

Dissecting the Terra-LUNA crash: Evidence from the spillover effect and information flow

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Abstract

The Terra-LUNA crash in May 2022 was triggered by the depeg of the ecosystem's stablecoin UST. It led to the unprecedented demise of a blockchain ecosystem and cost investors tens of billions of dollars. We examined the impact of the Terra-LUNA crash on the cryptocurrency market. Based on the hourly return and realized volatility from April 2022 to May 2022, we used the spillover index and effective transfer entropy to configure the interlinkage change between cryptocurrency markets. We conclude that the Terra-LUNA crash had a significant impact on the connectedness of the cryptocurrency market, investor attention, and market sentiment.

Keywords: Terra, LUNA, UST, Spillover effect, Effective transfer entropy, Information flow

1. Introduction

Before its epic meltdown in May 2022, the Terra protocol, which was developed by Terraform Labs, had been evaluated as a successful blockchain project among investors. LUNA - a native token of Terra - had the 8th largest market capitalization among cryptocurrencies with nearly 40 billion USD in April 2022. The role of LUNA is to maintain the value of TerraUSD (UST), which is a stablecoin pegged to the US dollar in the Terra ecosystem. Unlike other well-known stablecoins, such as USDC and USDT, whose stability is secured with reserves of assets, a dollar peg of UST solely relies on the use of LUNA. According to the Terra whitepaper (Kereiakes et al., 2019), LUNA absorbs the short-term volatility of UST value by providing an arbitrage opportunity to LUNA holders. Within the Terra ecosystem, anyone can swap UST with LUNA at the target exchange rate regardless of their current values. This arbitrage system provides an incentive to market participants to anchor a dollar peg of UST. The pegging mechanism of UST is presented in Appendix Figure A.1. Before UST collapsed in May 2022, the UST peg had remained stable.

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On May 9, 2022, 15:00 (UTC), the UST started to lose its dollar peg. After the UST depeg, the price of UST and LUNA dramatically plummeted and only after three weeks, they became useless in the ecosystem as Terra 2.0 launched on May 28. Figure 1 illustrates the LUNA and UST price movement during this period.

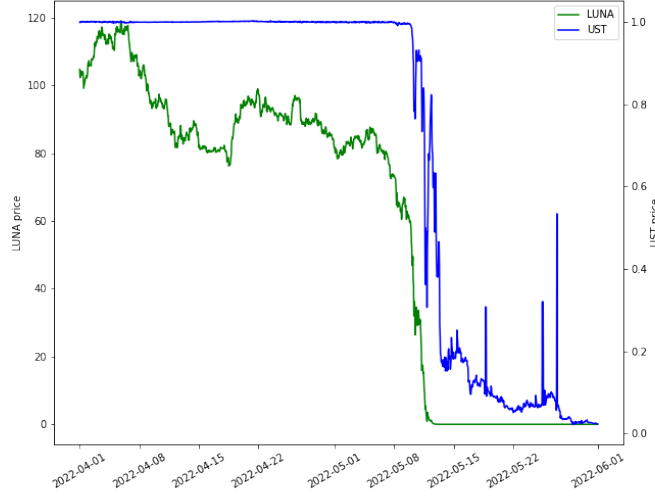


Figure 1: LUNA, UST price from April 2022 to May 2022

Note. While UST suffered from de-anchoring to as low as \$0.35, showing extreme volatility within a day, the LUNA price plunged almost simultaneously with the UST depeg, but even more severely that it became less than \$0.1 on May 12, 2022. Although the Terra blockchain officially halted on May 12, Terra tokens were still traded in the market. On May 25, Do Kwon's plan of launching a new blockchain called "Terra 2.0" was approved by chain validators, and LUNA and UST were renamed to LUNC and USTC, respectively. By May 28, Terra 2.0 was officially launched and the epic saga of LUNA and UST came to the end.

To the best of our knowledge, this is a pioneer study analyzing the Terra-LUNA crash and its impact on the cryptocurrency market. Several studies have reported on the connectedness within the cryptocurrency market using the spillover effect (Ji et al., 2019; Yi et al., 2018; Corbet et al., 2018; Moratis, 2021), and have adopted the methodology suggested by Diebold & Yilmaz (2009, 2012). Along with spillover effect, analyses based on information theory were also widely conducted to understand the interlinkage in the market (Assaf et al., 2022; Aslanidis et al., 2022). Katsiampa (2019) used a bivariate diagonal BEKK model to understand volatility movements in the cryptocurrency market.

There are several studies investigating shock transmission within the cryptocurrency market. Using a nonlinear autoregressive distributed lag model,

Demir et al. (2021) provided evidence that the asymmetric effect of Bitcoin price change on altcoins is mostly detected in the short-run. Bouri et al. (2019) and Zięba et al. (2019) focused on the shock transmission generated by Bitcoin to explain its influence on the entire market. Recently, some studies have reported how the cryptocurrency market has changed after the COVID-19 outbreak. Bouri et al. (2021), Demiralay & Golitsis (2021), and Aslanidis et al. (2021) reported a stronger connectedness between cryptocurrencies during the pandemic.

In this paper, we aim to explore the relationship between Terra tokens and the cryptocurrency market, focusing on the impact brought by the Terra-LUNA crash. The effect of the instability of stablecoins on the market was reported by Wei (2018), who demonstrated that Tether does not have a serious impact on the Bitcoin market. However, the relationship between UST and LUNA is quite different from that of Tether and Bitcoin. LUNA and UST construct the basic ecosystem of the Terra blockchain, which makes them highly dependent on each other. In other words, the depeg of UST can drive risk in the Terra ecosystem, which was what eventually lead to the shocking crash of the Terra-LUNA project. Faced with an unprecedented collapse, investors' attention to LUNA skyrocketed during the crash period and debates on Terra project's future became widespread on social media. This paper used the spillover index and effective transfer entropy to explain how the Terra-LUNA crash influenced the cryptocurrency market, investor attention, and market sentiment.

The rest of the paper is organized as follows. Section 2 describes the data and methodology. Section 3 discusses our experimental results and main findings. Lastly, Section 4 concludes.

2. Data and Methodology

2.1. Data

We utilized four hourly and 5-minute cryptocurrency prices for our empirical analysis, namely BTC (Bitcoin), ETH (Ethereum), LUNA (Luna), and UST (TerraUSD). The price series was downloaded from the CoinMarketCap API ². The sample period is from April 02, 2022 to May 30, 2022, and we separated our data into two periods: pre-Terra-LUNA crash period (April 02, 2022 to May 08, 2022) and Terra-LUNA crash period (May 09, 2022 to May 30, 2022). We then constructed the hourly realized volatility by summing up the 12 squared 5-minute log returns. Table 1 presents the descriptive statistics of the hourly asset returns for LUNA, UST, BTC, and ETH.

We also used the Google Trends index and tweets posted on StockTwits ³ containing the keyword "LUNA" as a proxy to quantify investor attention during the crash. Since Google Trends only provides hourly indexes for up to one week, we calibrated the index on a weekly basis by overlapping one item

²<https://api.coinmarketcap.com/data-api/v3/cryptocurrency/detail/>

³<https://stocktwits.com/>

continuously to obtain the overall hourly Google Trends index for the selected period. Based on the positive (Bullish tag) and negative (Bearish tag) labels used by StockTwits users for their tweets, we calculated the hourly sentiment score related to LUNA as follows⁴:

$$\text{Sent}_t = \frac{\text{Positive}_t - \text{Negative}_t}{\text{Positive}_t + \text{Negative}_t} \quad (1)$$

2.2. Methodology

Return and Volatility Spillovers. To investigate the return and volatility connectedness of cryptocurrency markets, the methodology developed by Diebold & Yilmaz (2009, 2012) (DY framework hereafter) was used. The DY framework quantifies the spillover effect between the variables in the system by using the generalized vector autoregression model (VAR) framework of Koop et al. (1996) and Pesaran & Shin (1998) (KPPS hereafter), which eliminates the effect of variable ordering in forecast-error variance decompositions. Consider an N -variable VAR(p) model, $x_t = \sum_{i=1}^p \Phi_i x_{t-i} + \epsilon_t$, where $\epsilon \sim (0, \Sigma)$ is a vector of i.i.d. disturbances. Then, the moving average form of such VAR model can be formulated as $x_t = \sum_{i=0}^{\infty} A_i \epsilon_{t-i}$, where A_i is the coefficient matrix with $A_i = 0$ for $i < 0$ and A_0 being an $N \times N$ identity matrix. For the variable x_i , for $i = 1, 2, \dots, N$, and the variable x_j causing the shock, the KPPS H -step ahead forecast error variance decompositions $\theta_{ij}^g(H)$ can be calculated as:

$$\theta_{ij}^g(H) = \frac{\sigma_{jj}^{-1} \sum_{h=0}^{H-1} (e_i' A_h \Sigma e_j)^2}{\sum_{h=0}^{H-1} (e_i' A_h \Sigma A_h' e_i)} \quad (2)$$

where e_i is the selection vector, Σ is the variance matrix for ϵ , and σ_{jj} is the standard deviation of the error for the j -th equation. The superscript g stands for the "generalized" forecast error variance decompositions. By normalizing $\theta_{ij}^g(H)$ so that the sum of all entries equal to 1, we obtain the following $\tilde{\theta}_{ij}^g(H)$:

$$\tilde{\theta}_{ij}^g(H) = \frac{\theta_{ij}^g(H)}{\sum_{j=1}^N \theta_{ij}^g(H)} \quad (3)$$

⁴*Positive_t* and *Negative_t* refer to the number of positive and negative labels during the period. This formula is widely used in calculating the sentiment score (Bakshi et al., 2016)

Table 1: Descriptive Statistics

Panel A: Full Period				
	LUNA	UST	BTC	ETH
Mean	-0.0104	-0.0027	-0.0004	-0.0005
Median	-0.0017	0.0000	-0.0002	-0.0002
Standard Deviation	0.1291	0.1360	0.0071	0.0088
Min	-2.7023	-1.9701	-0.0702	-0.1009
Max	1.1786	2.2441	0.0550	0.0681
Skewness	-9.0439	0.9042	-0.4203	-1.1130
Kurtosis	194.2254	141.9541	14.2093	19.6799
Augmented Dickey-Fuller	-5.0100***	-22.9248***	-8.6048***	-8.4717***
Jarque Bera	2092830.9949***	1108438.0220***	11136.9389***	21566.1152***
Panel B: Pre-Terra-LUNA Crash period				
	LUNA	UST	BTC	ETH
Mean	-0.0009	0.0000	-0.0005	-0.0005
Median	-0.0009	0.0000	-0.0003	-0.0002
Standard Deviation	0.0105	0.0009	0.0050	0.0058
Min	-0.0493	-0.0043	-0.0341	-0.0311
Max	0.0543	0.0039	0.0190	0.0266
Skewness	-0.0915	0.0652	-0.6670	-0.5643
Kurtosis	3.9297	2.7602	5.0400	4.3215
Augmented Dickey-Fuller	-13.2501***	-7.2622***	-18.6651***	-27.9490***
Jarque Bera	532.0117***	262.0924***	935.8159***	686.5126***
Panel C: Terra-LUNA Crash period				
	LUNA	UST	BTC	ETH
Mean	-0.0267	-0.0072	-0.0002	-0.0005
Median	-0.0084	-0.0041	0.0003	-0.0002
Standard Deviation	0.2110	0.2238	0.0096	0.0123
Min	-2.7023	-1.9701	-0.0702	-0.1009
Max	1.1786	2.2441	0.0550	0.0681
Skewness	-5.3924	0.6128	-0.3388	-1.0003
Kurtosis	70.7229	51.0731	9.6962	12.5048
Augmented Dickey-Fuller	-7.4236***	-16.5487***	-18.1315***	-17.0558***
Jarque Bera	102802.6500***	52400.5717***	1893.0245***	3216.2989***

Note. Table 1 reports descriptive statistics of hourly log returns of LUNA, UST, BTC, ETH. Panels A, B, and C report the values for the full period(April 02, 2022 to May 30, 2022), the pre-Terra-LUNA Crash period(April 02, 2022 to May 08, 2022), and the Terra-LUNA Crash period(May 09, 2022 to May 30, 2022). Asterisks flag levels of statistical significance of result statistic using t-test. The significance levels are flagged as follows: *** : p-value < 0.01, ** : p-value < 0.05

Then, the total spillovers, directional spillovers, net spillovers and net pairwise spillovers can be expressed as follows:

$$S^g(H) = \frac{\sum_{\substack{i,j=1 \\ j \neq i}}^N \tilde{\theta}_{ij}^g(H)}{\sum_{i,j=1}^N \tilde{\theta}_{ij}^g(H)} \cdot 100 = \frac{\sum_{\substack{i,j=1 \\ j \neq i}}^N \tilde{\theta}_{ij}^g(H)}{N} \cdot 100 \quad (4)$$

$$S_{i \cdot}^g(H) = \frac{\sum_{\substack{j=1 \\ j \neq i}}^N \tilde{\theta}_{ij}^g(H)}{\sum_{i,j=1}^N \tilde{\theta}_{ij}^g(H)} \cdot 100 = \frac{\sum_{j=1}^N \tilde{\theta}_{ij}^g(H)}{N} \cdot 100 \quad (5)$$

$$S_i^g(H) = S_{i \cdot}^g(H) - S_{\cdot i}^g(H) \quad (6)$$

$$\begin{aligned} S_{ij}^g(H) &= \left(\frac{\tilde{\theta}_{ji}^g(H)}{\sum_{i,k=1}^N \tilde{\theta}_{ik}^g(H)} - \frac{\tilde{\theta}_{ij}^g(H)}{\sum_{j,k=1}^N \tilde{\theta}_{jk}^g(H)} \right) \cdot 100 \\ &= \left(\frac{\tilde{\theta}_{ji}^g(H) - \tilde{\theta}_{ij}^g(H)}{N} \right) \cdot 100 \end{aligned} \quad (7)$$

Transfer Entropy. To measure information flows between cryptocurrency markets, Shannon Transfer Entropy (TE) can be used (see Schreiber (2000) for more details). TE overcomes the well-known limitations of Granger causality (Granger, 1969), such as the linearity assumption, because it can be reduced to Granger causality for vector autoregressive processes. TE can be useful in analyzing the linkage between two time series, as it can determine the direction of information flows and their magnitude. TE relies on the Kullback-Leibler distance to quantify the deviation between the transition probabilities. Considering two time series I and J , the information flow from J to I can be measured as:

$$T_{J \rightarrow I}(k, l) = \sum_{i,j} p(i_{t+1}, i_t^{(k)}, j_t^{(l)}) \cdot \log_2 \left(\frac{p(i_{t+1} | i_t^{(k)}, j_t^{(l)})}{p(i_{t+1} | i_t^{(k)})} \right) \quad (8)$$

where $p(i)$ and $p(j)$ are the marginal probability distributions of I and J , and $p(i, j)$ is the joint probability distribution. k and l denote the order of each process.

However, TE can be easily biased for the series with small sample sizes. As a result, Marschinski & Kantz (2002) suggested the Effective Transfer Entropy (ETE), which modifies TE by shuffling the time series J . Such modification

Table 2: Directional Return Spillover

Panel A: Full Period					
	LUNA	UST	BTC	ETH	from others
LUNA	80.6568	1.9412	9.0912	8.3106	19.3431
UST	1.7119	96.1950	1.1304	0.9625	3.8049
BTC	3.4916	0.6354	50.7683	45.1045	49.2316
ETH	3.5365	0.7278	45.1129	50.6226	49.3773
to others	8.7401	3.3046	55.3345	54.3778	30.4392
Panel B: Pre-Terra-LUNA Crash period					
	LUNA	UST	BTC	ETH	from others
LUNA	53.9226	1.9854	21.9487	22.1431	46.0773
UST	2.8644	91.8533	2.3194	2.9626	8.1466
BTC	18.0365	0.9415	43.9119	37.1099	56.0880
ETH	18.4208	0.9086	37.0854	43.5850	56.4149
to others	39.3218	3.8357	61.3536	62.2157	41.6817
Panel C: Terra-LUNA Crash period					
	LUNA	UST	BTC	ETH	from others
LUNA	77.6687	2.3796	11.2273	8.7244	22.3313
UST	2.0172	93.2487	2.5398	2.1943	6.7513
BTC	3.5992	0.8651	50.1467	45.3891	49.8533
ETH	3.7268	0.9038	45.8620	49.5074	50.4926
to others	9.3432	4.1484	59.6291	56.3078	32.3571

Note. Table 2 reports spillover matrix for hourly returns of LUNA, UST, BTC, ETH. Panels A, B, and C report the values for the full period(April 02, 2022 to May 30, 2022), the pre-Terra-LUNA Crash period(April 02, 2022 to May 08, 2022), and the Terra-LUNA Crash period(May 09, 2022 to May 30, 2022). The last column shows the total impact that the asset in each row received from the other assets and the last row shows the total impact sent to the other assets by the corresponding assets in each column.

eliminates the time series dependencies of J and the statistical dependencies between J and I . ETE can be calculated as:

$$ETE_{J \rightarrow I}(k, l) = T_{J \rightarrow I}(k, l) - T_{J_{\text{shuffled}} \rightarrow I}(k, l) \quad (9)$$

As our analysis focuses on a fairly short time frame (before and after the Terra-LUNA crash), we adopted ETE for our empirical analysis to correctly identify the linkage among the cryptocurrency markets during the crash.

3. Empirical Findings

3.1. Return and volatility spillover effects

To analyze the market situation during the testing period, we first calculated the spillovers between the markets. Table 2 reports the spillover matrix for hourly asset returns. Comparing the diagonal elements for Panels B and C in Table 2, values for LUNA increased from 53.9226 to 77.6687. This increase in portion value states that LUNA returns during the crash period are more likely to be attributable to the endogenous variation. Since the price crash of LUNA is claimed to have started due to the systematic risk of the Terra protocol, the enhancement of intrinsic impact on asset return is in line with the market situation. A similar characteristic can also be found in UST in that it also experienced an increase of endogenous impact on its hourly return.

Table 3: Directional Volatility Spillover

Panel A: Full Period					
	LUNA	UST	BTC	ETH	from others
LUNA	94.9909	0.6057	1.5220	2.8815	5.0091
UST	0.1705	97.6094	1.2858	0.9343	2.3906
BTC	0.2024	0.2211	50.0209	49.5557	49.9791
ETH	0.3451	0.2931	43.5771	55.7847	44.2153
to others	0.7179	1.1199	46.3849	53.3715	25.3985
Panel B: Pre-Terra-LUNA Crash period					
	LUNA	UST	BTC	ETH	from others
LUNA	64.8200	0.8491	15.5723	18.7587	35.1800
UST	5.2307	93.0103	1.2130	0.5460	6.9897
BTC	14.1800	0.8635	48.2365	36.7199	51.7635
ETH	16.7207	0.9985	36.6384	45.6424	54.3576
to others	36.1315	2.7111	53.4236	56.0246	37.0727
Panel C: Terra-LUNA Crash period					
	LUNA	UST	BTC	ETH	from others
LUNA	92.5806	0.9108	2.8771	3.6315	7.4194
UST	0.3300	95.7481	2.3773	1.5447	4.2519
BTC	0.3871	0.6978	48.6801	50.2350	51.3199
ETH	0.4732	0.7369	44.6548	54.1351	45.8649
to others	1.1903	2.3455	49.9091	55.4112	27.2140

Note. Table 3 reports spillover matrix for hourly realized volatility of LUNA, UST, BTC, ETH. Panels A, B, and C report the values for the full period(April 02, 2022 to May 30, 2022), the pre-Terra-LUNA Crash period(April 02, 2022 to May 08, 2022), and the Terra-LUNA Crash period(May 09, 2022 to May 30, 2022). For each panel, items in the first column are risk transmitters and the items in the first row are risk receivers. The last column shows the total impact that the asset in each row received from the other assets and the last row shows the total impact sent to the other assets by the corresponding assets in each column.

We applied the rolling-window VAR based spillover index and the results are shown in Figures 2a and 2b. Figure 2a shows that the net spillover from hourly returns suddenly changes immediately after the start of the depeg of UST. UST's net spillover rapidly increases to 50 while the net spillover of the other cryptocurrencies plunge to negative values. Net spillover indexes of UST and LUNA mostly remain positive for a week after the start of the depeg, which makes BTC and ETH lose its influence during this period. Figure 2b also suggests that UST's net pairwise spillover suddenly increases after the depeg and led to the dynamic change in market connectedness. This suggests that the Terra-LUNA crash was originated from the depeg of UST and not the meltdown of LUNA.

Table 3 reports the spillover matrix for asset volatility. In line with the findings in Table 2, the diagonal elements in Panel C increase compared to those in Panel B. LUNA especially shows an increase from 64.8200 to 92.5806, and the magnitude of this increase is even larger than that reported in Table 2. We conclude that this is due to the huge inflow of short-term investors right after the depeg of UST. After the start of the Terra-LUNA crash, many short-term investors entered the LUNA market and took positions to make a profit using high volatility. This caused the market to become extremely volatile, which naturally increased LUNA's volatility spillover on its own. Regarding net spillover index, LUNA's net spillover grew after the depeg, while UST also showed a significant

increase, as shown in Figure 2c. For net pairwise spillover indexes, according to Figure 2d, LUNA and UST transmitted high volatility to the market right after the start of the depeg. This pattern is similar to that shown in Figure 2a implying that the Terra-LUNA crash brought about a significant change in both market returns and volatility. In order to examine the impact of the crash on the other cryptocurrencies as well, we report the directional return and volatility spillover matrices for the top 10 cryptocurrencies by market capitalization in the Appendix. The market capitalization and names of 10 cryptocurrencies are reported in Appendix Table A.1 and the directional spillover matrices are shown in Appendix Table A.2 and Table A.3. We confirm that the results are quite similar to Table 2 and Table 3. However, one significant difference is that the diagonal element of UST in Panel C decreases compared to the one in Panel B for both return and volatility, confirming that the other cryptocurrencies had a stronger connectedness to UST than BTC and ETH.

3.2. *Effective Transfer Entropy*

As suggested in Section 2, we used ETE to measure the information transfer between time series sequences. Additional to the hourly asset return and volatility, we included hourly sequences of Google Trends index for LUNA, as well as the number of tweets with the cashtag "\$LUNA.X" and the sentiment score for "\$LUNA.X" on StockTwits in the analysis. Tables 4 and 5 report the ETE values calculated with asset return and volatility, respectively.

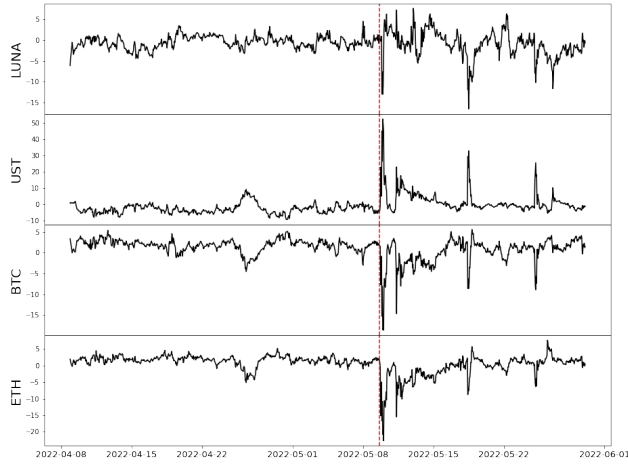
The results in Panel B in Table 4 show that there was an information flow from the sentiment score to LUNA returns before the Terra-LUNA crash. However, this flow disappears during the crash period and investor attention measured by Google Trends index and the number of tweets are shown to transmit information to LUNA returns. In other words, LUNA returns received information flow from investor attention, not investor sentiment, during the Terra-LUNA crash period. We conclude that the keen collusion between bearish and bullish opinions about the future of LUNA's price is the reason why market sentiment lost its influence. While investors had different opinions about LUNA on StockTwits, its price plunged drastically because the extent of the meltdown was unprecedented and LUNA seemed to be too large to collapse considering its market capitalization. Since the sentiment among investors became too diverse to be aggregated, it naturally lost its power as a transmitter of information flow to LUNA returns. On the other hand, investor attention drastically increased during the crash period; along with the LUNA meltdown, attention could have become a significant information transmitter.

The relationship between cryptocurrency returns also changed according to the findings in Panels B and C in Table 4. Before the crash, except for the flow from LUNA to ETH returns, asset returns did not show evidence of information flows. However, Panel C reports that LUNA returns transmitted information flow to UST, BTC, and ETH returns during the crash period, while also receiving information flows from BTC and ETH returns. This finding is in line with that from Corbet et al. (2022), which interlinkages between cryptocurrencies becoming stronger during bear markets. An interesting point is that

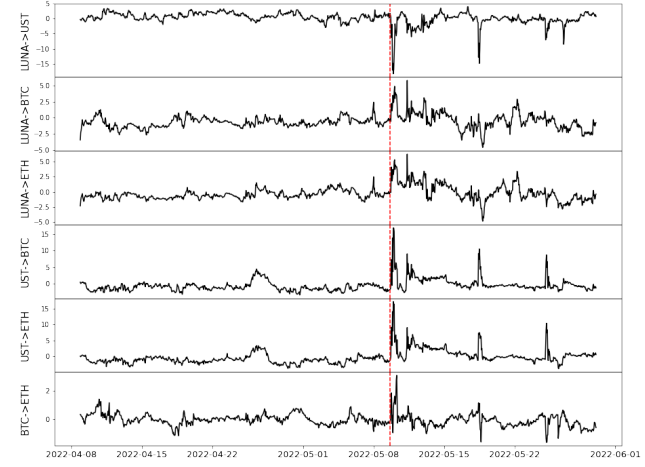
entropy values that LUNA returns transmit to other assets are larger than the values that LUNA returns receive. This indicates that LUNA returns show a strong influence on the market during the crash period and the bearish trends of the cryptocurrency market during this time may be explained by the LUNA meltdown.

In terms of volatility, according to Table 5, investor sentiment before the Terra-LUNA crash transmitted information flow to LUNA volatility. However, during the price crash, this information flow no longer becomes valid. We conclude that this is due to the diversification of investor sentiment during the crash period, similar to the situation with LUNA’s returns. Although sentiment score is a recipient of information flow for volatility, chaos in market sentiment during the price crash may also lead to the loss of information flow.

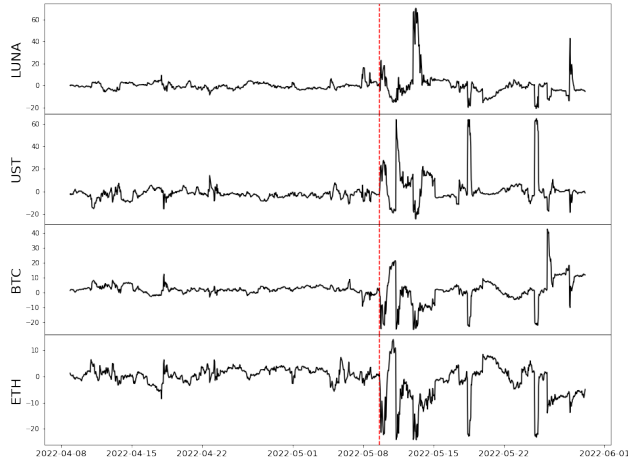
Additionally, from Panel B in Table 5, BTC and ETH used to transmit information flow to LUNA in terms of volatility, but this flow disappears during the crash period. This finding is in line with our result on spillover matrix from Table 3, which shows that LUNA’s volatility became more dependent on its intrinsic risk and not the market situation during its crash. In order to quantify the information transfer between a wider range of cryptocurrencies, we report the ETE values with 10 cryptocurrencies in Appendix Table A.4 and A.5. We confirm that the results are quite similar to Table 4 and Table 5.



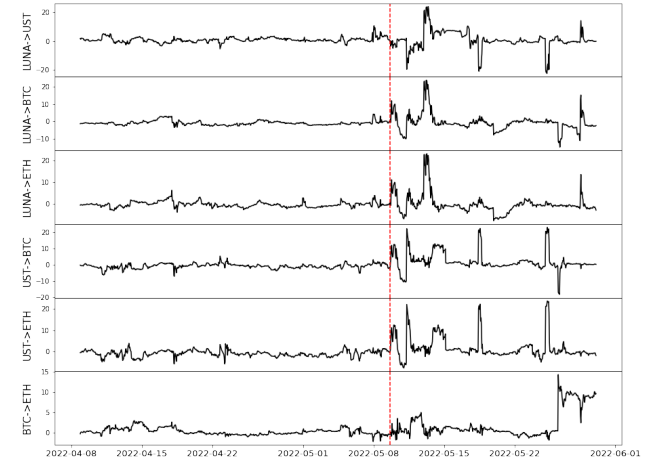
(a) Net spillover from hourly returns



(b) Pairwise spillover between assets from hourly returns



(c) Net spillover from realized volatility of asset returns



(d) Pairwise spillover between assets from realized volatility of asset returns

Figure 2: Spillover index calculated with hourly return and realized volatility. The red line denotes the time (2022-05-09 15:00(UTC)) when UST started to depeg from its target value

Table 4: Effective Transfer Entropy: Return

Panel A: Full Period							
	LUNA	UST	BTC	ETH	Google Trends	Number of Tweets	Sentiment Score
LUNA		0.0197***	0.0218***	0.0314***	0.005	0.0217***	0.0004
UST	0.0023		0.0059**	0.0088***	0.0004	0.006	0.0017
BTC	0.0122***	0.0002		0.0063**	0.0000	0.0055	0.0005
ETH	0.0199***	0.0048**	0.0000		0.0000	0.0086***	0.0023
Google Trends	0.0172***	0.0137***	0.0105***	0.0127***		0.0365***	0.0000
Number of Tweets	0.0191***	0.0158***	0.0025**	0.0057***	0.0266***		0.0000
Sentiment Score	0.0000	0.0004	0.0051***	0.0023	0.0000	0.0021	
Panel B: Pre-Terra-LUNA Crash period							
	LUNA	UST	BTC	ETH	Google Trends	Number of Tweets	Sentiment Score
LUNA		0.0043	0.0000	0.0102**	0.0000	0.0014	0.0031
UST	0.0029		0.0000	0.0005	0.0002	0.0002	0.0071**
BTC	0.0000	0.0000		0.0006	0.0010	0.0018	0.0009
ETH	0.0009	0.0019	0.0000		0.0000	0.0005	0.0030
Google Trends	0.0000	0.0016	0.0018	0.0000		0.0217***	0.0000
Number of Tweets	0.0039	0.0000	0.0002	0.0000	0.0048		0.0000
Sentiment Score	0.0103***	0.0091***	0.0000	0.0071***	0.0031	0.0058**	
Panel C: Terra-LUNA Crash period							
	LUNA	UST	BTC	ETH	Google Trends	Number of Tweets	Sentiment Score
LUNA		0.0189**	0.0374***	0.0353***	0.0045	0.0083	0.0000
UST	0.0001		0.0173***	0.0045	0.0000	0.0000	0.0000
BTC	0.0191***	0.0038		0.0000	0.0096	0.0028	0.0135
ETH	0.0160**	0.0007	0.0058		0.0099	0.0052	0.0068
Google Trends	0.0132***	0.0053	0.0158***	0.0142***		0.0283***	0.0042
Number of Tweets	0.0276***	0.0000	0.0017	0.0026	0.0056		0.0000
Sentiment Score	0.0000	0.0040	0.0308***	0.0106***	0.0003	0.0000	

Note. Table 4 reports effective transfer entropy values calculated with hourly asset returns. Panels A, B, and C report the values for the full period(April 02, 2022 to May 30, 2022), the pre-Terra-LUNA Crash period(April 02, 2022 to May 08, 2022), and the Terra-LUNA Crash period(May 09, 2022 to May 30, 2022). For each panel, items in the first column are sequences that transmit information and the items in the first row are sequences that receive information. Asterisks flag levels of statistical significance of result statistic using t-test. The significance levels are flagged as follows: *** : p-value < 0.01, ** : p-value < 0.05

Table 5: Effective Transfer Entropy: Volatility

Panel A: Full Period							
	LUNA	UST	BTC	ETH	Google Trends	Number of Tweets	Sentiment Score
LUNA		0.0136***	0.0289***	0.0250***	0.0035**	0.0161***	0.0000
UST	0.0031		0.0010	0.0026	0.0023	0.0058**	0.0010
BTC	0.0239***	0.0007		0.0002	0.0040**	0.0075***	0.0000
ETH	0.0293***	0.0010	0.0171***		0.0059**	0.0054**	0.0004
Google Trends	0.0114***	0.0056***	0.0080***	0.0133***		0.0365***	0.0000
Number of Tweets	0.0122***	0.0021	0.0063**	0.0105***	0.0266***		0.0000
Sentiment Score	0.0029	0.0000	0.0015	0.0013	0.0000	0.0021	
Panel B: Pre-Terra-LUNA Crash period							
	LUNA	UST	BTC	ETH	Google Trends	Number of Tweets	Sentiment Score
LUNA		0.0000	0.0055	0.0140***	0.0000	0.0033	0.0081***
UST	0.0000		0.0010	0.0012	0.0000	0.0018	0.0005
BTC	0.0158***	0.0000		0.0021	0.0047	0.0047	0.0000
ETH	0.0129***	0.0000	0.0037		0.0006	0.0035	0.0000
Google Trends	0.0013	0.0011	0.0000	0.0003		0.0217***	0.0000
Number of Tweets	0.0053	0.0000	0.0000	0.0052	0.0048		0.0000
Sentiment Score	0.0002	0.0000	0.0003	0.0008	0.0031	0.0058**	
Panel C: Terra-LUNA Crash period							
	LUNA	UST	BTC	ETH	Google Trends	Number of Tweets	Sentiment Score
LUNA		0.0185***	0.0000	0.0000	0.0050	0.0065	0.0000
UST	0.0074		0.0000	0.0003	0.0000	0.0000	0.0006
BTC	0.0038	0.0000		0.0000	0.0085***	0.0196***	0.0000
ETH	0.0000	0.0045	0.0059		0.0059	0.0077	0.0000
Google Trends	0.0000	0.0000	0.0000	0.0024		0.0283***	0.0042
Number of Tweets	0.0023	0.0000	0.0116**	0.0000	0.0056		0.0000
Sentiment Score	0.0000	0.0014	0.0013	0.0000	0.0003	0.0000	

Note. Table 5 reports effective transfer entropy values calculated with hourly realized volatility of each asset. Panels A, B, and C report the values for the full period(April 02, 2022 to May 30, 2022), the pre-Terra-LUNA Crash period(April 02, 2022 to May 08, 2022), and the Terra-LUNA Crash period(May 09, 2022 to May 30, 2022). For each panel, items in the first column are sequences that transmit information and the items in the first row are sequences that receive information. Asterisks flag levels of statistical significance of result statistic using t-test. The significance levels are flagged as follows: *** : p-value < 0.01, ** : p-value < 0.05

4. Conclusion

In this paper, we analyzed the impact of the Terra-LUNA crash on the cryptocurrency market from April 2022 to May 2022 by investigating the spillover effect and ETE. We confirm that the internal spillover effect for the returns and volatility of both LUNA and UST increased during the crash, which means that the crash was due to the systematic risk of the project and not the market situation. LUNA and UST also show an increase in net spillovers during this period, which implies that their crash brought a significant change to the market.

We also show that market sentiment loses its role as a transmitter and recipient of information flow to LUNA’s returns and volatility, respectively, during the crash. We conclude that this is due to the growing discrepancy in investors’ opinions about the future of the Terra-LUNA project. Investor attention, however, rapidly increases during the price crash and transmitted information flow to LUNA returns. Moreover, while the information flow between asset returns emerged during the price crash, LUNA’s volatility loses its connectedness to the volatility of BTC and ETH after the price crash.

In future research, our investigation could be enriched by including traditional assets, such as equities and bonds, into the universe to measure the impact that the Terra-LUNA crash brought to the returns and volatility of traditional asset classes.

5. Acknowledgements

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Appendix A.

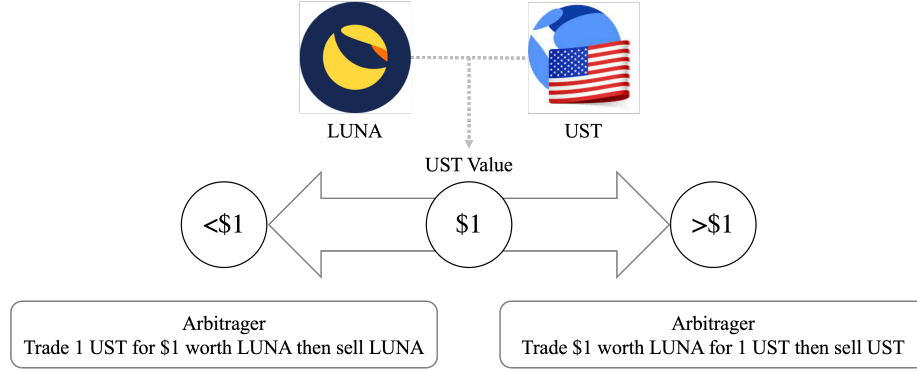


Figure A.1: Figure A.1 represents the pegging mechanism of UST. When UST is traded above peg, arbitragers can trade \$1 worth of LUNA for 1 UST then sell the UST on the open market. When UST is traded below peg, arbitragers can trade 1 UST to \$1 worth of LUNA and sell LUNA on the open market.

Table A.1: Market capitalization of the 10 cryptocurrencies

Name	Symbol	Market Capitalization
Bitcoin	BTC	\$884,585,801,886
Ethereum	ETH	\$412,362,544,752
BNB	BNB	\$72,623,207,488
Solana	SOL	\$43,111,128,032
Ripple	XRP	\$39,815,777,701
Cardano	ADA	\$39,180,026,439
Terra	LUNA	\$37,747,677,146
Polkadot	DOT	\$21,529,251,333
Dogecoin	DOGE	\$18,463,699,718
Polygon	MATIC	\$13,083,649,216

Note. Table A.1 reports the top 10 cryptocurrencies by market capitalization as of April 02, 2022. These cryptocurrencies were used for our experimental results in the Appendix. The price data was collected from coinmarketcap.com.

Table A.2: Directional Return Spillover

Panel A: Full Period												
	LUNA	UST	BTC	ETH	DOGE	ADA	BNB	XRP	DOT	SOL	MATIC	from others
LUNA	68.3253	3.1127	7.7938	7.2544	1.2387	1.5801	3.3732	2.8160	1.7345	1.5989	1.1724	31.6747
UST	2.0595	93.5181	1.1494	0.8509	0.3481	0.1057	0.2850	0.3334	0.1963	0.7955	0.3581	6.4819
BTC	4.9639	0.8236	47.6385	42.0862	0.5382	0.4868	0.6574	0.8106	1.1270	0.4964	0.3715	52.3615
ETH	4.8023	0.9640	41.9496	47.5529	0.7796	0.3492	0.5855	0.8971	1.0021	0.5528	0.5649	52.4471
DOGE	5.4258	0.6849	24.1461	26.1619	26.4595	2.3859	3.0039	3.5556	3.3330	2.2532	2.5902	73.5405
ADA	5.4229	1.0521	30.2692	32.1784	1.5620	11.8881	3.2726	3.4097	3.6045	3.3282	4.0122	88.1119
BNB	5.6303	0.7419	31.1165	33.3612	1.5002	3.0854	12.2119	2.5477	3.8783	2.7445	3.1821	87.7881
XRP	7.0961	0.7433	27.0015	28.9767	2.5632	3.6696	3.0223	14.7957	4.5863	3.5642	3.9811	85.2043
DOT	5.5827	0.7891	28.0519	30.2676	1.4252	3.5494	3.2423	3.9640	14.2714	4.3654	4.4911	85.7286
SOL	5.2948	0.8796	28.3938	30.2382	1.3917	3.2853	3.3779	3.3669	4.9500	13.6663	5.1555	86.3337
MATIC	5.6799	0.7928	28.6190	30.7704	1.4498	4.1416	3.4875	3.5921	4.6078	4.8282	12.0307	87.9693
to others	51.9581	10.5840	248.4908	262.1460	12.7969	22.6390	24.3076	25.2932	29.0199	24.5273	25.8790	67.0583
Panel B: Pre-Terra-LUNA Crash period												
	LUNA	UST	BTC	ETH	DOGE	ADA	BNB	XRP	DOT	SOL	MATIC	from others
LUNA	51.0975	2.1814	21.4255	22.0659	0.0999	0.3076	0.8318	0.2697	0.6029	0.7272	0.3907	48.9025
UST	2.6017	84.9141	2.0573	2.6915	1.5141	1.2652	0.7325	1.7087	1.0159	1.1348	0.3642	15.0859
BTC	17.6788	1.0117	41.7566	35.3806	0.4191	0.5055	0.7580	0.7086	1.0265	0.4196	0.3349	58.2434
ETH	18.4460	1.0846	35.4304	41.5192	0.5742	0.3512	0.4062	0.5595	0.8980	0.4093	0.3214	58.4808
DOGE	9.7045	0.8728	17.4697	18.4711	37.4669	3.4284	2.8113	3.7806	2.0822	2.1616	1.7508	62.5331
ADA	15.2283	0.8517	23.0977	24.1358	1.5813	14.3326	4.5391	4.0012	4.9343	4.0458	3.2522	85.6674
BNB	15.5256	1.1584	24.6173	26.0564	1.1883	3.9203	13.9259	2.9071	4.0192	3.7121	2.9695	86.0741
XRP	13.0128	0.4709	21.4613	22.3442	1.8205	5.1517	4.1930	20.1325	4.6581	3.4788	3.2761	79.8675
DOT	15.7433	1.0369	23.6671	25.0143	0.8849	4.0896	4.2615	3.3943	14.0504	4.7566	3.1011	85.9496
SOL	16.4670	0.8554	22.7990	23.4126	1.0158	4.1020	3.8897	2.4217	5.1452	15.5066	4.3850	84.4934
MATIC	14.4255	0.9660	22.0177	22.7657	1.0614	4.1123	3.9607	3.1194	4.4469	5.6073	17.5171	82.4829
to others	138.8335	10.4899	214.0429	222.3381	10.1596	27.2338	26.3840	22.8708	28.8292	26.4531	20.1458	67.9800
Panel C: Terra-LUNA Crash period												
	LUNA	UST	BTC	ETH	DOGE	ADA	BNB	XRP	DOT	SOL	MATIC	from others
LUNA	56.6986	3.1410	7.4190	7.5241	5.2476	3.0122	4.7971	5.5252	2.1260	2.9832	1.5261	43.3014
UST	4.1143	77.0469	2.7972	1.9184	1.5518	1.2519	1.4553	2.7703	1.9457	2.7529	2.3953	22.9531
BTC	7.6126	1.1939	41.6455	38.3821	1.1328	1.6236	2.0225	1.7407	1.6734	1.6028	1.3702	58.3545
ETH	7.9356	1.3409	37.8404	42.6655	1.0883	1.3893	2.0115	1.7388	1.4999	1.4187	1.0711	57.3345
DOGE	8.7930	0.9169	24.3044	28.4545	12.2144	2.7518	4.8714	4.7970	4.6675	4.2182	4.0109	87.7856
ADA	7.8015	1.3124	30.3187	33.3969	2.9739	9.6398	2.9093	2.8159	3.0020	2.8047	3.0246	90.3602
BNB	7.5604	1.3329	28.8237	32.4303	2.4150	3.5158	11.7215	2.3255	4.4177	2.1830	3.2742	88.2785
XRP	9.5577	0.9053	27.2670	32.0675	4.2263	2.9496	2.9593	9.7907	3.8238	3.2509	3.2019	90.2093
DOT	7.3027	1.0441	27.2082	30.9489	4.0175	2.7458	3.6541	3.6160	11.5524	3.7006	4.2098	88.4476
SOL	7.2904	1.0642	28.0355	31.4740	3.7041	2.6391	3.9048	3.3567	4.2821	10.0252	4.2238	89.9748
MATIC	7.3813	1.0860	28.7041	31.8455	3.2193	4.3227	3.8994	3.0821	4.5686	4.1526	7.7384	92.2616
to others	75.3493	13.3375	242.7182	268.4422	29.5767	26.2018	32.4848	31.7683	32.0066	29.0677	28.3078	73.5692

Note. Table reports spillover matrix for hourly returns of LUNA, UST, BTC, ETH, DOGE, ADA, BNB, XRP, DOT, SOL, and MATIC. Panels A, B, and C report the values for the full period(April 02, 2022 to May 30, 2022), the pre-Terra-LUNA Crash period(April 02, 2022 to May 08, 2022), and the Terra-LUNA Crash period(May 09, 2022 to May 30, 2022). The last column shows the total impact that the asset in each row received from the other assets and the last row shows the total impact sent to the other assets by the corresponding assets in each column.

Table A.3: Directional Volatility Spillover

Panel A: Full Period												
	LUNA	UST	BTC	ETH	DOGE	ADA	BNB	XRP	DOT	SOL	MATIC	from others
LUNA	82.7404	3.9802	1.0477	1.2787	1.0472	0.9401	2.9024	1.1032	1.2435	1.4112	2.3055	17.2596
UST	0.2966	81.5437	1.3848	0.8644	0.2938	2.1697	1.8636	2.6889	2.7934	3.3126	2.7886	18.4563
BTC	0.4639	0.0689	30.4551	30.9047	2.2466	4.3237	5.5474	6.2414	5.6058	7.4993	6.6432	69.5449
ETH	0.5956	0.1293	26.7704	36.5596	1.9419	3.5918	4.9494	5.9514	5.3147	7.6191	6.5768	63.4404
DOGE	0.8451	0.1644	10.2734	16.0323	36.0727	4.5167	5.8314	6.3012	6.0145	7.2255	6.7229	63.9273
ADA	0.5589	0.3624	15.6200	22.3346	2.2313	12.1390	8.7345	8.1535	8.9903	10.6337	10.2418	87.8610
BNB	0.7154	0.2948	14.2045	21.5513	2.5042	9.4758	15.7605	7.5983	8.4692	9.6704	9.7558	84.2395
XRP	0.5821	0.2140	14.6001	21.9262	2.8219	6.0957	6.9922	12.9428	10.5994	12.1676	11.0581	87.0572
DOT	0.6913	0.2489	15.3971	23.6958	2.5201	5.0765	5.5943	10.8537	12.2199	12.2844	11.4179	87.7801
SOL	0.4387	0.4347	13.8234	21.4617	2.5341	6.9316	7.9709	10.2305	10.6251	14.0284	11.5211	85.9716
MATIC	0.6220	0.3001	15.0991	22.8972	2.4582	6.3189	7.0887	9.6706	10.2860	11.8036	13.4557	86.5443
C. to others (spillover)	5.8097	6.1976	128.2203	182.9469	20.5992	49.4403	57.4748	68.7925	69.9421	83.6273	79.0316	68.3711
Panel B: Pre-Terra-LUNA Crash period												
	LUNA	UST	BTC	ETH	DOGE	ADA	BNB	XRP	DOT	SOL	MATIC	from others
LUNA	55.7043	1.2191	10.0569	13.0199	0.6486	2.1370	7.1917	1.0240	1.5678	3.1136	4.3173	44.2957
UST	7.0385	79.4591	1.4858	0.6345	2.2710	2.4257	1.0099	1.6180	1.1231	1.6284	1.3060	20.5409
BTC	9.6215	0.7945	37.9405	28.4617	1.5381	3.9145	7.1486	1.6298	3.5399	2.0819	3.3290	62.0595
ETH	12.1988	1.3360	29.0507	37.5687	1.4144	3.4850	5.7299	1.2084	2.3324	2.5797	3.0959	62.4313
DOGE	1.4861	1.3393	1.4983	1.1295	62.4829	6.9851	5.8983	11.6312	2.6134	2.0632	2.8727	37.5171
ADA	1.1514	0.7334	3.8298	3.8618	0.9016	25.7854	16.0060	11.1924	14.0054	11.1803	11.3526	74.2146
BNB	2.4260	0.7507	3.4976	3.6677	1.3334	16.1254	28.9771	9.2390	13.3428	9.7416	10.8988	71.0229
XRP	1.5240	0.5479	2.8079	3.5478	1.7764	14.5472	12.6596	33.0526	11.8162	8.4253	9.2950	66.9474
DOT	2.1807	0.1690	5.1438	4.8491	0.8262	14.5315	13.8633	9.7777	27.6205	11.2055	9.8326	72.3795
SOL	3.7205	0.4772	4.1125	5.4066	1.0985	13.6832	11.9240	8.1827	12.2357	29.0696	10.0895	70.9304
MATIC	2.3765	0.7710	4.3777	4.4815	0.6775	13.1567	13.2682	8.3066	11.3570	10.3040	30.9234	69.0766
C. to others (spillover)	43.7239	8.1381	65.8610	69.0601	12.4857	90.9911	94.6994	63.8098	73.9338	62.3236	66.3894	59.2196
Panel C: Terra-LUNA Crash period												
	LUNA	UST	BTC	ETH	DOGE	ADA	BNB	XRP	DOT	SOL	MATIC	from others
LUNA	62.2341	7.6061	1.5458	1.7762	5.8919	2.2838	2.5314	4.5166	4.0307	3.9477	3.6357	37.7659
UST	0.7134	55.8580	2.3156	2.1037	3.2200	4.7541	5.4153	5.5849	6.9342	7.1838	5.9171	44.1420
BTC	0.8781	0.8759	28.6515	28.1251	7.7689	3.2353	4.1494	7.0751	4.7460	7.9015	6.5930	71.3485
ETH	1.1497	1.0302	27.4569	33.2478	7.4368	2.4130	3.6191	6.3205	4.2389	7.0112	6.0759	66.7522
DOGE	1.6309	1.1514	18.2425	23.7062	14.3353	4.7863	6.6414	7.5019	6.4903	7.6847	7.8289	85.6647
ADA	0.9201	1.4260	22.2232	26.7157	7.3147	7.8998	5.4091	6.6907	6.3666	7.4091	7.6250	92.1002
BNB	1.0584	1.1844	20.7898	26.6211	7.7424	5.5888	11.0793	6.0130	5.9391	6.4600	7.5237	88.9207
XRP	1.2906	1.0526	18.7881	21.9565	8.9288	5.0469	6.8715	9.8044	7.5814	9.6815	8.9978	90.1956
DOT	1.2008	1.1073	20.3895	25.9042	8.3069	3.7133	4.7969	8.7190	8.6080	8.6670	8.5873	91.3920
SOL	1.4562	1.2749	18.4928	22.9930	7.5717	6.2382	7.9027	8.1993	7.4669	9.7378	8.6664	90.2622
MATIC	1.2861	1.3741	21.2947	27.2753	7.7103	4.5916	5.6213	7.3625	6.7435	7.9204	8.8202	91.1798
C. to others (spillover)	11.5843	18.0829	171.5390	207.1769	71.8925	42.6513	52.9582	67.9835	60.5377	73.8668	71.4508	77.2476

Note. Table reports spillover matrix for hourly realized volatility of LUNA, UST, BTC, ETH, DOGE, ADA, BNB, XRP, DOT, SOL, and MATIC. Panels A, B, and C report the values for the full period(April 02, 2022 to May 30, 2022), the pre-Terra-LUNA Crash period(April 02, 2022 to May 08, 2022), and the Terra-LUNA Crash period(May 09, 2022 to May 30, 2022). For each panel, items in the first column are risk transmitters and the items in the first row are risk receivers. The last column shows the total impact that the asset in each row received from the other assets and the last row shows the total impact sent to the other assets by the corresponding assets in each column.

Table A.4: Effective Transfer Entropy: Return

Panel A: Full Period														
	LUNA	UST	BTC	ETH	DOGE	ADA	BNB	XRP	DOT	SOL	MATIC	Google Trends	Number of Tweets	Sentiment Score
LUNA		0.0197***	0.0218***	0.0314***	0.0226***	0.0416***	0.0385***	0.0350***	0.0399***	0.0410***	0.0476***	0.0050	0.0222***	0.0004
UST	0.0023		0.0059***	0.0091***	0.0172***	0.0189***	0.0158***	0.0210***	0.0210***	0.0154***	0.0196***	0.0003	0.0060	0.0013
BTC	0.0122***	0.0003		0.0061***	0.1205***	0.1793***	0.1867***	0.1589***	0.1494***	0.1524***	0.1780***	0.0000	0.0053	0.0005
ETH	0.0199***	0.0050***	0.0000		0.1262***	0.2213***	0.2199***	0.1748***	0.1868***	0.1859***	0.2138***	0.0000	0.0088***	0.0023
DOGE	0.0038	0.0055***	0.0163***	0.0137***		0.0039***	0.0034	0.0000	0.0001	0.0042	0.0000	0.0059	0.0017	0.0000
ADA	0.0146***	0.0106***	0.0066***	0.0113***	0.0000		0.0048***	0.0000	0.0000	0.0074***	0.0011	0.0020	0.0025	0.0012
BNB	0.0203***	0.0105***	0.0149***	0.0189***	0.0000	0.0015		0.0000	0.0017	0.0000	0.0041	0.0038	0.0075***	0.0006
XRP	0.0172***	0.0069***	0.0099***	0.0064***	0.0000	0.0020	0.0021		0.0039	0.0080***	0.0021	0.0053	0.0039	0.0000
DOT	0.0189***	0.0063***	0.0158***	0.0104***	0.0013	0.0030	0.0077***	0.0044***		0.0112***	0.0003	0.0067***	0.0121***	0.0001
SOL	0.0095***	0.0065***	0.0206***	0.0185***	0.0019	0.0111***	0.0094***	0.0046***	0.0057***		0.0054***	0.0000	0.0049	0.0000
MATIC	0.0156***	0.0084***	0.0188***	0.0185***	0.0000	0.0007	0.0074***	0.0024	0.0000	0.0003		0.0014	0.0053	0.0000
Google Trends	0.0176***	0.0135***	0.0108***	0.0132***	0.0086***	0.0277***	0.0262***	0.0216***	0.0240***	0.0188***	0.0136***		0.0365***	0.0000
Number of Tweets	0.0190***	0.0162***	0.0028***	0.0059***	0.0032***	0.0149***	0.0194***	0.0076***	0.0197***	0.0148***	0.0139***	0.0268***		0.0000
Sentiment Score	0.0000	0.0010	0.0049***	0.0024	0.0063***	0.0000	0.0016	0.0009	0.0009	0.0043***	0.0022***	0.0000	0.0018	
Panel B: Pre-Terra-LUNA Crash Period														
	LUNA	UST	BTC	ETH	DOGE	ADA	BNB	XRP	DOT	SOL	MATIC	Google Trends	Number of Tweets	Sentiment Score
LUNA		0.0042	0.0000	0.0096***	0.0750***	0.1004***	0.0920***	0.0680***	0.0866***	0.1006***	0.1016***	0.0000	0.0013	0.0032
UST	0.0026		0.0000	0.0003	0.0000	0.0011	0.0047	0.0000	0.0006	0.0058	0.0045	0.0002	0.0003	0.0071***
BTC	0.0000	0.0000		0.0006	0.0516***	0.1391***	0.1405***	0.1260***	0.1542***	0.1309***	0.1116***	0.0011	0.0022	0.0006
ETH	0.0010	0.0015	0.0000		0.0966***	0.1592***	0.1688***	0.1506***	0.1940***	0.1255***	0.1507***	0.0000	0.0000	0.0032
DOGE	0.0057	0.0000	0.0000	0.0000		0.0000	0.0000	0.0000	0.0000	0.0000	0.0018	0.0000	0.0000	0.0030
ADA	0.0007	0.0000	0.0000	0.0021	0.0000		0.0000	0.0000	0.0000	0.0003	0.0000	0.0009	0.0000	0.0000
BNB	0.0023	0.0000	0.0000	0.0000	0.0000	0.0000		0.0000	0.0000	0.0000	0.0024	0.0012	0.0051	0.0020
XRP	0.0071***	0.0000	0.0000	0.0000	0.0008	0.0000	0.0054		0.0056	0.0000	0.0048	0.0022	0.0055	0.0000
DOT	0.0037	0.0000	0.0000	0.0000	0.0047	0.0118***	0.0020	0.0082***		0.0011	0.0038	0.0054	0.0003	0.0047
SOL	0.0056***	0.0032	0.0000	0.0006	0.0090***	0.0079***	0.0015	0.0090***	0.0072***		0.0035	0.0000	0.0000	0.0000
MATIC	0.0081***	0.0007	0.0007	0.0057	0.0030	0.0000	0.0000	0.0022	0.0000	0.0000		0.0022	0.0000	0.0000
Google Trends	0.0000	0.0019	0.0019	0.0000	0.0000	0.0017	0.0000	0.0000	0.0004	0.0042***	0.0000		0.0215***	0.0000
Number of Tweets	0.0035	0.0000	0.0000	0.0000	0.0004	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0049		0.0000
Sentiment Score	0.0101***	0.0095***	0.0000	0.0073***	0.0008	0.0004	0.0015	0.0015	0.0010	0.0026	0.0005	0.0032***	0.0056***	
Panel C: Terra-LUNA Crash Period														
	LUNA	UST	BTC	ETH	DOGE	ADA	BNB	XRP	DOT	SOL	MATIC	Google Trends	Number of Tweets	Sentiment Score
LUNA		0.0189***	0.0371***	0.0353***	0.0532***	0.0457***	0.0499***	0.0515***	0.0586***	0.0228***	0.0299***	0.0048	0.0081	0.0000
UST	0.0000		0.0169***	0.0071	0.0017	0.0063***	0.0087***	0.0023	0.0136***	0.0084***	0.0070	0.0000	0.0000	0.0003
BTC	0.0191***	0.0022		0.0000	0.1593***	0.1689***	0.1392***	0.1413***	0.1618***	0.1793***	0.1754***	0.0094	0.0024	0.0134***
ETH	0.0164***	0.0012	0.0056		0.1987***	0.2249***	0.2122***	0.1493***	0.1724***	0.1891***	0.2144***	0.0101	0.0055	0.0058
DOGE	0.0299***	0.0030	0.0400***	0.0248***		0.0224***	0.0111***	0.0274***	0.0237***	0.0306***	0.0198***	0.0026	0.0108	0.0097
ADA	0.0236***	0.0048	0.0242***	0.0354***	0.0000		0.0011	0.0033	0.0014	0.0000	0.0022	0.0172***	0.0099	0.0056
BNB	0.0330***	0.0054	0.0154***	0.0285***	0.0108***	0.0081		0.0005	0.0036	0.0000	0.0000	0.0050	0.0178***	0.0092
XRP	0.0263***	0.0047	0.0156***	0.0361***	0.0072	0.0063	0.0072		0.0120***	0.0041	0.0044	0.0031	0.0195***	0.0065
DOT	0.0252***	0.0111	0.0158***	0.0301***	0.0018	0.0000	0.0000	0.0007		0.0000	0.0000	0.0162***	0.0083	0.0059
SOL	0.0039	0.0093	0.0261***	0.0258***	0.0183***	0.0188***	0.0093***	0.0194***	0.0195***		0.0204***	0.0053	0.0102	0.0068
MATIC	0.0274***	0.0115***	0.0110***	0.0080***	0.0063	0.0001	0.0000	0.0000	0.0059	0.0000		0.0118	0.0102	0.0075
Google Trends	0.0121***	0.0051	0.0152***	0.0136***	0.0033***	0.0239***	0.0050	0.0156***	0.0207***	0.0092***	0.0177***		0.0285***	0.0036
Number of Tweets	0.0275***	0.0000	0.0007	0.0016	0.0077***	0.0000	0.0013	0.0007	0.0096***	0.0086***	0.0076***	0.0048		0.0000
Sentiment Score	0.0000	0.0042	0.0293***	0.0123***	0.0105***	0.0000	0.0000	0.0000	0.0000	0.0000	0.0005	0.0007	0.0000	

Note. Table A.4 reports effective transfer entropy values calculated with hourly asset returns. Panels A, B, and C report the values for the full period (April 02, 2022 to May 30, 2022), the pre-Terra-LUNA Crash period (April 02, 2022 to May 08, 2022), and the Terra-LUNA Crash period (May 09, 2022 to May 30, 2022). For each panel, items in the first column are sequences that transmit information and the items in the first row are sequences that receive information. Asterisks flag levels of statistical significance of result statistic using t-test. The significance levels are flagged as follows: *** : p-value < 0.01, ** : p-value < 0.05

Table A.5: Effective Transfer Entropy: Volatility

Panel A: Full Period															
	LUNA	UST	BTC	ETH	DOGE	ADA	BNB	XRP	DOT	SOL	MATIC	Google Trends	Number of Tweets	Sentiment Score	
LUNA		0.0134***	0.0292***	0.0248***	0.0108***	0.0222***	0.0198***	0.0203***	0.0296***	0.0201***	0.0342***	0.0032	0.0157***	0.0000	
UST	0.0038***		0.0005	0.0025	0.0015	0.0048***	0.0030	0.0095***	0.0074***	0.0102***	0.0024	0.0027	0.0058***	0.0011	
BTC	0.0241***	0.0004		0.0003	0.0256***	0.0476***	0.0459***	0.0277***	0.0271***	0.0316***	0.0350***	0.0043***	0.0078***	0.0000	
ETH	0.0286***	0.0013	0.0168***		0.0268***	0.0449***	0.0391***	0.0307***	0.0376***	0.0292***	0.0311***	0.0063***	0.0054***	0.0004	
DOGE	0.0085***	0.0000	0.0139***	0.0146***		0.0065***	0.0027	0.0022	0.0055***	0.0050***	0.0049***	0.0015	0.0000	0.0000	
ADA	0.0084***	0.0036	0.0109***	0.0084***	0.0019		0.0050***	0.0000	0.0014	0.0083***	0.0049***	0.0000	0.0052***	0.0000	
BNB	0.0065***	0.0000	0.0158***	0.0073***	0.0011	0.0038		0.0000	0.0040	0.0120***	0.0089***	0.0084***	0.0051	0.0000	
XRP	0.0107***	0.0044***	0.0090***	0.0111***	0.0029	0.0070***	0.0013		0.0106***	0.0109***	0.0056***	0.0028	0.0051	0.0000	
DOT	0.0087***	0.0003	0.0153***	0.0078***	0.0031	0.0000	0.0060***	0.0064***		0.0070***	0.0097***	0.0009	0.0052***	0.0000	
SOL	0.0103***	0.0000	0.0080***	0.0114***	0.0075***	0.0058***	0.0067***	0.0046***	0.0069***		0.0034	0.0000	0.0027	0.0000	
MATIC	0.0081***	0.0000	0.0095***	0.0116***	0.0000	0.0007	0.0030	0.0000	0.0011	0.0046***		0.0000	0.0049	0.0015	
Google Trends	0.0111***	0.0052***	0.0078***	0.0136***	0.0043***	0.0216***	0.0154***	0.0201***	0.0248***	0.0184***	0.0197***		0.0365***	0.0000	
Number of Tweets	0.0120***	0.0024	0.0062***	0.0103***	0.0027	0.0167***	0.0107***	0.0058***	0.0167***	0.0200***	0.0195***	0.0268***		0.0000	
Sentiment Score	0.0026***	0.0000	0.0016	0.0014	0.0049***	0.0024	0.0014	0.0065***	0.0002	0.0000	0.0007	0.0000	0.0018		
Panel B: Pre-Terra-LUNA Crash Period															
	LUNA	UST	BTC	ETH	DOGE	ADA	BNB	XRP	DOT	SOL	MATIC	Google Trends	Number of Tweets	Sentiment Score	
LUNA		0.0000	0.0054***	0.0147***	0.0002	0.0132***	0.0063***	0.0059***	0.0040	0.0047	0.0049	0.0000	0.0039	0.0080***	
UST	0.0000		0.0001	0.0012	0.0000	0.0034	0.0000	0.0087***	0.0021	0.0070***	0.0000	0.0000	0.0024	0.0004	
BTC	0.0154***	0.0000		0.0021	0.0007	0.0131***	0.0229***	0.0032	0.0132***	0.0019	0.0086***	0.0045***	0.0042	0.0000	
ETH	0.0134***	0.0002	0.0041		0.0012	0.0157***	0.0196***	0.0062	0.0141***	0.0046	0.0117***	0.0004	0.0037	0.0000	
DOGE	0.0000	0.0000	0.0056	0.0008		0.0000	0.0000	0.0000	0.0013	0.0061	0.0000	0.0000	0.0000	0.0000	
ADA	0.0000	0.0000	0.0013	0.0000	0.0016		0.0000	0.0000	0.0000	0.0000	0.0004	0.0000	0.0061	0.0000	
BNB	0.0017	0.0005	0.0000	0.0027	0.0008	0.0000		0.0000	0.0007	0.0000	0.0000	0.0000	0.0000	0.0000	
XRP	0.0000	0.0000	0.0048	0.0000	0.0000	0.0000	0.0000		0.0000	0.0000	0.0002	0.0000	0.0039	0.0004	
DOT	0.0033	0.0001	0.0048	0.0020	0.0091***	0.0057	0.0026	0.0000		0.0033	0.0032	0.0001	0.0031	0.0002	
SOL	0.0000	0.0000	0.0013	0.0031	0.0030	0.0024	0.0000	0.0016	0.0010		0.0042	0.0000	0.0005	0.0001	
MATIC	0.0000	0.0000	0.0050***	0.0032	0.0000	0.0037	0.0000	0.0000	0.0044***	0.0000		0.0041	0.0038	0.0025	
Google Trends	0.0020	0.0019	0.0000	0.0002	0.0000	0.0070***	0.0000	0.0000	0.0050***	0.0000	0.0000		0.0215***	0.0000	
Number of Tweets	0.0050	0.0000	0.0000	0.0059	0.0000	0.0059	0.0000	0.0000	0.0000	0.0000	0.0000	0.0049		0.0000	
Sentiment Score	0.0003	0.0000	0.0000	0.0010	0.0023	0.0000	0.0000	0.0037	0.0000	0.0000	0.0007	0.0032***	0.0056***		
Panel C: Terra-LUNA Crash Period															
	LUNA	UST	BTC	ETH	DOGE	ADA	BNB	XRP	DOT	SOL	MATIC	Google Trends	Number of Tweets	Sentiment Score	
LUNA		0.0174***	0.0000	0.0000	0.0054	0.0000	0.0028	0.0000	0.0000	0.0021	0.0000	0.0041	0.0051***	0.0000	
UST	0.0078		0.0000	0.0002	0.0000	0.0051	0.0000	0.0024	0.0000	0.0000	0.0012	0.0000	0.0000	0.0015	
BTC	0.0027	0.0000		0.0000	0.0165***	0.0260***	0.0089	0.0400***	0.0252***	0.0064	0.0199***	0.0083***	0.0200***	0.0000	
ETH	0.0000	0.0041	0.0067***		0.0320***	0.0440***	0.0238***	0.0202***	0.0323***	0.0144***	0.0339***	0.0060	0.0074	0.0000	
DOGE	0.0016	0.0000	0.0219***	0.0044		0.0140***	0.0093***	0.0176***	0.0048	0.0183***	0.0084	0.0070	0.0000	0.0000	
ADA	0.0000	0.0000	0.0112***	0.0008	0.0000		0.0000	0.0000	0.0000	0.0055	0.0000	0.0079***	0.0012	0.0146***	
BNB	0.0000	0.0000	0.0359***	0.0024	0.0082	0.0290***		0.0021	0.0049	0.0205***	0.0233***	0.0068***	0.0056	0.0031	
XRP	0.0000	0.0000	0.0183***	0.0154***	0.0019	0.0124***	0.0000		0.0056	0.0129***	0.0152***	0.0000	0.0012	0.0000	
DOT	0.0079	0.0019	0.0194***	0.0029	0.0000	0.0078	0.0030	0.0000		0.0045	0.0007	0.0098***	0.0019	0.0007	
SOL	0.0000	0.0033	0.0061	0.0000	0.0000	0.0183***	0.0000	0.0023	0.0009		0.0040	0.0096***	0.0000	0.0000	
MATIC	0.0029	0.0000	0.0100***	0.0120***	0.0015	0.0049	0.0039	0.0069	0.0000	0.0173***		0.0069	0.0052	0.0039	
Google Trends	0.0000	0.0000	0.0000	0.0019	0.0059	0.0162***	0.0088***	0.0000	0.0000	0.0002	0.0000		0.0285***	0.0036	
Number of Tweets	0.0027	0.0000	0.0116***	0.0000	0.0112***	0.0138***	0.0157***	0.0103***	0.0093***	0.0072***	0.0044	0.0048		0.0000	
Sentiment Score	0.0005	0.0004	0.0023	0.0000	0.0000	0.0068	0.0000	0.0022	0.0000	0.0010	0.0039	0.0007	0.0000		

Note. Table A.5 reports effective transfer entropy values calculated with hourly asset returns. Panels A, B, and C report the values for the full period (April 02, 2022 to May 30, 2022), the pre-Terra-LUNA Crash period (April 02, 2022 to May 08, 2022), and the Terra-LUNA Crash period (May 09, 2022 to May 30, 2022). For each panel, items in the first column are sequences that transmit information and the items in the first row are sequences that receive information. Asterisks flag levels of statistical significance of result statistic using t-test. The significance levels are flagged as follows: *** : p-value < 0.01, ** : p-value < 0.05