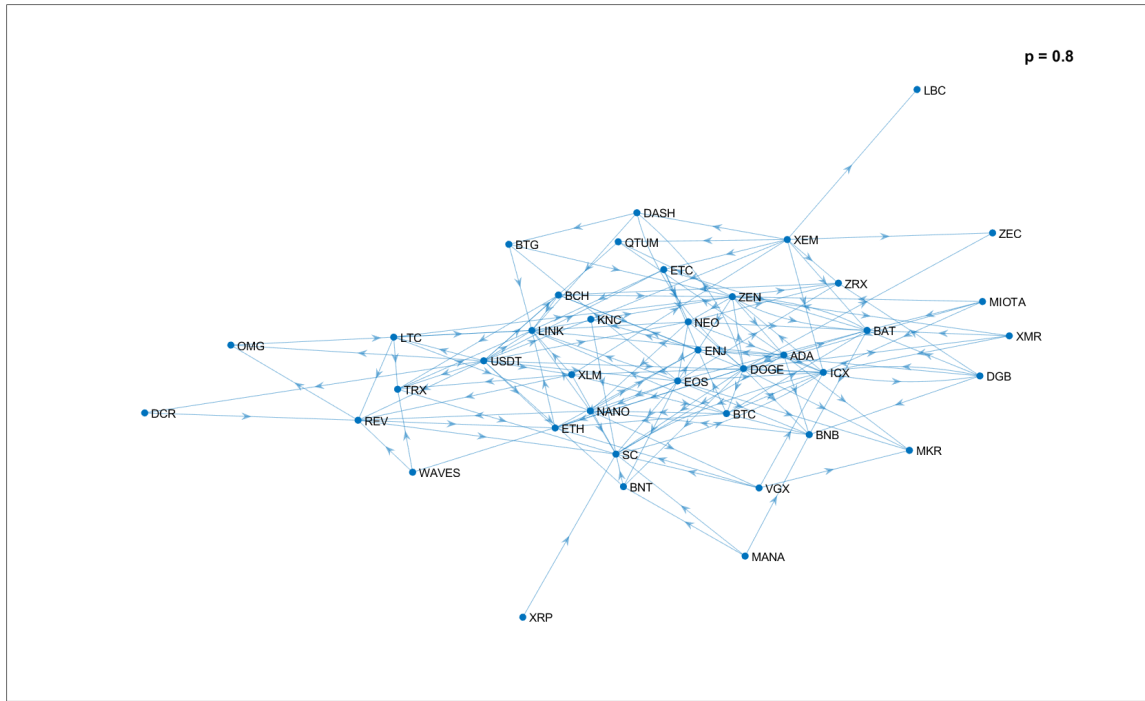
(a)  $p = 1.0$



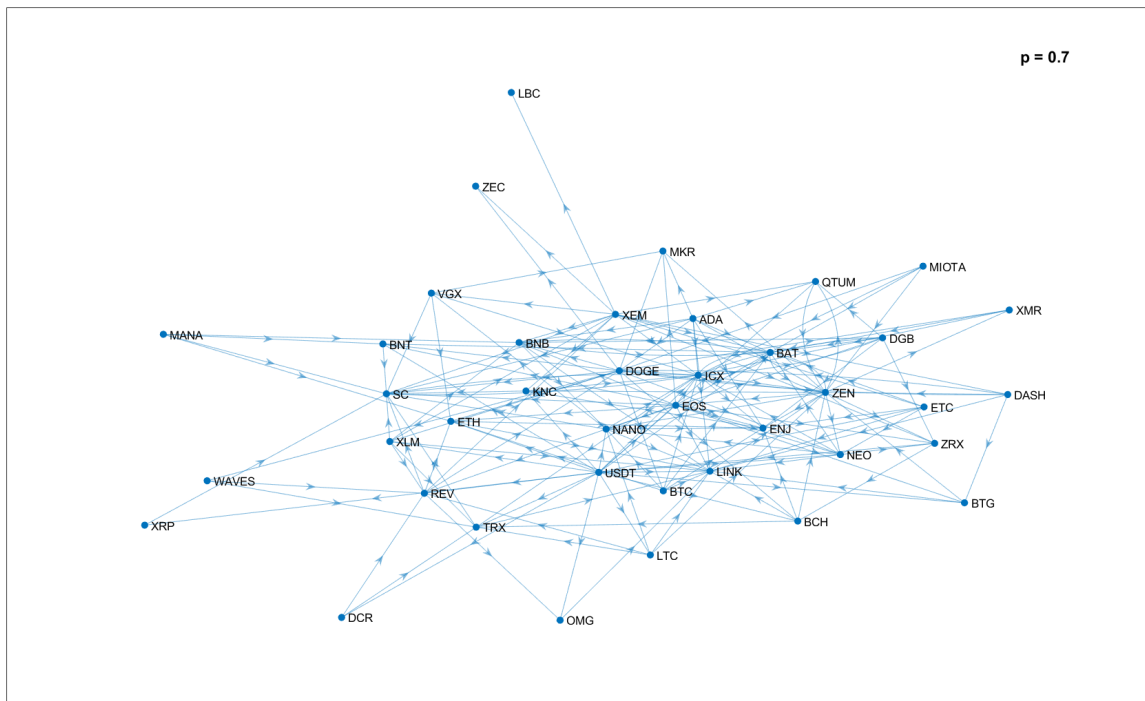
(b)  $p = 0.9$

Figure 3: Stable causality network of cryptocurrency returns for period 2018-2020

*The full name of each cryptocurrency are shown in table 7.*



(c)  $p = 0.8$

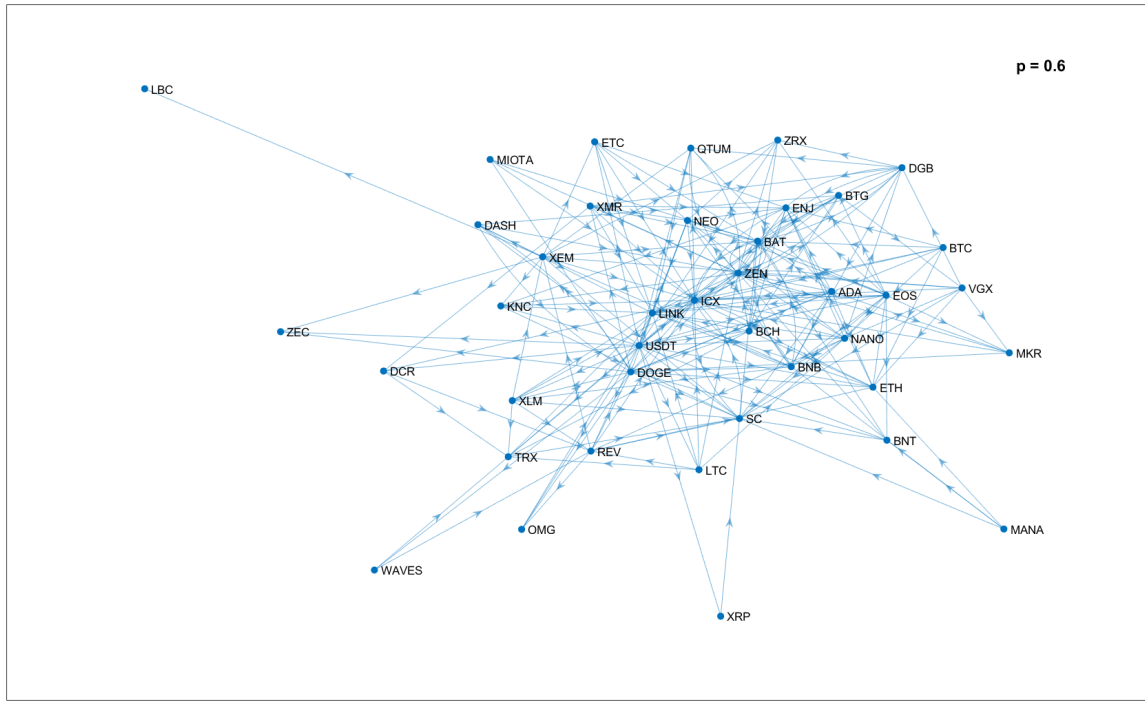


(d)  $p = 0.7$

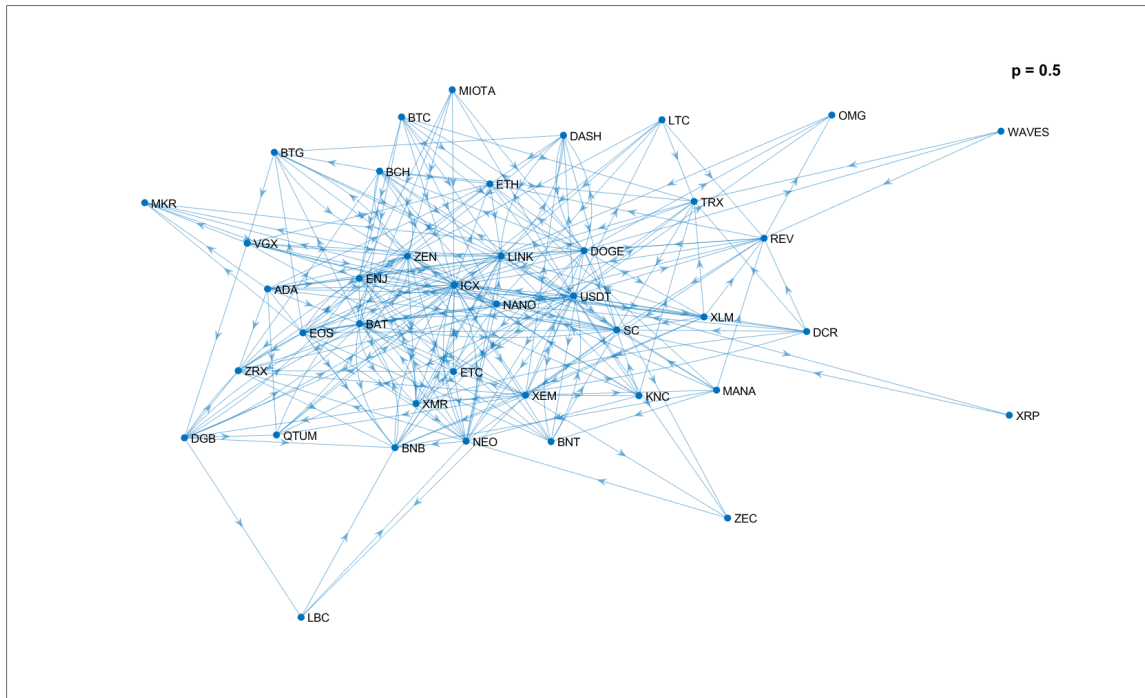
Figure 3: Stable causality network of cryptocurrency returns for period 2018-2020

*The full name of each cryptocurrency are shown in table 7.*





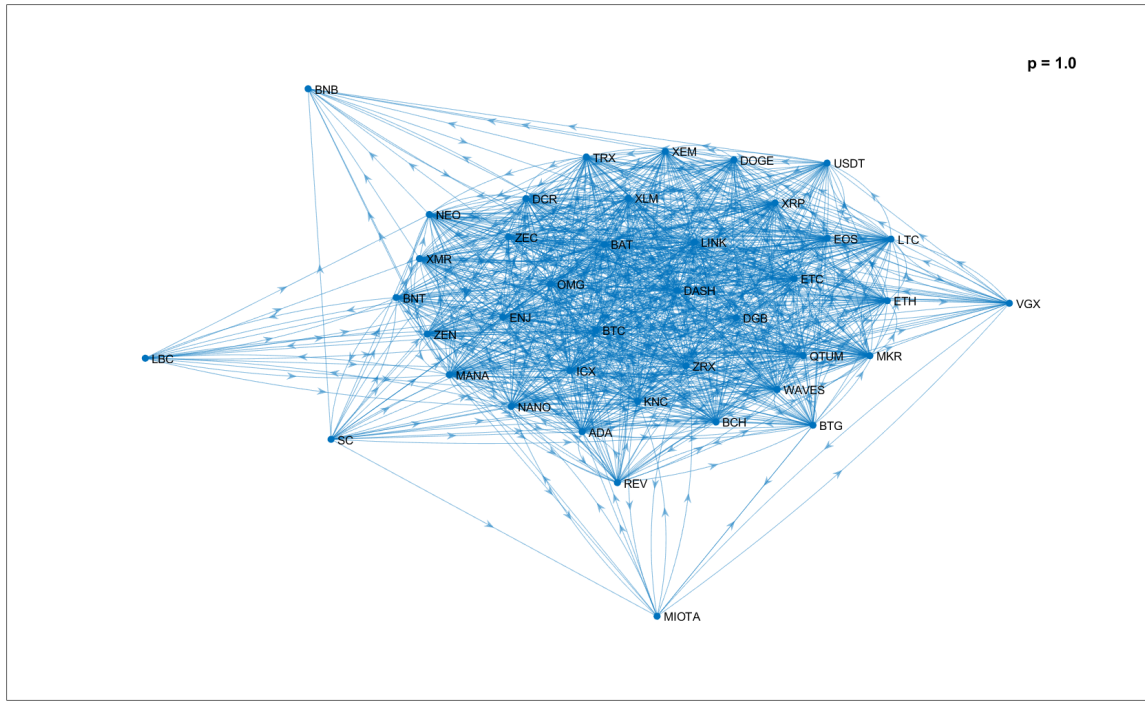
(e)  $p = 0.6$



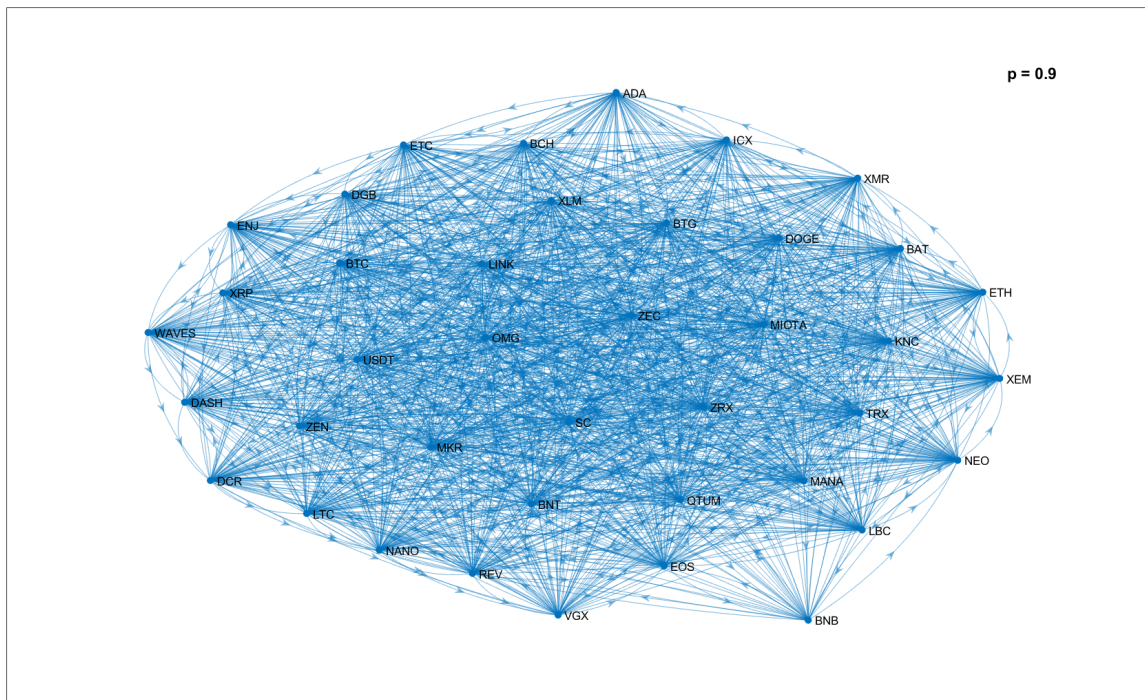
(f)  $p = 0.5$

Figure 3: Stable causality network of forty cryptocurrency returns for period 2018-2020

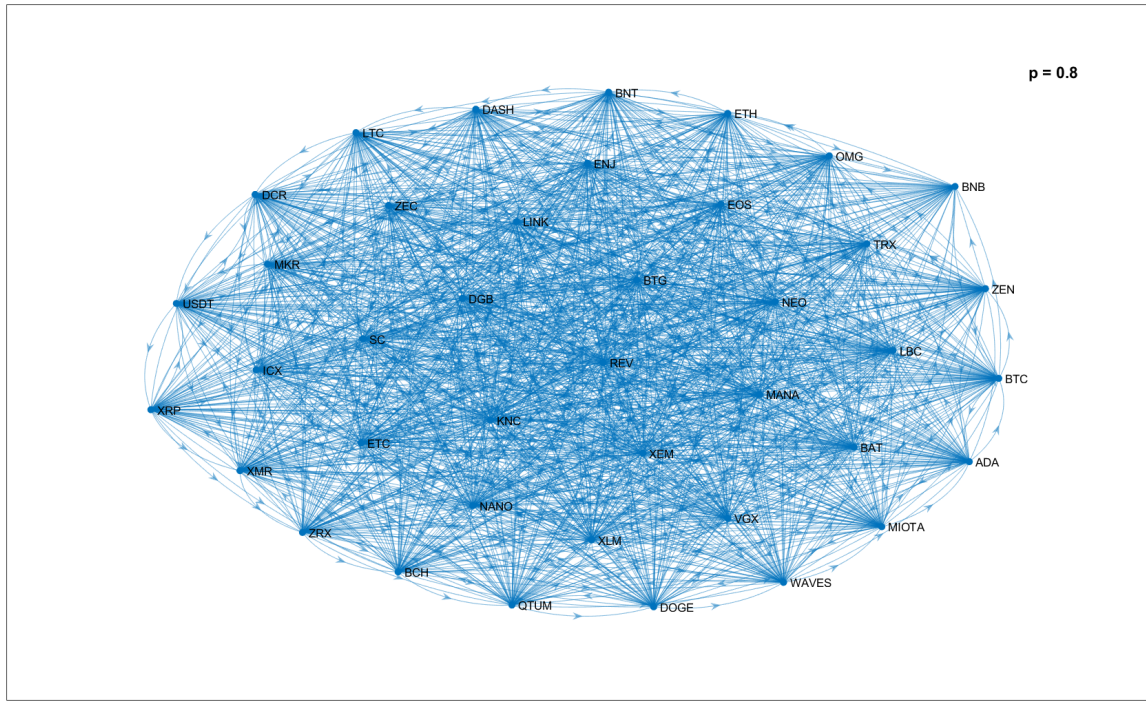
*The full name of each cryptocurrency are shown in Table 7.*



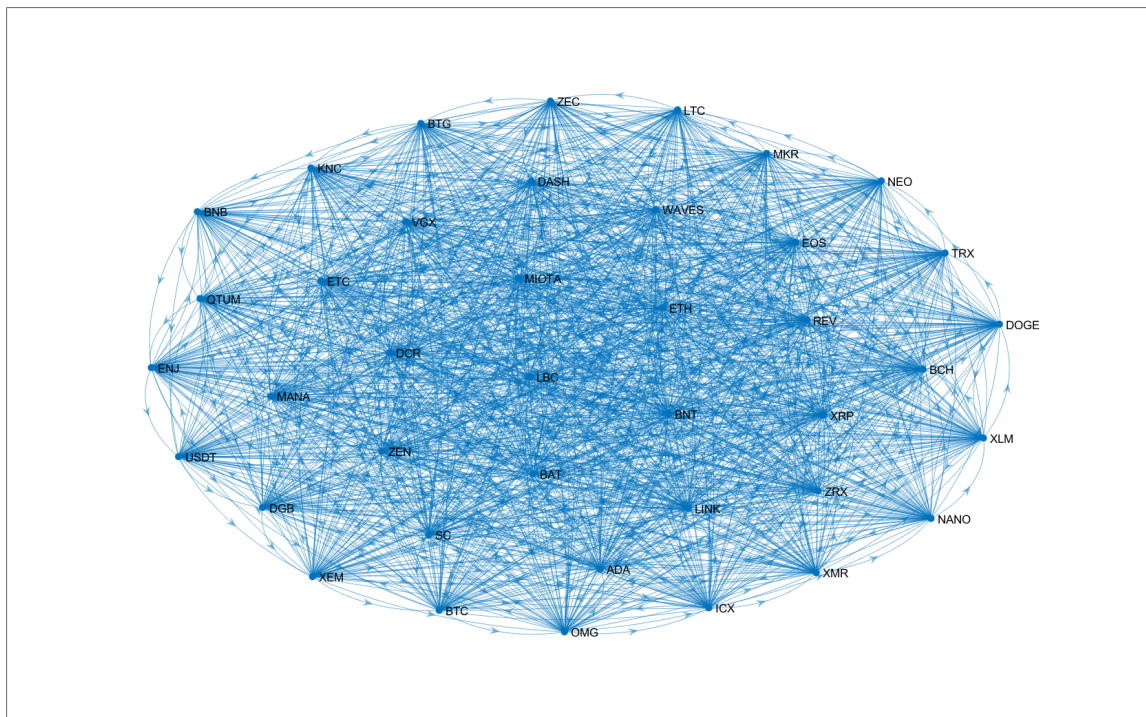
(a)  $p = 1.0$



(b)  $p = 0.9$



(c)  $p = 0.8$

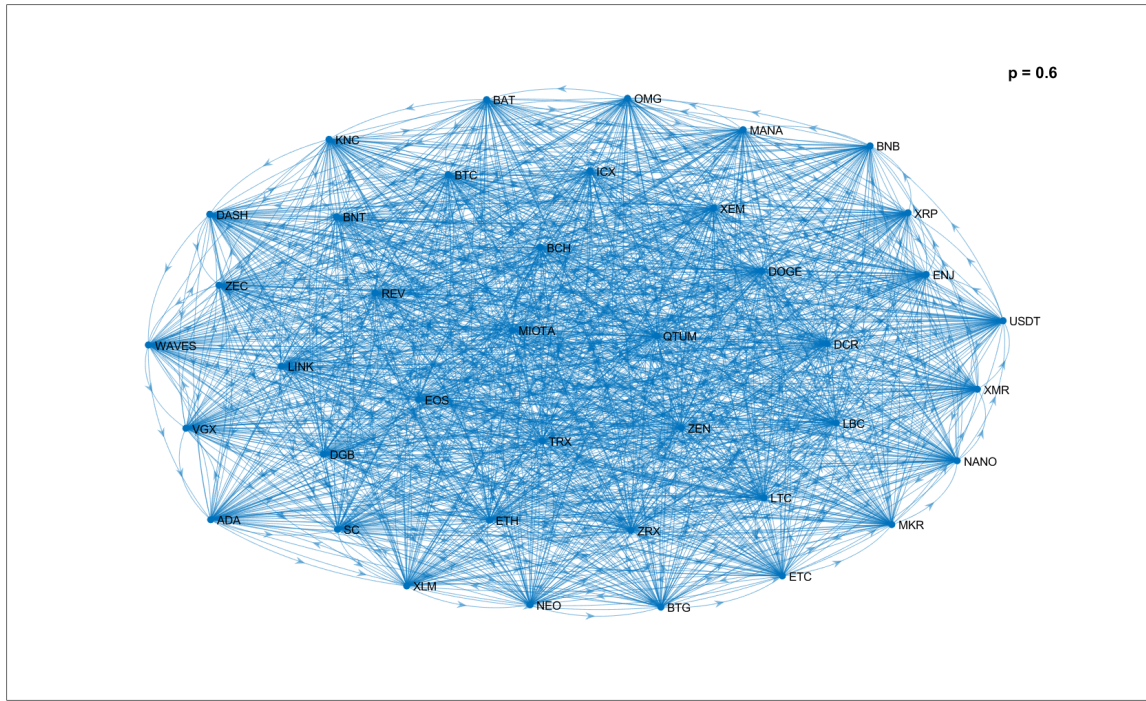


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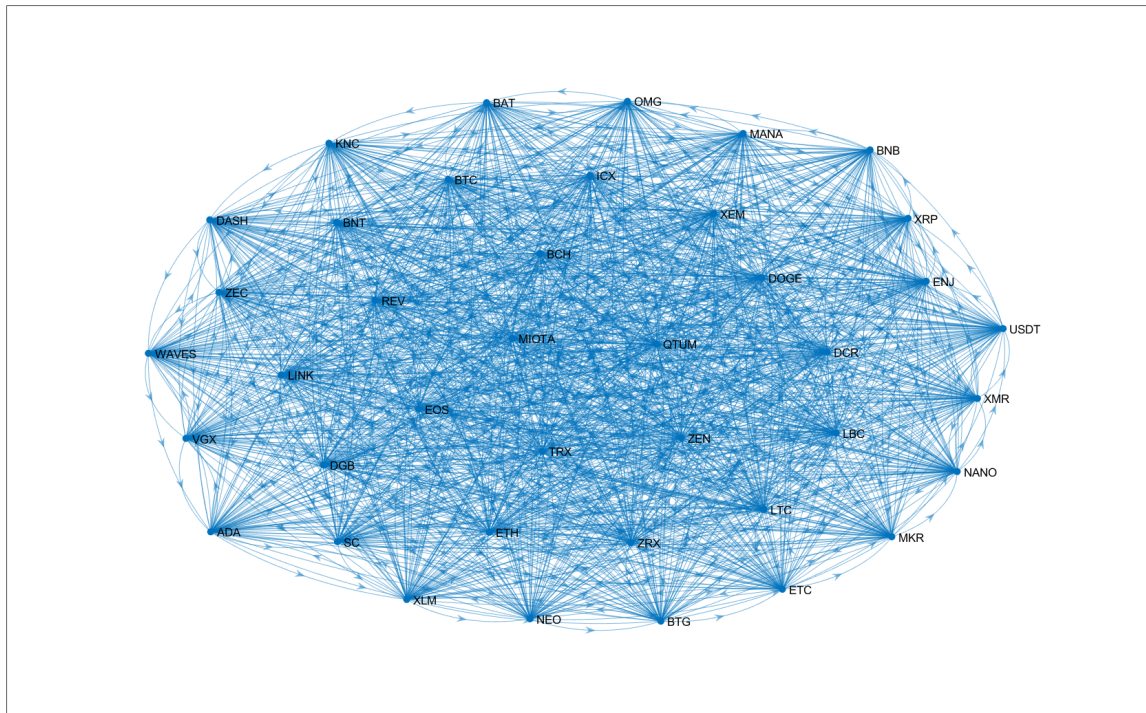
Figure 4: Stable causality network of forty cryptocurrency liquidity for period 2018-2020

*The full name of each cryptocurrency are shown in table 7.*





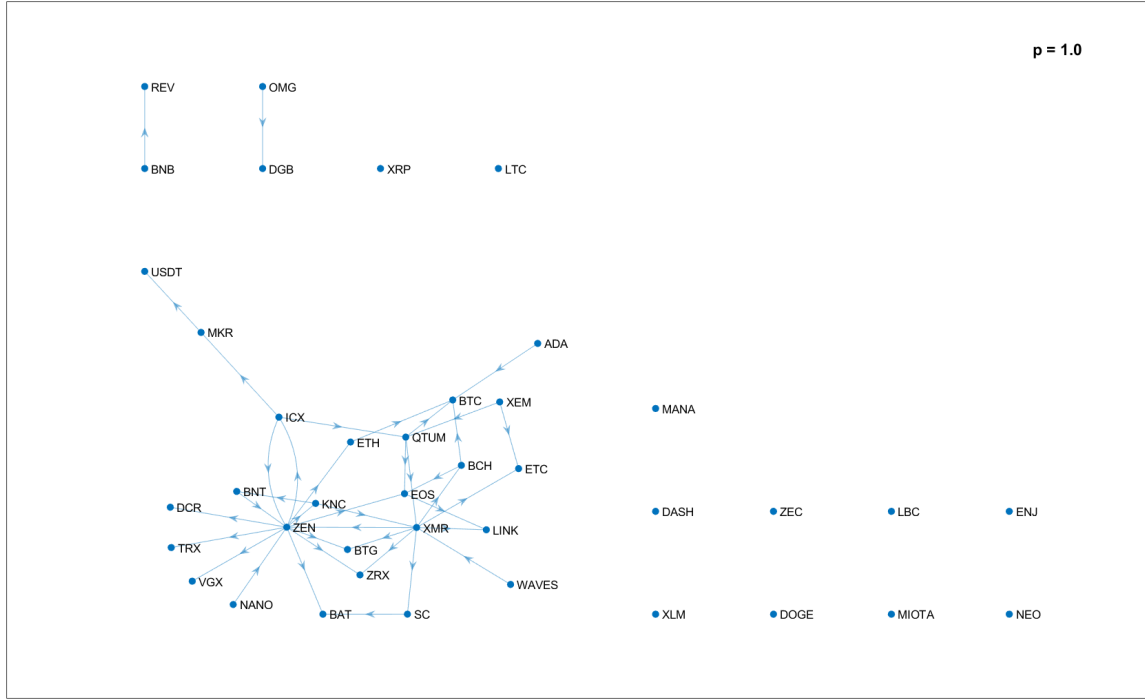
(e)  $p = 0.6$



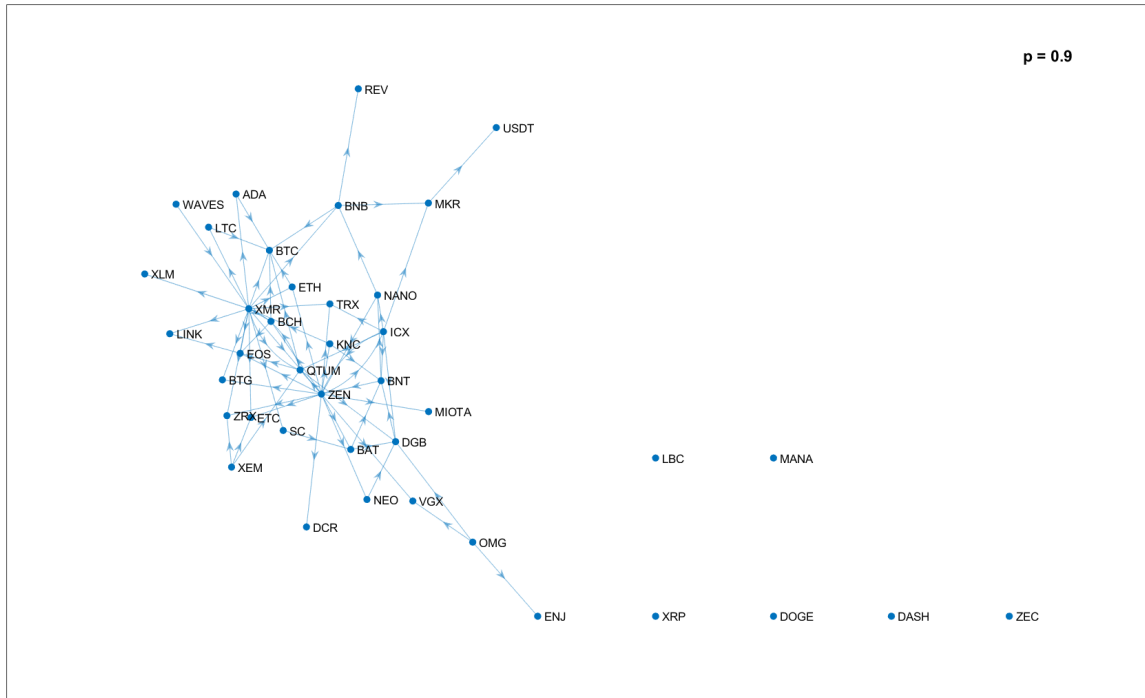
(f)  $p = 0.5$

Figure 4: Stable causality network of forty cryptocurrency liquidity for period 2018-2020

*The full name of each cryptocurrency are shown in table 7.*



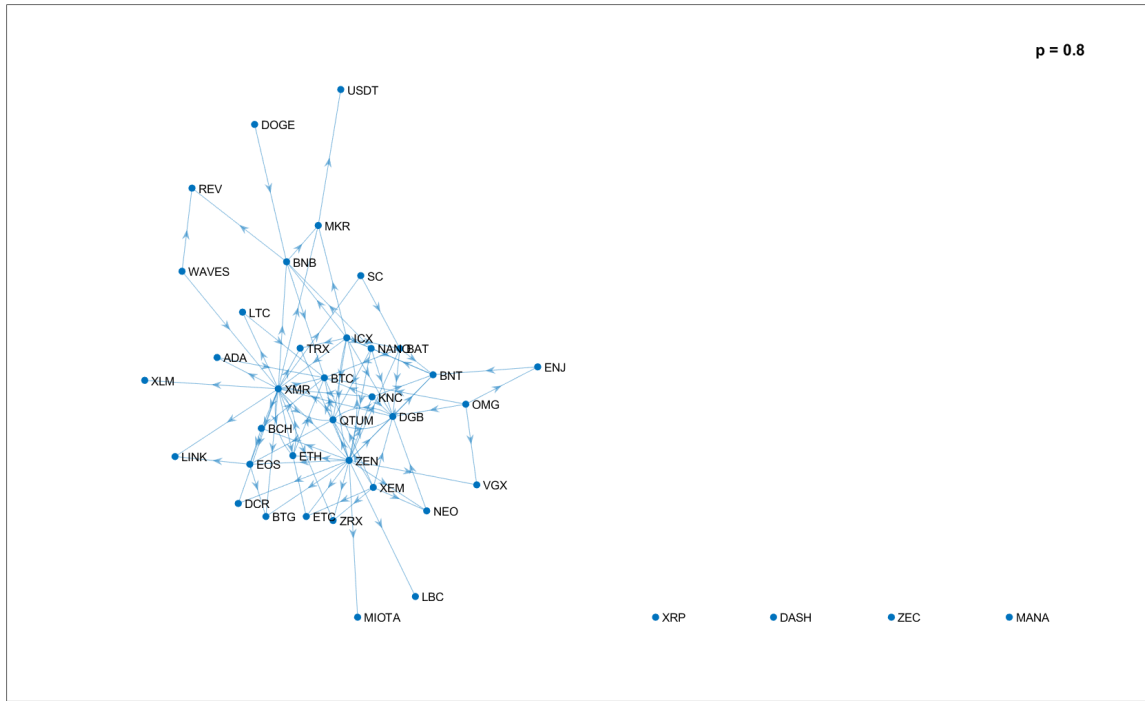
(a)  $p = 1.0$



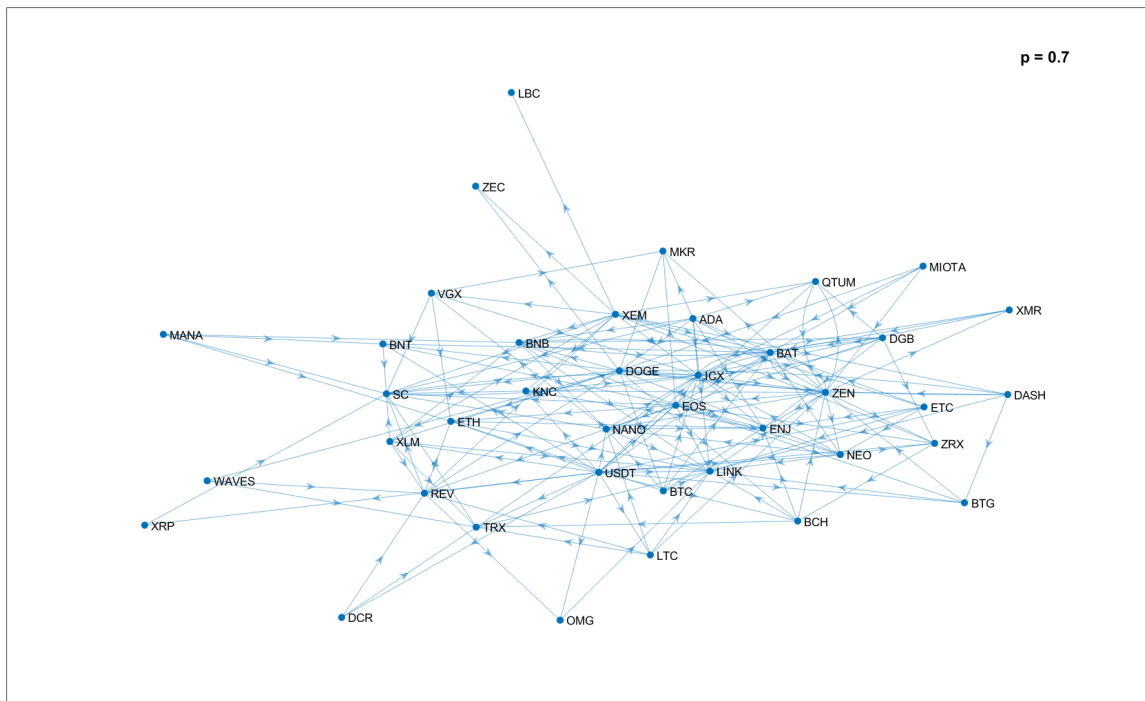
(b)  $p = 0.9$

Figure 5: Stable causality network of forty cryptocurrency returns for period 2018-2019

*The full name of each cryptocurrency are shown in table 7.*



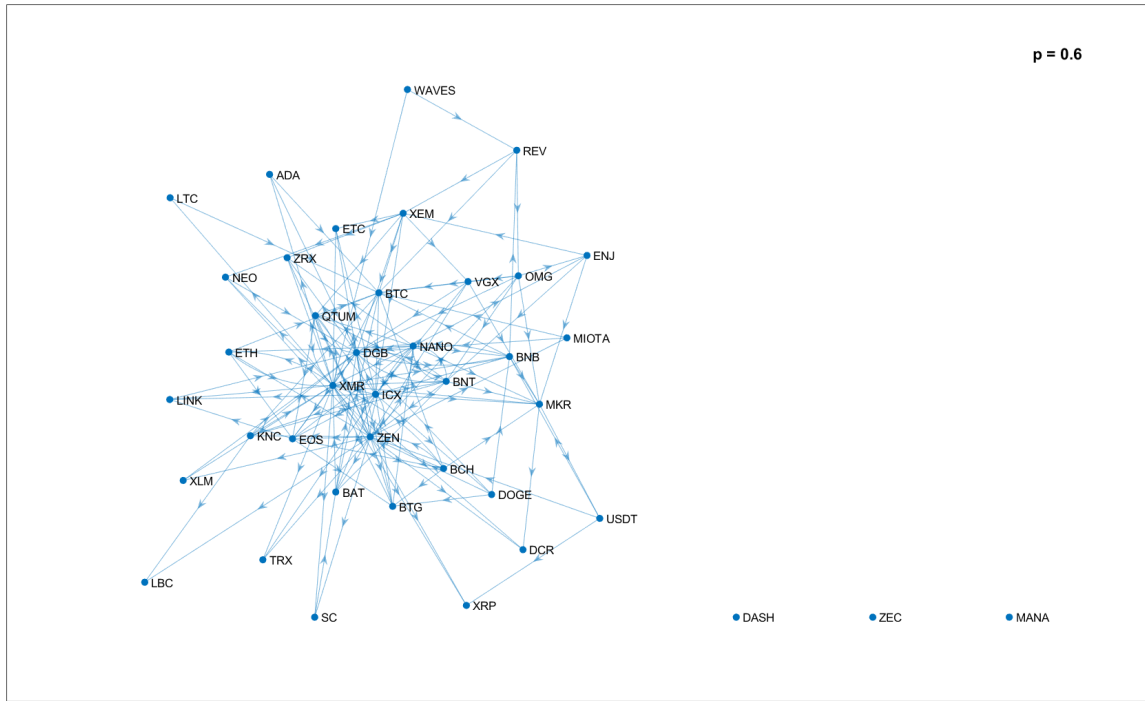
(c)  $p = 0.8$



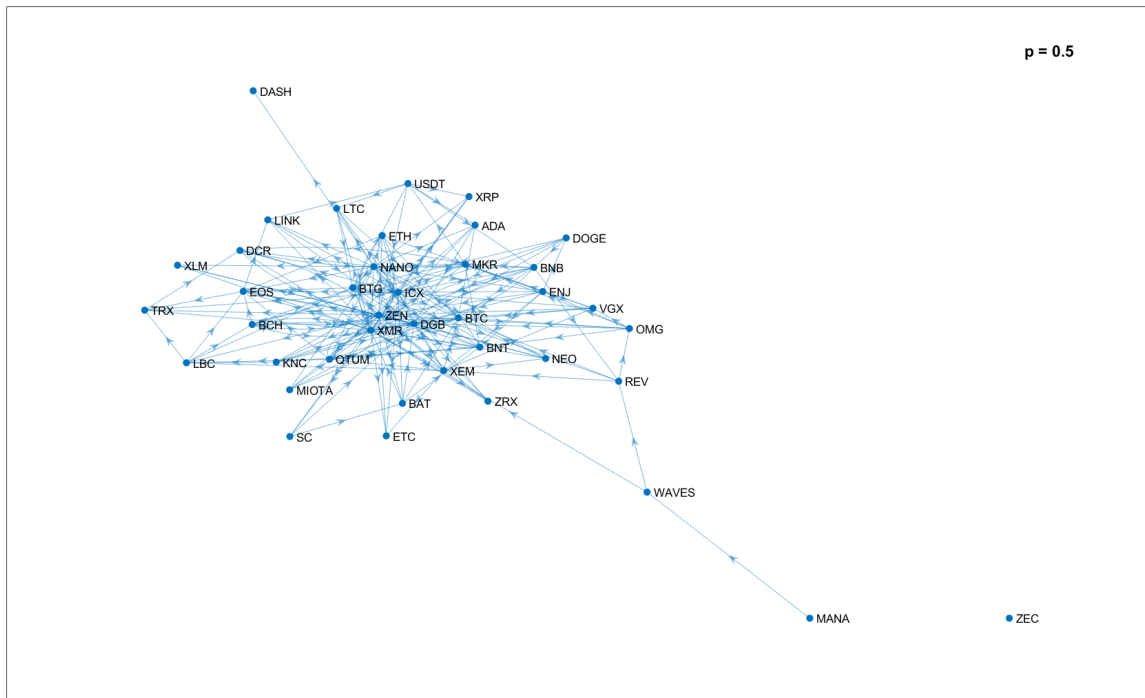
(d)  $p = 0.7$

Figure 5: Stable causality network of forty cryptocurrency returns for period 2019-2020

*The full name of each cryptocurrency are shown in table 7.*



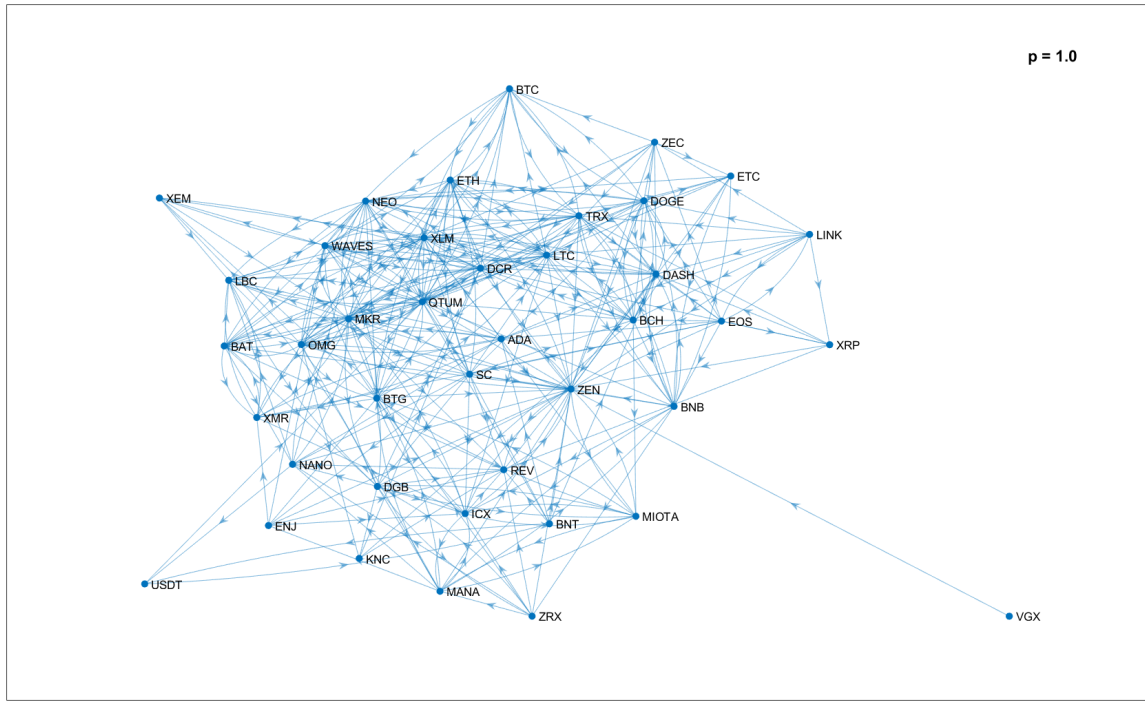
(e)  $p = 0.6$



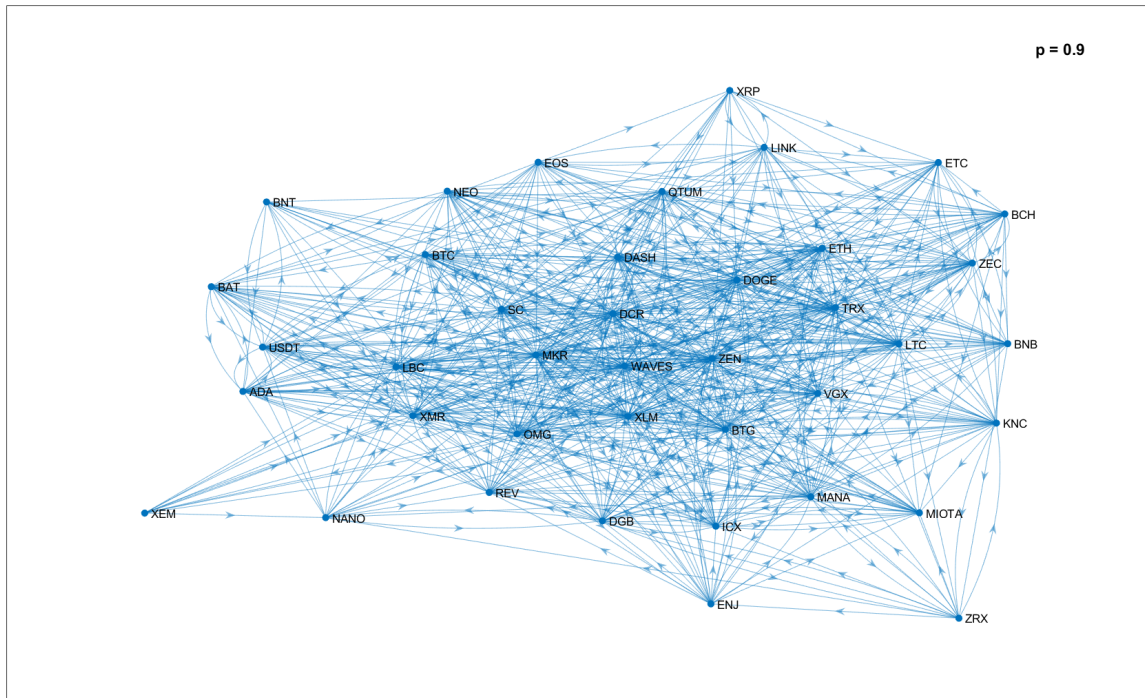
(f)  $p = 0.5$

Figure 5: Stable causality network of forty cryptocurrency returns for period 2019-2020

*The full name of each cryptocurrency are shown in Table 7.*



(a)  $p = 1.0$

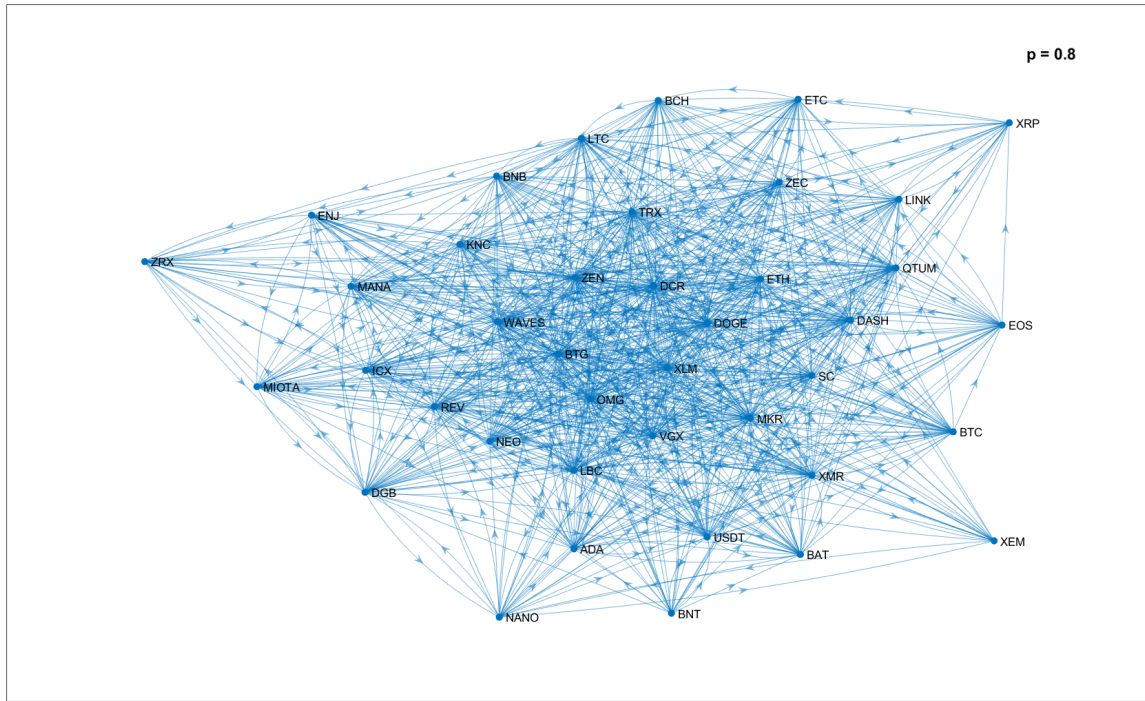


(b)  $p = 0.9$

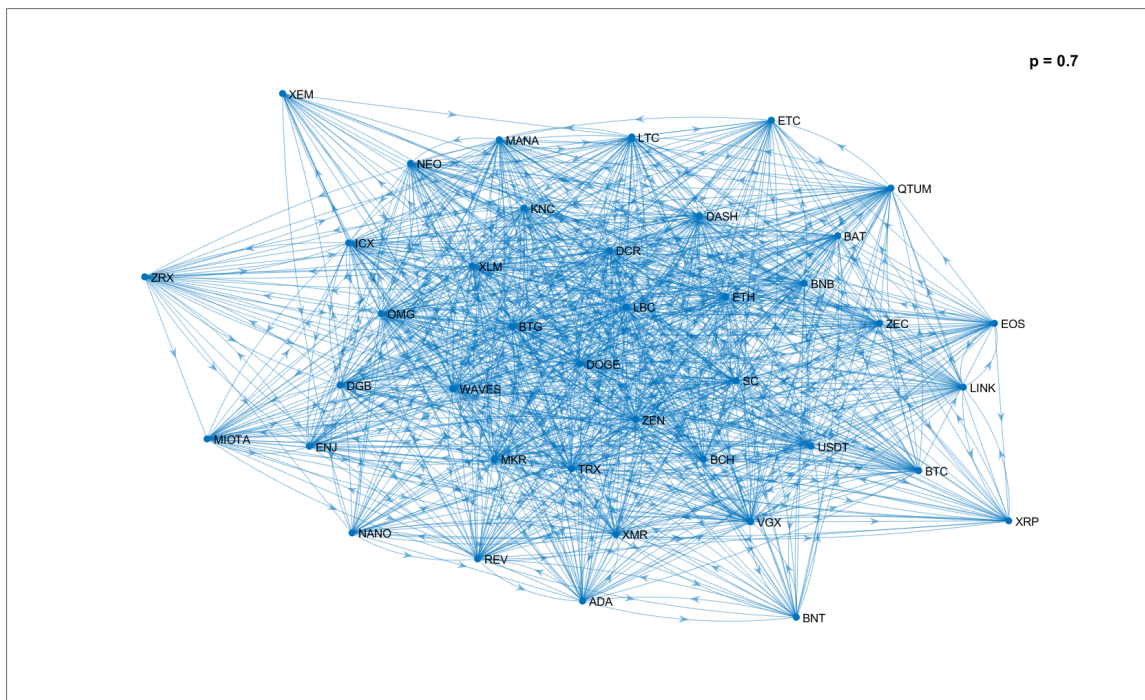
Figure 6: Stable causality network of forty cryptocurrency liquidity for period 2019-2020

*The full name of each cryptocurrency are shown in table 7.*

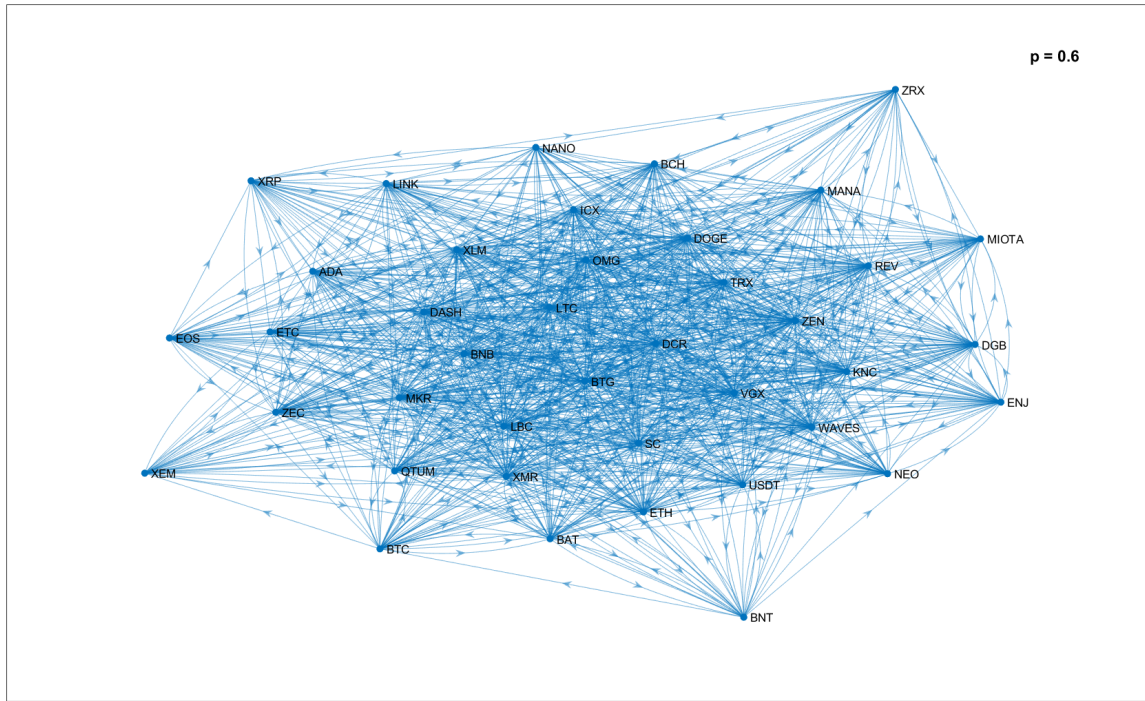




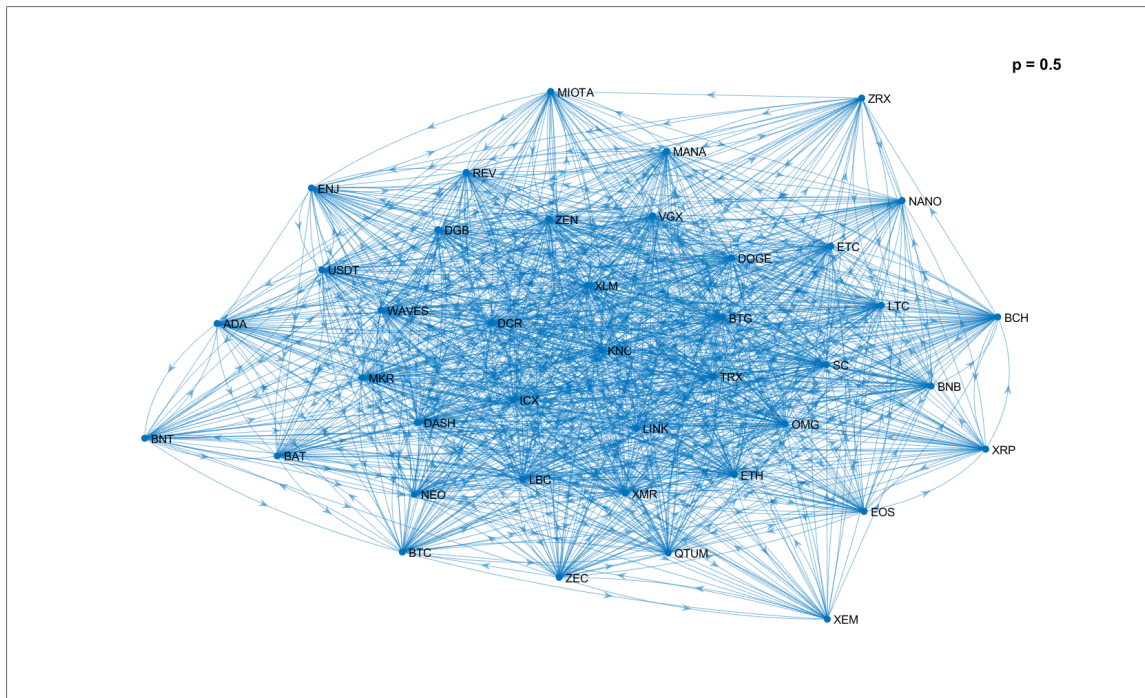
(c)  $p = 0.8$



(d)  $p = 0.7$



(e)  $p = 0.6$



(f)  $p = 0.5$

## Tables

Table 1: Descriptive statistics and stationary tests of forty cryptocurrency returns

	Mean	Median	Stdev	Skewness	Kurtosis	J.B.	ADF
<b>Panel A: Return</b>							
ADA	-0.001	0.000	0.059	-0.292	6.731	0.000	-9.501
BAT	-0.001	-0.001	0.063	-0.602	6.257	0.000	-9.813
BCH	-0.002	-0.002	0.062	-0.500	12.067	0.000	-9.501
BNB	0.001	0.001	0.056	-0.122	17.907	0.000	-11.734
BNT	-0.001	0.000	0.064	-0.113	7.287	0.000	-9.377
BTC	0.001	0.001	0.040	-1.557	19.175	0.000	-10.207
BTG	-0.003	-0.001	0.063	1.119	25.358	0.000	-10.359
DASH	-0.002	-0.001	0.055	-0.005	10.027	0.000	-9.709
DCR	-0.001	-0.001	0.056	-0.676	8.422	0.000	-10.061
DGB	-0.001	-0.002	0.069	-0.019	6.791	0.000	-9.458
DOGE	-0.001	-0.001	0.054	0.605	12.064	0.000	-10.339
ENJ	0.000	-0.002	0.078	1.513	22.997	0.000	-9.353
EOS	-0.001	0.000	0.062	-0.219	8.179	0.000	-10.095
ETC	-0.001	0.000	0.056	-1.004	9.314	0.000	-9.603
ETH	0.000	0.000	0.051	-1.406	14.081	0.000	-9.707
ICX	-0.002	-0.002	0.070	-0.454	7.023	0.000	-10.067
KNC	-0.001	-0.002	0.070	-0.404	8.156	0.000	-9.616
LBC	-0.002	-0.003	0.079	0.837	11.051	0.000	-9.526
LINK	0.003	0.000	0.073	0.016	8.601	0.000	-10.024
LTC	-0.001	-0.001	0.052	-0.286	7.557	0.000	-10.003
MANA	0.000	0.001	0.071	0.008	11.210	0.000	-11.180
MIOTA	-0.002	-0.002	0.059	-0.826	8.735	0.000	-10.107
MKR	0.000	-0.001	0.060	-1.781	35.909	0.000	-9.682
NANO	-0.003	-0.002	0.072	-0.356	7.182	0.000	-9.822
NEO	-0.002	-0.001	0.059	-0.399	5.531	0.000	-9.743
OMG	-0.002	-0.002	0.067	0.049	10.233	0.000	-9.613
QTUM	-0.003	0.000	0.065	-0.686	12.471	0.000	-10.577
REV	-0.004	-0.002	0.066	-0.708	22.749	0.000	-9.258
SC	-0.002	-0.002	0.069	-0.109	13.824	0.000	-11.094
TRX	0.000	0.000	0.068	1.135	21.815	0.000	-11.474
USDT	0.000	0.000	0.006	0.098	10.825	0.000	-13.708
VGX	-0.003	-0.003	0.085	0.259	10.005	0.000	-9.885
WAVES	-0.001	0.000	0.062	0.073	9.291	0.000	-10.340
XEM	-0.001	0.000	0.060	0.446	6.053	0.000	-9.988
XTM	-0.001	-0.002	0.059	0.590	9.811	0.000	-9.877
XMR	-0.001	0.001	0.052	-1.079	8.943	0.000	-10.594
XRP	-0.002	-0.002	0.057	-0.670	15.934	0.000	-9.107
ZEC	-0.002	-0.003	0.056	-0.413	4.957	0.000	-10.359
ZEN	-0.001	-0.002	0.063	-0.478	7.317	0.000	-9.735
ZRX	-0.001	-0.003	0.066	0.084	4.130	0.000	-10.175

Note: The Table provides the descriptive statistics for the daily return series for forty cryptocurrencies for January 2018 - December 2020. J.B. means p-value results from the Jarque-Bera normality test. ADF refers to the Augmented (Dickey and Fuller, 1981) unit root test. Given that the critical value at significance levels of 10%, 5%, and 1% are  $-1.62$ ,  $-1.95$ , and  $-2.58$ , respectively, both tests indicate that all of forty return series are stationary. The full name of each cryptocurrency is shown in Table 7.

Table 2: Descriptive statistics and stationary tests of forty cryptocurrency liquidity

	Mean	Median	Stdev	Skewness	Kurtosis	J.B.	ADF
<b>Panel B: Illiquidity Ratios</b>							
ADA	0.000	0.000	0.000	3.866	24.035	0.000	-9.981
BAT	0.001	0.000	0.002	3.067	10.683	0.000	-4.669
BCH	0.029	0.005	0.060	4.550	34.244	0.000	-6.593
BNB	0.116	0.002	3.676	33.015	1088.999	0.000	-10.076
BNT	0.011	0.003	0.019	3.597	18.943	0.000	-6.721
BTC	0.017	0.009	0.024	2.491	6.896	0.000	-4.501
BTG	0.062	0.028	0.086	2.473	7.384	0.000	-5.517
DASH	0.050	0.008	0.124	4.543	25.848	0.000	-4.639
DCR	0.615	0.127	1.484	5.124	32.595	0.000	-4.475
DGB	0.000	0.000	0.000	2.585	9.687	0.000	-7.203
DOGE	0.000	0.000	0.000	3.056	10.987	0.000	-4.611
ENJ	0.001	0.001	0.003	21.413	590.740	0.000	-7.488
EOS	0.000	0.000	0.000	3.841	18.648	0.000	-4.184
ETC	0.001	0.000	0.002	4.125	24.906	0.000	-6.080
ETH	0.003	0.001	0.006	2.951	9.694	0.000	-4.373
ICX	0.002	0.001	0.003	4.401	27.929	0.000	-5.343
KNC	0.004	0.001	0.008	5.508	41.786	0.000	-6.434
LBC	0.029	0.013	0.047	7.042	100.150	0.000	-6.541
LINK	0.003	0.001	0.006	2.969	10.406	0.000	-4.556
LTC	0.004	0.001	0.007	2.949	9.815	0.000	-4.342
MANA	0.000	0.000	0.000	2.242	5.958	0.000	-6.482
MIOTA	0.001	0.001	0.001	2.656	14.206	0.000	-5.734
MKR	35.083	4.739	81.849	5.153	39.480	0.000	-6.195
NANO	0.013	0.007	3.000	4.730	30.952	0.000	-6.024
NEO	0.006	0.001	0.013	2.899	8.940	0.000	-4.209
OMG	0.004	0.001	0.007	3.807	18.894	0.000	-5.066
QTUM	0.001	0.000	0.003	4.258	22.342	0.000	-5.493
REV	0.005	0.001	0.014	7.243	74.064	0.000	-7.517
SC	0.000	0.000	0.000	3.768	25.443	0.000	-5.422
TRX	0.000	0.000	0.000	3.237	15.532	0.000	-6.333
USDT	0.000	0.000	0.000	3.911	21.421	0.000	-7.310
VGX	0.024	0.006	0.149	24.783	687.909	0.000	-7.561
WAVES	0.005	0.002	0.008	3.814	23.038	0.000	-5.435
XEM	0.000	0.000	0.000	4.111	23.306	0.000	-6.392
XLM	0.000	0.000	0.000	3.074	10.905	0.000	-4.419
XMR	0.068	0.023	0.101	2.311	5.438	0.000	-4.918
XRP	0.000	0.000	0.000	2.864	10.277	0.000	-6.026
ZEC	0.050	0.008	0.111	3.662	15.801	0.000	-3.905
ZEN	0.497	0.148	0.912	3.597	16.130	0.000	-5.079
ZRX	0.002	0.000	0.003	3.443	15.149	0.000	-4.727

Note: The Table provides the descriptive statistics for the daily illiquidity series for forty cryptocurrencies for January 2018 - December 2020. J.B. means p-value results from the Jarque-Bera normality test. ADF refers to the Augmented (Dickey and Fuller, 1981) unit root test. Given that the critical value at significance levels of 10%, 5%, and 1% are  $-1.62$ ,  $-1.95$ , and  $-2.58$ , respectively, both tests indicate that all of forty illiquidity series are stationary. The full name of each cryptocurrency is shown in Table 7.

Table 3: Centrality scores:  $p$  – stable causality network of cryptocurrency returns for the period 2018-2020

$p = 1.0$	InDegree	OutDegree	InCloseness	OutCloseness	Betweenness	Pagerank	Hub	Authority
ADA	0	4	0.000	0.007	0.000	0.009	0.047	0.000
BAT	6	1	0.004	0.001	17.000	0.076	0.014	0.053
BCH	2	2	0.004	0.001	27.933	0.068	0.021	0.031
BNB	4	1	0.003	0.001	7.000	0.016	0.001	0.070
BNT	2	0	0.002	0.000	0.000	0.011	0.000	0.055
BTC	1	3	0.002	0.002	0.600	0.011	0.053	0.029
BTG	1	2	0.001	0.002	1.000	0.010	0.032	0.026
DASH	2	2	0.002	0.006	25.100	0.012	0.023	0.038
DCR	0	1	0.000	0.001	0.000	0.009	0.001	0.000
DGB	0	3	0.000	0.003	0.000	0.009	0.053	0.000
DOGE	3	14	0.002	0.010	83.500	0.019	0.192	0.016
ENJ	1	0	0.001	0.000	0.000	0.010	0.000	0.026
EOS	0	11	0.000	0.008	0.000	0.009	0.169	0.000
ETC	1	1	0.001	0.001	0.500	0.011	0.018	0.008
ETH	3	1	0.003	0.001	0.600	0.014	0.018	0.063
ICX	4	1	0.004	0.002	35.000	0.052	0.014	0.047
KNC	1	0	0.001	0.000	0.000	0.011	0.000	0.008
LBC	1	0	0.001	0.000	0.000	0.011	0.000	0.008
LINK	9	0	0.005	0.000	0.000	0.078	0.000	0.058
LTC	0	3	0.000	0.002	0.000	0.009	0.023	0.000
MANA	0	0	0.000	0.000	0.000	0.009	0.025	0.025
MIOTA	0	3	0.000	0.007	0.000	0.009	0.035	0.000
MKR	2	0	0.001	0.000	0.000	0.018	0.000	0.027
NANO	2	1	0.003	0.001	13.000	0.028	0.019	0.003
NEO	2	2	0.002	0.002	4.500	0.011	0.017	0.055
OMG	0	0	0.000	0.000	0.000	0.009	0.025	0.025
QTUM	2	0	0.002	0.000	0.000	0.013	0.000	0.016
REV	2	0	0.001	0.000	0.000	0.020	0.000	0.004
SC	4	1	0.004	0.002	27.000	0.043	0.015	0.061
TRX	4	0	0.004	0.000	0.000	0.053	0.000	0.011
USDT	0	0	0.000	0.000	0.000	0.009	0.025	0.025
VGX	0	1	0.000	0.001	0.000	0.009	0.008	0.000
WAVES	1	1	0.002	0.001	1.333	0.011	0.003	0.029
XEM	1	7	0.001	0.007	36.000	0.012	0.056	0.003
XLM	1	3	0.002	0.005	20.933	0.011	0.023	0.029
XMR	2	1	0.004	0.001	9.500	0.064	0.017	0.033
XRP	0	1	0.000	0.001	0.000	0.009	0.019	0.000
ZEC	1	0	0.002	0.000	0.000	0.011	0.000	0.029
ZEN	5	2	0.006	0.002	61.500	0.126	0.025	0.044
ZRX	4	1	0.005	0.001	39.000	0.068	0.010	0.046
$p = 0.9$	InDegree	OutDegree	InCloseness	OutCloseness	Betweenness	Pagerank	Hub	Authority
ADA	0	8	0.000	0.009	0.000	0.006	0.072	0.000
BAT	10	2	0.008	0.004	49.900	0.057	0.014	0.069
BCH	3	4	0.006	0.004	53.310	0.033	0.030	0.025
BNB	7	1	0.007	0.003	30.883	0.036	0.005	0.059
BNT	4	1	0.003	0.002	0.143	0.010	0.012	0.044
BTC	1	6	0.002	0.005	3.493	0.007	0.058	0.013
BTG	2	2	0.002	0.004	2.200	0.009	0.019	0.018
DASH	2	3	0.002	0.008	24.393	0.008	0.020	0.020
DCR	0	1	0.000	0.002	0.000	0.006	0.004	0.000
DGB	0	4	0.000	0.005	0.000	0.006	0.037	0.000
DOGE	3	15	0.002	0.012	80.774	0.011	0.085	0.019
ENJ	5	0	0.007	0.000	0.000	0.027	0.000	0.043
EOS	1	12	0.001	0.008	5.976	0.007	0.093	0.011
ETC	2	3	0.002	0.004	4.750	0.008	0.030	0.018
ETH	6	2	0.006	0.001	17.976	0.026	0.021	0.058
ICX	10	2	0.010	0.004	160.643	0.139	0.017	0.074
KNC	2	1	0.002	0.002	0.643	0.008	0.012	0.018
LBC	1	0	0.002	0.000	0.000	0.007	0.000	0.007
LINK	14	0	0.010	0.000	0.000	0.060	0.000	0.088
LTC	1	4	0.001	0.003	1.000	0.007	0.028	0.011
MANA	0	3	0.000	0.003	0.000	0.006	0.028	0.000
MIOTA	0	4	0.000	0.008	0.000	0.006	0.030	0.000
MKR	3	0	0.005	0.000	0.000	0.012	0.000	0.034
NANO	5	3	0.007	0.003	115.167	0.049	0.017	0.034

NEO	4	3	0.007	0.004	81.952	0.031	0.030	0.037
OMG	0	1	0.000	0.001	0.000	0.006	0.014	0.000
QTUM	3	0	0.002	0.000	0.000	0.008	0.000	0.029
REV	6	2	0.006	0.003	43.143	0.031	0.021	0.028
SC	13	1	0.011	0.003	123.750	0.130	0.012	0.075
TRX	5	2	0.005	0.002	12.476	0.019	0.026	0.029
USDT	0	13	0.000	0.010	0.000	0.006	0.072	0.000
VGX	1	4	0.005	0.004	47.500	0.020	0.038	0.003
WAVES	1	2	0.002	0.003	3.417	0.007	0.009	0.013
XEM	1	8	0.002	0.009	38.417	0.007	0.042	0.007
XLM	2	6	0.002	0.008	30.369	0.007	0.045	0.025
XMR	2	2	0.006	0.003	5.783	0.029	0.022	0.017
XRP	0	1	0.000	0.002	0.000	0.006	0.012	0.000
ZEC	1	0	0.002	0.000	0.000	0.007	0.000	0.013
ZEN	6	4	0.009	0.005	219.610	0.102	0.024	0.031
ZRX	4	1	0.007	0.003	59.333	0.031	0.004	0.031
<hr/>								
$p = 0.8$	InDegree	OutDegree	InCloseness	OutCloseness	Betweenness	Pagerank	Hub	Authority
ADA	1	9	0.008	0.010	367.211	0.019	0.072	0.005
BAT	10	2	0.009	0.006	58.667	0.043	0.011	0.067
BCH	3	4	0.007	0.007	60.485	0.031	0.028	0.021
BNB	7	1	0.008	0.005	48.417	0.035	0.005	0.050
BNT	4	1	0.005	0.004	0.143	0.007	0.009	0.037
BTC	1	6	0.005	0.006	3.201	0.005	0.054	0.010
BTG	2	2	0.004	0.006	4.976	0.007	0.016	0.016
DASH	2	3	0.005	0.008	46.058	0.006	0.017	0.016
DCR	1	1	0.001	0.004	0.000	0.005	0.004	0.010
DGB	1	5	0.008	0.006	49.917	0.042	0.043	0.002
DOGE	3	15	0.006	0.012	370.914	0.009	0.073	0.017
ENJ	9	1	0.011	0.004	32.490	0.050	0.002	0.060
EOS	1	13	0.001	0.008	4.393	0.005	0.096	0.010
ETC	2	4	0.004	0.006	5.333	0.005	0.037	0.016
ETH	6	2	0.007	0.005	25.885	0.014	0.021	0.049
ICX	12	3	0.011	0.006	286.476	0.132	0.014	0.084
KNC	3	1	0.008	0.004	33.476	0.048	0.009	0.016
LBC	1	0	0.004	0.000	0.000	0.005	0.000	0.006
LINK	15	1	0.010	0.006	205.743	0.053	0.004	0.083
LTC	1	5	0.001	0.008	2.017	0.005	0.028	0.010
MANA	0	3	0.000	0.005	0.000	0.005	0.022	0.000
MIOTA	0	4	0.000	0.009	0.000	0.005	0.028	0.000
MKR	4	0	0.007	0.000	0.000	0.010	0.000	0.039
NANO	5	5	0.007	0.006	130.355	0.040	0.034	0.032
NEO	5	5	0.008	0.006	76.736	0.021	0.044	0.045
OMG	2	1	0.005	0.005	15.333	0.010	0.012	0.013
QTUM	4	0	0.008	0.000	0.000	0.021	0.000	0.032
REV	6	3	0.007	0.005	75.345	0.020	0.018	0.026
SC	13	1	0.012	0.005	178.774	0.118	0.012	0.063
TRX	5	2	0.006	0.005	28.012	0.015	0.021	0.024
USDT	0	16	0.000	0.012	0.000	0.005	0.072	0.000
VGX	1	4	0.006	0.006	12.619	0.011	0.034	0.005
WAVES	1	2	0.005	0.005	5.500	0.005	0.007	0.010
XEM	1	9	0.004	0.009	85.026	0.005	0.042	0.005
XLM	2	6	0.005	0.009	109.377	0.005	0.036	0.021
XMR	2	2	0.008	0.005	5.536	0.019	0.022	0.016
XRP	0	1	0.000	0.004	0.000	0.005	0.009	0.000
ZEC	2	0	0.005	0.000	0.000	0.006	0.000	0.016
ZEN	8	7	0.011	0.008	625.086	0.117	0.038	0.029
ZRX	5	1	0.008	0.005	54.500	0.030	0.003	0.037
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$p = 0.7$	InDegree	OutDegree	InCloseness	OutCloseness	Betweenness	Pagerank	Hub	Authority
ADA	1	9	0.008	0.010	109.964	0.014	0.061	0.005
BAT	13	4	0.013	0.009	79.785	0.062	0.026	0.073
BCH	3	4	0.008	0.008	7.846	0.015	0.024	0.018
BNB	8	3	0.010	0.008	63.160	0.027	0.023	0.048
BNT	5	1	0.010	0.005	0.911	0.021	0.008	0.034
BTC	1	6	0.006	0.009	2.602	0.005	0.046	0.008
BTG	3	2	0.007	0.008	1.086	0.007	0.014	0.023
DASH	2	4	0.006	0.010	12.660	0.005	0.019	0.015
DCR	1	2	0.006	0.008	0.000	0.005	0.007	0.010
DGB	2	6	0.009	0.009	62.633	0.027	0.041	0.010
DOGE	4	15	0.008	0.013	217.385	0.010	0.060	0.016

ENJ	10	1	0.012	0.005	15.961	0.054	0.003	0.053
EOS	2	13	0.009	0.011	73.643	0.015	0.081	0.015
ETC	2	4	0.006	0.008	2.500	0.005	0.030	0.017
ETH	7	2	0.009	0.006	10.942	0.012	0.016	0.043
ICX	15	6	0.013	0.009	285.889	0.149	0.033	0.081
KNC	4	2	0.010	0.006	44.611	0.061	0.018	0.023
LBC	1	0	0.005	0.000	0.000	0.005	0.000	0.007
LINK	16	1	0.013	0.008	125.010	0.057	0.005	0.071
LTC	1	5	0.006	0.011	0.361	0.005	0.025	0.010
MANA	0	4	0.000	0.007	0.000	0.004	0.024	0.000
MIOTA	0	4	0.000	0.010	0.000	0.004	0.026	0.000
MKR	5	0	0.010	0.000	0.000	0.019	0.000	0.035
NANO	6	8	0.009	0.011	150.858	0.018	0.045	0.037
NEO	5	5	0.010	0.009	48.415	0.018	0.038	0.037
OMG	2	1	0.007	0.006	0.500	0.007	0.009	0.012
QTUM	5	1	0.010	0.008	5.059	0.021	0.005	0.035
REV	6	5	0.007	0.011	185.240	0.013	0.018	0.025
SC	14	1	0.013	0.006	85.623	0.099	0.010	0.062
TRX	7	2	0.010	0.006	15.453	0.035	0.017	0.026
USDT	1	20	0.007	0.015	213.191	0.014	0.079	0.000
VGX	2	4	0.007	0.007	5.183	0.007	0.028	0.013
WAVES	1	2	0.006	0.008	4.000	0.005	0.007	0.008
XEM	2	12	0.006	0.012	108.393	0.007	0.054	0.006
XLM	2	6	0.006	0.010	31.980	0.006	0.030	0.018
XMR	2	2	0.009	0.007	2.475	0.015	0.020	0.013
XRP	1	1	0.006	0.005	0.211	0.005	0.008	0.010
ZEC	2	0	0.006	0.000	0.000	0.005	0.000	0.015
ZEN	11	10	0.013	0.011	547.857	0.116	0.041	0.036
ZRX	5	2	0.010	0.010	244.615	0.023	0.002	0.033
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$p = 0.6$	InDegree	OutDegree	InCloseness	OutCloseness	Betweenness	Pagerank	Hub	Authority
ADA	2	10	0.009	0.011	81.431	0.015	0.054	0.012
BAT	13	7	0.013	0.010	62.858	0.045	0.034	0.062
BCH	3	6	0.008	0.009	8.133	0.016	0.029	0.014
BNB	10	4	0.011	0.009	36.330	0.031	0.026	0.049
BNT	5	2	0.010	0.008	15.496	0.013	0.012	0.028
BTC	1	6	0.006	0.009	1.829	0.005	0.037	0.006
BTG	6	3	0.011	0.008	19.375	0.025	0.014	0.029
DASH	3	4	0.007	0.011	9.671	0.006	0.017	0.019
DCR	3	2	0.010	0.008	62.544	0.015	0.005	0.019
DGB	6	6	0.011	0.010	56.319	0.038	0.032	0.024
DOGE	4	16	0.008	0.014	178.677	0.011	0.051	0.013
ENJ	12	3	0.013	0.008	36.129	0.050	0.013	0.053
EOS	2	14	0.009	0.012	20.560	0.015	0.069	0.012
ETC	2	5	0.007	0.009	2.042	0.006	0.032	0.013
ETH	10	2	0.012	0.007	5.151	0.024	0.013	0.050
ICX	21	12	0.015	0.010	267.590	0.113	0.055	0.085
KNC	4	3	0.011	0.008	3.906	0.030	0.023	0.018
LBC	1	0	0.006	0.000	0.000	0.005	0.000	0.005
LINK	20	1	0.016	0.008	97.886	0.091	0.005	0.074
LTC	1	6	0.006	0.011	0.162	0.005	0.029	0.008
MANA	0	4	0.000	0.008	0.000	0.005	0.020	0.000
MIOTA	0	4	0.000	0.011	0.000	0.005	0.021	0.000
MKR	6	0	0.012	0.000	0.000	0.027	0.000	0.033
NANO	6	8	0.009	0.011	75.073	0.016	0.039	0.031
NEO	6	7	0.011	0.011	34.487	0.020	0.039	0.033
OMG	3	1	0.008	0.006	0.433	0.008	0.008	0.017
QTUM	6	2	0.012	0.008	4.266	0.030	0.013	0.033
REV	6	6	0.009	0.012	191.740	0.017	0.025	0.021
SC	16	1	0.014	0.007	53.261	0.059	0.009	0.066
TRX	7	2	0.011	0.007	6.500	0.025	0.014	0.026
USDT	1	24	0.007	0.017	177.063	0.015	0.074	0.000
VGX	3	6	0.009	0.009	9.686	0.014	0.032	0.011
WAVES	1	2	0.006	0.008	2.083	0.005	0.005	0.006
XEM	2	12	0.007	0.013	92.264	0.008	0.042	0.007
XLM	2	7	0.007	0.011	20.540	0.006	0.034	0.014
XMR	2	7	0.009	0.010	14.923	0.015	0.036	0.010
XRP	1	1	0.006	0.006	0.000	0.005	0.007	0.008
ZEC	3	0	0.007	0.000	0.000	0.006	0.000	0.019
ZEN	14	11	0.014	0.011	427.864	0.131	0.033	0.048
ZRX	5	2	0.011	0.011	208.727	0.024	0.001	0.024

$p = 0.5$	InDegree	OutDegree	InCloseness	OutCloseness	Betweenness	Pagerank	Hub	Authority
ADA	2	11	0.010	0.013	20.075	0.009	0.047	0.010
BAT	14	8	0.015	0.011	69.334	0.050	0.030	0.055
BCH	4	8	0.011	0.011	12.291	0.018	0.035	0.016
BNB	12	4	0.013	0.010	30.297	0.040	0.022	0.043
BNT	7	3	0.013	0.011	83.777	0.027	0.010	0.031
BTC	1	8	0.007	0.012	1.521	0.005	0.035	0.005
BTG	6	4	0.011	0.010	17.542	0.020	0.019	0.026
DASH	4	6	0.012	0.011	41.167	0.024	0.025	0.017
DCR	3	5	0.011	0.010	10.160	0.012	0.016	0.016
DGB	6	7	0.012	0.011	43.626	0.029	0.026	0.021
DOGE	6	16	0.010	0.014	146.953	0.014	0.044	0.020
ENJ	15	6	0.015	0.011	91.810	0.058	0.023	0.052
EOS	2	14	0.010	0.013	5.251	0.009	0.058	0.010
ETC	2	7	0.008	0.011	1.076	0.005	0.033	0.011
ETH	11	2	0.014	0.009	3.610	0.026	0.011	0.046
ICX	23	14	0.018	0.013	200.853	0.074	0.052	0.081
KNC	4	5	0.012	0.010	6.827	0.018	0.026	0.017
LBC	2	2	0.009	0.008	0.611	0.008	0.007	0.007
LINK	24	5	0.019	0.011	287.066	0.110	0.011	0.075
LTC	1	6	0.007	0.012	0.083	0.004	0.026	0.007
MANA	2	6	0.011	0.012	7.598	0.023	0.022	0.005
MIOTA	1	5	0.007	0.012	2.182	0.004	0.023	0.007
MKR	6	1	0.012	0.008	0.311	0.016	0.005	0.028
NANO	8	8	0.011	0.012	53.769	0.024	0.033	0.031
NEO	11	7	0.014	0.011	92.850	0.042	0.033	0.040
OMG	3	1	0.010	0.008	0.424	0.010	0.007	0.014
QTUM	6	2	0.012	0.009	3.202	0.018	0.011	0.028
REV	8	6	0.013	0.013	182.352	0.034	0.020	0.023
SC	18	4	0.015	0.010	66.345	0.058	0.022	0.061
TRX	10	2	0.013	0.009	6.341	0.020	0.012	0.035
USDT	3	26	0.010	0.018	233.922	0.020	0.064	0.007
VGX	3	7	0.010	0.011	4.310	0.011	0.032	0.010
WAVES	1	2	0.007	0.009	1.011	0.005	0.005	0.005
XEM	2	16	0.009	0.016	67.751	0.009	0.039	0.006
XLM	2	8	0.008	0.013	8.572	0.005	0.034	0.012
XMR	7	7	0.013	0.011	21.899	0.026	0.030	0.026
XRP	1	1	0.008	0.007	0.000	0.004	0.005	0.007
ZEC	3	1	0.008	0.008	0.111	0.006	0.004	0.016
ZEN	15	12	0.015	0.012	207.306	0.067	0.030	0.046
ZRX	8	4	0.014	0.012	128.812	0.038	0.013	0.030

The full name of each cryptocurrency is shown in Table 7.



Table 4: Centrality scores:  $p$  – stable causality network of cryptocurrency liquidity for the period 2018-2020

$p = 1.0$	InDegree	OutDegree	InCloseness	OutCloseness	Betweenness	Pagerank	Hub	Authority
ADA	29	32	0.020	0.022	18.487	0.028	0.166	0.190
BAT	33	29	0.022	0.020	22.903	0.033	0.188	0.162
BCH	30	27	0.021	0.020	8.521	0.027	0.170	0.162
BNB	12	3	0.015	0.013	2.023	0.013	0.064	0.016
BNT	15	30	0.016	0.021	13.449	0.015	0.077	0.170
BTC	26	31	0.019	0.021	18.637	0.023	0.139	0.177
BTG	18	31	0.017	0.021	15.58	0.017	0.091	0.183
DASH	32	21	0.022	0.017	3.236	0.029	0.186	0.126
DCR	31	30	0.021	0.021	18.231	0.028	0.173	0.174
DGB	9	23	0.014	0.018	14.314	0.013	0.039	0.125
DOGE	30	29	0.021	0.020	11.243	0.029	0.182	0.166
ENJ	24	29	0.019	0.020	11.147	0.022	0.128	0.170
EOS	33	28	0.022	0.020	9.006	0.031	0.192	0.163
ETC	33	27	0.022	0.020	8.45	0.03	0.189	0.159
ETH	30	28	0.021	0.020	6.926	0.029	0.183	0.163
ICX	33	31	0.022	0.021	23.39	0.031	0.188	0.178
KNC	35	29	0.023	0.020	20.875	0.031	0.183	0.166
LBC	7	11	0.014	0.015	0.852	0.008	0.032	0.068
LINK	35	32	0.023	0.022	16.602	0.032	0.200	0.186
LTC	32	30	0.022	0.021	10.554	0.03	0.183	0.174
MANA	30	35	0.021	0.023	29.91	0.027	0.164	0.194
MIOTA	7	8	0.014	0.014	1.176	0.009	0.035	0.048
MKR	33	30	0.022	0.021	14.031	0.031	0.194	0.175
NANO	28	36	0.020	0.024	30.25	0.025	0.144	0.200
NEO	32	25	0.022	0.019	11.279	0.029	0.178	0.140
OMG	30	29	0.021	0.020	14.364	0.027	0.166	0.168
QTUM	31	25	0.021	0.019	6.966	0.028	0.180	0.145
REV	16	23	0.016	0.018	3.245	0.015	0.087	0.141
SC	5	21	0.013	0.018	2.028	0.007	0.022	0.115
TRX	32	31	0.022	0.021	13.164	0.03	0.188	0.179
USDT	23	19	0.018	0.017	6.78	0.022	0.132	0.114
VGX	15	16	0.016	0.016	7.275	0.016	0.085	0.085
WAVES	26	33	0.019	0.022	17.63	0.024	0.148	0.192
XEM	28	28	0.020	0.020	10.564	0.026	0.163	0.160
XLM	34	29	0.023	0.020	20.751	0.034	0.195	0.174
XMR	33	29	0.022	0.020	10.903	0.03	0.185	0.167
XRP	33	31	0.022	0.021	8.487	0.031	0.194	0.184
ZEC	34	22	0.023	0.018	6.555	0.031	0.193	0.126
ZEN	30	29	0.021	0.020	18.546	0.027	0.167	0.164
ZRX	33	30	0.022	0.021	17.671	0.031	0.190	0.172
$p = 0.9$	InDegree	OutDegree	InCloseness	OutCloseness	Betweenness	Pagerank	Hub	Authority
ADA	37	37	0.024	0.024	0.028	0.024	0.025	0.025
BAT	39	39	0.026	0.026	1.759	0.026	0.026	0.025
BCH	39	39	0.026	0.026	1.759	0.026	0.026	0.025
BNB	26	19	0.019	0.017	0.000	0.018	0.013	0.017
BNT	38	38	0.025	0.025	0.202	0.025	0.025	0.025
BTC	38	38	0.025	0.025	0.202	0.025	0.025	0.025
BTG	39	38	0.026	0.025	1.257	0.026	0.025	0.025
DASH	38	39	0.025	0.026	0.703	0.025	0.026	0.025
DCR	38	39	0.025	0.026	0.703	0.025	0.026	0.025
DGB	39	39	0.026	0.026	1.759	0.026	0.026	0.025
DOGE	38	39	0.025	0.026	0.703	0.025	0.026	0.025
ENJ	39	39	0.026	0.026	1.759	0.026	0.026	0.025
EOS	39	39	0.026	0.026	1.759	0.026	0.026	0.025
ETC	39	39	0.026	0.026	1.759	0.026	0.026	0.025
ETH	38	39	0.025	0.026	0.703	0.025	0.026	0.025
ICX	38	38	0.025	0.025	0.202	0.025	0.025	0.025
KNC	39	39	0.026	0.026	1.759	0.026	0.026	0.025
LBC	37	37	0.024	0.024	0.462	0.024	0.024	0.025
LINK	39	39	0.026	0.026	1.759	0.026	0.026	0.025
LTC	39	39	0.026	0.026	1.759	0.026	0.026	0.025
MANA	38	39	0.025	0.026	0.703	0.025	0.026	0.025
MIOTA	38	39	0.025	0.026	0.703	0.025	0.026	0.025
MKR	39	38	0.026	0.025	1.257	0.026	0.025	0.025
NANO	39	39	0.026	0.026	1.759	0.026	0.026	0.025

NEO	39	39	0.026	0.026	1.759	0.026	0.026	0.025
OMG	38	38	0.025	0.025	0.202	0.025	0.025	0.025
QTUM	39	39	0.026	0.026	1.759	0.026	0.026	0.025
REV	39	38	0.026	0.025	1.257	0.026	0.025	0.025
SC	37	39	0.024	0.026	0.645	0.024	0.026	0.025
TRX	38	39	0.025	0.026	0.703	0.025	0.026	0.025
USDT	38	39	0.025	0.026	0.703	0.025	0.026	0.025
VGX	34	36	0.023	0.024	0.000	0.023	0.024	0.023
WAVES	38	38	0.025	0.025	0.202	0.025	0.025	0.025
XEM	38	39	0.025	0.026	0.703	0.025	0.026	0.025
XLM	39	37	0.026	0.024	1.083	0.026	0.025	0.026
XMR	39	39	0.026	0.026	1.759	0.026	0.026	0.025
XRP	38	37	0.025	0.024	0.083	0.025	0.025	0.025
ZEC	39	39	0.026	0.026	1.759	0.026	0.026	0.025
ZEN	38	39	0.025	0.026	0.703	0.025	0.026	0.025
ZRX	39	38	0.026	0.025	1.257	0.026	0.025	0.025
<hr/>								
$p = 0.8$	InDegree	OutDegree	InCloseness	OutCloseness	Betweenness	Pagerank	Hub	Authority
ADA	37	37	0.024	0.024	0.000	0.024	0.024	0.024
BAT	39	39	0.026	0.026	0.759	0.025	0.025	0.025
BCH	39	39	0.026	0.026	0.759	0.025	0.025	0.025
BNB	35	25	0.023	0.019	0.000	0.023	0.016	0.023
BNT	39	39	0.026	0.026	0.759	0.025	0.025	0.025
BTC	39	39	0.026	0.026	0.759	0.025	0.025	0.025
BTG	39	39	0.026	0.026	0.759	0.025	0.025	0.025
DASH	39	39	0.026	0.026	0.759	0.025	0.025	0.025
DCR	39	39	0.026	0.026	0.759	0.025	0.025	0.025
DGB	39	39	0.026	0.026	0.759	0.025	0.025	0.025
DOGE	38	39	0.025	0.026	0.197	0.025	0.025	0.025
ENJ	39	39	0.026	0.026	0.759	0.025	0.025	0.025
EOS	39	39	0.026	0.026	0.759	0.025	0.025	0.025
ETC	39	39	0.026	0.026	0.759	0.025	0.025	0.025
ETH	38	39	0.025	0.026	0.197	0.025	0.025	0.025
ICX	38	39	0.025	0.026	0.197	0.025	0.025	0.025
KNC	39	39	0.026	0.026	0.759	0.025	0.025	0.025
LBC	39	38	0.026	0.025	0.661	0.025	0.025	0.025
LINK	39	39	0.026	0.026	0.759	0.025	0.025	0.025
LTC	39	39	0.026	0.026	0.759	0.025	0.025	0.025
MANA	38	39	0.025	0.026	0.197	0.025	0.025	0.025
MIOTA	39	39	0.026	0.026	0.759	0.025	0.025	0.025
MKR	39	39	0.026	0.026	0.759	0.025	0.025	0.025
NANO	39	39	0.026	0.026	0.759	0.025	0.025	0.025
NEO	39	39	0.026	0.026	0.759	0.025	0.025	0.025
OMG	38	39	0.025	0.026	0.197	0.025	0.025	0.025
QTUM	39	39	0.026	0.026	0.759	0.025	0.025	0.025
REV	39	39	0.026	0.026	0.759	0.025	0.025	0.025
SC	38	39	0.025	0.026	0.197	0.025	0.025	0.025
TRX	38	39	0.025	0.026	0.197	0.025	0.025	0.025
USDT	38	39	0.025	0.026	0.197	0.025	0.025	0.025
VGX	36	37	0.024	0.024	0.000	0.023	0.024	0.024
WAVES	38	39	0.025	0.026	0.197	0.025	0.025	0.025
XEM	38	39	0.025	0.026	0.197	0.025	0.025	0.025
XLM	39	38	0.026	0.025	0.644	0.025	0.025	0.025
XMR	39	39	0.026	0.026	0.759	0.025	0.025	0.025
XRP	38	38	0.025	0.025	0.083	0.025	0.025	0.025
ZEC	39	39	0.026	0.026	0.759	0.025	0.025	0.025
ZEN	38	39	0.025	0.026	0.197	0.025	0.025	0.025
ZRX	39	39	0.026	0.026	0.759	0.025	0.025	0.025
<hr/>								
$p = 0.7$	InDegree	OutDegree	InCloseness	OutCloseness	Betweenness	Pagerank	Hub	Authority
ADA	38	38	0.025	0.025	0.026	0.025	0.025	0.025
BAT	39	39	0.026	0.026	0.257	0.025	0.025	0.025
BCH	39	39	0.026	0.026	0.257	0.025	0.025	0.025
BNB	36	34	0.024	0.023	0.026	0.023	0.022	0.023
BNT	39	39	0.026	0.026	0.257	0.025	0.025	0.025
BTC	39	39	0.026	0.026	0.257	0.025	0.025	0.025
BTG	39	39	0.026	0.026	0.257	0.025	0.025	0.025
DASH	39	39	0.026	0.026	0.257	0.025	0.025	0.025
DCR	39	39	0.026	0.026	0.257	0.025	0.025	0.025
DGB	39	39	0.026	0.026	0.257	0.025	0.025	0.025
DOGE	39	39	0.026	0.026	0.257	0.025	0.025	0.025

ENJ	39	39	0.026	0.026	0.257	0.025	0.025	0.025
EOS	39	39	0.026	0.026	0.257	0.025	0.025	0.025
ETC	39	39	0.026	0.026	0.257	0.025	0.025	0.025
ETH	39	39	0.026	0.026	0.257	0.025	0.025	0.025
ICX	39	39	0.026	0.026	0.257	0.025	0.025	0.025
KNC	39	39	0.026	0.026	0.257	0.025	0.025	0.025
LBC	39	38	0.026	0.025	0.23	0.025	0.025	0.025
LINK	39	39	0.026	0.026	0.257	0.025	0.025	0.025
LTC	39	39	0.026	0.026	0.257	0.025	0.025	0.025
MANA	39	39	0.026	0.026	0.257	0.025	0.025	0.025
MIOTA	39	39	0.026	0.026	0.257	0.025	0.025	0.025
MKR	39	39	0.026	0.026	0.257	0.025	0.025	0.025
NANO	39	39	0.026	0.026	0.257	0.025	0.025	0.025
NEO	39	39	0.026	0.026	0.257	0.025	0.025	0.025
OMG	39	39	0.026	0.026	0.257	0.025	0.025	0.025
QTUM	39	39	0.026	0.026	0.257	0.025	0.025	0.025
REV	39	39	0.026	0.026	0.257	0.025	0.025	0.025
SC	38	39	0.025	0.026	0.11	0.025	0.025	0.025
TRX	38	39	0.025	0.026	0.11	0.025	0.025	0.025
USDT	39	39	0.026	0.026	0.257	0.025	0.025	0.025
VGX	38	38	0.025	0.025	0.147	0.025	0.025	0.025
WAVES	39	39	0.026	0.026	0.257	0.025	0.025	0.025
XEM	38	39	0.025	0.026	0.11	0.025	0.025	0.025
XLM	39	39	0.026	0.026	0.257	0.025	0.025	0.025
XMR	39	39	0.026	0.026	0.257	0.025	0.025	0.025
XRP	38	38	0.025	0.025	0.026	0.025	0.025	0.025
ZEC	39	39	0.026	0.026	0.257	0.025	0.025	0.025
ZEN	39	39	0.026	0.026	0.257	0.025	0.025	0.025
ZRX	39	39	0.026	0.026	0.257	0.025	0.025	0.025

$p = 0.6$	InDegree	OutDegree	InCloseness	OutCloseness	Betweenness	Pagerank	Hub	Authority
ADA	38	38	0.025	0.025	0.000	0.025	0.024	0.024
BAT	39	39	0.026	0.026	0.137	0.025	0.025	0.025
BCH	39	39	0.026	0.026	0.137	0.025	0.025	0.025
BNB	37	36	0.024	0.024	0.000	0.024	0.023	0.024
BNT	39	39	0.026	0.026	0.137	0.025	0.025	0.025
BTC	39	39	0.026	0.026	0.137	0.025	0.025	0.025
BTG	39	39	0.026	0.026	0.137	0.025	0.025	0.025
DASH	39	39	0.026	0.026	0.137	0.025	0.025	0.025
DCR	39	39	0.026	0.026	0.137	0.025	0.025	0.025
DGB	39	39	0.026	0.026	0.137	0.025	0.025	0.025
DOGE	39	39	0.026	0.026	0.137	0.025	0.025	0.025
ENJ	39	39	0.026	0.026	0.137	0.025	0.025	0.025
EOS	39	39	0.026	0.026	0.137	0.025	0.025	0.025
ETC	39	39	0.026	0.026	0.137	0.025	0.025	0.025
ETH	39	39	0.026	0.026	0.137	0.025	0.025	0.025
ICX	39	39	0.026	0.026	0.137	0.025	0.025	0.025
KNC	39	39	0.026	0.026	0.137	0.025	0.025	0.025
LBC	39	39	0.026	0.026	0.137	0.025	0.025	0.025
LINK	39	39	0.026	0.026	0.137	0.025	0.025	0.025
LTC	39	39	0.026	0.026	0.137	0.025	0.025	0.025
MANA	39	39	0.026	0.026	0.137	0.025	0.025	0.025
MIOTA	39	39	0.026	0.026	0.137	0.025	0.025	0.025
MKR	39	39	0.026	0.026	0.137	0.025	0.025	0.025
NANO	39	39	0.026	0.026	0.137	0.025	0.025	0.025
NEO	39	39	0.026	0.026	0.137	0.025	0.025	0.025
OMG	39	39	0.026	0.026	0.137	0.025	0.025	0.025
QTUM	39	39	0.026	0.026	0.137	0.025	0.025	0.025
REV	39	39	0.026	0.026	0.137	0.025	0.025	0.025
SC	38	39	0.025	0.026	0.054	0.025	0.025	0.024
TRX	38	39	0.025	0.026	0.054	0.025	0.025	0.024
USDT	39	39	0.026	0.026	0.137	0.025	0.025	0.025
VGX	39	38	0.026	0.025	0.083	0.025	0.024	0.025
WAVES	39	39	0.026	0.026	0.137	0.025	0.025	0.025
XEM	39	39	0.026	0.026	0.137	0.025	0.025	0.025
XLM	39	39	0.026	0.026	0.137	0.025	0.025	0.025
XMR	39	39	0.026	0.026	0.137	0.025	0.025	0.025
XRP	39	39	0.026	0.026	0.137	0.025	0.025	0.025
ZEC	39	39	0.026	0.026	0.137	0.025	0.025	0.025
ZEN	39	39	0.026	0.026	0.137	0.025	0.025	0.025
ZRX	39	39	0.026	0.026	0.137	0.025	0.025	0.025

$p = 0.5$	InDegree	OutDegree	InCloseness	OutCloseness	Betweenness	Pagerank	Hub	Authority
ADA	38	38	0.025	0.025	0	0.025	0.024	0.024
BAT	39	39	0.026	0.026	0.108	0.025	0.025	0.025
BCH	39	39	0.026	0.026	0.108	0.025	0.025	0.025
BNB	37	37	0.024	0.024	0	0.024	0.024	0.024
BNT	39	39	0.026	0.026	0.108	0.025	0.025	0.025
BTC	39	39	0.026	0.026	0.108	0.025	0.025	0.025
BTG	39	39	0.026	0.026	0.108	0.025	0.025	0.025
DASH	39	39	0.026	0.026	0.108	0.025	0.025	0.025
DCR	39	39	0.026	0.026	0.108	0.025	0.025	0.025
DGB	39	39	0.026	0.026	0.108	0.025	0.025	0.025
DOGE	39	39	0.026	0.026	0.108	0.025	0.025	0.025
ENJ	39	39	0.026	0.026	0.108	0.025	0.025	0.025
EOS	39	39	0.026	0.026	0.108	0.025	0.025	0.025
ETC	39	39	0.026	0.026	0.108	0.025	0.025	0.025
ETH	39	39	0.026	0.026	0.108	0.025	0.025	0.025
ICX	39	39	0.026	0.026	0.108	0.025	0.025	0.025
KNC	39	39	0.026	0.026	0.108	0.025	0.025	0.025
LBC	39	39	0.026	0.026	0.108	0.025	0.025	0.025
LINK	39	39	0.026	0.026	0.108	0.025	0.025	0.025
LTC	39	39	0.026	0.026	0.108	0.025	0.025	0.025
MANA	39	39	0.026	0.026	0.108	0.025	0.025	0.025
MIOTA	39	39	0.026	0.026	0.108	0.025	0.025	0.025
MKR	39	39	0.026	0.026	0.108	0.025	0.025	0.025
NANO	39	39	0.026	0.026	0.108	0.025	0.025	0.025
NEO	39	39	0.026	0.026	0.108	0.025	0.025	0.025
OMG	39	39	0.026	0.026	0.108	0.025	0.025	0.025
QTUM	39	39	0.026	0.026	0.108	0.025	0.025	0.025
REV	39	39	0.026	0.026	0.108	0.025	0.025	0.025
SC	38	39	0.025	0.026	0.054	0.025	0.025	0.024
TRX	39	39	0.026	0.026	0.108	0.025	0.025	0.025
USDT	39	39	0.026	0.026	0.108	0.025	0.025	0.025
VGX	39	38	0.026	0.025	0.054	0.025	0.024	0.025
WAVES	39	39	0.026	0.026	0.108	0.025	0.025	0.025
XEM	39	39	0.026	0.026	0.108	0.025	0.025	0.025
XLM	39	39	0.026	0.026	0.108	0.025	0.025	0.025
XMR	39	39	0.026	0.026	0.108	0.025	0.025	0.025
XRP	39	39	0.026	0.026	0.108	0.025	0.025	0.025
ZEC	39	39	0.026	0.026	0.108	0.025	0.025	0.025
ZEN	39	39	0.026	0.026	0.108	0.025	0.025	0.025
ZRX	39	39	0.026	0.026	0.108	0.025	0.025	0.025

The full name of each cryptocurrency is shown in Table 7.

Table 5: Centrality scores:  $p$  – stable causality network of cryptocurrency returns for the period 2019-2020

$p = 1.0$	InDegree	OutDegree	InCloseness	OutCloseness	Betweenness	Pagerank	Hub	Authority
ADA	0	1	0	0.001	0	0.016	0.009	0
BAT	2	0	0.003	0	0	0.04	0	0.045
BCH	1	2	0.002	0.001	4.333	0.022	0.039	0.021
BNB	0	1	0	0.001	0	0.016	0.05	0
BNT	1	1	0.002	0.005	5.167	0.025	0.017	0.001
BTC	4	0	0.004	0	0	0.065	0	0.016
BTG	2	0	0.003	0	0	0.027	0	0.062
DASH	0	0	0	0	0	0.016	0.025	0.025
DCR	1	0	0.002	0	0	0.021	0	0.041
DGB	1	0	0.001	0	0	0.029	0	0.05
DOGE	0	0	0	0	0	0.016	0.025	0.025
ENJ	0	0	0	0	0	0.016	0.025	0.025
EOS	3	1	0.003	0.001	5.667	0.039	0.013	0.054
ETC	2	0	0.002	0	0	0.028	0	0.024
ETH	1	1	0.002	0.001	3	0.021	0.009	0.041
ICX	1	3	0.002	0.006	22	0.021	0.022	0.041
KNC	1	2	0.002	0.005	19	0.021	0.005	0.041
LBC	0	0	0	0	0	0.016	0.025	0.025
LINK	2	0	0.003	0	0	0.054	0	0.024
LTC	0	0	0	0	0	0.016	0.025	0.025
MANA	0	0	0	0	0	0.016	0.025	0.025
MIOTA	0	0	0	0	0	0.016	0.025	0.025
MKR	1	1	0.002	0.001	9	0.022	0	0.003
NANO	0	1	0	0.005	0	0.016	0.017	0
NEO	0	0	0	0	0	0.016	0.025	0.025
OMG	0	1	0	0.001	0	0.016	0.05	0
QTUM	2	3	0.002	0.005	25.167	0.029	0.044	0.006
REV	1	0	0.001	0	0	0.029	0	0.05
SC	1	1	0.002	0.001	2.333	0.022	0.025	0.021
TRX	1	0	0.002	0	0	0.021	0	0.041
USDT	1	0	0.002	0	0	0.035	0	0
VGX	1	0	0.002	0	0	0.021	0	0.041
WAVES	0	1	0	0.005	0	0.016	0.005	0
XEM	0	2	0	0.004	0	0.016	0.017	0
XLM	0	0	0	0	0	0.016	0.025	0.025
XMR	3	7	0.003	0.007	77.167	0.047	0.138	0.008
XRP	0	0	0	0	0	0.016	0.025	0.025
ZEC	0	0	0	0	0	0.016	0.025	0.025
ZEN	4	10	0.003	0.008	99.167	0.062	0.265	0.03
ZRX	2	0	0.003	0	0	0.027	0	0.062
$p = 0.9$	InDegree	OutDegree	InCloseness	OutCloseness	Betweenness	Pagerank	Hub	Authority
ADA	1	1	0.002	0.001	0	0.014	0.015	0.025
BAT	2	2	0.003	0.006	30.217	0.029	0.009	0.023
BCH	2	2	0.004	0.001	1.833	0.018	0.036	0.047
BNB	2	3	0.004	0.002	34.5	0.034	0.019	0.027
BNT	4	2	0.004	0.008	141.333	0.076	0.017	0.009
BTC	7	0	0.005	0	0	0.077	0	0.039
BTG	2	0	0.004	0	0	0.018	0	0.047
DASH	0	0	0	0	0	0.013	0.025	0.025
DCR	1	0	0.003	0	0	0.016	0	0.022
DGB	5	1	0.004	0.006	60.4	0.049	0.004	0.015
DOGE	0	0	0	0	0	0.013	0.025	0.025
ENJ	1	0	0.001	0	0	0.016	0	0.002
EOS	4	1	0.004	0.001	10.667	0.031	0.01	0.055
ETC	3	0	0.004	0	0	0.022	0	0.053
ETH	2	1	0.004	0.001	1.833	0.018	0.015	0.047
ICX	1	7	0.003	0.01	13.483	0.016	0.074	0.022
KNC	1	2	0.003	0.008	21.233	0.016	0.006	0.022
LBC	0	0	0	0	0	0.013	0.025	0.025
LINK	2	0	0.004	0	0	0.041	0	0.026
LTC	1	1	0.002	0.001	0	0.014	0.015	0.025
MANA	0	0	0	0	0	0.013	0.025	0.025
MIOTA	1	0	0.003	0	0	0.016	0	0.022
MKR	2	1	0.003	0.001	15	0.024	0	0.009
NANO	2	2	0.003	0.008	22.167	0.047	0.024	0.009

NEO	1	1	0.003	0.004	0.75	0.016	0.006	0.022
OMG	0	3	0	0.005	0	0.013	0.015	0
QTUM	4	4	0.004	0.008	60.317	0.024	0.044	0.061
REV	1	0	0.003	0	0	0.022	0	0.002
SC	1	1	0.002	0.005	2.733	0.014	0.009	0.025
TRX	3	0	0.004	0	0	0.02	0	0.054
USDT	1	0	0.003	0	0	0.033	0	0
VGX	2	0	0.003	0	0	0.02	0	0.024
WAVES	0	1	0	0.008	0	0.013	0.002	0
XEM	0	3	0	0.006	0	0.013	0.064	0
XLM	1	0	0.002	0	0	0.014	0	0.025
XMR	3	16	0.003	0.012	131.333	0.035	0.247	0.005
XRP	0	0	0	0	0	0.013	0.025	0.025
ZEC	0	0	0	0	0	0.013	0.025	0.025
ZEN	4	15	0.004	0.011	202.2	0.068	0.219	0.036
ZRX	3	0	0.004	0	0	0.022	0	0.053
<hr/>								
$p = 0.8$	InDegree	OutDegree	InCloseness	OutCloseness	Betweenness	Pagerank	Hub	Authority
ADA	1	1	0.003	0.001	0	0.014	0.014	0.019
BAT	3	3	0.004	0.007	29.986	0.027	0.039	0.026
BCH	2	2	0.004	0.002	0.486	0.016	0.024	0.035
BNB	4	3	0.005	0.002	25.369	0.034	0.022	0.035
BNT	5	2	0.005	0.008	119	0.064	0.012	0.022
BTC	11	0	0.008	0	0	0.087	0	0.056
BTG	3	0	0.005	0	0	0.031	0	0.036
DASH	0	0	0	0	0	0.012	0.025	0.025
DCR	2	0	0.004	0	0	0.016	0	0.035
DGB	10	2	0.007	0.007	77.833	0.067	0.02	0.079
DOGE	0	1	0	0.002	0	0.012	0.009	0
ENJ	1	1	0.001	0.006	7.417	0.014	0.005	0.004
EOS	4	2	0.005	0.001	11.417	0.035	0.014	0.043
ETC	3	0	0.004	0	0	0.018	0	0.043
ETH	2	2	0.004	0.008	3.736	0.016	0.02	0.035
ICX	1	10	0.003	0.012	13.333	0.014	0.091	0.016
KNC	1	4	0.003	0.009	3.986	0.014	0.045	0.016
LBC	1	0	0.004	0	0	0.014	0	0.016
LINK	2	0	0.004	0	0	0.029	0	0.02
LTC	1	1	0.003	0.001	0	0.014	0.014	0.019
MANA	0	0	0	0	0	0.012	0.025	0.025
MIOTA	1	0	0.004	0	0	0.014	0	0.016
MKR	3	1	0.005	0.001	18	0.024	0	0.031
NANO	2	4	0.004	0.01	19.238	0.04	0.052	0.011
NEO	2	1	0.004	0.005	0	0.016	0.02	0.024
OMG	0	4	0	0.006	0	0.012	0.04	0
QTUM	6	4	0.006	0.009	87.105	0.056	0.05	0.06
REV	2	0	0.004	0	0	0.026	0	0.003
SC	1	1	0.003	0.005	2.667	0.014	0.007	0.019
TRX	3	0	0.004	0	0	0.017	0	0.044
USDT	1	0	0.004	0	0	0.033	0	0
VGX	2	0	0.004	0	0	0.017	0	0.02
WAVES	0	2	0	0.009	0	0.012	0.006	0
XEM	0	6	0	0.007	0	0.012	0.076	0
XLM	1	0	0.003	0	0	0.014	0	0.019
XMR	5	19	0.004	0.014	182.833	0.04	0.175	0.023
XRP	0	0	0	0	0	0.012	0.025	0.025
ZEC	0	0	0	0	0	0.012	0.025	0.025
ZEN	4	17	0.005	0.012	166.595	0.051	0.145	0.036
ZRX	3	0	0.004	0	0	0.018	0	0.043
<hr/>								
$p = 0.7$	InDegree	OutDegree	InCloseness	OutCloseness	Betweenness	Pagerank	Hub	Authority
ADA	1	2	0.005	0.006	0	0.012	0.027	0.015
BAT	3	3	0.005	0.007	32.017	0.025	0.033	0.023
BCH	2	3	0.005	0.009	0.367	0.014	0.027	0.028
BNB	4	4	0.006	0.007	48.367	0.02	0.033	0.033
BNT	7	3	0.008	0.009	199	0.066	0.028	0.03
BTC	13	0	0.009	0	0	0.077	0	0.054
BTG	4	0	0.007	0	0	0.04	0	0.033
DASH	0	0	0	0	0	0.01	0.025	0.025
DCR	3	0	0.006	0	0	0.023	0	0.029
DGB	16	3	0.011	0.008	186.933	0.103	0.025	0.086
DOGE	0	3	0	0.007	0	0.01	0.029	0

ENJ	1	2	0.001	0.007	2.5	0.012	0.011	0.004
EOS	6	2	0.008	0.001	22.833	0.056	0.011	0.048
ETC	3	0	0.006	0	0	0.016	0	0.035
ETH	2	2	0.005	0.009	1.567	0.014	0.016	0.028
ICX	2	12	0.005	0.013	51.267	0.014	0.087	0.02
KNC	1	4	0.005	0.01	1.967	0.012	0.038	0.013
LBC	1	0	0.005	0	0	0.012	0	0.013
LINK	3	0	0.006	0	0	0.037	0	0.025
LTC	1	1	0.005	0.001	0	0.012	0.01	0.015
MANA	0	0	0	0	0	0.01	0.025	0.025
MIOTA	1	2	0.005	0.006	0.367	0.012	0.027	0.013
MKR	4	2	0.006	0.001	29.333	0.023	0.006	0.029
NANO	3	6	0.006	0.011	47.05	0.032	0.053	0.026
NEO	3	1	0.006	0.006	0	0.016	0.016	0.035
OMG	0	5	0	0.008	0	0.01	0.037	0
QTUM	6	5	0.008	0.01	86.283	0.05	0.047	0.053
REV	2	2	0.004	0.007	28.25	0.019	0.011	0.004
SC	2	1	0.005	0.005	2.167	0.014	0.004	0.028
TRX	3	0	0.006	0	0	0.015	0	0.038
USDT	1	1	0.005	0.001	3	0.02	0.003	0.001
VGX	2	1	0.005	0.006	0	0.014	0.016	0.017
WAVES	0	2	0	0.01	0	0.01	0.006	0
XEM	1	7	0.003	0.009	36.75	0.019	0.062	0.001
XLM	2	0	0.005	0	0	0.014	0	0.028
XMR	6	20	0.006	0.015	203.95	0.037	0.138	0.027
XRP	2	0	0.006	0	0	0.029	0	0.014
ZEC	0	0	0	0	0	0.01	0.025	0.025
ZEN	5	21	0.007	0.014	247.033	0.04	0.125	0.036
ZRX	4	0	0.006	0	0	0.02	0	0.041
<hr/>								
$p = 0.6$	InDegree	OutDegree	InCloseness	OutCloseness	Betweenness	Pagerank	Hub	Authority
ADA	1	2	0.006	0.007	0	0.011	0.02	0.011
BAT	3	4	0.006	0.01	36.231	0.022	0.032	0.019
BCH	2	6	0.006	0.012	2.238	0.012	0.042	0.02
BNB	6	4	0.009	0.008	64.217	0.039	0.027	0.036
BNT	9	4	0.01	0.011	188.1	0.048	0.027	0.047
BTC	15	0	0.011	0	0	0.072	0	0.056
BTG	8	0	0.01	0	0	0.052	0	0.049
DASH	0	0	0	0	0	0.01	0.025	0.025
DCR	3	0	0.007	0	0	0.031	0	0.02
DGB	18	6	0.013	0.009	271.968	0.114	0.04	0.073
DOGE	1	4	0.005	0.011	0	0.01	0.03	0.01
ENJ	2	3	0.006	0.009	8.5	0.014	0.014	0.011
EOS	8	2	0.01	0.005	13.6	0.042	0.011	0.051
ETC	4	0	0.007	0	0	0.015	0	0.034
ETH	3	3	0.006	0.01	2.155	0.014	0.021	0.027
ICX	2	18	0.006	0.015	66.181	0.013	0.1	0.013
KNC	2	5	0.006	0.01	3.565	0.012	0.034	0.019
LBC	2	0	0.006	0	0	0.013	0	0.012
LINK	3	1	0.007	0.007	33	0.029	0.011	0.022
LTC	1	1	0.006	0.001	0	0.011	0.009	0.011
MANA	0	0	0	0	0	0.01	0.025	0.025
MIOTA	1	2	0.006	0.007	0.178	0.011	0.02	0.009
MKR	9	2	0.009	0.007	49.75	0.044	0.003	0.045
NANO	3	12	0.007	0.014	40.387	0.022	0.075	0.021
NEO	3	1	0.007	0.007	0	0.014	0.011	0.024
OMG	2	6	0.006	0.009	18.037	0.017	0.039	0.01
QTUM	6	5	0.009	0.01	72.306	0.033	0.04	0.045
REV	2	3	0.006	0.008	34.417	0.022	0.01	0.003
SC	2	1	0.006	0.007	2.167	0.012	0.003	0.02
TRX	3	0	0.007	0	0	0.013	0	0.029
USDT	1	3	0.006	0.01	46.35	0.029	0.015	0
VGX	4	3	0.007	0.007	1.778	0.016	0.027	0.027
WAVES	0	2	0	0.011	0	0.01	0.006	0
XEM	2	8	0.005	0.011	45.217	0.02	0.047	0.002
XLM	2	1	0.006	0.007	0	0.012	0.011	0.02
XMR	8	22	0.008	0.016	234.4	0.034	0.112	0.034
XRP	3	0	0.007	0	0	0.02	0	0.021
ZEC	0	0	0	0	0	0.01	0.025	0.025
ZEN	7	22	0.008	0.015	303.258	0.035	0.091	0.039
ZRX	5	0	0.01	0	0	0.032	0	0.035

$p = 0.5$	InDegree	OutDegree	InCloseness	OutCloseness	Betweenness	Pagerank	Hub	Authority
ADA	4	2	0.009	0.007	2.006	0.019	0.016	0.027
BAT	3	4	0.008	0.011	19.722	0.013	0.027	0.016
BCH	3	7	0.008	0.013	25.54	0.013	0.045	0.017
BNB	6	5	0.011	0.012	56.927	0.033	0.027	0.031
BNT	9	4	0.01	0.012	108.85	0.033	0.022	0.04
BTC	17	0	0.013	0	0	0.071	0	0.054
BTG	11	2	0.012	0.009	89.267	0.049	0.001	0.048
DASH	1	0	0.006	0	0	0.007	0	0.008
DCR	6	2	0.009	0.011	57.154	0.054	0.011	0.033
DGB	21	6	0.014	0.01	220.992	0.084	0.031	0.066
DOGE	2	4	0.006	0.012	1.083	0.009	0.025	0.011
ENJ	4	7	0.007	0.012	27.395	0.013	0.031	0.021
EOS	9	3	0.011	0.007	23.514	0.034	0.013	0.044
ETC	4	0	0.009	0	0	0.012	0	0.028
ETH	4	4	0.008	0.011	8.59	0.011	0.021	0.032
ICX	2	24	0.008	0.018	47.636	0.011	0.105	0.011
KNC	2	5	0.008	0.011	1.15	0.009	0.029	0.015
LBC	4	4	0.009	0.009	6.858	0.016	0.018	0.016
LINK	4	2	0.008	0.009	14.9	0.018	0.009	0.026
LTC	4	2	0.009	0.007	1.7	0.019	0.014	0.027
MANA	0	1	0	0.008	0	0.007	0	0
MIOTA	3	2	0.008	0.007	0.231	0.011	0.016	0.023
MKR	10	2	0.011	0.008	28.381	0.055	0.005	0.04
NANO	3	22	0.009	0.017	78.764	0.016	0.101	0.017
NEO	4	2	0.009	0.007	0.231	0.012	0.016	0.028
OMG	2	6	0.008	0.01	21.143	0.02	0.033	0.008
QTUM	6	6	0.011	0.011	36.431	0.024	0.035	0.039
REV	3	3	0.009	0.009	46.117	0.038	0.01	0.003
SC	2	2	0.008	0.008	2.5	0.01	0.011	0.015
TRX	5	1	0.01	0.007	8.431	0.023	0.004	0.026
USDT	3	5	0.009	0.012	117.875	0.058	0.021	0.001
VGX	5	3	0.008	0.008	1.207	0.015	0.022	0.025
WAVES	1	2	0.001	0.011	37	0.013	0.006	0
XEM	3	11	0.008	0.014	46.619	0.021	0.052	0.01
XLM	3	1	0.008	0.007	0	0.011	0.009	0.023
XMR	10	23	0.01	0.017	211.089	0.029	0.103	0.041
XRP	5	0	0.009	0	0	0.021	0	0.034
ZEC	0	0	0	0	0	0.007	0.025	0.025
ZEN	10	24	0.011	0.018	416.696	0.059	0.087	0.04
ZRX	5	0	0.011	0	0	0.024	0	0.03

The full name of each cryptocurrency is shown in Table 7.



Table 6: Centrality scores:  $p$  – stable causality network of cryptocurrency liquidity for the period 2019-2020

$p = 1.0$	InDegree	OutDegree	InCloseness	OutCloseness	Betweenness	Pagerank	Hub	Authority
ADA	8	7	0.014	0.012	36.78	0.032	0.024	0.017
BAT	7	12	0.013	0.013	31.383	0.027	0.039	0.022
BCH	8	12	0.012	0.013	23.301	0.014	0.03	0.028
BNB	9	9	0.012	0.012	56.721	0.019	0.025	0.027
BNT	2	6	0.008	0.01	8.093	0.007	0.017	0.005
BTC	10	6	0.013	0.011	10.321	0.026	0.019	0.034
BTG	11	12	0.013	0.014	72.371	0.032	0.033	0.031
DASH	12	8	0.013	0.011	32.914	0.021	0.026	0.033
DCR	18	9	0.016	0.012	94.924	0.048	0.029	0.051
DGB	6	11	0.012	0.012	49.553	0.02	0.026	0.017
DOGE	11	10	0.013	0.012	24.413	0.021	0.032	0.034
ENJ	2	6	0.009	0.01	1.727	0.006	0.017	0.006
EOS	2	11	0.008	0.013	14.516	0.005	0.024	0.006
ETC	7	3	0.011	0.01	2.539	0.015	0.012	0.023
ETH	9	13	0.014	0.014	100.718	0.035	0.042	0.03
ICX	11	7	0.014	0.011	27.598	0.036	0.019	0.029
KNC	3	2	0.011	0.009	0.75	0.01	0.006	0.009
LBC	11	6	0.014	0.012	30.152	0.036	0.019	0.03
LINK	2	9	0.009	0.012	33.605	0.005	0.02	0.008
LTC	8	19	0.013	0.016	100.427	0.019	0.058	0.027
MANA	6	8	0.011	0.012	41.649	0.02	0.02	0.012
MIOTA	7	5	0.013	0.011	24.955	0.031	0.013	0.017
MKR	17	16	0.016	0.015	196.786	0.052	0.045	0.051
NANO	6	7	0.011	0.011	47.856	0.013	0.02	0.018
NEO	14	11	0.015	0.013	50.8	0.036	0.034	0.049
OMG	13	12	0.015	0.013	68.589	0.049	0.036	0.042
QTUM	19	9	0.016	0.012	75.376	0.044	0.027	0.059
REV	13	1	0.015	0.008	1.798	0.04	0.006	0.029
SC	2	18	0.011	0.016	98.856	0.009	0.046	0.008
TRX	13	14	0.014	0.014	73.943	0.03	0.044	0.038
USDT	2	2	0.008	0.009	5.044	0.006	0.005	0.003
VGX	0	1	0	0.008	0	0.004	0.006	0
WAVES	9	14	0.014	0.014	44.034	0.027	0.044	0.027
XEM	5	3	0.012	0.01	1.793	0.018	0.011	0.017
XLM	14	16	0.014	0.014	98.302	0.04	0.043	0.046
XMR	9	4	0.013	0.01	13.111	0.029	0.01	0.024
XRP	2	5	0.007	0.011	1.289	0.005	0.018	0.004
ZEC	5	7	0.01	0.011	4.713	0.009	0.024	0.014
ZEN	29	6	0.02	0.011	157.825	0.097	0.013	0.072
ZRX	2	7	0.01	0.011	5.476	0.007	0.017	0.005
$p = 0.9$	InDegree	OutDegree	InCloseness	OutCloseness	Betweenness	Pagerank	Hub	Authority
ADA	18	15	0.017	0.016	7.151	0.024	0.021	0.023
BAT	16	14	0.016	0.016	6.255	0.021	0.018	0.021
BCH	12	19	0.015	0.017	4.821	0.014	0.025	0.016
BNB	14	14	0.016	0.015	8.916	0.018	0.018	0.019
BNT	6	10	0.014	0.015	1.57	0.011	0.014	0.007
BTC	18	19	0.017	0.017	8.467	0.024	0.025	0.026
BTG	29	28	0.02	0.02	37.665	0.036	0.036	0.037
DASH	25	23	0.019	0.018	35.094	0.03	0.029	0.031
DCR	35	31	0.023	0.021	73.57	0.042	0.037	0.042
DGB	19	19	0.017	0.017	17.986	0.025	0.024	0.024
DOGE	29	27	0.02	0.02	35.315	0.035	0.034	0.037
ENJ	11	15	0.015	0.016	2.619	0.015	0.021	0.016
EOS	10	18	0.014	0.017	11.222	0.014	0.021	0.013
ETC	16	11	0.016	0.015	3.193	0.02	0.016	0.02
ETH	23	25	0.018	0.019	16.33	0.029	0.033	0.032
ICX	18	19	0.017	0.017	9.744	0.023	0.027	0.024
KNC	20	15	0.017	0.016	12.411	0.025	0.021	0.026
LBC	26	23	0.019	0.018	27.026	0.034	0.03	0.033
LINK	9	17	0.014	0.016	5.953	0.011	0.021	0.012
LTC	22	27	0.018	0.02	35.567	0.027	0.032	0.031
MANA	19	22	0.017	0.018	18.51	0.025	0.028	0.025
MIOTA	17	12	0.016	0.015	6.468	0.023	0.016	0.022
MKR	34	28	0.023	0.02	57.041	0.043	0.035	0.04
NANO	11	10	0.015	0.014	4.707	0.016	0.013	0.013

NEO	18	15	0.017	0.016	5.639	0.023	0.022	0.025
OMG	23	26	0.018	0.019	23.219	0.03	0.034	0.03
QTUM	24	18	0.019	0.017	15.771	0.029	0.025	0.031
REV	23	13	0.018	0.015	15.181	0.03	0.018	0.027
SC	10	27	0.015	0.02	16.61	0.016	0.032	0.013
TRX	26	26	0.019	0.019	31.75	0.031	0.032	0.034
USDT	18	15	0.017	0.016	11.503	0.025	0.019	0.024
VGX	25	20	0.019	0.017	20.646	0.031	0.026	0.033
WAVES	33	28	0.022	0.02	52.032	0.042	0.035	0.04
XEM	5	7	0.014	0.014	0.696	0.009	0.01	0.008
XLM	29	30	0.02	0.021	45.306	0.037	0.037	0.037
XMR	23	18	0.018	0.017	32.792	0.03	0.023	0.028
XRP	4	13	0.013	0.015	1.491	0.007	0.017	0.005
ZEC	17	22	0.016	0.018	11.998	0.021	0.028	0.023
ZEN	35	28	0.023	0.02	60.462	0.042	0.035	0.041
ZRX	7	10	0.014	0.014	2.306	0.011	0.011	0.009
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$p = 0.8$	InDegree	OutDegree	InCloseness	OutCloseness	Betweenness	Pagerank	Hub	Authority
ADA	23	20	0.018	0.017	6.735	0.024	0.022	0.024
BAT	21	18	0.018	0.017	5.929	0.022	0.019	0.022
BCH	20	21	0.017	0.018	5.942	0.02	0.022	0.021
BNB	20	21	0.017	0.018	8.016	0.02	0.022	0.021
BNT	11	14	0.015	0.016	1.31	0.013	0.015	0.012
BTC	20	21	0.017	0.018	3.598	0.021	0.023	0.023
BTG	34	34	0.023	0.023	34.705	0.034	0.033	0.034
DASH	30	29	0.021	0.02	21.723	0.03	0.03	0.03
DCR	38	36	0.025	0.024	44.769	0.037	0.035	0.037
DGB	24	22	0.019	0.018	9.45	0.025	0.023	0.025
DOGE	33	34	0.022	0.023	30.928	0.033	0.034	0.033
ENJ	16	17	0.016	0.016	2.491	0.017	0.019	0.018
EOS	15	20	0.016	0.017	5.999	0.016	0.02	0.016
ETC	22	16	0.018	0.016	2.429	0.022	0.018	0.024
ETH	27	32	0.02	0.022	17.332	0.027	0.032	0.029
ICX	28	22	0.02	0.018	8.687	0.028	0.024	0.03
KNC	28	25	0.02	0.019	14.298	0.029	0.026	0.029
LBC	31	30	0.021	0.021	23.306	0.031	0.03	0.031
LINK	18	22	0.017	0.018	6.883	0.019	0.023	0.019
LTC	24	28	0.019	0.02	14.513	0.024	0.028	0.026
MANA	24	26	0.019	0.019	11.614	0.025	0.027	0.025
MIOTA	20	17	0.017	0.016	4.097	0.021	0.018	0.021
MKR	35	34	0.023	0.023	42.429	0.035	0.033	0.034
NANO	14	15	0.016	0.016	5.11	0.016	0.015	0.014
NEO	19	21	0.017	0.018	4.998	0.02	0.023	0.021
OMG	31	28	0.021	0.02	17.417	0.031	0.029	0.032
QTUM	29	22	0.02	0.018	10.561	0.028	0.024	0.03
REV	28	24	0.02	0.019	16.971	0.028	0.025	0.028
SC	18	31	0.017	0.021	18.038	0.02	0.03	0.018
TRX	32	34	0.022	0.023	27.232	0.032	0.034	0.033
USDT	24	22	0.019	0.018	8.385	0.025	0.024	0.025
VGX	28	29	0.02	0.02	19.622	0.029	0.03	0.029
WAVES	35	33	0.023	0.022	32.94	0.035	0.033	0.034
XEM	10	11	0.015	0.015	1.649	0.013	0.012	0.011
XLM	33	32	0.022	0.022	23.253	0.033	0.033	0.034
XMR	27	22	0.02	0.018	18.951	0.028	0.022	0.026
XRP	10	13	0.015	0.015	1.086	0.012	0.014	0.01
ZEC	22	26	0.018	0.019	11.561	0.022	0.027	0.023
ZEN	37	35	0.024	0.023	40.864	0.036	0.034	0.036
ZRX	13	15	0.015	0.016	2.18	0.015	0.016	0.014
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$p = 0.7$	InDegree	OutDegree	InCloseness	OutCloseness	Betweenness	Pagerank	Hub	Authority
ADA	25	22	0.019	0.018	6.334	0.023	0.021	0.023
BAT	23	20	0.018	0.017	4.861	0.022	0.019	0.022
BCH	24	25	0.019	0.019	5.797	0.022	0.023	0.023
BNB	23	23	0.018	0.018	5.96	0.021	0.022	0.022
BNT	16	17	0.016	0.016	1.822	0.016	0.017	0.016
BTC	22	23	0.018	0.018	3.484	0.021	0.023	0.022
BTG	35	38	0.023	0.025	26.828	0.032	0.033	0.031
DASH	36	30	0.024	0.021	19.376	0.032	0.027	0.032
DCR	39	37	0.026	0.024	31.705	0.035	0.033	0.034
DGB	28	28	0.02	0.02	10.478	0.026	0.026	0.026
DOGE	35	35	0.023	0.023	23.652	0.031	0.031	0.031

ENJ	23	20	0.018	0.017	3.376	0.022	0.02	0.022
EOS	17	24	0.016	0.019	4.727	0.017	0.022	0.016
ETC	24	21	0.019	0.018	3.202	0.022	0.021	0.023
ETH	32	34	0.022	0.023	17.143	0.029	0.031	0.03
ICX	31	26	0.021	0.019	10.133	0.028	0.025	0.029
KNC	30	29	0.021	0.02	12.349	0.028	0.027	0.028
LBC	34	34	0.023	0.023	23.685	0.031	0.03	0.03
LINK	22	23	0.018	0.018	6.314	0.021	0.022	0.021
LTC	28	31	0.02	0.021	13.032	0.025	0.028	0.026
MANA	27	29	0.02	0.02	10.637	0.026	0.027	0.025
MIOTA	21	19	0.018	0.017	3.612	0.02	0.018	0.02
MKR	35	34	0.023	0.023	25.497	0.032	0.03	0.031
NANO	17	20	0.016	0.017	6.202	0.017	0.019	0.015
NEO	23	26	0.018	0.019	5.233	0.022	0.025	0.022
OMG	32	33	0.022	0.022	15.031	0.029	0.03	0.03
QTUM	30	24	0.021	0.019	7.492	0.027	0.023	0.028
REV	31	27	0.021	0.02	13.274	0.028	0.025	0.028
SC	21	33	0.018	0.022	11.44	0.02	0.03	0.02
TRX	33	35	0.022	0.023	18.205	0.03	0.031	0.03
USDT	27	27	0.02	0.02	9.553	0.025	0.025	0.025
VGX	32	33	0.022	0.022	17.374	0.029	0.03	0.029
WAVES	37	34	0.024	0.023	24.271	0.033	0.031	0.033
XEM	11	13	0.015	0.015	1.136	0.012	0.013	0.011
XLM	34	33	0.023	0.022	16.723	0.03	0.03	0.031
XMR	29	26	0.02	0.019	16.108	0.027	0.023	0.025
XRP	16	16	0.016	0.016	2.647	0.016	0.015	0.015
ZEC	23	28	0.018	0.02	9.403	0.021	0.026	0.021
ZEN	38	36	0.025	0.024	27.888	0.034	0.032	0.034
ZRX	18	16	0.017	0.016	2.018	0.018	0.015	0.018
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$p = 0.6$	InDegree	OutDegree	InCloseness	OutCloseness	Betweenness	Pagerank	Hub	Authority
ADA	27	23	0.02	0.018	5.548	0.023	0.02	0.023
BAT	27	24	0.02	0.019	5.47	0.023	0.021	0.023
BCH	26	29	0.019	0.02	5.291	0.022	0.025	0.023
BNB	28	26	0.02	0.019	6.693	0.024	0.023	0.024
BNT	16	19	0.016	0.017	1.394	0.016	0.017	0.014
BTC	24	25	0.019	0.019	3.635	0.021	0.022	0.022
BTG	38	38	0.025	0.025	21.349	0.032	0.031	0.031
DASH	37	34	0.024	0.023	17.174	0.031	0.028	0.031
DCR	39	38	0.026	0.025	22.739	0.032	0.031	0.032
DGB	28	31	0.02	0.021	7.93	0.025	0.027	0.024
DOGE	38	37	0.025	0.024	18.855	0.032	0.031	0.031
ENJ	29	22	0.02	0.018	3.655	0.025	0.02	0.025
EOS	20	25	0.017	0.019	3.59	0.018	0.022	0.018
ETC	27	26	0.02	0.019	4.387	0.023	0.023	0.024
ETH	35	35	0.023	0.023	13.774	0.029	0.029	0.03
ICX	31	29	0.021	0.02	7.499	0.026	0.025	0.027
KNC	34	31	0.023	0.021	12.318	0.028	0.026	0.029
LBC	37	34	0.024	0.023	17.291	0.031	0.028	0.031
LINK	25	26	0.019	0.019	5.453	0.022	0.022	0.022
LTC	29	35	0.02	0.023	10.623	0.025	0.03	0.025
MANA	29	29	0.02	0.02	7.022	0.025	0.025	0.025
MIOTA	22	23	0.018	0.018	3.223	0.02	0.02	0.02
MKR	37	36	0.024	0.024	18.56	0.031	0.03	0.031
NANO	21	21	0.018	0.018	5.43	0.019	0.018	0.017
NEO	25	27	0.019	0.02	3.912	0.022	0.024	0.022
OMG	33	34	0.022	0.023	11.069	0.028	0.029	0.028
QTUM	32	27	0.022	0.02	5.764	0.026	0.024	0.028
REV	33	30	0.022	0.021	10.657	0.028	0.026	0.028
SC	25	35	0.019	0.023	9.694	0.022	0.029	0.022
TRX	35	36	0.023	0.024	14.613	0.029	0.03	0.03
USDT	29	31	0.02	0.021	9.462	0.025	0.027	0.025
VGX	34	33	0.023	0.022	12.341	0.028	0.028	0.029
WAVES	37	36	0.024	0.024	17.609	0.031	0.03	0.031
XEM	16	17	0.016	0.016	1.865	0.016	0.015	0.014
XLM	38	34	0.025	0.023	15.777	0.031	0.029	0.031
XMR	34	30	0.023	0.021	14.477	0.028	0.025	0.028
XRP	17	21	0.016	0.018	2.239	0.016	0.018	0.015
ZEC	24	31	0.019	0.021	7.275	0.021	0.027	0.021
ZEN	38	37	0.025	0.024	19.757	0.031	0.03	0.031
ZRX	19	18	0.017	0.017	1.584	0.018	0.016	0.017

$p = 0.5$	InDegree	OutDegree	InCloseness	OutCloseness	Betweenness	Pagerank	Hub	Authority
ADA	27	25	0.02	0.019	3.802	0.022	0.021	0.022
BAT	29	24	0.02	0.019	4.57	0.024	0.02	0.023
BCH	28	31	0.02	0.021	4.282	0.023	0.025	0.023
BNB	29	29	0.02	0.02	5.947	0.023	0.024	0.023
BNT	19	22	0.017	0.018	1.387	0.017	0.019	0.016
BTC	28	28	0.02	0.02	4.715	0.023	0.023	0.023
BTG	39	38	0.026	0.025	16	0.031	0.03	0.03
DASH	37	36	0.024	0.024	13.044	0.029	0.028	0.029
DCR	39	38	0.026	0.025	16.295	0.031	0.03	0.03
DGB	33	32	0.022	0.022	7.603	0.027	0.026	0.026
DOGE	38	37	0.025	0.024	13.251	0.03	0.029	0.03
ENJ	30	24	0.021	0.019	2.582	0.024	0.021	0.025
EOS	25	25	0.019	0.019	3.519	0.02	0.02	0.021
ETC	29	31	0.02	0.021	5.258	0.023	0.025	0.024
ETH	36	37	0.024	0.024	12.459	0.028	0.029	0.029
ICX	33	30	0.022	0.021	7.463	0.027	0.024	0.027
KNC	37	32	0.024	0.022	11.474	0.029	0.025	0.029
LBC	38	37	0.025	0.024	14.134	0.03	0.029	0.03
LINK	25	31	0.019	0.021	4.889	0.021	0.025	0.021
LTC	31	35	0.021	0.023	7.526	0.025	0.028	0.025
MANA	32	32	0.022	0.022	6.324	0.026	0.026	0.026
MIOTA	24	25	0.019	0.019	2.84	0.02	0.021	0.02
MKR	38	36	0.025	0.024	13.516	0.03	0.028	0.03
NANO	22	24	0.018	0.019	5.034	0.019	0.02	0.017
NEO	29	27	0.02	0.02	3.459	0.024	0.023	0.024
OMG	36	35	0.024	0.023	10.161	0.028	0.028	0.029
QTUM	32	27	0.022	0.02	3.615	0.025	0.023	0.026
REV	33	31	0.022	0.021	7.959	0.026	0.025	0.026
SC	26	37	0.019	0.024	7.784	0.022	0.029	0.021
TRX	37	36	0.024	0.024	11.779	0.029	0.029	0.029
USDT	32	33	0.022	0.022	8.814	0.026	0.026	0.026
VGX	36	36	0.024	0.024	11.338	0.028	0.028	0.029
WAVES	37	36	0.024	0.024	12.809	0.029	0.029	0.029
XEM	16	20	0.016	0.017	1.524	0.015	0.017	0.013
XLM	38	37	0.025	0.024	14.594	0.03	0.029	0.03
XMR	36	35	0.024	0.023	12.766	0.028	0.027	0.028
XRP	20	26	0.017	0.019	2.213	0.017	0.021	0.017
ZEC	26	31	0.019	0.021	5.399	0.021	0.025	0.021
ZEN	38	38	0.025	0.025	14.394	0.03	0.03	0.03
ZRX	24	18	0.019	0.017	1.479	0.02	0.015	0.02

The full name of each cryptocurrency is shown in Table 7.

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## Appendix

Code	Cryptocurrency name	Market Capitalization on December 31, 2020	Code	Cryptocurrency name	Market Capitalization on December 31, 2020
BTC	Bitcoin	539,051,138,108	MKR	Maker	585,318,127
ETH	Ethereum	84,156,810,765	ETC	Ethereum Classic	542,606,445
USDT	Tether	20,939,440,705	WAVES	Waves	529,873,902
XRP	XRP	9,981,874,643	DCR	Decred	506,943,695
LTC	Litecoin	8,256,035,501	DGB	DigiByte	347,030,365
BCH	Bitcoin Cash	6,381,074,871	OMG	OMG Network	343,502,087
ADA	Cardano	5,643,713,241	BAT	Basic Attention Token	298,008,812
BNB	Binance Coin	5,397,344,408	ICX	ICON	269,252,235
LINK	Chainlink	4,491,417,083	ZRX	0x	218,248,064
XLM	Stellar	2,813,168,655	QTUM	Qtum	217,737,367
XMR	Monero	2,787,140,073	BTG	Bitcoin Gold	147,377,756
EOS	EOS	2,439,720,347	SC	Siacoin	141,192,642
TRX	TRON	1,922,848,320	NANO	Nano	136,101,705
XEM	NEM	1,840,707,891	KNC	Kyber Network	130,790,290
NEO	Neo	1,009,954,292	ZEN	Horizen	122,762,296
REV	Revain	990,679,815	BNT	Bancor	121,894,998
DASH	Dash	985,902,608	MANA	Decentraland	116,107,505
MIOTA	IOTA	825,223,190	ENJ	Enjin Coin	107,554,251
ZEC	Zcash	691,772,359	LBC	LBRY Credits	42,884,644
DOGE	Dogecoin	598,149,001	VGX	Voyager Token	35,004,025

Table 7: List of studied cryptocurrencies