Price Dynamics and Structural Breaks in Speculative Markets: A Case Study of Cryptocurrency

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Outline

Introduction

Information About Cryptocurrency Markets

- A novel idea by Nakamoto (2008): Bitcoin, the first cryptocurrency
  - Decentralized digital currency designed to work as medium of exchange
  - Peer–to–peer network secured by a system of cryptographic hashes
  - No third–party intervention
  - Significantly lower transaction costs
  - Decentralized and fully distributed public ledger, called blockchain
  - Mining process for the security and integrity of the blockchain
- Alternative digital currencies, called altcoins
- Unprecedented growth over the last few years
- As of July 2017, more than 980 cryptocurrencies exist with a total market capitalization of approximately $89 billion (CoinMarketCap, 2017).

See the Figure

Purpose

- Examining how the dynamic relationships between rival cryptocurrencies have changed over time and affected by shocks
- Understanding the price dynamics between these rival cryptocurrencies and how they change over time can help small investors to take trade positions in advance and reduce risks by hedging in highly speculative cryptocurrency markets.
- The price dynamics are investigated by allowing multiple structural breaks.
  - Data segments determined by the endogenously estimated two structural breaks.
  - Vector Autoregressive Model
  - Granger–Causality
  - Generalized Impulse Response Functions

See the Figure

Literature Review

- The literature mainly focused on
  - Speculative behavior of the Bitcoin price.
  - Microeconomic and macroeconomic determinants of the Bitcoin price.
  - Cointegration relations among the Bitcoin prices in different exchanges.
  - Cointegration and dynamic relationships between the Bitcoin price, Dow Jones Industry Average, oil price, Federal Funds Rate, and gold price.
- Only one study
  - Examined the structural breaks in the Bitcoin prices (Malhotra and Maloo, 2014).
  - Investigated correlations and tail dependencies between various cryptocurrencies using copula (Osterrieder et al., 2017).

Data Descriptions

- A daily dataset
  - Collected by BraveNewCoin (2017) and distributed by Quandl (2017).
  - Covers from 04-01-2014 to 07-29-2017.
- Historical global price indices for rival cryptocurrencies based on volume–weighted average prices from multiple exchanges
- Rival cryptocurrencies are selected in terms of market capitalization and monthly volume as of July 30, 2017.
  - Bitcoin (BTC)
  - Litecoin (LTC)
  - Ripple (XRP)
- In total, the selected cryptocurrencies represent %59.95 and %45.93 of the market capitalization and monthly volume shares respectively as of July 30, 2017.
- The final merged data covers three variables in the rate of return form.

Vector Autoregressive Model (VAR)

The k-dimensional VAR(p) is employed as the main model.

$$\mathbf{y_t} = \mathbf{c} + A_1\mathbf{y_{t-1}} + \cdots + A_p\mathbf{y_{t-p}} + \varepsilon_\mathbf{t} \tag{1}$$

where p is the lag length; T is the sample size; t indicates a temporal observation for $t = (1, \ldots, T)$; k is the number of endogenous time series variables and the total number of equations; $\mathbf{y_t} = (y_{1t}, \ldots, y_{kt})'$ is a $k \times 1$ vector for a set of k endogenous time series variables; $\mathbf{c} = (c_1, \ldots, c_k)'$ is a $k \times 1$ vector of constants; A_i's are $k \times k$ coefficient matrices for $i = (1, \ldots, p)$; and $\varepsilon_\mathbf{t} = (\varepsilon_{1t}, \ldots, \varepsilon_{kt})'$ is a $k \times 1$ vector of errors with $\varepsilon_\mathbf{t} \overset{iid}{\sim} (0, \Sigma_\varepsilon)$.

Methods Applied Before the VAR

- Seasonal unit root tests
  - Osborn–Chui–Smith–Birchenhall and Canova–Hansen
- Unit root tests
  - Augmented Dickey–Fuller
  - Phillips–Perron
  - Elliott–Rothenberg–Stock
- Stationary tests
  - Kwiatkowski–Phillips–Schmidt–Shin
- All unit root and stationary tests are performed under two models (i.e., a model with constant or trend) with various lag lengths.

Estimation of the VAR

- The 3-dimensional VAR(p) is estimated using Bayesian Information Criterion (BIC) for the lag length selection.
- The VAR(p) results are used for
  1. Univariate and multivariate diagnostic tests for model residuals
     - Autocorrelation: Ljung–Box test
     - Heteroskedasticity: Autoregressive conditional heteroskedasticity Lagrange Multiplier test
     - Normality: Jarque–Bera test and separate tests for skewness and kurtosis
  2. Granger–causality test using BIC for the lag length selection
  3. Impulse response analysis
     - Generalized impulse response functions (IRFs) by Koop et al. (1996)
     - A 90% confidence interval generated with 10000 bootstrap replications.
     - A one-unit positive shock.
- All IRFs are interpreted in percentage-points since a one-unit positive shock in the rate of return form equals to a one-percentage-point positive shock.

Procedure in Structural Break Testing

- Employing the entire data with the 3-dimensional VAR(p), two structural breaks are endogenously estimated using Qu and Perron (2007) methodology.
- The methodology is performed under following conditions.
  - Maximum number of breaks is fixed to $m = 2$ in order to target the extreme events occurred in the history of cryptocurrencies.
  - Structural breaks are allowed in both the regression and covariance parameters.
  - No restrictions on the model parameters.
- The methodology is performed using
  - WD max $LR_T(M)$ test to check whether at least one structural break is present.
  - $SEQ_T(\ell + 1 \mid \ell)$ test to check whether two structural breaks are present.
  - sup $LR_T(m, p_b, n_{bd}, n_{bo}, \epsilon)$ test to endogenously estimate two structural breaks dates.

Results for the Structural Break Tests

- For the entire data
  - No seasonal unit root is found and all of the variables are $I(0)$.
  - A 3-dimensional VAR(1) is constructed.
- Structural break tests for the VAR using the Qu and Perron (2007) methodology.
  - $WD\max LR_T(M)$ test: At least one structural break at the 1% significance level.
  - $SEQ_T(2 \mid 1)$ test: Two structural breaks at the 1% significance level.
  - $\sup LR_T(m, p_b, n_{bd}, n_{bo}, \epsilon)$ test: Two structural break dates are 11-12-2015 and 09-28-2016 at the 1% significance level.
- The data are separated into three segments on the structural break dates.

Conclusion:

The structural break dates are 11-12-2015 and 09-28-2016.

Results for the 1st Segment

- No seasonal unit root is found and all of the variables are $I(0)$.
- A 3-dimensional VAR(1) is estimated.
- Serial correlation, heteroskedasticity, and non–normality in the model residuals
- Granger–causalities: $BTC \Rightarrow XRP$

Table 1: Impulse Response Results - 1st Segment

$\longrightarrow$	BTC	LTC	XRP
BTC	$1 \overset{4D}{\Longrightarrow} 0$	$1.05 \overset{2D}{\Longrightarrow} 0.04$	$0.35 \overset{1D}{\Longrightarrow} 0$
LTC	$0.35 \overset{4D}{\Longrightarrow} 0$	$1 \overset{4D}{\Longrightarrow} 0$	$0.2 \overset{1D}{\Longrightarrow} 0$
XRP	$0.12 \overset{1D}{\Longrightarrow} 0.03$	$0.22 \overset{1D}{\Longrightarrow} 0.05$	$1 \overset{6D}{\Longrightarrow} 0$

See the Figure

Results for the 2nd Segment

- No seasonal unit root is found and all of the variables are $I(0)$.
- A 3-dimensional VAR(1) is estimated.
- Serial correlation, heteroskedasticity, and non–normality in the model residuals
- Granger–causalities: None

Table 2: Impulse Response Results - 2nd Segment

⟶	BTC	LTC	XRP
BTC	1 $\overset{4D}{\Longrightarrow}$ 0	0.9 $\overset{2D}{\Longrightarrow}$ 0.03	•
LTC	0.75 $\overset{4D}{\Longrightarrow}$ 0	1 $\overset{4D}{\Longrightarrow}$ 0	•
XRP	•	•	1 $\overset{1D}{\Longrightarrow}$ 0.03

Notes: • indicates statistical insignificance.

See the Figure

Results for the 3rd Segment

- No seasonal unit root is found and all of the variables are $I(0)$.
- A 3-dimensional VAR(1) is estimated.
- Serial correlation, heteroskedasticity, and non–normality in the model residuals
- Granger–causalities: $BTC \Longrightarrow XRP$ and $LTC \Longrightarrow XRP$

Table 3: Impulse Response Results - 3rd Segment

$\longrightarrow$	BTC	LTC	XRP
BTC	1	$\overset{4D}{\Longrightarrow}$0	0.81 $\overset{1D}{\Longrightarrow}$ 0.15	0.38 $\overset{1D}{\Longrightarrow}$ 0.3
LTC	0.25 $\overset{5D}{\Longrightarrow}$ 0	1	$\overset{3D}{\Longrightarrow}$0.01	0.41 $\overset{3D}{\Longrightarrow}$ 0.02
XRP	0.05 $\overset{4D}{\Longrightarrow}$ 0	0.15 $\overset{1D}{\Longrightarrow}$ 0.05	1	$\overset{3D}{\Longrightarrow}$0.01

Notes: • indicates statistical insignificance.

See the Figure

Comparison of the Segments

Granger–causalities:

- 1^{st} Segment: $BTC \Longrightarrow XRP$
- 2^{nd} Segment: None
- 3^{rd} Segment: $BTC \Longrightarrow XRP$ and $LTC \Longrightarrow XRP$

Table 4: Impulse Response Results - All Segments

$\longrightarrow$	*BTC:*			*LTC:*			*XRP:*		
	1^{st}	2^{nd}	3^{rd}	1^{st}	2^{nd}	3^{rd}	1^{st}	2^{nd}	3^{rd}
BTC	$1 \overset{4D}{\Longrightarrow} 0$	$1 \overset{4D}{\Longrightarrow} 0$	$1 \overset{4D}{\Longrightarrow} 0$	$1.05 \overset{2D}{\Longrightarrow} 0.04$	$0.9 \overset{2D}{\Longrightarrow} 0.03$	$0.81 \overset{1D}{\Longrightarrow} 0.15$	$0.35 \overset{1D}{\Longrightarrow} 0$	•	$0.38 \overset{1D}{\Longrightarrow} 0.3$
LTC	$0.35 \overset{4D}{\Longrightarrow} 0$	$0.75 \overset{4D}{\Longrightarrow} 0$	$0.25 \overset{5D}{\Longrightarrow} 0$	$1 \overset{4D}{\Longrightarrow} 0$	$1 \overset{4D}{\Longrightarrow} 0$	$1 \overset{3D}{\Longrightarrow} 0.01$	$0.2 \overset{1D}{\Longrightarrow} 0$	•	$0.41 \overset{3D}{\Longrightarrow} 0.02$
XRP	$0.12 \overset{1D}{\Longrightarrow} 0.03$	•	$0.05 \overset{4D}{\Longrightarrow} 0$	$0.22 \overset{1D}{\Longrightarrow} 0.05$	•	$0.15 \overset{1D}{\Longrightarrow} 0.05$	$1 \overset{6D}{\Longrightarrow} 0$	$1 \overset{1D}{\Longrightarrow} 0.03$	$1 \overset{3D}{\Longrightarrow} 0.01$

Notes: • indicates statistical insignificance.

Conclusion:

The Granger–causalities and dynamic relationships between the prices of rival cryptocurrencies have been affected by the structural breaks.

Conclusion

1. Two robust structural breaks that appear to have affected the price dynamics between the rival cryptocurrencies.
   - The first break date might be linked to two distinct events that declared cryptocurrencies not only as a commodity but also as a currency.
   - The second break might be linked to the 2nd halving of the Bitcoin blockchain.
2. After the second structural break, the Granger–causality from the prices of other coins to Ripple price have gained strength.
3. The response of each coin to a shock in Bitcoin price is same across segments.
4. In response to a shock in Litecoin price, the impact on Bitcoin price is decreasing over time; however, the impact on Ripple price is increasing.
5. In response to a shock in Ripple price, the impact on the prices of Bitcoin and Litecoin are decreasing over time.

Thank You!

Questions?

References

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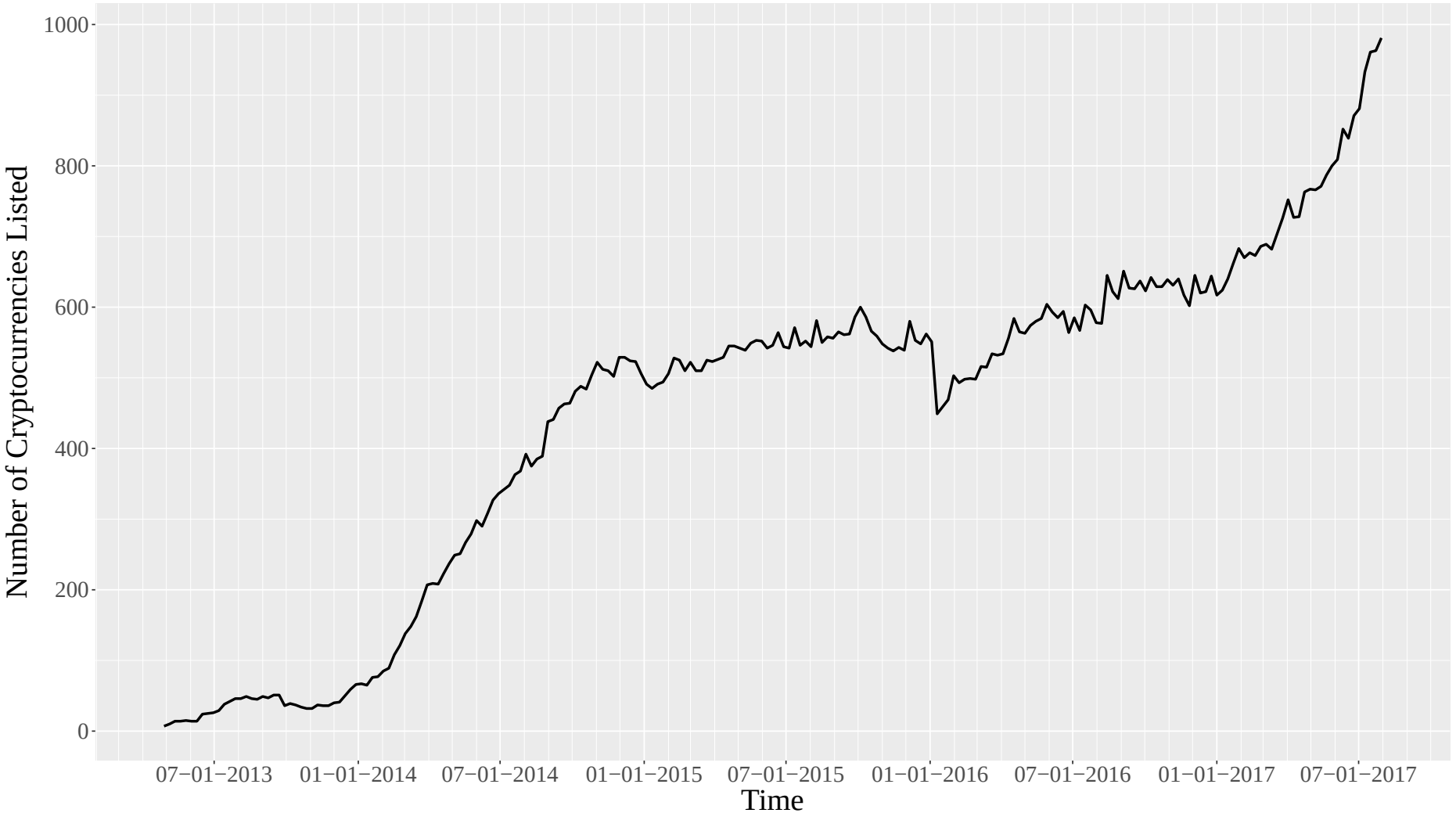
Additional Figure



Note: Based on weekly snapshots from April 28, 2013 to July 30, 2017 (CoinMarketCap, 2017).

Figure 1: Number of Cryptocurrencies Listed

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Additional Figure

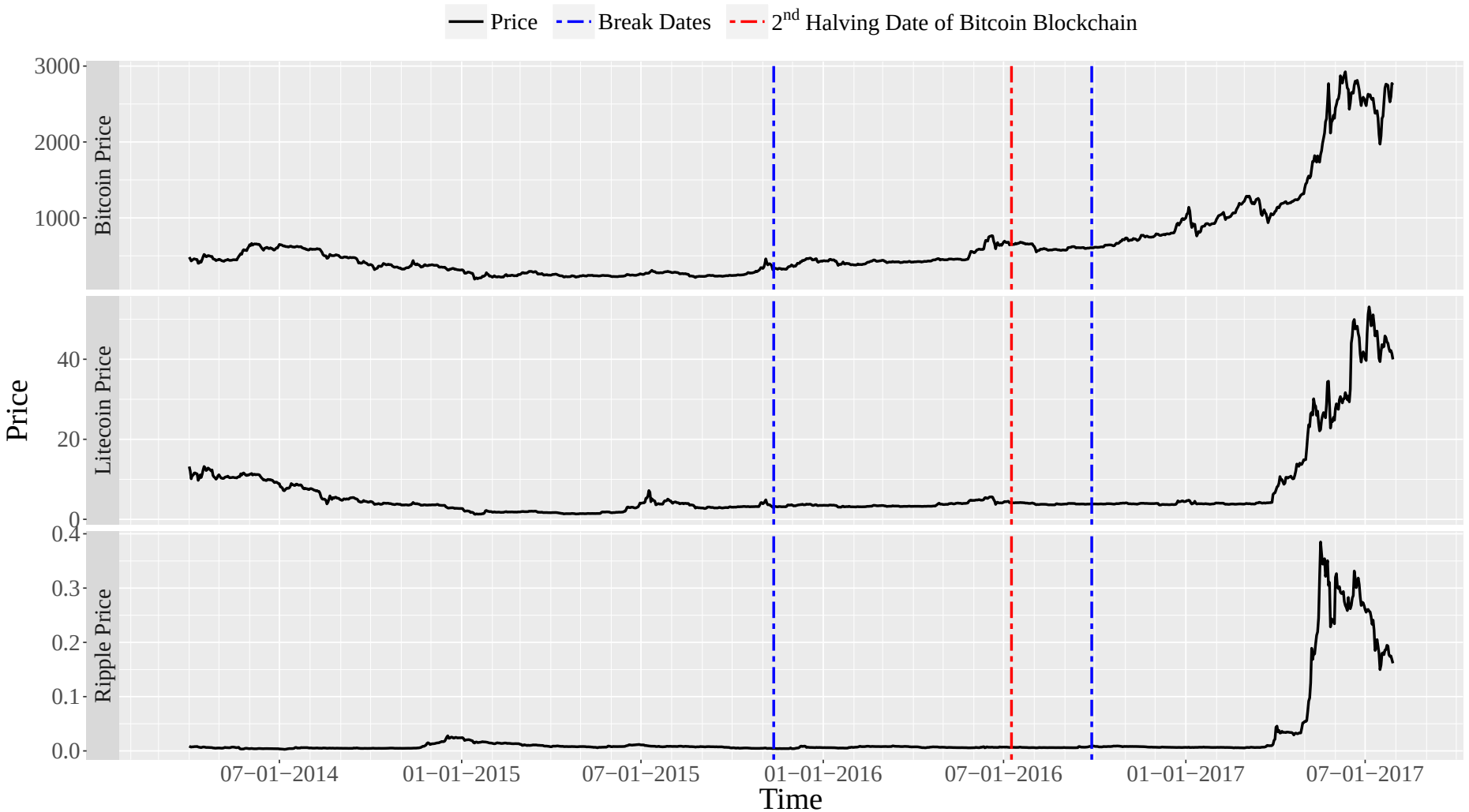

Figure 2: Plot of All Variables Together

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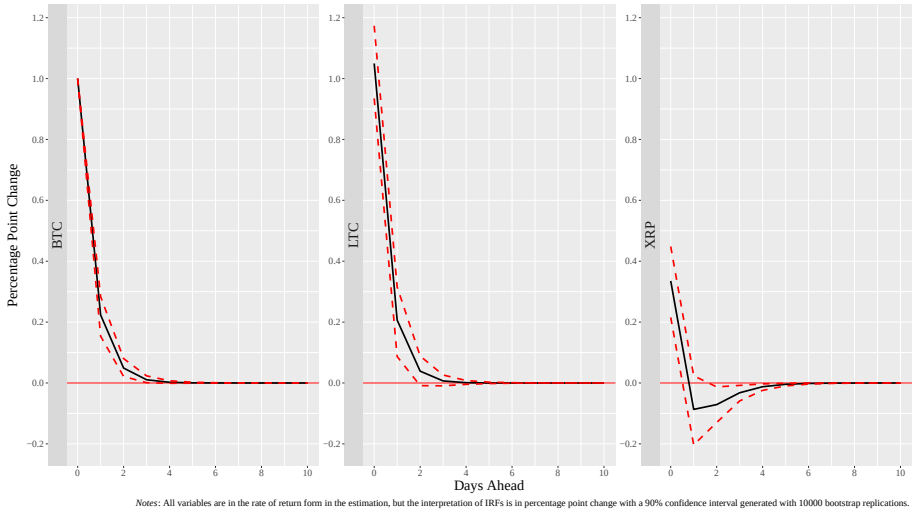
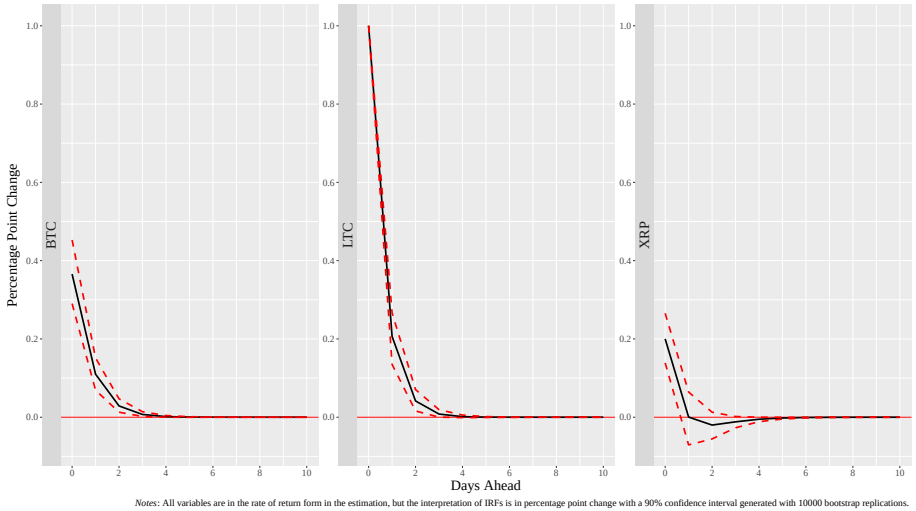
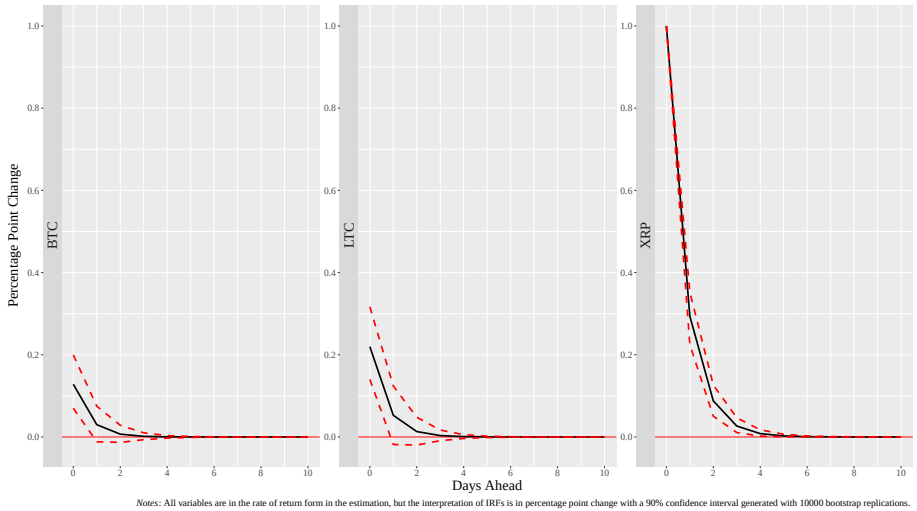
Additional Figure



(a) BTC



(b) LTC



(c) XRP

Figure 3: Impulse Responses Analysis - 1st Segment

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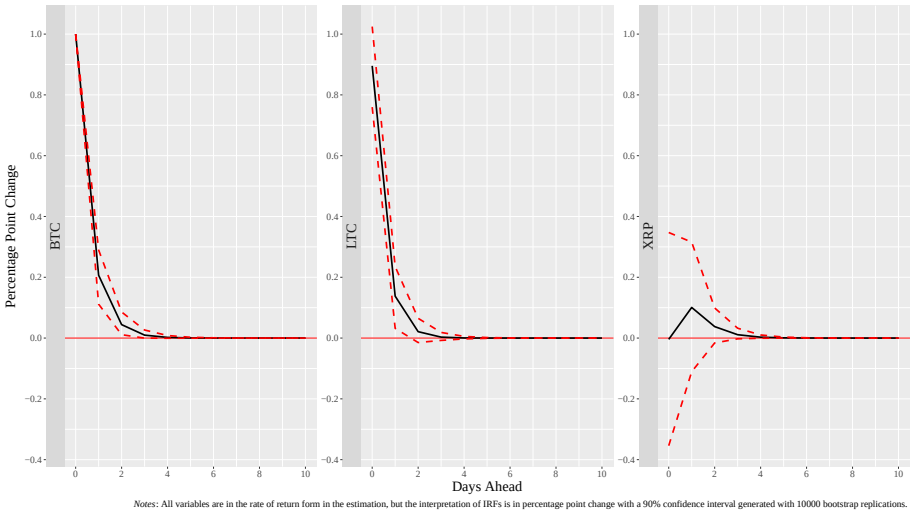
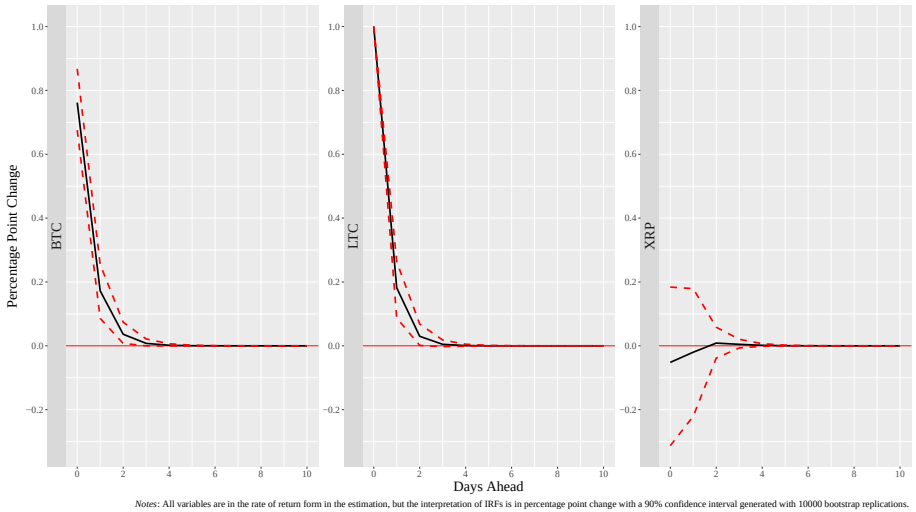
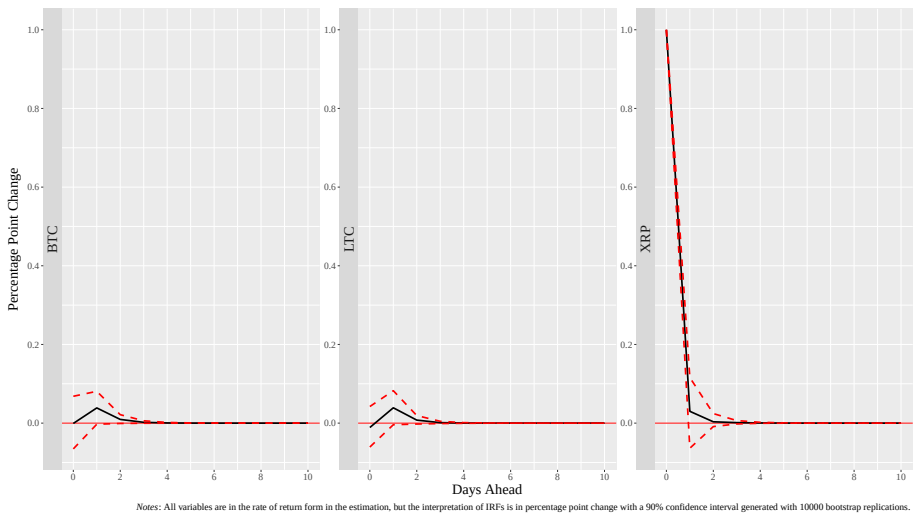
Additional Figure



(a) BTC



(b) LTC



(c) XRP

Figure 4: Impulse Responses Analysis - 2nd Segment

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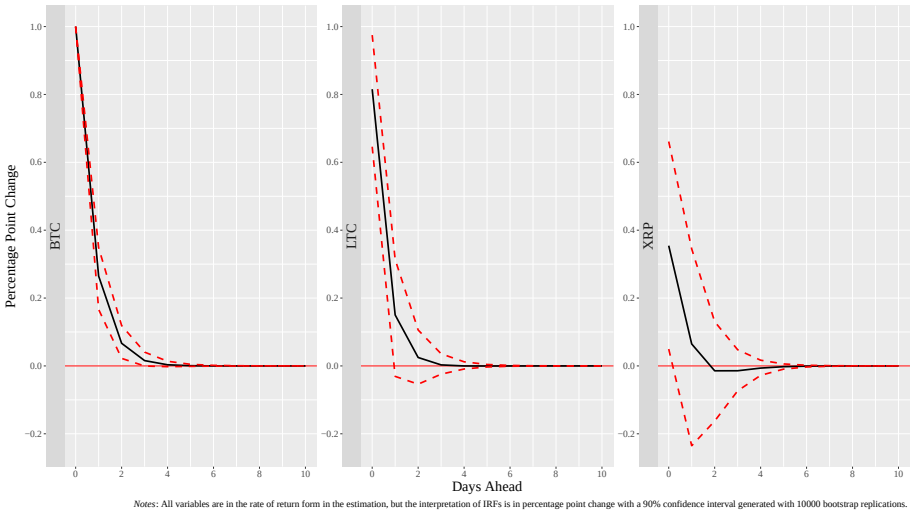
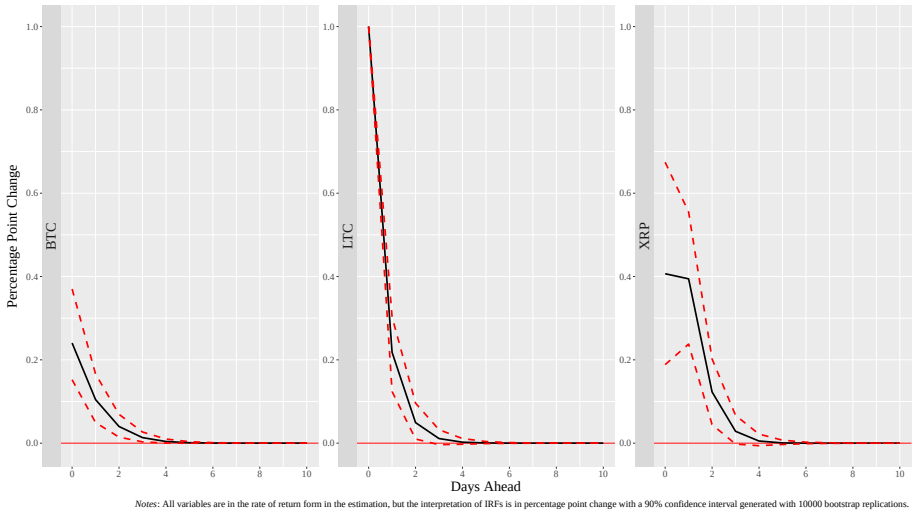
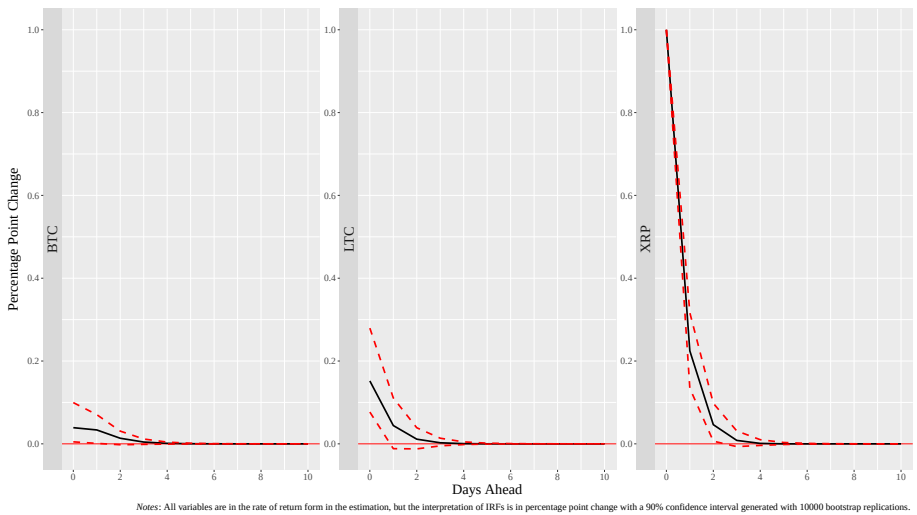
Additional Figure



(a) BTC



(b) LTC



(c) XRP

Figure 5: Impulse Responses Analysis - 3rd Segment

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