Code ▾

A Time Series Analysis of Bitcoin Price

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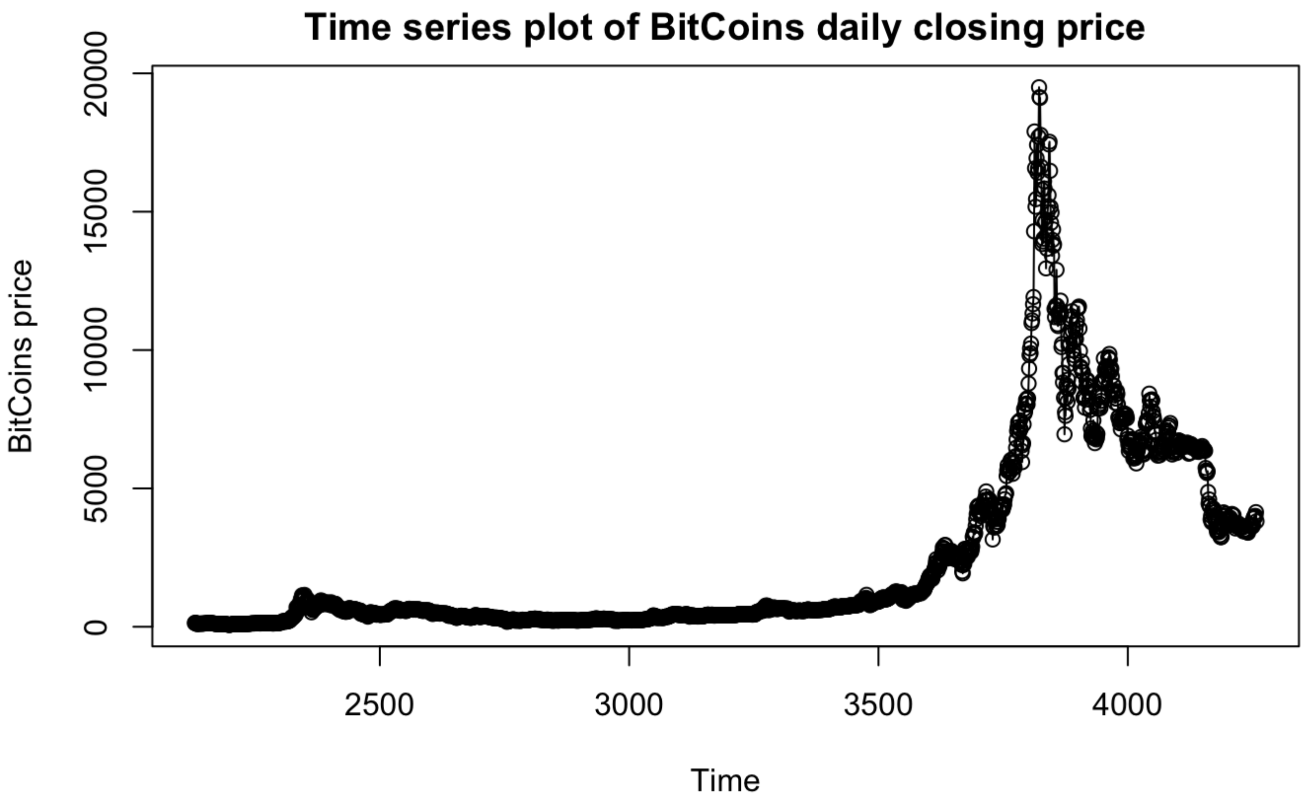
Data Preparation

Loading data

Hide

```
bitcoin_data<- read_excel("~/Documents/databitcoin.xlsx", col_types = c("date", "numeric"))
bitcoin_ts<- ts(as.vector(bitcoin_data$Close),start=c(2013,117))
plot(bitcoin_ts,type='o',main="Time series plot of BitCoins daily closing price", ylab='BitCoins price')
```



First impression:

```
Trend: Overall, we can observe an upward trend. The trend starts to change to a sudde
n upward movement at around 3500 days; after around 3800 days the trend switches to a
downward movement.
Seasonality: we can not observe any clear sign of seasonality; this could be the resu
lt of the late and quick popularity of BitCoins which lead to a dampen visual signs o
f seasonality.
Behaviours: We can observe clear auto-regressive behaviours, especially during the pe
riod of surging. In addition, there is possible moving average as well.
Change in variance: We can observe clear sign of change in variance during this time
period.
Influence points: We can observe 2 influence points which caused the surge of BitCoin
s and its down fall later on.
```

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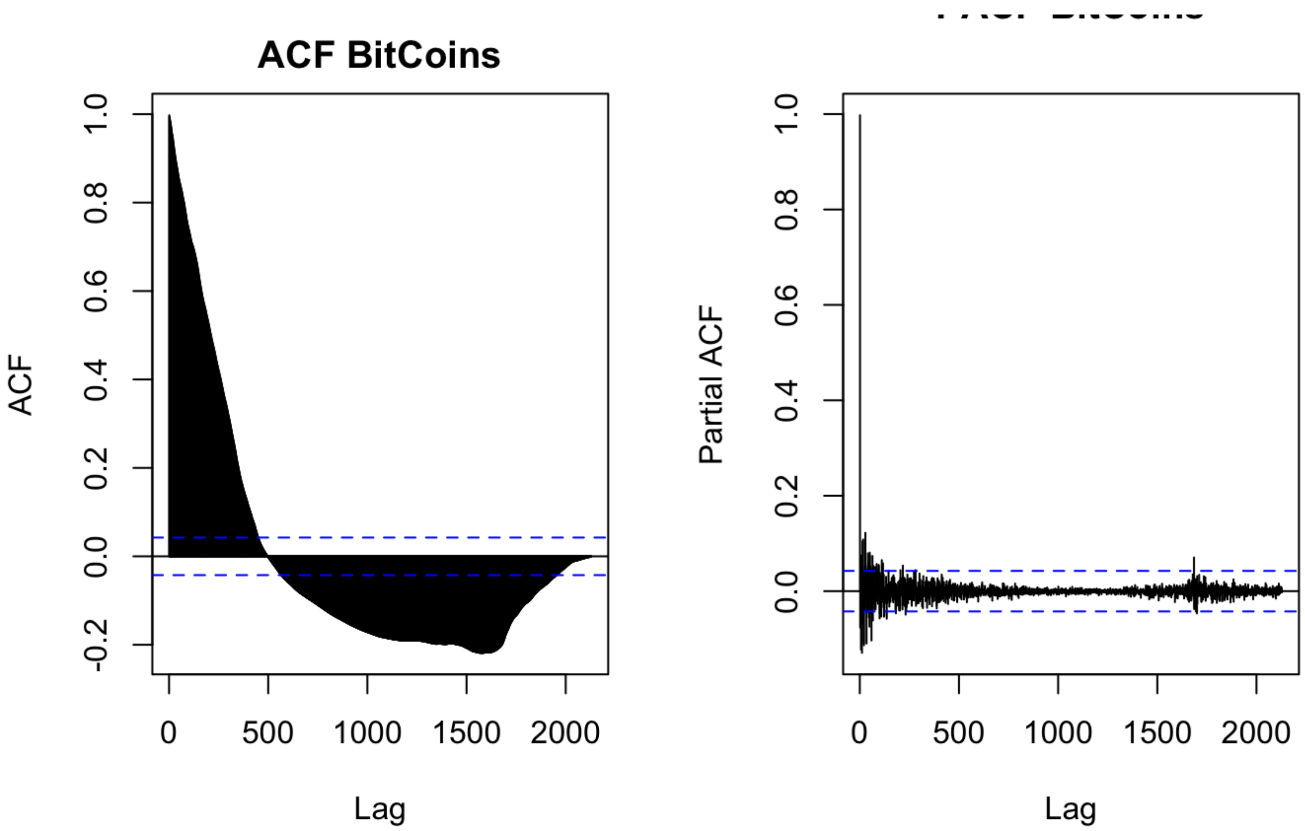
```
par(mfrow=c(1,2))
acf(bitcoin_ts,lag.max = 3000,main="ACF BitCoins")
pacf(bitcoin_ts,lag.max = 3000,main="PACF BitCoins")
```



```
     We can observe the cleat implications of trends and change in variance in ACF a
nd PACF plots of the data.
```

Transformation

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```
ar(diff(bitcoin_ts))
```

```
Call:
ar(x = diff(bitcoin_ts))

Coefficients:
      1        2        3        4        5        6        7        8        9  
10       11  
 0.0543  -0.0472   0.0040  -0.0265   0.1460  -0.0157  -0.0185   0.0894   0.0520   0.1
259   0.0110  
     12       13       14       15       16       17       18       19       20  
21       22  
-0.0603  -0.1135  -0.0991  -0.0260  -0.1369   0.0834  -0.0005   0.1371   0.1285   0.0
286   0.0624  
     23       24       25       26       27       28       29       30       31  
32       33  
-0.0329  -0.0438   0.0205   0.0320  -0.1346  -0.0425  -0.0571  -0.0286  -0.0425  -0.0
183   0.1225  

Order selected 33  sigma^2 estimated as  45811
```

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```
adfTest(bitcoin_ts,lags = 33 ,title = NULL,description = NULL)
```

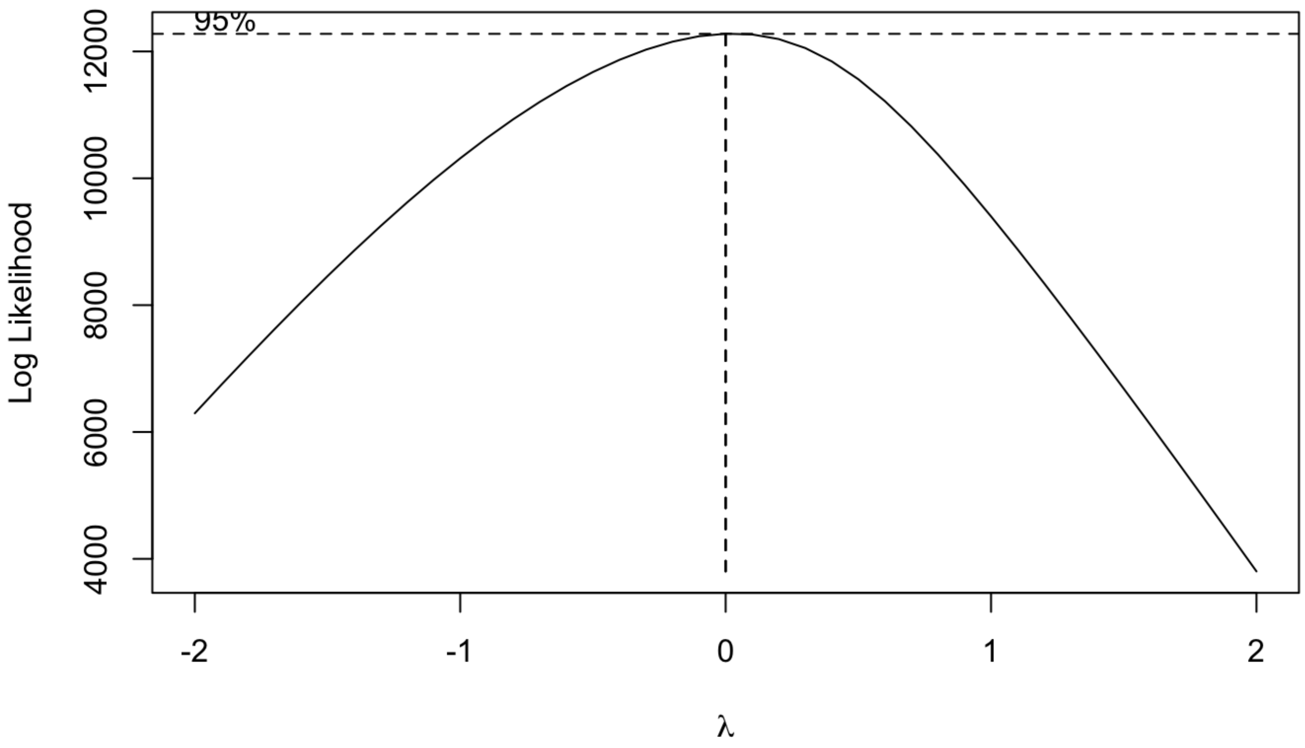
```
Title:
 Augmented Dickey-Fuller Test

Test Results:
  PARAMETER:
    Lag Order: 33
  STATISTIC:
    Dickey-Fuller: -1.2548
  P VALUE:
    0.2164 

Description:
 Wed Jun  5 16:18:24 2019 by user: 
```

Hide

```
bc_coin<-BoxCox.ar(bitcoin_ts,method = "yule-walker")
```



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```
bc_coin$ci
```

```
[1] 0 0
```

```
The p-value of the Dickey-Fuller is 0.2164, which indicates that the series is non-st
ationary; in addition the BoxCox test suggests a lamda of 0, therefore, we will use a
n log transformation to take care of the chance in variance.
```

Hide

```
log_bitcoin<-log(bitcoin_ts)
ar(diff(log_bitcoin))
```

```

Call:
ar(x = diff(log_bitcoin))

Coefficients:
      1        2        3        4        5        6        7        8        9       
10       11  
-0.0012  -0.0140   0.0069   0.0226   0.0383   0.0607  -0.0215  -0.0010  -0.0042   0.0
495   0.0563  
     12       13       14       15       16       17       18       19       20       
21       22  
-0.0066   0.0058   0.0052   0.0024  -0.0111   0.0688   0.0064  -0.0117   0.0552  -0.0
230   0.0292  
     23       24       25       26       27       28       29       30       31  
-0.0450  -0.0203  -0.0139   0.0343   0.0198  -0.0436  -0.0376  -0.0472   0.0386  

Order selected 31  sigma^2 estimated as  0.001853
```

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```
adfTest(log_bitcoin,lags = 31 ,title = NULL,description = NULL)
```

```


Title:
 Augmented Dickey-Fuller Test

Test Results:
  PARAMETER:
    Lag Order: 31
  STATISTIC:
    Dickey-Fuller: 1.0713
  P VALUE:
    0.9232 

Description:
 Wed Jun  5 16:18:29 2019 by user: 
```

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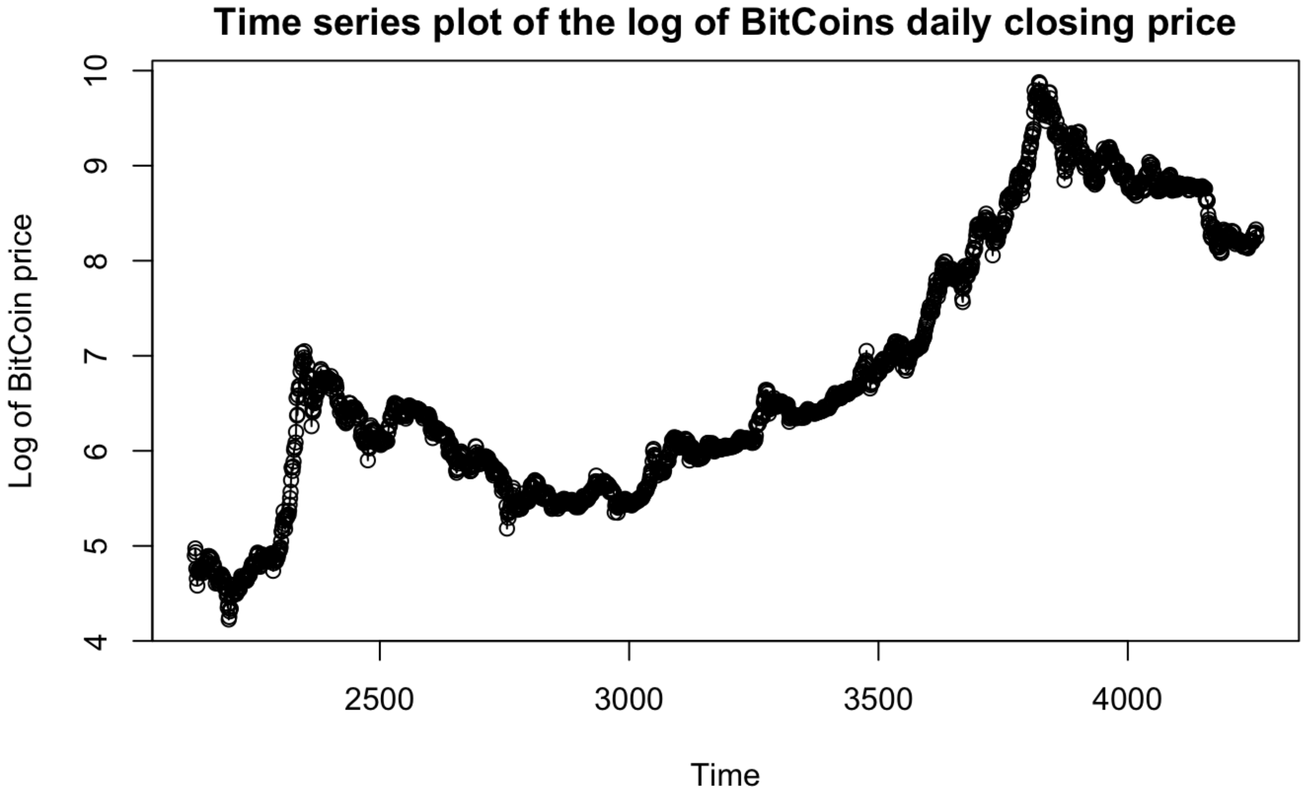
```
plot(log_bitcoin,type='o',main="Time series plot of the log of BitCoins daily closing
price", ylab='Log of BitCoin price')
```



```
After the log transformation, the The p-value of the Dickey-Fuller is still bigger th
an 0.05, which indicates the series is still non-stationary. Therefore, we will use d
ifferncing to de-trend the series.
```

Differencing

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```
diff_bitcoin<-diff(log_bitcoin)
ar(diff(diff_bitcoin))
```

```


Call:
ar(x = diff(diff_bitcoin))

Coefficients:
      1        2        3        4        5        6        7        8        9  
10       11  
-0.9421  -0.9044  -0.8482  -0.7827  -0.7065  -0.6114  -0.6052  -0.5769  -0.5536  -0.4
762  -0.3997  
     12       13       14       15       16       17       18       19       20  
21       22  
-0.3867  -0.3642  -0.3395  -0.3179  -0.3147  -0.2289  -0.2100  -0.2085  -0.1389  -0.1
495  -0.1071  
     23       24       25       26       27       28       29       30       31  
32  
-0.1405  -0.1441  -0.1403  -0.0856  -0.0503  -0.0772  -0.0950  -0.1201  -0.0560  -0.0
465  

Order selected 32  sigma^2 estimated as  0.001961
```

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```
adfTest(diff_bitcoin,lags = 31 ,title = NULL,description = NULL)
```

```
p-value smaller than printed p-value
```

```


Title:
 Augmented Dickey-Fuller Test

Test Results:
  PARAMETER:
    Lag Order: 31
  STATISTIC:
    Dickey-Fuller: -7.7432
  P VALUE:
    0.01 

Description:
 Wed Jun  5 16:18:32 2019 by user: 
```

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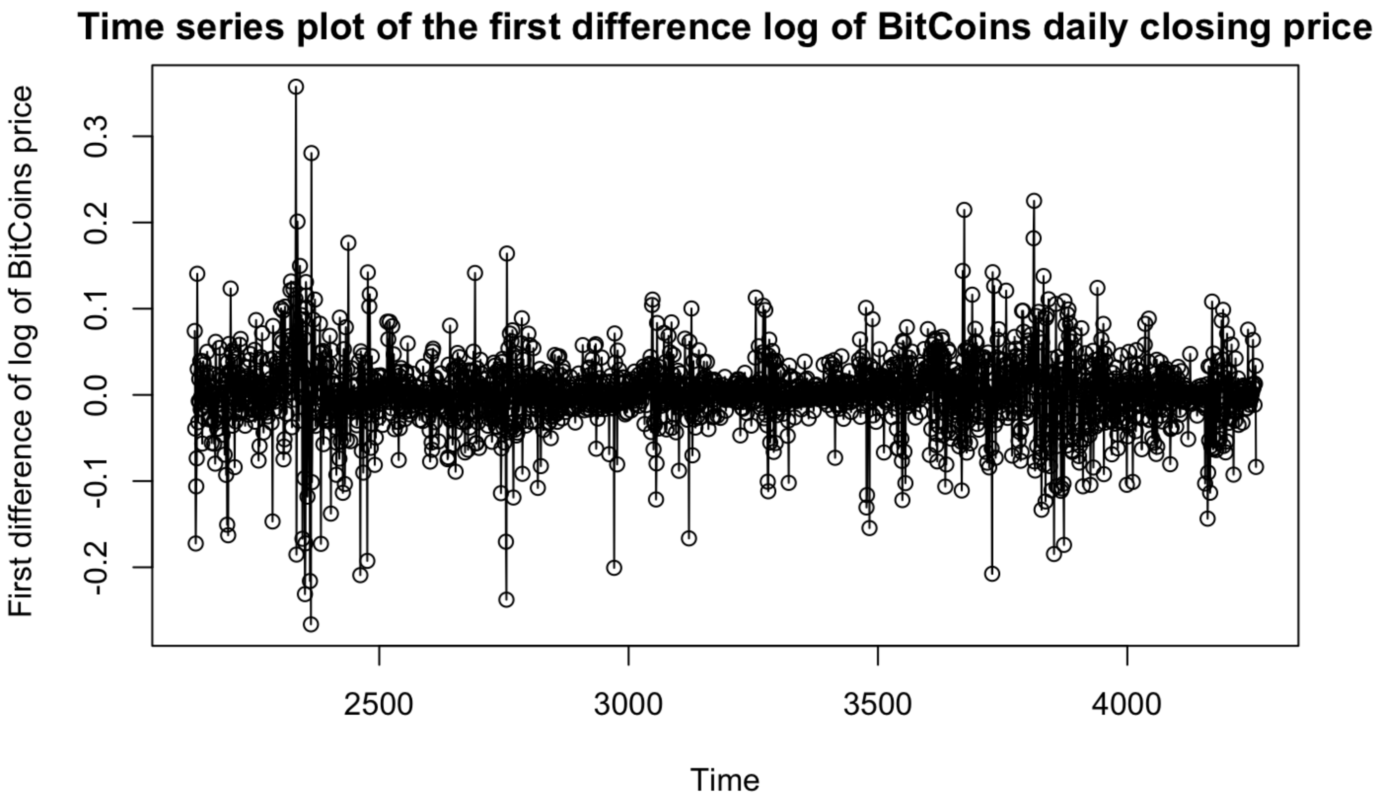
```
plot(diff_bitcoin,type='o',main='Time series plot of the first difference log of BitC
oins daily closing price', ylab=' First difference of log of BitCoins price')
```



```
  We can observe that the series has become more stationary based on the visual impre
ssions. In addition, the Dickey-Fuller Test showed a p-value much smaller than 0.05;
this indicates that the series is stationary and ready for modelling.
```

Change in variance effect

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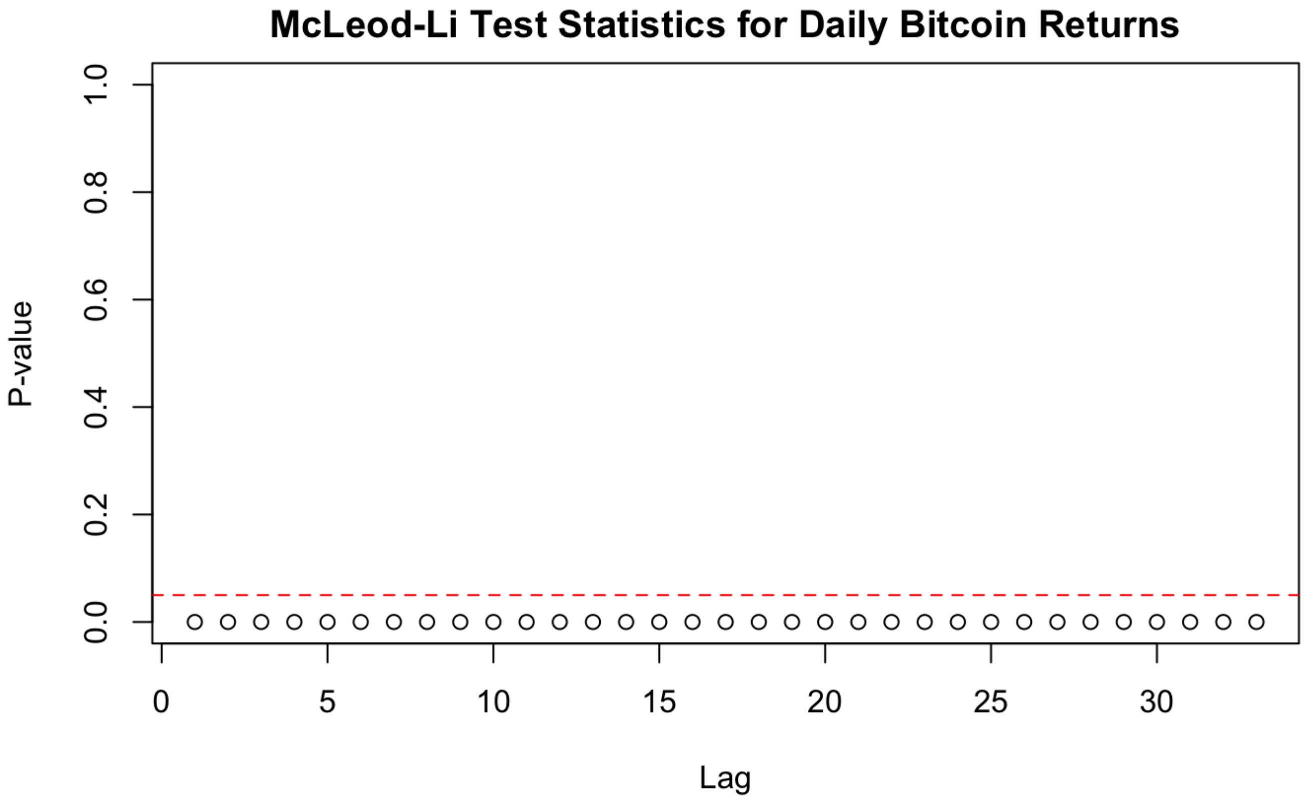
```
#Considering ARCH effect.
McLeod.Li.test(y=diff_bitcoin,main="McLeod-Li Test Statistics for Daily Bitcoin Retur
ns")
```



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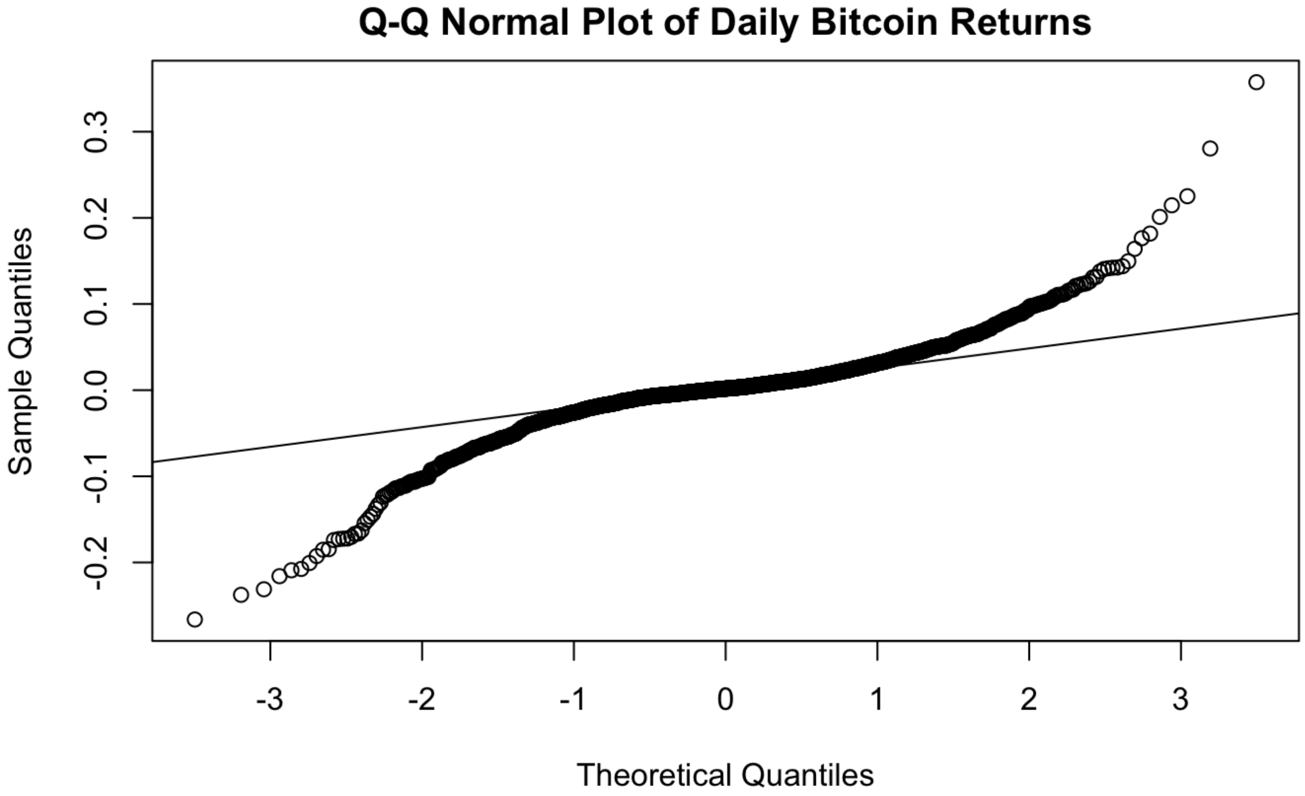
```
qqnorm(diff_bitcoin,main="Q-Q Normal Plot of Daily Bitcoin Returns")
qqline(diff_bitcoin) # Fat tails is in accordance with volatiliy clustering
```



```
We can see the evidences of change in variance in the QQ-plot with the wide tails. Be
sides, McLeod Li test exhibits that all the points were below the line. We will fit a
n ARIMA x GARCH model.
```

ARIMA models fitting

```
  Since we de-trend the series with one difference, therefore, d is 1
```

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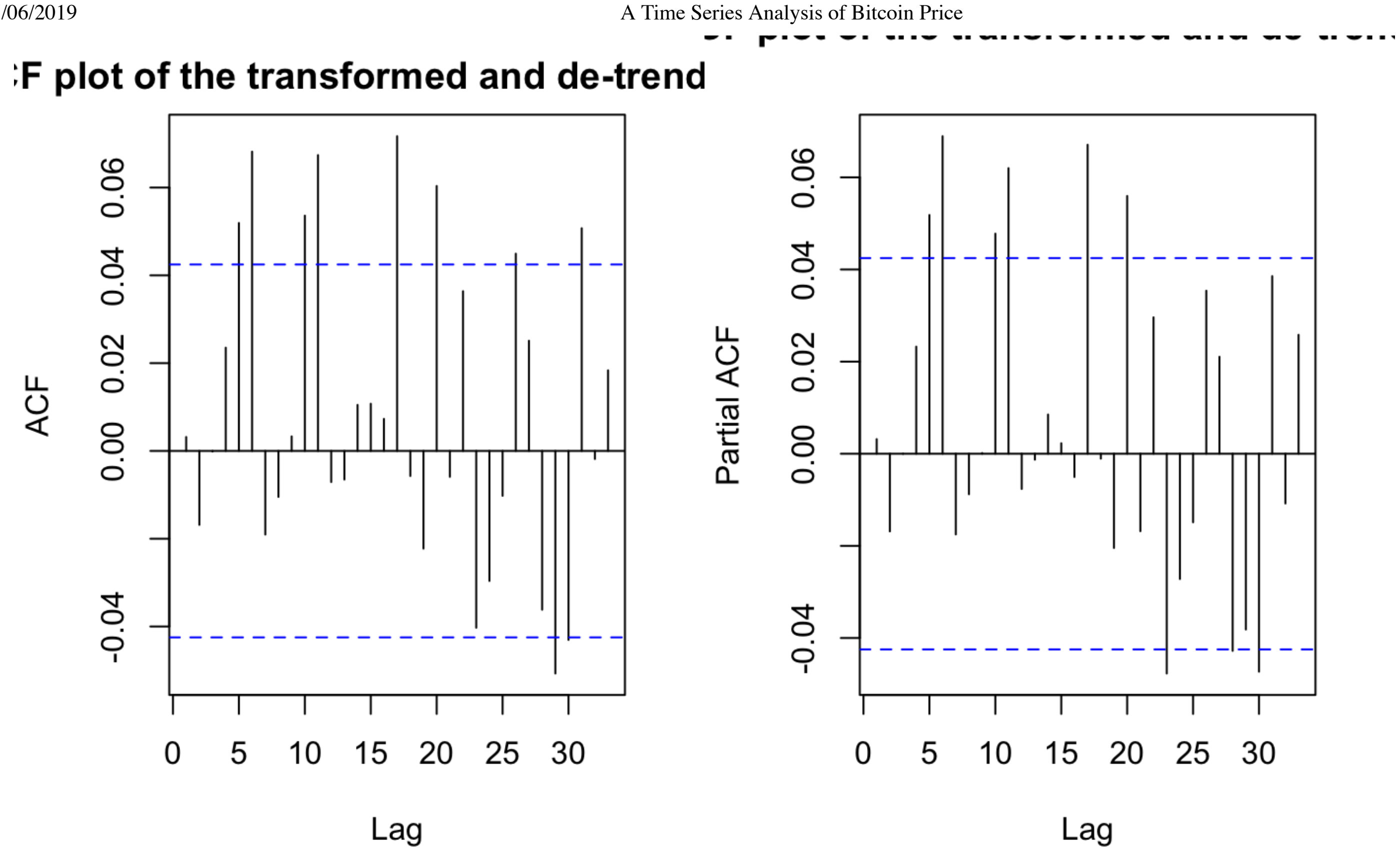
```
par(mfrow=c(1,2))
acf(diff_bitcoin,main='ACF plot of the transformed and de-trend series')
pacf(diff_bitcoin,main='PACF plot of the transformed and de-trend series')
```



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```
eacf(diff_bitcoin,ar.max = 20,ma.max = 20)
```

```
AR/MA
   0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
0  o o o o x x o o o x x  o  o  o  o  o  x  o  o  x  o
1  x o o o o x o o o o x  o  o  o  o  o  x  o  o  x  o
2  o x o o o x o o o o x  o  o  o  o  o  x  o  o  x  o
3  o x o o o x o o o o x  o  o  o  o  o  o  o  o  x  o
4  x x o x o x o o o o x  o  o  o  o  o  o  o  o  x  o
5  x x x x x o o o o o x  o  o  o  o  o  o  o  o  x  o
6  x x x x x o o o o o o  o  o  o  o  o  o  o  o  x  o
7  x x o x x x x o o o o  o  o  o  o  o  o  o  o  x  o
8  x x x x x x x x o o o  o  o  o  o  o  o  o  o  x  o
9  o x x o x x x x o o o  o  o  o  o  o  o  o  o  x  o
10 x x x x x x x o x x o  o  o  o  o  o  o  o  o  x  o
11 x o x o x x x x x x x  o  o  o  o  o  o  o  o  x  o
12 x x x x o x x x x x x  o  o  o  o  o  o  x  o  o  o
13 x x o o o x x x o o x  o  x  o  o  o  o  x  o  o  o
14 x x o o o x x x x o x  o  x  o  o  o  o  x  o  o  o
15 x o x x o x x o o o x  o  x  o  x  o  o  x  o  o  o
16 x o x x x x x o x x x  x  x  o  o  o  o  o  o  o  o
17 o x x x x x o x x x x  o  x  x  x  x  x  o  o  o  o
18 o x x x x x o x x x o  x  x  x  x  x  x  x  o  o  o
19 x x x x x x x x x x o  x  x  x  o  x  x  x  x  o  o
20 x x x x x o x x o x x  x  x  o  x  x  x  x  x  x  o
```

Hide

```
res1 = armasubsets(y=diff_bitcoin,nar=19,nma=19,y.name='test',ar.method='ols')
```

```
8  linear dependencies found
```

```
Reordering variables and trying again:
```

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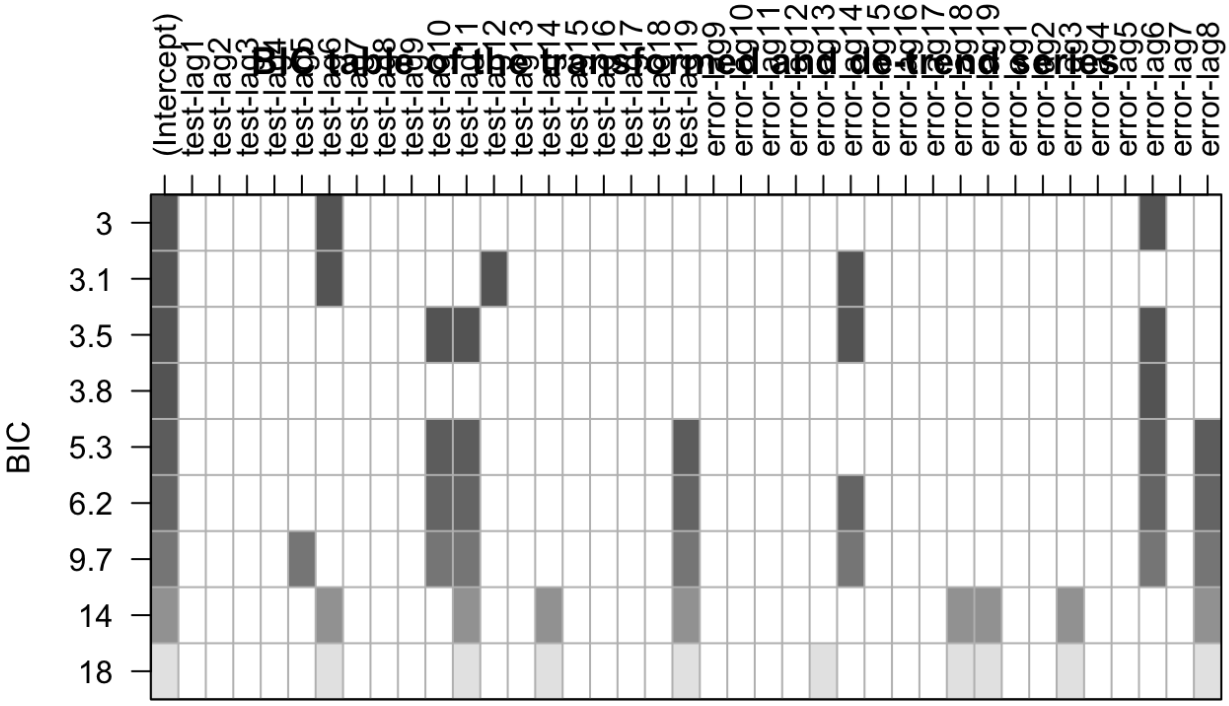
```
plot(res1, main= 'BIC table of the transformed and de-trend series')
```



```
  Based on the ACF, PACF ,EACF plots and BIC table we suggests the following subset o
f models {(ARIMA(9,1,8), ARIMA(1,1,1), ARIMA(1,1,2), ARIMA(2,1,2),ARIMA(1,1,6), ARIMA
(3,1,13),ARIMA(6,1,5), ARIMA(6,1,14), ARIMA(6,1,6), ARIMA(6,1,8),ARIMA(10,1,4), ARIMA
(10,1,6), ARIMA(10,1,8),ARIMA(11,1,4), ARIMA(11,1,6), ARIMA(11,1,8)}
```

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```
modelList <- list(c(9,1,8), c(1,1,1), c(1,1,2), c(2,1,2),c(1,1,6), c(3,1,13),c(6,1,5
), c(6,1,14),c(6,1,6), c(6,1,8),c(10,1,4), c(10,1,6), c(10,1,8),c(11,1,4), c(11,1,6),
c(11,1,8))
```

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```
source('~/Downloads/TSHandy.r')
```

```
Loading required package: forecast
package ‘forecast’ was built under R version 3.5.2
```

Hide

```
modelEstimation <- myCandidate(diff_bitcoin, orderList = modelList, methodType = "ML"
)
```

```
NaNs producedNaNs producedNaNs producedNaNs producedNaNs producedNaNs producedNaNs pr
oducedNaNs producedNaNs producedNaNs produced
```

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```
modelEstimation$IC
```

	p	d	q	AIC	AICc	BIC
	<dbl>	<dbl>	<dbl>	<dbl>	<dbl>	<dbl>
9	6	1	6	-7316.791	-7316.619	-7243.173
10	6	1	8	-7316.699	-7316.472	-7231.755
12	10	1	6	-7315.376	-7315.086	-7219.106
1	9	1	8	-7313.142	-7312.818	-7211.209
13	10	1	8	-7312.699	-7312.339	-7205.104
16	11	1	8	-7311.615	-7311.216	-7198.356
7	6	1	5	-7307.228	-7307.080	-7239.272
15	11	1	6	-7299.815	-7299.490	-7197.882
14	11	1	4	-7294.969	-7294.712	-7204.362
11	10	1	4	-7293.057	-7292.829	-7208.113

1-10 of 16 rows Previous **1** 2 Next

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```
arima_918<-arima(diff_bitcoin, order= c(9,1,8), method = "ML")
```

```
NaNs producedNaNs producedNaNs producedNaNs producedpossible convergence problem: opt
im gave code = 1
```

Hide

```
coeftest(arima_918)
```

```
NaNs produced
```

```

z test of coefficients:

     Estimate Std. Error z value  Pr(>|z|)    
ar1 -0.542716         NA      NA        NA    
ar2 -0.498408         NA      NA        NA    
ar3 -0.538746   0.087883 -6.1302 8.774e-10 ***
ar4  0.217935   0.096123  2.2673   0.02337 *  
ar5  0.422227   0.038739 10.8993 < 2.2e-16 ***
ar6  0.400752         NA      NA        NA    
ar7  0.747153         NA      NA        NA    
ar8  0.032031   0.027523  1.1638   0.24452    
ar9  0.025190   0.025190  1.0000   0.31732    
ma1 -0.459295         NA      NA        NA    
ma2 -0.056895         NA      NA        NA    
ma3  0.057434         NA      NA        NA    
ma4 -0.729129   0.104462 -6.9799 2.955e-12 ***
ma5 -0.195484         NA      NA        NA    
ma6  0.093075         NA      NA        NA    
ma7 -0.398986   0.095521 -4.1769 2.955e-05 ***
ma8  0.689285         NA      NA        NA    
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Hide

```
arima_918_css<-arima(diff_bitcoin, order= c(9,1,8), method = "CSS")
coeftest(arima_918_css)
```

```
NaNs produced
```

```

z test of coefficients:

     Estimate Std. Error z value Pr(>|z|)
ar1 -0.350039         NA      NA       NA
ar2 -0.135239         NA      NA       NA
ar3 -0.031149   0.052102 -0.5978   0.5499
ar4  0.039537         NA      NA       NA
ar5  0.043572   0.090483  0.4816   0.6301
ar6  0.011663   0.037295  0.3127   0.7545
ar7 -0.052480   0.080518 -0.6518   0.5145
ar8 -0.016516   0.022832 -0.7234   0.4695
ar9 -0.020446   0.024652 -0.8294   0.4069
ma1 -0.656031         NA      NA       NA
ma2 -0.223053         NA      NA       NA
ma3 -0.086259         NA      NA       NA
ma4 -0.050658         NA      NA       NA
ma5  0.019152   0.109147  0.1755   0.8607
ma6  0.065162         NA      NA       NA
ma7 -0.012300   0.156055 -0.0788   0.9372
ma8 -0.058995   0.101152 -0.5832   0.5597
```

Hide

```
arima_111<-arima(diff_bitcoin, order= c(1,1,1), method = "ML")
coeftest(arima_111)
```

```


z test of coefficients:

      Estimate Std. Error   z value Pr(>|z|)
ar1 -0.0015776  0.0220419   -0.0716   0.9429
ma1 -0.9938029  0.0041141 -241.5577   <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

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```
arima_111_css<-arima(diff_bitcoin, order= c(1,1,1), method = "CSS")
coeftest(arima_111_css)
```

```


z test of coefficients:

      Estimate Std. Error   z value Pr(>|z|)
ar1 -0.0287102  0.0214228   -1.3402   0.1802
ma1 -0.9746954  0.0054057 -180.3085   <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

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```
arima_112<-arima(diff_bitcoin, order= c(1,1,2), method = "ML")
coeftest(arima_112)
```

```


z test of coefficients:

    Estimate Std. Error z value Pr(>|z|)
ar1 -0.37515    1.19977 -0.3127   0.7545
ma1 -0.61407    1.20708 -0.5087   0.6109
ma2 -0.37760    1.20029 -0.3146   0.7531
```

Hide

```
arima_112_css<-arima(diff_bitcoin, order= c(1,1,2), method = "CSS")
coeftest(arima_112)
```

```


z test of coefficients:

    Estimate Std. Error z value Pr(>|z|)
ar1 -0.37515    1.19977 -0.3127   0.7545
ma1 -0.61407    1.20708 -0.5087   0.6109
ma2 -0.37760    1.20029 -0.3146   0.7531
```

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```
arima_212<-arima(diff_bitcoin, order= c(2,1,2), method = "ML")
coeftest(arima_212)
```

```


z test of coefficients:

     Estimate Std. Error z value Pr(>|z|)
ar1 -0.191941   0.994895 -0.1929   0.8470
ar2 -0.020506   0.027196 -0.7540   0.4509
ma1 -0.803388   0.994642 -0.8077   0.4193
ma2 -0.188502   0.989528 -0.1905   0.8489
```

Hide

```
arima_212_css<-arima(diff_bitcoin, order= c(2,1,2), method = "CSS")
coeftest(arima_212)
```

```


z test of coefficients:

     Estimate Std. Error z value Pr(>|z|)
ar1 -0.191941   0.994895 -0.1929   0.8470
ar2 -0.020506   0.027196 -0.7540   0.4509
ma1 -0.803388   0.994642 -0.8077   0.4193
ma2 -0.188502   0.989528 -0.1905   0.8489
```

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```
arima_116<-arima(diff_bitcoin, order= c(1,1,6), method = "ML")
coeftest(arima_116)
```

```


z test of coefficients:

     Estimate Std. Error z value Pr(>|z|)
ar1  0.570621   0.995877  0.5730   0.5667
ma1 -1.569847   1.002005 -1.5667   0.1172
ma2  0.551459   0.991327  0.5563   0.5780
ma3  0.028540   0.046965  0.6077   0.5434
ma4  0.012004   0.043349  0.2769   0.7818
ma5  0.016077   0.066440  0.2420   0.8088
ma6 -0.038141   0.060601 -0.6294   0.5291
```

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```
arima_116_css<-arima(diff_bitcoin, order= c(1,1,6), method = "CSS")
coeftest(arima_116_css)
```

```
z test of coefficients:

      Estimate Std. Error z value  Pr(>|z|)    
ar1 -0.4885462  0.1178534 -4.1454 3.393e-05 ***
ma1 -0.5113439  0.1190161 -4.2964 1.736e-05 ***
ma2 -0.5035010  0.1215041 -4.1439 3.414e-05 ***
ma3  0.0128479  0.0267390  0.4805    0.6309    
ma4  0.0360730  0.0272694  1.3228    0.1859    
ma5 -0.0043872  0.0254778 -0.1722    0.8633    
ma6 -0.0203321  0.0227251 -0.8947    0.3709    
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Hide

```
arima_3113<-arima(diff_bitcoin, order= c(3,1,13), method = "ML")
```

```
possible convergence problem: optim gave code = 1
```

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```
coeftest(arima_3113)
```

```
NaNs produced
```

```
z test of coefficients:

        Estimate  Std. Error z value  Pr(>|z|)    
ar1  -1.16476040          NA      NA        NA    
ar2  -1.09427393          NA      NA        NA    
ar3  -0.35190537          NA      NA        NA    
ma1   0.16819851          NA      NA        NA    
ma2  -0.07952706  0.14158322 -0.5617 0.5743215    
ma3  -0.73989342  0.20599147 -3.5919 0.0003283 ***
ma4  -0.33003433          NA      NA        NA    
ma5   0.05717945  0.02788549  2.0505 0.0403148 *  
ma6   0.06561806  0.02616234  2.5081 0.0121378 *  
ma7  -0.03770188  0.02692439 -1.4003 0.1614273    
ma8  -0.06461817  0.02453722 -2.6335 0.0084516 ** 
ma9  -0.08344904  0.02029650 -4.1115 3.931e-05 ***
ma10  0.01436628          NA      NA        NA    
ma11  0.05643501  0.01902052  2.9671 0.0030066 ** 
ma12 -0.00024086  0.02535800 -0.0095 0.9924214    
ma13 -0.00710597  0.02321772 -0.3061 0.7595604    
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Hide

```
arima_3113_css<-arima(diff_bitcoin, order= c(3,1,13), method = "CSS")
coeftest(arima_3113)
```

```
NaNs produced
```

```


z test of coefficients:

        Estimate  Std. Error z value  Pr(>|z|)    
ar1  -1.16476040          NA      NA        NA    
ar2  -1.09427393          NA      NA        NA    
ar3  -0.35190537          NA      NA        NA    
ma1   0.16819851          NA      NA        NA    
ma2  -0.07952706  0.14158322 -0.5617 0.5743215    
ma3  -0.73989342  0.20599147 -3.5919 0.0003283 ***
ma4  -0.33003433          NA      NA        NA    
ma5   0.05717945  0.02788549  2.0505 0.0403148 *  
ma6   0.06561806  0.02616234  2.5081 0.0121378 *  
ma7  -0.03770188  0.02692439 -1.4003 0.1614273    
ma8  -0.06461817  0.02453722 -2.6335 0.0084516 ** 
ma9  -0.08344904  0.02029650 -4.1115 3.931e-05 ***
ma10  0.01436628          NA      NA        NA    
ma11  0.05643501  0.01902052  2.9671 0.0030066 ** 
ma12 -0.00024086  0.02535800 -0.0095 0.9924214    
ma13 -0.00710597  0.02321772 -0.3061 0.7595604    
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Hide

```
arima_615<-arima(diff_bitcoin, order= c(6,1,5), method = "ML")
coeftest(arima_615)
```

```
NaNs produced
```

```


z test of coefficients:

      Estimate Std. Error  z value  Pr(>|z|)    
ar1 -0.7441772         NA       NA        NA    
ar2 -0.5483430  0.0567078  -9.6696 < 2.2e-16 ***
ar3 -0.9116542  0.0190508 -47.8539 < 2.2e-16 ***
ar4 -0.6481374         NA       NA        NA    
ar5  0.0015324  0.0297068   0.0516   0.95886    
ar6  0.0408808  0.0234579   1.7427   0.08138 .  
ma1 -0.2549561         NA       NA        NA    
ma2 -0.2030475         NA       NA        NA    
ma3  0.3708945  0.0840631   4.4121 1.024e-05 ***
ma4 -0.2509871         NA       NA        NA    
ma5 -0.6372837         NA       NA        NA    
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Hide

```
arima_615_css<-arima(diff_bitcoin, order= c(6,1,5), method = "CSS")
coeftest(arima_615_css)
```

```
NaNs produced
```

```


z test of coefficients:

     Estimate Std. Error z value  Pr(>|z|)    
ar1 -0.341667         NA      NA        NA    
ar2 -0.262355   0.028899 -9.0785 < 2.2e-16 ***
ar3 -0.232400         NA      NA        NA    
ar4 -0.154133         NA      NA        NA    
ar5  0.063605   0.021914  2.9025  0.003702 ** 
ar6  0.087951   0.021545  4.0822 4.461e-05 ***
ma1 -0.664662         NA      NA        NA    
ma2 -0.083549         NA      NA        NA    
ma3 -0.012111         NA      NA        NA    
ma4 -0.052406         NA      NA        NA    
ma5 -0.189283         NA      NA        NA    
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Hide

```
arima_616<-arima(diff_bitcoin, order= c(6,1,6), method = "ML")
coeftest(arima_616)
```

```
NaNs produced
```

```


z test of coefficients:

      Estimate Std. Error  z value  Pr(>|z|)    
ar1 -0.1102474  0.0342143  -3.2223  0.001272 ** 
ar2  0.2889258  0.0359306   8.0412 8.895e-16 ***
ar3 -0.3844821  0.0217800 -17.6530 < 2.2e-16 ***
ar4  0.0032173         NA       NA        NA    
ar5  0.8366165         NA       NA        NA    
ar6  0.0586946  0.0215138   2.7282  0.006367 ** 
ma1 -0.8945848  0.0269328 -33.2155 < 2.2e-16 ***
ma2 -0.4082144         NA       NA        NA    
ma3  0.6983907  0.0579692  12.0476 < 2.2e-16 ***
ma4 -0.3703206         NA       NA        NA    
ma5 -0.8258008         NA       NA        NA    
ma6  0.8005299         NA       NA        NA    
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Hide

```
arima_616_css<-arima(diff_bitcoin, order= c(6,1,6), method = "CSS")
coeftest(arima_616_css)
```

```
NaNs produced
```

```

z test of coefficients:

      Estimate Std. Error z value  Pr(>|z|)
ar1 -0.3212706         NA      NA        NA
ar2 -0.2295952         NA      NA        NA
ar3 -0.2012785         NA      NA        NA
ar4 -0.1573047         NA      NA        NA
ar5 -0.0015744         NA      NA        NA
ar6  0.0785242  0.0200632  3.9138 9.084e-05 ***
ma1 -0.6866234         NA      NA        NA
ma2 -0.1035454         NA      NA        NA
ma3 -0.0079021         NA      NA        NA
ma4 -0.0217153         NA      NA        NA
ma5 -0.1290289         NA      NA        NA
ma6 -0.0542239         NA      NA        NA
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Hide

```
arima_618<-arima(diff_bitcoin, order= c(6,1,8), method = "ML")
```

```
possible convergence problem: optim gave code = 1
```

Hide

```
coeftest(arima_618)
```

```

z test of coefficients:

     Estimate Std. Error z value  Pr(>|z|)
ar1 -0.393971   0.149756 -2.6307 0.0085199 **
ar2 -0.227358   0.083418 -2.7255 0.0064202 **
ar3 -0.018396   0.129931 -0.1416 0.8874065
ar4 -0.053841   0.093406 -0.5764 0.5643317
ar5  0.400007   0.107319  3.7273 0.0001936 ***
ar6  0.802109   0.122479  6.5490 5.793e-11 ***
ma1 -0.609707   0.151562 -4.0228 5.750e-05 ***
ma2 -0.156943   0.188130 -0.8342 0.4041542
ma3 -0.205249   0.149225 -1.3754 0.1689961
ma4  0.050647   0.153672  0.3296 0.7417186
ma5 -0.422838   0.143008 -2.9567 0.0031091 **
ma6 -0.392845   0.205473 -1.9119 0.0558882 .
ma7  0.753024   0.127933  5.8861 3.955e-09 ***
ma8 -0.016078   0.025286 -0.6358 0.5248743
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Hide

```
arima_618_css<-arima(diff_bitcoin, order= c(6,1,8), method = "CSS")
coeftest(arima_618_css)
```

```
NaNs produced
```

```


z test of coefficients:

      Estimate Std. Error z value Pr(>|z|)
ar1 -0.2838156         NA      NA       NA
ar2 -0.2128760         NA      NA       NA
ar3 -0.1935526         NA      NA       NA
ar4 -0.1443392         NA      NA       NA
ar5  0.0153140         NA      NA       NA
ar6  0.0779941         NA      NA       NA
ma1 -0.7194192         NA      NA       NA
ma2 -0.0858318         NA      NA       NA
ma3  0.0037769         NA      NA       NA
ma4 -0.0288544         NA      NA       NA
ma5 -0.1316530         NA      NA       NA
ma6 -0.0374839         NA      NA       NA
ma7 -0.0047976         NA      NA       NA
ma8  0.0015685  0.0162642  0.0964   0.9232
```

Hide

```
arima_1016<-arima(diff_bitcoin, order= c(10,1,6), method = "ML")
```

```
NaNs producedNaNs producedNaNs producedNaNs producedNaNs producedpossible convergence
problem: optim gave code = 1
```

Hide

```
coeftest(arima_1016)
```

```


z test of coefficients:

       Estimate Std. Error  z value  Pr(>|z|)    
ar1  -0.1070716  0.0329680  -3.2477  0.001163 ** 
ar2   0.3599000  0.0338480  10.6328 < 2.2e-16 ***
ar3  -0.3681638  0.0382240  -9.6318 < 2.2e-16 ***
ar4  -0.0010484  0.0361549  -0.0290  0.976866    
ar5   0.9249403  0.0303532  30.4725 < 2.2e-16 ***
ar6   0.0443667  0.0261751   1.6950  0.090076 .  
ar7  -0.0010427  0.0263846  -0.0395  0.968477    
ar8  -0.0103740  0.0258600  -0.4012  0.688304    
ar9   0.0013576  0.0244688   0.0555  0.955754    
ar10 -0.0037546  0.0229796  -0.1634  0.870212    
ma1  -0.8899182  0.0259638 -34.2753 < 2.2e-16 ***
ma2  -0.4856525  0.0185906 -26.1236 < 2.2e-16 ***
ma3   0.7516115  0.0335903  22.3759 < 2.2e-16 ***
ma4  -0.3415365  0.0214433 -15.9274 < 2.2e-16 ***
ma5  -0.9338681  0.0243289 -38.3852 < 2.2e-16 ***
ma6   0.8993799  0.0191379  46.9947 < 2.2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Hide

```
arima_1016_css<-arima(diff_bitcoin, order= c(10,1,6), method = "CSS")
coeftest(arima_1016_css)
```

```
NaNs produced
```

```


z test of coefficients:

       Estimate Std. Error z value  Pr(>|z|)    
ar1  -0.3490949         NA      NA        NA    
ar2  -0.1359056         NA      NA        NA    
ar3  -0.0449492         NA      NA        NA    
ar4  -0.0148113         NA      NA        NA    
ar5   0.0452017  0.0539781  0.8374 0.4023636    
ar6   0.0948000  0.0269796  3.5138 0.0004418 ***
ar7   0.0397702  0.0306320  1.2983 0.1941762    
ar8   0.0169391  0.0288176  0.5878 0.5566641    
ar9   0.0034144  0.0220010  0.1552 0.8766683    
ar10  0.0253351  0.0201764  1.2557 0.2092331    
ma1  -0.6528750         NA      NA        NA    
ma2  -0.2269859         NA      NA        NA    
ma3  -0.0681568         NA      NA        NA    
ma4   0.0013165         NA      NA        NA    
ma5  -0.0192619         NA      NA        NA    
ma6  -0.0361599  0.0612358 -0.5905 0.5548541    
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Hide

```
arima_1018<-arima(diff_bitcoin, order= c(10,1,8), method = "ML")
```

```
possible convergence problem: optim gave code = 1
```

Hide

```
coeftest(arima_1018)
```

```
NaNs produced
```

```

z test of coefficients:

       Estimate Std. Error z value  Pr(>|z|)    
ar1  -1.0580279  0.2652174 -3.9893 6.627e-05 ***
ar2  -0.6203535  0.1765403 -3.5139 0.0004415 ***
ar3  -0.2663226  0.1317981 -2.0207 0.0433123 *  
ar4   0.0473287  0.1758327  0.2692 0.7877998    
ar5   0.5092869  0.1216067  4.1880 2.814e-05 ***
ar6   0.8906283  0.1096701  8.1210 4.625e-16 ***
ar7   0.8124325  0.0421547 19.2726 < 2.2e-16 ***
ar8   0.0437233  0.0487434  0.8970 0.3697138    
ar9  -0.0086742  0.0436390 -0.1988 0.8424408    
ar10 -0.0364045  0.0292512 -1.2445 0.2132981    
ma1   0.0575211  0.2599628  0.2213 0.8248849    
ma2  -0.4517936  0.1013067 -4.4597 8.209e-06 ***
ma3  -0.3423752  0.1469347 -2.3301 0.0197999 *  
ma4  -0.2699640  0.1051433 -2.5676 0.0102410 *  
ma5  -0.4208240         NA      NA        NA    
ma6  -0.3459628  0.1356173 -2.5510 0.0107408 *  
ma7   0.0317830  0.0392138  0.8105 0.4176498    
ma8   0.7416280  0.0540469 13.7219 < 2.2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Hide

```
arima_1018_css<-arima(diff_bitcoin, order= c(10,1,8), method = "CSS")
coeftest(arima_1018_css)
```

```
NaNs produced
```

```

z test of coefficients:

        Estimate  Std. Error z value Pr(>|z|)  
ar1  -0.36163794          NA      NA       NA  
ar2  -0.13726530          NA      NA       NA  
ar3  -0.05336475          NA      NA       NA  
ar4  -0.03413733          NA      NA       NA  
ar5  -0.00049748          NA      NA       NA  
ar6   0.04934181          NA      NA       NA  
ar7   0.02993730          NA      NA       NA  
ar8   0.00530035  0.02153938  0.2461  0.80562  
ar9  -0.00173235  0.01924305 -0.0900  0.92827  
ar10  0.02943148  0.01606255  1.8323  0.06691 .
ma1  -0.64545089          NA      NA       NA  
ma2  -0.22143067          NA      NA       NA  
ma3  -0.06889468          NA      NA       NA  
ma4   0.00180218          NA      NA       NA  
ma5  -0.01164902          NA      NA       NA  
ma6  -0.01665617          NA      NA       NA  
ma7  -0.05325831          NA      NA       NA  
ma8   0.01372279          NA      NA       NA  
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Hide

```
arima_1118<-arima(diff_bitcoin, order= c(11,1,8), method = "ML")
coeftest(arima_1118)
```

```
NaNs produced
```

```

z test of coefficients:

       Estimate Std. Error z value  Pr(>|z|)    
ar1  -0.8633456         NA      NA        NA    
ar2  -0.6216959  0.1981661 -3.1372  0.001705 ** 
ar3  -0.4620711         NA      NA        NA    
ar4   0.0056955  0.1896471  0.0300  0.976041    
ar5   0.3574280  0.1175219  3.0414  0.002355 ** 
ar6   0.5993340         NA      NA        NA    
ar7   0.7609936  0.0979577  7.7686 7.936e-15 ***
ar8   0.0674557  0.0523846  1.2877  0.197850    
ar9   0.0285017  0.0393572  0.7242  0.468955    
ar10  0.0230727  0.0154284  1.4955  0.134794    
ar11  0.0472564  0.0260816  1.8119  0.070007 .  
ma1  -0.1370974         NA      NA        NA    
ma2  -0.2556324         NA      NA        NA    
ma3  -0.1465507         NA      NA        NA    
ma4  -0.4445790         NA      NA        NA    
ma5  -0.3244430         NA      NA        NA    
ma6  -0.1916379         NA      NA        NA    
ma7  -0.1823347         NA      NA        NA    
ma8   0.6822817  0.1020866  6.6834 2.335e-11 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Hide

```
arima_1118_css<-arima(diff_bitcoin, order= c(11,1,8), method = "CSS")
coeftest(arima_1118_css)
```

```
NaNs produced
```

```
z test of coefficients:

        Estimate  Std. Error z value  Pr(>|z|)    
ar1  -0.37205300          NA      NA        NA    
ar2  -0.14583006          NA      NA        NA    
ar3  -0.07757004          NA      NA        NA    
ar4  -0.04557752          NA      NA        NA    
ar5   0.04046838          NA      NA        NA    
ar6   0.22221227          NA      NA        NA    
ar7   0.02103328          NA      NA        NA    
ar8  -0.00085942  0.02218306 -0.0387 0.9690958    
ar9   0.00059370  0.02349342  0.0253 0.9798389    
ar10  0.04024416  0.01797166  2.2393 0.0251356 *  
ar11  0.07398598  0.02012065  3.6771 0.0002359 ***
ma1  -0.63641315          NA      NA        NA    
ma2  -0.22000233          NA      NA        NA    
ma3  -0.05525286          NA      NA        NA    
ma4  -0.00884851          NA      NA        NA    
ma5  -0.05569465          NA      NA        NA    
ma6  -0.15675017          NA      NA        NA    
ma7   0.13514948  0.04154788  3.2529 0.0011425 ** 
ma8  -0.00419563          NA      NA        NA    
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Hide

```
arima_1116<-arima(diff_bitcoin, order= c(11,1,6), method = "ML")
```

```
NaNs producedpossible convergence problem: optim gave code = 1
```

Hide

```
coeftest(arima_1116)
```

```
NaNs produced
```

```

z test of coefficients:

      Estimate Std. Error z value  Pr(>|z|)    
ar1  -0.327599         NA      NA        NA    
ar2  -0.253595         NA      NA        NA    
ar3  -0.139316         NA      NA        NA    
ar4  -0.423766         NA      NA        NA    
ar5  -0.751294         NA      NA        NA    
ar6   0.083193   0.015321  5.4300 5.637e-08 ***
ar7   0.015675   0.022513  0.6963    0.4862    
ar8   0.038652   0.024062  1.6063    0.1082    
ar9   0.053355         NA      NA        NA    
ar10  0.097899   0.022922  4.2709 1.947e-05 ***
ar11  0.097296         NA      NA        NA    
ma1  -0.677563         NA      NA        NA    
ma2  -0.086931         NA      NA        NA    
ma3  -0.098984         NA      NA        NA    
ma4   0.315450         NA      NA        NA    
ma5   0.362828         NA      NA        NA    
ma6  -0.814786         NA      NA        NA    
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Hide

```
arima_1116_css<-arima(diff_bitcoin, order= c(11,1,6), method = "CSS")
coeftest(arima_1116_css)
```

```
NaNs produced
```

```

z test of coefficients:

       Estimate Std. Error z value  Pr(>|z|)    
ar1  -0.5099232         NA      NA        NA    
ar2  -0.0196733         NA      NA        NA    
ar3  -0.1800143         NA      NA        NA    
ar4  -0.2507490         NA      NA        NA    
ar5   0.2655917         NA      NA        NA    
ar6   0.0909077  0.0248950  3.6516 0.0002606 ***
ar7   0.0251950  0.0222152  1.1341 0.2567387    
ar8  -0.0221275  0.0158377 -1.3971 0.1623706    
ar9  -0.0091655  0.0140637 -0.6517 0.5145869    
ar10  0.0563583  0.0189132  2.9798 0.0028839 ** 
ar11  0.0366040  0.0195222  1.8750 0.0607937 .  
ma1  -0.4976789         NA      NA        NA    
ma2  -0.4899818         NA      NA        NA    
ma3   0.1796780         NA      NA        NA    
ma4   0.0904486         NA      NA        NA    
ma5  -0.4940463         NA      NA        NA    
ma6   0.2086988         NA      NA        NA    
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

The AIC values suggests that the best model is ARIMA(6,1,6). In addition, its parameters are mostly significant.

Hide

```
coeftest(arima_616)
```

```
NaNs produced
```

```


z test of coefficients:

      Estimate Std. Error  z value  Pr(>|z|)    
ar1 -0.1102474  0.0342143  -3.2223  0.001272 ** 
ar2  0.2889258  0.0359306   8.0412 8.895e-16 ***
ar3 -0.3844821  0.0217800 -17.6530 < 2.2e-16 ***
ar4  0.0032173         NA       NA        NA    
ar5  0.8366165         NA       NA        NA    
ar6  0.0586946  0.0215138   2.7282  0.006367 ** 
ma1 -0.8945848  0.0269328 -33.2155 < 2.2e-16 ***
ma2 -0.4082144         NA       NA        NA    
ma3  0.6983907  0.0579692  12.0476 < 2.2e-16 ***
ma4 -0.3703206         NA       NA        NA    
ma5 -0.8258008         NA       NA        NA    
ma6  0.8005299         NA       NA        NA    
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Overfitting

In order to make sure we dont miss any parameters, we will over-fit the ARIMA(6,1,6) using ARIMA(6,1,7) and ARIMA(7,1,6)

Hide

```
arima_617<-arima(diff_bitcoin, order= c(6,1,7), method = "ML")
coeftest(arima_617)
```

```
NaNs produced
```

```

z test of coefficients:

     Estimate Std. Error z value Pr(>|z|)
ar1 -0.263753         NA      NA       NA
ar2 -0.145392         NA      NA       NA
ar3 -0.023922         NA      NA       NA
ar4  0.025448         NA      NA       NA
ar5  0.463165         NA      NA       NA
ar6  0.693106         NA      NA       NA
ma1 -0.741741         NA      NA       NA
ma2 -0.114545         NA      NA       NA
ma3 -0.110994         NA      NA       NA
ma4 -0.044691         NA      NA       NA
ma5 -0.404266         NA      NA       NA
ma6 -0.211487         NA      NA       NA
ma7  0.627728         NA      NA       NA
```

Hide

```
arima_617_css<-arima(diff_bitcoin, order= c(6,1,7), method = "CSS")
coeftest(arima_617_css)
```

```

z test of coefficients:

     Estimate Std. Error z value Pr(>|z|)
ar1 -0.352696   0.213393 -1.6528 0.098371 .
ar2 -0.272243   0.254641 -1.0691 0.285013
ar3 -0.236227   0.249057 -0.9485 0.342882
ar4 -0.145609   0.085417 -1.7047 0.088252 .
ar5  0.039149   0.124551  0.3143 0.753280
ar6  0.097376   0.091741  1.0614 0.288499
ma1 -0.654676   0.213312 -3.0691 0.002147 **
ma2 -0.083698   0.450071 -0.1860 0.852471
ma3 -0.016965   0.496841 -0.0341 0.972760
ma4 -0.068865   0.138735 -0.4964 0.619629
ma5 -0.159069   0.188001 -0.8461 0.397492
ma6 -0.032049   0.142881 -0.2243 0.822518
ma7  0.013214   0.086694  0.1524 0.878852
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Hide

```
arima_716<-arima(diff_bitcoin, order= c(7,1,6), method = "ML")
coeftest(arima_716)
```

```
NaNs produced
```

```

z test of coefficients:

      Estimate Std. Error   z value Pr(>|z|)    
ar1 -0.2081813         NA        NA       NA    
ar2  0.4045530  0.0417963    9.6792  < 2e-16 ***
ar3 -0.5362832  0.0364985  -14.6933  < 2e-16 ***
ar4  0.0531509  0.0341931    1.5544  0.12008    
ar5  0.8570787  0.0323403   26.5018  < 2e-16 ***
ar6  0.0454674  0.0262942    1.7292  0.08378 .  
ar7  0.0245398  0.0234689    1.0456  0.29573    
ma1 -0.7935915         NA        NA       NA    
ma2 -0.6264487         NA        NA       NA    
ma3  0.9544591  0.0453297   21.0559  < 2e-16 ***
ma4 -0.5374908  0.0393531  -13.6582  < 2e-16 ***
ma5 -0.8223068  0.0037976 -216.5321  < 2e-16 ***
ma6  0.8253823  0.0455265   18.1297  < 2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Hide

```
arima_716_css<-arima(diff_bitcoin, order= c(7,1,6), method = "CSS")
coeftest(arima_716_css)
```

```
NaNs produced
```

```

z test of coefficients:

     Estimate Std. Error z value  Pr(>|z|)    
ar1 -0.347029         NA      NA        NA    
ar2 -0.131095         NA      NA        NA    
ar3 -0.102198         NA      NA        NA    
ar4 -0.020768         NA      NA        NA    
ar5  0.072630         NA      NA        NA    
ar6  0.098522   0.021007  4.6901 2.731e-06 ***
ar7  0.015358   0.019040  0.8066    0.4199    
ma1 -0.652437         NA      NA        NA    
ma2 -0.220601         NA      NA        NA    
ma3 -0.011025         NA      NA        NA    
ma4 -0.057397         NA      NA        NA    
ma5 -0.070881         NA      NA        NA    
ma6  0.010621         NA      NA        NA    
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

```
Both ARIMA(7,1,6) and ARIMA(6,1,7) showed that the additional parameters are insignid
icant in both cases of Moving-avarage component and Auto-regressive component.
```

Resisuals analysis of ARIMA(6,1,6)

Hide

```
residual.analysis <- function(model, std = TRUE,start = 2, class = c("ARIMA","GARCH",
"ARMA-GARCH")[1]){
  # If you have an output from arima() function use class = "ARIMA"
  # If you have an output from garch() function use class = "GARCH"
  # If you have an output from ugarchfit() function use class = "ARMA-GARCH"
  if (class == "ARIMA"){
    if (std == TRUE){
      res.model = rstandard(model)
    }else{
      res.model = residuals(model)
    }
  }else if (class == "GARCH"){
    res.model = model$residuals[start:model$n.used]
  }else if (class == "ARMA-GARCH"){
    res.model = model@fit$residuals
  }else {
    stop("The argument 'class' must be either 'ARIMA' or 'GARCH' ")
  }
  par(mfrow=c(3,2))
  plot(res.model,type='o',ylab='Standardised residuals', main="Time series plot of st
andardised residuals")
  abline(h=0)
  hist(res.model,main="Histogram of standardised residuals")
  acf(res.model,main="ACF of standardised residuals")
  pacf(res.model,main="PACF of standardised residuals")
  qqnorm(res.model,main="QQ plot of standardised residuals")
  qqline(res.model, col = 2)
  print(shapiro.test(res.model))
  k=0
  LBQPlot(res.model, lag.max = 30, StartLag = k + 1, k = 0, SquaredQ = FALSE)
}
```

Hide

```
r_diff_log_bicoin<-arima_616$residuals
```

Hide

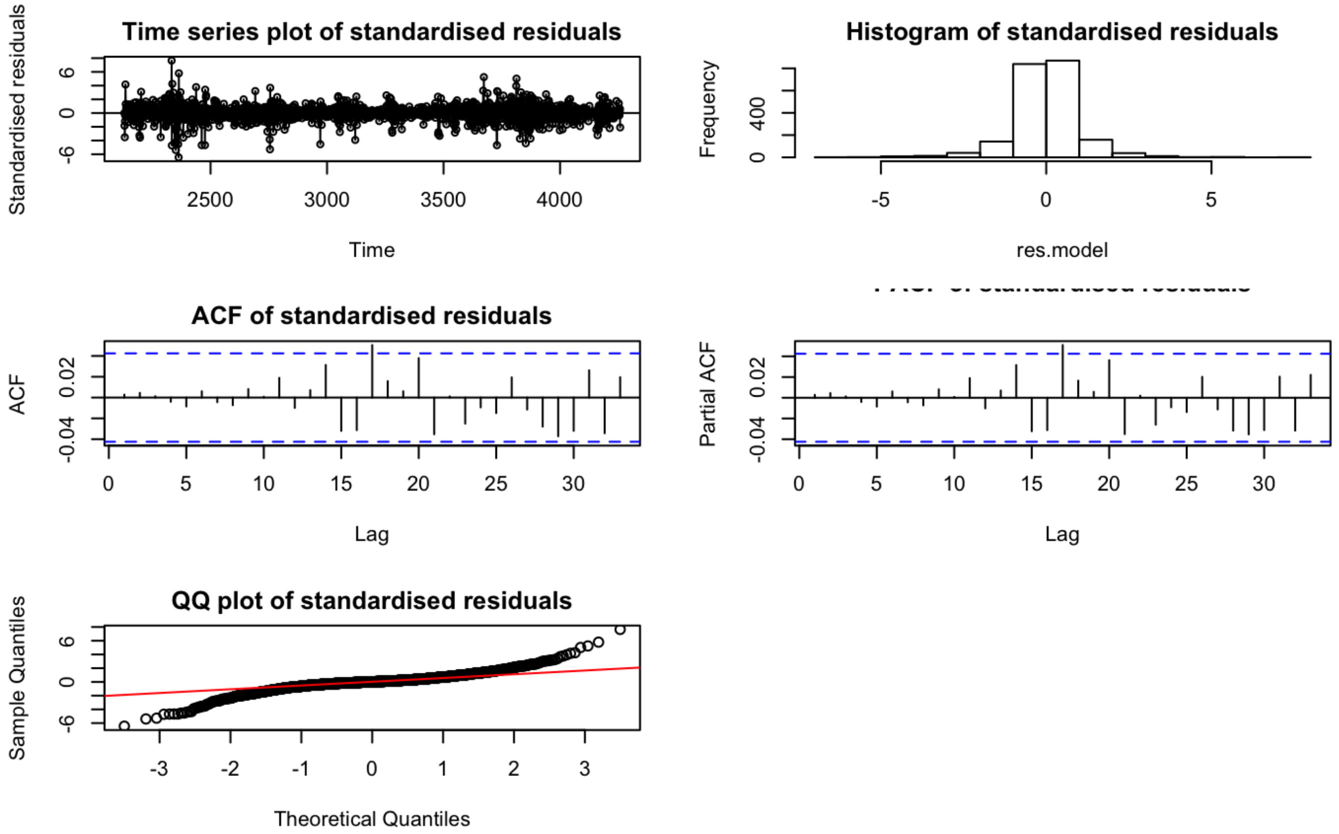
```
residual.analysis(arima_616, std = TRUE,start = 1)
```

```


    Shapiro-Wilk normality test

data:  res.model
W = 0.89374, p-value < 2.2e-16
```

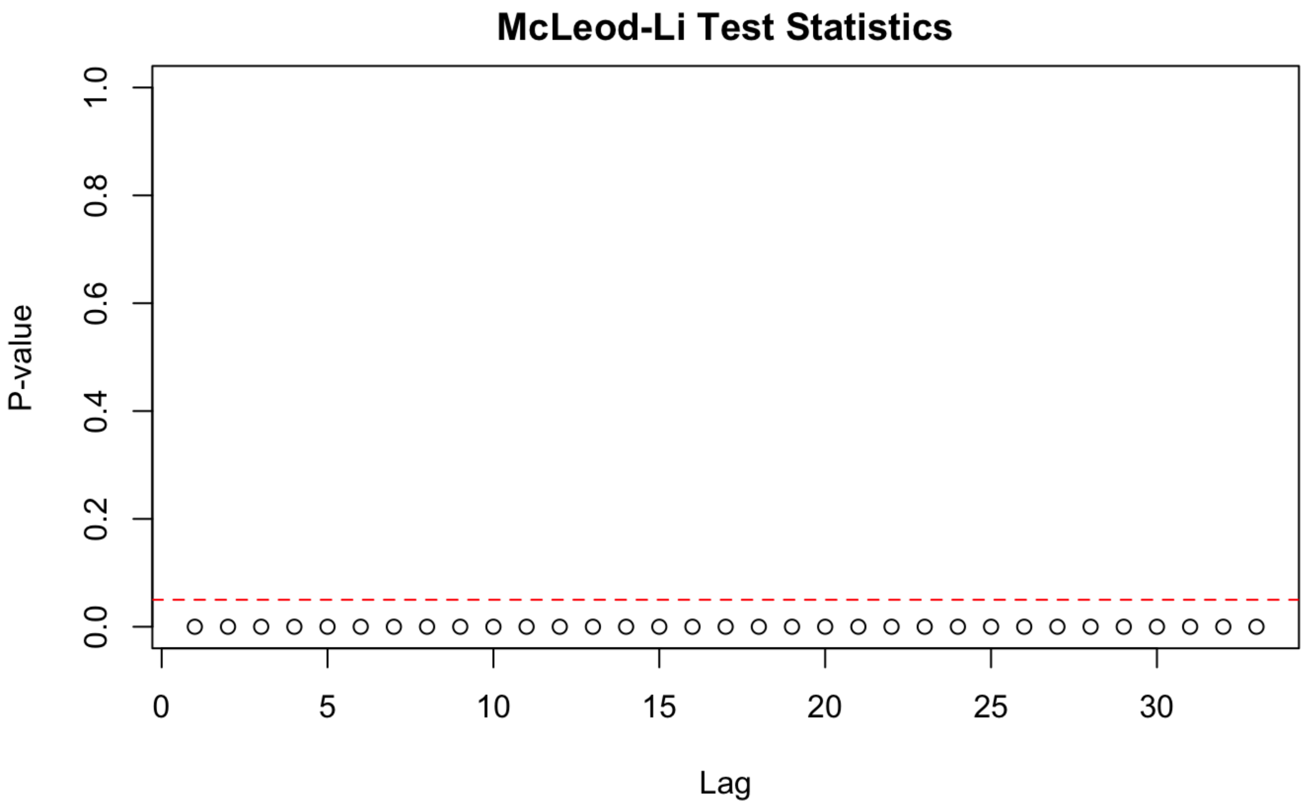
```
Error in LBQPlot(res.model, lag.max = 30, StartLag = k + 1, k = 0, SquaredQ = FALSE)
:
  could not find function "LBQPlot"
```



```
    The residuals of ARIMA(6,1,6) passed most of the assumptions. However we can obse
rve the thick tails in QQ-plot, therefore we will fit an GARCH model with the residua
ls.
```

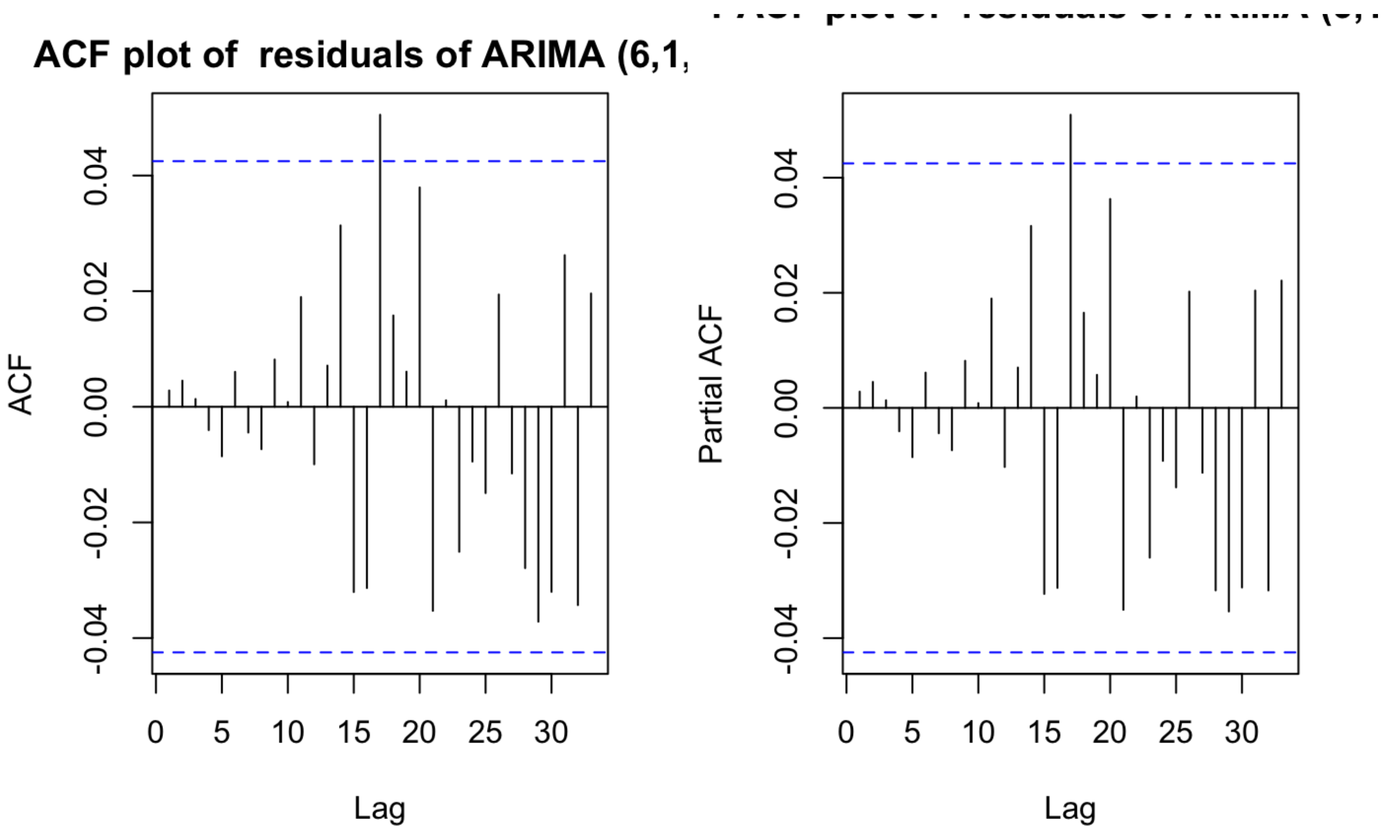
Hide

```
McLeod.Li.test(y=r_diff_log_bicoin,main="McLeod-Li Test Statistics")
```



Hide

```
par(mfrow=c(1,2))
acf(r_diff_log_bicoin,main='ACF plot of  residuals of ARIMA (6,1,6)')
pacf(r_diff_log_bicoin,main='PACF plot of  residuals of ARIMA (6,1,6)')
```



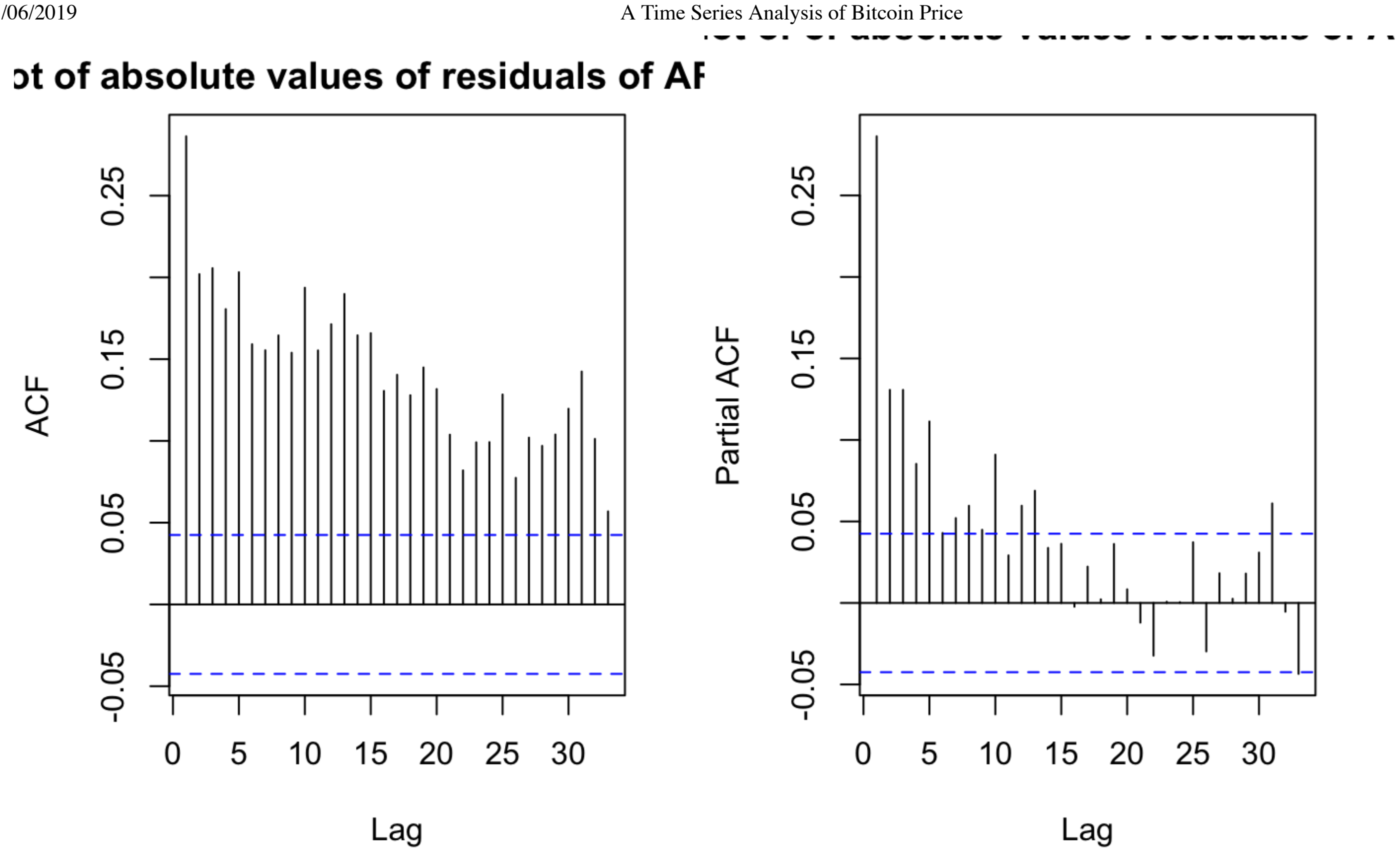
```
In order to confirm the effect of change in variance of the residuals, we will consid
er the ACF and PACF plots of the absolute values and squared values of the residuals.
```

Hide

```
abs_r_bitcoin<-abs(r_diff_log_bicoin)
squared_r_bitcoin<-r_diff_log_bicoin^2
```

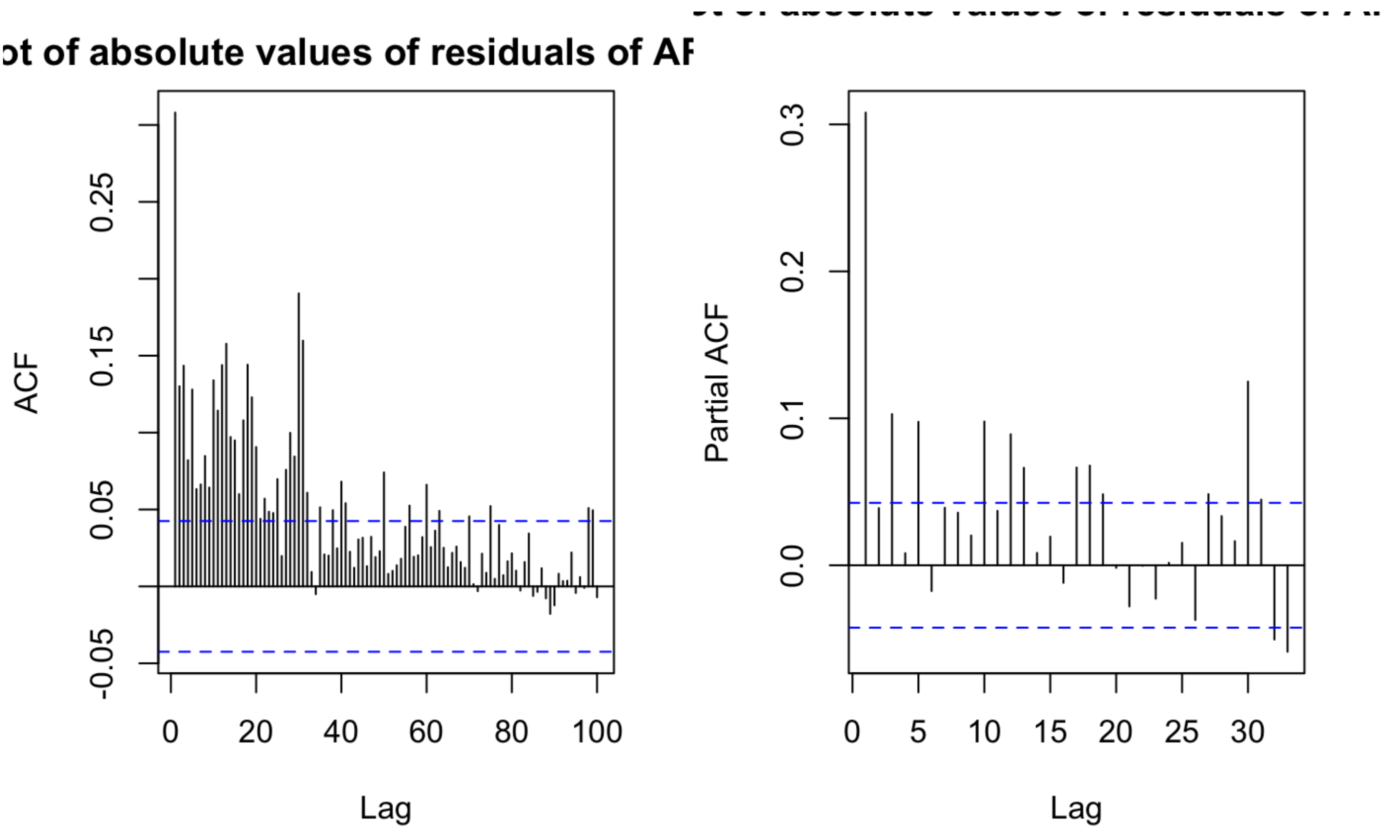
Hide

```
par(mfrow=c(1,2))
acf(abs_r_bitcoin,main='ACF plot of absolute values of residuals of ARIMA (6,1,6)')
pacf(abs_r_bitcoin,main='PACF plot of of absolute values residuals of ARIMA (6,1,6)')
```



Hide

```
par(mfrow=c(1,2))
acf(squared_r_bitcoin,lag.max = 100,,main='ACF plot of absolute values of residuals of ARIMA (6,1,6)')
pacf(squared_r_bitcoin,,main='ACF plot of absolute values of residuals of ARIMA (6,1,6)')
```



```
  We can confirm the ARCH effect by looking the ACF and PACF plots of both absolute v
alues and squared values of the residuals of ARIMA(6,1,6)
```

Hide

```
par(mfrow=c(1,2))
eacf(abs_r_bitcoin)
```

```
AR/MA
  0 1 2 3 4 5 6 7 8 9 10 11 12 13
0 x x x x x x x x x x x  x  x  x 
1 x x o o x o o o o x o  o  o  o 
2 x x o o o o o o o o o  o  o  o 
3 x x o o o o o o o o o  o  o  o 
4 x x o x o o o o o o o  o  o  o 
5 x x x x o x o o o o o  o  o  o 
6 x o x x x x o o o o o  o  o  o 
7 x x o o x x x o o o o  o  o  o 
```

Hide

```
eacf(squared_r_bitcoin)
```

```
AR/MA
  0 1 2 3 4 5 6 7 8 9 10 11 12 13
0 x x x x x x x x x x x  x  x  x 
1 x x x x x x o o o x o  o  x  o 
2 x x x o x x o o o o o  o  x  o 
3 x x o o o x o o o o o  o  x  o 
4 x x o x o o o o o o o  o  x  o 
5 x x x x x x o o o o o  o  o  o 
6 x x x x x o o o o o o  o  o  o 
7 x x x x x x o x o o o  o  o  o 
```

```
Based on EACF plots, we can suggest GARCH (2, 2), GARCH (3, 3), GARCH (4, 4), GARCH
(3, 2), GARCH (1, 1),GARCH (2, 1),
```

Hide

```
model1<-ugarchspec(variance.model = list(model = "sGARCH", garchOrder = c(2, 2)),
                   mean.model = list(armaOrder = c(6, 6), include.mean = FALSE),
                   distribution.model = "norm")
m.66_22<-ugarchfit(spec = model1, data = diff_bitcoin, out.sample = 1000)
m.66_22
```

```
*---------------------------------*
*          GARCH Model Fit        *
*---------------------------------*

Conditional Variance Dynamics
-----------------------------------
GARCH Model : sGARCH(2,2)
Mean Model  : ARFIMA(6,0,6)
Distribution    : norm

Optimal Parameters
------------------------------------
        Estimate  Std. Error   t value Pr(>|t|)
ar1     0.007479    0.033679   0.22208 0.824253
ar2    -0.014131    0.038632  -0.36579 0.714519
ar3    -0.511308    0.051655  -9.89852 0.000000
ar4     0.116980    0.040488   2.88927 0.003861
ar5    -0.136944    0.029711  -4.60923 0.000004
ar6    -0.770596    0.016447 -46.85412 0.000000
ma1     0.015144    0.020337   0.74467 0.456473
ma2    -0.007986    0.021254  -0.37573 0.707114
ma3     0.539130    0.034991  15.40761 0.000000
ma4    -0.078521    0.029309  -2.67904 0.007383
ma5     0.094843    0.018760   5.05568 0.000000
ma6     0.885261    0.017674  50.08833 0.000000
omega   0.000067    0.000023   2.88665 0.003894
alpha1  0.256015    0.045621   5.61173 0.000000
alpha2  0.024743    0.029566   0.83688 0.402660
beta1   0.095063    0.062740   1.51518 0.129726
beta2   0.623179    0.052826  11.79682 0.000000

Robust Standard Errors:
        Estimate  Std. Error   t value Pr(>|t|)
ar1     0.007479    0.055028   0.13592 0.891886
ar2    -0.014131    0.075645  -0.18681 0.851808
ar3    -0.511308    0.087659  -5.83295 0.000000
ar4     0.116980    0.071055   1.64633 0.099696
ar5    -0.136944    0.045143  -3.03354 0.002417
ar6    -0.770596    0.055003 -14.01014 0.000000
ma1     0.015144    0.037066   0.40858 0.682851
ma2    -0.007986    0.048041  -0.16623 0.867976
ma3     0.539130    0.061880   8.71256 0.000000
ma4    -0.078521    0.051532  -1.52372 0.127579
ma5     0.094843    0.028845   3.28799 0.001009
ma6     0.885261    0.024110  36.71734 0.000000
omega   0.000067    0.000058   1.14583 0.251864
alpha1  0.256015    0.084253   3.03863 0.002377
alpha2  0.024743    0.053085   0.46610 0.641143
beta1   0.095063    0.079187   1.20048 0.229952
beta2   0.623179    0.061346  10.15838 0.000000

LogLikelihood : 2136.361

Information Criteria
------------------------------------
```

```
Akaike       -3.7544
Bayes        -3.6787
Shibata      -3.7548
Hannan-Quinn -3.7258

Weighted Ljung-Box Test on Standardized Residuals
------------------------------------
                         statistic p-value
Lag[1]                       2.003 0.15703
Lag[2*(p+q)+(p+q)-1][35]    26.208 0.00000
Lag[4*(p+q)+(p+q)-1][59]    38.924 0.01949
d.o.f=12
H0 : No serial correlation

Weighted Ljung-Box Test on Standardized Squared Residuals
------------------------------------
                         statistic p-value
Lag[1]                   0.0008931  0.9762
Lag[2*(p+q)+(p+q)-1][11] 2.9790862  0.8712
Lag[4*(p+q)+(p+q)-1][19] 6.6663180  0.8158
d.o.f=4

Weighted ARCH LM Tests
------------------------------------
            Statistic Shape Scale P-Value
ARCH Lag[5]  0.009182 0.500 2.000  0.9237
ARCH Lag[7]  0.593404 1.473 1.746  0.8717
ARCH Lag[9]  1.278406 2.402 1.619  0.8896

Nyblom stability test
------------------------------------
Joint Statistic:  4.5634
Individual Statistics:
ar1    0.03173
ar2    0.08223
ar3    0.04481
ar4    0.03122
ar5    0.19867
ar6    0.05594
ma1    0.10657
ma2    0.07160
ma3    0.02653
ma4    0.03218
ma5    0.24351
ma6    0.04426
omega  0.23742
alpha1 0.17708
alpha2 0.33056
beta1  0.15362
beta2  0.18659

Asymptotic Critical Values (10% 5% 1%)
Joint Statistic:         3.64 3.95 4.51
Individual Statistic:    0.35 0.47 0.75

Sign Bias Test
------------------------------------
```

	t-value <dbl>	prob <dbl>	sig <chr>
Sign Bias	0.14720453	0.8829970	
Negative Sign Bias	0.07355792	0.9413752	
Positive Sign Bias	0.49759565	0.6188664	
Joint Effect	0.27129248	0.9653340	

4 rows

```
Adjusted Pearson Goodness-of-Fit Test:
------------------------------------
  group statistic p-value(g-1)
1    20     146.6    9.794e-22
2    30     159.2    6.452e-20
3    40     167.3    7.855e-18
4    50     183.5    1.974e-17


Elapsed time : 0.6826708
```

Hide

```
model2<-ugarchspec(variance.model = list(model = "sGARCH", garchOrder = c(3, 2)),
                   mean.model = list(armaOrder = c(6, 6), include.mean = FALSE),
                   distribution.model = "norm")
m.66_32<-ugarchfit(spec = model2, data = diff_bitcoin, out.sample = 1000)
m.66_32
```

```
*---------------------------------*
*          GARCH Model Fit        *
*---------------------------------*

Conditional Variance Dynamics
-----------------------------------
GARCH Model : sGARCH(3,2)
Mean Model  : ARFIMA(6,0,6)
Distribution    : norm

Optimal Parameters
------------------------------------
        Estimate  Std. Error   t value Pr(>|t|)
ar1    -0.774998    0.056443 -13.73057 0.000000
ar2    -0.828332    0.066255 -12.50214 0.000000
ar3    -0.935671    0.080415 -11.63559 0.000000
ar4    -0.728156    0.082568  -8.81884 0.000000
ar5    -0.798732    0.074605 -10.70614 0.000000
ar6    -0.741477    0.065188 -11.37438 0.000000
ma1     0.790832    0.047626  16.60500 0.000000
ma2     0.798321    0.061764  12.92544 0.000000
ma3     0.930513    0.069718  13.34686 0.000000
ma4     0.734524    0.067523  10.87812 0.000000
ma5     0.774029    0.061881  12.50833 0.000000
ma6     0.830963    0.045030  18.45367 0.000000
omega   0.000050    0.000032   1.55805 0.119221
alpha1  0.164459    0.045300   3.63045 0.000283
alpha2  0.006696    0.030498   0.21956 0.826212
alpha3  0.060511    0.107366   0.56359 0.573031
beta1   0.137545    0.073379   1.87446 0.060867
beta2   0.629789    0.073485   8.57029 0.000000

Robust Standard Errors:
        Estimate  Std. Error    t value Pr(>|t|)
ar1    -0.774998    0.065681 -11.799405 0.000000
ar2    -0.828332    0.098486  -8.410671 0.000000
ar3    -0.935671    0.130686  -7.159694 0.000000
ar4    -0.728156    0.119771  -6.079553 0.000000
ar5    -0.798732    0.135745  -5.884042 0.000000
ar6    -0.741477    0.101417  -7.311177 0.000000
ma1     0.790832    0.074185  10.660311 0.000000
ma2     0.798321    0.103458   7.716356 0.000000
ma3     0.930513    0.135432   6.870688 0.000000
ma4     0.734524    0.102125   7.192399 0.000000
ma5     0.774029    0.127933   6.050263 0.000000
ma6     0.830963    0.061048  13.611525 0.000000
omega   0.000050    0.000150   0.335707 0.737092
alpha1  0.164459    0.143160   1.148778 0.250648
alpha2  0.006696    0.109776   0.060999 0.951360
alpha3  0.060511    0.494540   0.122358 0.902616
beta1   0.137545    0.235096   0.585061 0.558507
beta2   0.629789    0.248201   2.537418 0.011167

LogLikelihood : 2135.873

Information Criteria
```

```
------------------------------------

Akaike       -3.7518
Bayes        -3.6716
Shibata      -3.7523
Hannan-Quinn -3.7215

Weighted Ljung-Box Test on Standardized Residuals
------------------------------------
                         statistic   p-value
Lag[1]                       1.628 2.020e-01
Lag[2*(p+q)+(p+q)-1][35]    21.761 7.998e-10
Lag[4*(p+q)+(p+q)-1][59]    33.065 2.181e-01
d.o.f=12
H0 : No serial correlation

Weighted Ljung-Box Test on Standardized Squared Residuals
------------------------------------
                         statistic p-value
Lag[1]                      0.2021  0.6530
Lag[2*(p+q)+(p+q)-1][14]    3.2965  0.9375
Lag[4*(p+q)+(p+q)-1][24]    6.7198  0.9440
d.o.f=5

Weighted ARCH LM Tests
------------------------------------
             Statistic Shape Scale P-Value
ARCH Lag[6]     0.4006 0.500 2.000  0.5268
ARCH Lag[8]     0.5658 1.480 1.774  0.8833
ARCH Lag[10]    2.5942 2.424 1.650  0.6578

Nyblom stability test
------------------------------------
Joint Statistic:  4.8471
Individual Statistics:
ar1    0.17437
ar2    0.81219
ar3    0.67054
ar4    0.02466
ar5    0.03902
ar6    0.03891
ma1    0.35032
ma2    0.32062
ma3    0.67818
ma4    0.02621
ma5    0.04402
ma6    0.05107
omega  0.21442
alpha1 0.16375
alpha2 0.30672
alpha3 0.12796
beta1  0.15315
beta2  0.18933

Asymptotic Critical Values (10% 5% 1%)
Joint Statistic:         3.83 4.14 4.73
Individual Statistic:    0.35 0.47 0.75
```

```
Sign Bias Test
------------------------------------
```

	t-value <dbl>	prob <dbl>	sig <chr>
Sign Bias	0.4170473	0.6767234	
Negative Sign Bias	0.3552242	0.7224883	
Positive Sign Bias	0.4495659	0.6531102	
Joint Effect	0.3359702	0.9531274	

4 rows

```
Adjusted Pearson Goodness-of-Fit Test:
------------------------------------
  group statistic p-value(g-1)
1    20     172.3    9.863e-27
2    30     193.0    3.839e-26
3    40     205.0    2.091e-24
4    50     216.8    5.543e-23


Elapsed time : 0.6455162
```

Hide

```
#AIC -3.7518
```

Hide

```
model3<-ugarchspec(variance.model = list(model = "sGARCH", garchOrder = c(3,3 )),
                   mean.model = list(armaOrder = c(6, 6), include.mean = FALSE),
                   distribution.model = "norm")
m.66_33<-ugarchfit(spec = model3, data = diff_bitcoin, out.sample = 1000)
m.66_33
```

```
*---------------------------------*
*          GARCH Model Fit        *
*---------------------------------*

Conditional Variance Dynamics
-----------------------------------
GARCH Model : sGARCH(3,3)
Mean Model  : ARFIMA(6,0,6)
Distribution    : norm

Optimal Parameters
------------------------------------
        Estimate  Std. Error   t value Pr(>|t|)
ar1    -0.028927    0.303540 -0.095298 0.924078
ar2     0.729862    0.256213  2.848649 0.004391
ar3    -0.524507    0.210807 -2.488085 0.012843
ar4    -0.623464    0.229328 -2.718657 0.006555
ar5     0.504298    0.209237  2.410180 0.015945
ar6     0.235849    0.245791  0.959548 0.337283
ma1     0.063265    0.304899  0.207496 0.835623
ma2    -0.742497    0.262102 -2.832854 0.004613
ma3     0.534673    0.225812  2.367779 0.017895
ma4     0.713028    0.231495  3.080099 0.002069
ma5    -0.495022    0.231648 -2.136956 0.032602
ma6    -0.195702    0.270504 -0.723472 0.469390
omega   0.000074    0.000019  3.807389 0.000140
alpha1  0.138321    0.029020  4.766458 0.000002
alpha2  0.028311    0.011121  2.545736 0.010905
alpha3  0.154480    0.017668  8.743373 0.000000
beta1   0.000000    0.118130  0.000000 1.000000
beta2   0.556096    0.062423  8.908493 0.000000
beta3   0.121791    0.071979  1.692047 0.090637

Robust Standard Errors:
        Estimate  Std. Error  t value Pr(>|t|)
ar1    -0.028927    0.204108 -0.14172 0.887298
ar2     0.729862    0.326300  2.23678 0.025300
ar3    -0.524507    0.160890 -3.26004 0.001114
ar4    -0.623464    0.132398 -4.70902 0.000002
ar5     0.504298    0.282216  1.78692 0.073950
ar6     0.235849    0.221124  1.06659 0.286156
ma1     0.063265    0.203781  0.31046 0.756214
ma2    -0.742497    0.337509 -2.19993 0.027812
ma3     0.534673    0.154345  3.46413 0.000532
ma4     0.713028    0.143738  4.96061 0.000001
ma5    -0.495022    0.288252 -1.71733 0.085920
ma6    -0.195702    0.257601 -0.75971 0.447428
omega   0.000074    0.000067  1.09807 0.272175
alpha1  0.138321    0.045555  3.03638 0.002394
alpha2  0.028311    0.063197  0.44798 0.654165
alpha3  0.154480    0.053897  2.86623 0.004154
beta1   0.000000    0.316242  0.00000 1.000000
beta2   0.556096    0.092938  5.98352 0.000000
beta3   0.121791    0.242739  0.50174 0.615852

LogLikelihood : 2134.689
```

```
Information Criteria
------------------------------------

Akaike       -3.7479
Bayes        -3.6633
Shibata      -3.7485
Hannan-Quinn -3.7159

Weighted Ljung-Box Test on Standardized Residuals
------------------------------------
                         statistic p-value
Lag[1]                      0.3556 0.55097
Lag[2*(p+q)+(p+q)-1][35]   19.3082 0.01415
Lag[4*(p+q)+(p+q)-1][59]   32.6076 0.25082
d.o.f=12
H0 : No serial correlation

Weighted Ljung-Box Test on Standardized Squared Residuals
------------------------------------
                         statistic p-value
Lag[1]                      0.6428  0.4227
Lag[2*(p+q)+(p+q)-1][17]    5.6619  0.8332
Lag[4*(p+q)+(p+q)-1][29]    9.5541  0.9017
d.o.f=6

Weighted ARCH LM Tests
------------------------------------
             Statistic Shape Scale P-Value
ARCH Lag[7]     0.2812 0.500 2.000  0.5959
ARCH Lag[9]     1.3117 1.485 1.796  0.6860
ARCH Lag[11]    2.8547 2.440 1.677  0.6216

Nyblom stability test
------------------------------------
Joint Statistic:  9.8614
Individual Statistics:
ar1    0.12494
ar2    0.19604
ar3    0.39172
ar4    0.04197
ar5    0.12702
ar6    0.08535
ma1    0.09367
ma2    0.06817
ma3    0.37581
ma4    0.05093
ma5    0.04913
ma6    0.10845
omega  0.28868
alpha1 0.19590
alpha2 0.60316
alpha3 0.19059
beta1  0.18461
beta2  0.29155
beta3  0.17201

Asymptotic Critical Values (10% 5% 1%)
```

```
Joint Statistic:         4.03 4.33 4.92
Individual Statistic:    0.35 0.47 0.75

Sign Bias Test
------------------------------------
```

	t-value <dbl>	prob <dbl>	sig <chr>
Sign Bias	0.4230412	0.6723461	
Negative Sign Bias	0.7578375	0.4487071	
Positive Sign Bias	0.3179514	0.7505808	
Joint Effect	0.6775386	0.8784739	

4 rows

```
Adjusted Pearson Goodness-of-Fit Test:
------------------------------------
  group statistic p-value(g-1)
1    20     161.5    1.272e-24
2    30     174.0    1.302e-22
3    40     192.5    3.489e-22
4    50     224.4    2.840e-24


Elapsed time : 0.777642
```

Hide

```
#AIC-3.7479
```

Hide

```
model4<-ugarchspec(variance.model = list(model = "sGARCH", garchOrder = c(4, 4)),
                   mean.model = list(armaOrder = c(6, 6), include.mean = FALSE),
                   distribution.model = "norm")
m.66_44<-ugarchfit(spec = model4, data = diff_bitcoin, out.sample = 1000)
m.66_44
```

```
*---------------------------------*
*          GARCH Model Fit        *
*---------------------------------*

Conditional Variance Dynamics
-----------------------------------
GARCH Model : sGARCH(4,4)
Mean Model  : ARFIMA(6,0,6)
Distribution    : norm

Optimal Parameters
------------------------------------
        Estimate  Std. Error     t value Pr(>|t|)
ar1     1.403285    0.026491  5.2972e+01 0.000000
ar2    -1.765675    0.045468 -3.8833e+01 0.000000
ar3     1.470757    0.053704  2.7386e+01 0.000000
ar4    -1.027545    0.065469 -1.5695e+01 0.000000
ar5     0.282550    0.054715  5.1641e+00 0.000000
ar6     0.210125    0.028168  7.4597e+00 0.000000
ma1    -1.376436    0.000301 -4.5704e+03 0.000000
ma2     1.715834    0.002334  7.3508e+02 0.000000
ma3    -1.389857    0.000403 -3.4510e+03 0.000000
ma4     0.962673    0.011339  8.4899e+01 0.000000
ma5    -0.188691    0.029283 -6.4437e+00 0.000000
ma6    -0.232419    0.003119 -7.4515e+01 0.000000
omega   0.000102    0.000035  2.9607e+00 0.003070
alpha1  0.134056    0.028064  4.7769e+00 0.000002
alpha2  0.084183    0.034687  2.4269e+00 0.015227
alpha3  0.231427    0.024237  9.5486e+00 0.000000
alpha4  0.000000    0.029914  0.0000e+00 1.000000
beta1   0.000000    0.118843  1.0000e-06 1.000000
beta2   0.000000    0.083850  2.0000e-06 0.999998
beta3   0.135675    0.058125  2.3342e+00 0.019586
beta4   0.413658    0.072285  5.7226e+00 0.000000

Robust Standard Errors:
        Estimate  Std. Error     t value Pr(>|t|)
ar1     1.403285    0.031985  4.3874e+01 0.000000
ar2    -1.765675    0.051980 -3.3969e+01 0.000000
ar3     1.470757    0.065411  2.2485e+01 0.000000
ar4    -1.027545    0.098210 -1.0463e+01 0.000000
ar5     0.282550    0.095010  2.9739e+00 0.002940
ar6     0.210125    0.035028  5.9987e+00 0.000000
ma1    -1.376436    0.000542 -2.5387e+03 0.000000
ma2     1.715834    0.008148  2.1060e+02 0.000000
ma3    -1.389857    0.000650 -2.1383e+03 0.000000
ma4     0.962673    0.024575  3.9172e+01 0.000000
ma5    -0.188691    0.063839 -2.9558e+00 0.003119
ma6    -0.232419    0.014827 -1.5675e+01 0.000000
omega   0.000102    0.000122  8.4085e-01 0.400431
alpha1  0.134056    0.048608  2.7579e+00 0.005817
alpha2  0.084183    0.091595  9.1909e-01 0.358051
alpha3  0.231427    0.081642  2.8347e+00 0.004587
alpha4  0.000000    0.132387  0.0000e+00 1.000000
beta1   0.000000    0.311923  0.0000e+00 1.000000
beta2   0.000000    0.220024  1.0000e-06 0.999999
```

```
beta3   0.135675    0.183040  7.4123e-01 0.458553
beta4   0.413658    0.134919  3.0660e+00 0.002170

LogLikelihood : 2132.915

Information Criteria
------------------------------------

Akaike       -3.7412
Bayes        -3.6477
Shibata      -3.7419
Hannan-Quinn -3.7059

Weighted Ljung-Box Test on Standardized Residuals
------------------------------------
                         statistic p-value
Lag[1]                       1.142 0.28514
Lag[2*(p+q)+(p+q)-1][35]    19.051 0.03816
Lag[4*(p+q)+(p+q)-1][59]    32.655 0.24728
d.o.f=12
H0 : No serial correlation

Weighted Ljung-Box Test on Standardized Squared Residuals
------------------------------------
                         statistic p-value
Lag[1]                      0.5594  0.4545
Lag[2*(p+q)+(p+q)-1][23]    6.3455  0.9443
Lag[4*(p+q)+(p+q)-1][39]    9.5837  0.9925
d.o.f=8

Weighted ARCH LM Tests
------------------------------------
             Statistic Shape Scale P-Value
ARCH Lag[9]     0.8979 0.500  2.00  0.3434
ARCH Lag[11]    2.7923 1.490  1.83  0.3804
ARCH Lag[13]    3.4708 2.459  1.72  0.5331

Nyblom stability test
------------------------------------
Joint Statistic:  no.parameters>20 (not available)
Individual Statistics:
ar1    0.29265
ar2    0.23016
ar3    0.11325
ar4    0.05889
ar5    0.10627
ar6    0.12111
ma1    0.08249
ma2    0.24730
ma3    0.09690
ma4    0.06630
ma5    0.10638
ma6    0.03475
omega  0.19216
alpha1 0.21495
alpha2 0.44549
alpha3 0.08574
alpha4 0.40690
```

```
beta1  0.11432
beta2  0.17676
beta3  0.15101
beta4  0.23598

Asymptotic Critical Values (10% 5% 1%)
Individual Statistic:    0.35 0.47 0.75

Sign Bias Test
------------------------------------
```

	t-value	prob	sig
	<dbl>	<dbl>	<chr>
Sign Bias	1.2074786	0.2275019	
Negative Sign Bias	0.1010178	0.9195544	
Positive Sign Bias	0.2524713	0.8007230	
Joint Effect	1.8335798	0.6076550	

4 rows

```
Adjusted Pearson Goodness-of-Fit Test:
------------------------------------
  group statistic p-value(g-1)
1    20     178.3    6.797e-28
2    30     204.7    2.378e-28
3    40     221.3    2.523e-27
4    50     237.6    1.461e-26


Elapsed time : 1.132892
```

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```
#AIC -3.7412
```

Hide

```
model5<-ugarchspec(variance.model = list(model = "sGARCH", garchOrder = c(1, 1)),
                   mean.model = list(armaOrder = c(6, 6), include.mean = FALSE),
                   distribution.model = "norm")
m.66_11<-ugarchfit(spec = model5, data = diff_bitcoin, out.sample = 1000)
m.66_11
```

```
*---------------------------------*
*          GARCH Model Fit        *
*---------------------------------*

Conditional Variance Dynamics
-----------------------------------
GARCH Model : sGARCH(1,1)
Mean Model  : ARFIMA(6,0,6)
Distribution    : norm

Optimal Parameters
------------------------------------
        Estimate  Std. Error  t value Pr(>|t|)
ar1    -0.769656    0.083030  -9.2697 0.000000
ar2    -0.805025    0.088364  -9.1103 0.000000
ar3    -0.937002    0.111579  -8.3976 0.000000
ar4    -0.701832    0.092354  -7.5993 0.000000
ar5    -0.783444    0.104765  -7.4781 0.000000
ar6    -0.708810    0.102015  -6.9481 0.000000
ma1     0.784827    0.075492  10.3961 0.000000
ma2     0.769084    0.089459   8.5971 0.000000
ma3     0.926850    0.097372   9.5186 0.000000
ma4     0.704371    0.081062   8.6893 0.000000
ma5     0.759680    0.090528   8.3917 0.000000
ma6     0.805601    0.073054  11.0275 0.000000
omega   0.000026    0.000009   2.8655 0.004164
alpha1  0.119968    0.019688   6.0935 0.000000
beta1   0.879032    0.016452  53.4302 0.000000

Robust Standard Errors:
        Estimate  Std. Error  t value Pr(>|t|)
ar1    -0.769656    0.141998  -5.4202 0.000000
ar2    -0.805025    0.167136  -4.8166 0.000001
ar3    -0.937002    0.213486  -4.3890 0.000011
ar4    -0.701832    0.164792  -4.2589 0.000021
ar5    -0.783444    0.210406  -3.7235 0.000196
ar6    -0.708810    0.215789  -3.2847 0.001021
ma1     0.784827    0.149465   5.2509 0.000000
ma2     0.769084    0.188448   4.0811 0.000045
ma3     0.926850    0.198414   4.6713 0.000003
ma4     0.704371    0.156041   4.5140 0.000006
ma5     0.759680    0.187431   4.0531 0.000051
ma6     0.805601    0.149596   5.3852 0.000000
omega   0.000026    0.000026   1.0208 0.307357
alpha1  0.119968    0.043640   2.7490 0.005977
beta1   0.879032    0.040435  21.7396 0.000000

LogLikelihood : 2129.722

Information Criteria
------------------------------------

Akaike       -3.7462
Bayes        -3.6794
Shibata      -3.7465
Hannan-Quinn -3.7209
```

```
Weighted Ljung-Box Test on Standardized Residuals
------------------------------------
                         statistic   p-value
Lag[1]                       1.642 2.000e-01
Lag[2*(p+q)+(p+q)-1][35]    20.803 2.435e-06
Lag[4*(p+q)+(p+q)-1][59]    31.606 3.317e-01
d.o.f=12
H0 : No serial correlation

Weighted Ljung-Box Test on Standardized Squared Residuals
------------------------------------
                        statistic p-value
Lag[1]                     0.7855  0.3755
Lag[2*(p+q)+(p+q)-1][5]    1.3820  0.7689
Lag[4*(p+q)+(p+q)-1][9]    2.1437  0.8872
d.o.f=2

Weighted ARCH LM Tests
------------------------------------
            Statistic Shape Scale P-Value
ARCH Lag[3]    0.1114 0.500 2.000  0.7385
ARCH Lag[5]    1.1259 1.440 1.667  0.6960
ARCH Lag[7]    1.5290 2.315 1.543  0.8155

Nyblom stability test
------------------------------------
Joint Statistic:  3.99
Individual Statistics:
ar1    0.18701
ar2    0.75853
ar3    0.81171
ar4    0.03184
ar5    0.05395
ar6    0.05137
ma1    0.36198
ma2    0.28854
ma3    0.78526
ma4    0.07331
ma5    0.04344
ma6    0.05223
omega  0.18453
alpha1 0.10100
beta1  0.12875

Asymptotic Critical Values (10% 5% 1%)
Joint Statistic:         3.26 3.54 4.07
Individual Statistic:    0.35 0.47 0.75

Sign Bias Test
------------------------------------
```

	t-value <dbl>	prob <dbl>	sig <chr>
Sign Bias	0.7735714	0.4393469	

	t-value <dbl>	prob <dbl>	sig <chr>
Negative Sign Bias	0.8790121	0.3795826	
Positive Sign Bias	0.3472435	0.7284734	
Joint Effect	0.9961452	0.8021847	

4 rows

```


Adjusted Pearson Goodness-of-Fit Test:
------------------------------------
  group statistic p-value(g-1)
1    20     162.6    7.901e-25
2    30     181.7    4.812e-24
3    40     197.9    3.911e-23
4    50     209.6    9.490e-22


Elapsed time : 0.657347
```

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```
#AIC -3.7462
```

Hide

```
model7<-ugarchspec(variance.model = list(model = "sGARCH", garchOrder = c(2, 1)),
                   mean.model = list(armaOrder = c(6, 6), include.mean = FALSE),
                   distribution.model = "norm")
m.66_21<-ugarchfit(spec = model7, data = diff_bitcoin, out.sample = 1000)
m.66_21
```

```
*---------------------------------*
*          GARCH Model Fit        *
*---------------------------------*

Conditional Variance Dynamics
-----------------------------------
GARCH Model : sGARCH(2,1)
Mean Model  : ARFIMA(6,0,6)
Distribution    : norm

Optimal Parameters
------------------------------------
        Estimate  Std. Error  t value Pr(>|t|)
ar1    -0.769609    0.086351  -8.9126 0.000000
ar2    -0.805024    0.089888  -8.9559 0.000000
ar3    -0.936952    0.115953  -8.0804 0.000000
ar4    -0.701793    0.096446  -7.2765 0.000000
ar5    -0.783418    0.108725  -7.2055 0.000000
ar6    -0.708759    0.107364  -6.6014 0.000000
ma1     0.784796    0.079634   9.8551 0.000000
ma2     0.769085    0.091754   8.3820 0.000000
ma3     0.926814    0.103031   8.9955 0.000000
ma4     0.704351    0.085604   8.2280 0.000000
ma5     0.759659    0.094172   8.0667 0.000000
ma6     0.805573    0.076487  10.5322 0.000000
omega   0.000026    0.000011   2.4427 0.014579
alpha1  0.119977    0.030205   3.9720 0.000071
alpha2  0.000000    0.047941   0.0000 1.000000
beta1   0.879023    0.027779  31.6438 0.000000

Robust Standard Errors:
        Estimate  Std. Error  t value Pr(>|t|)
ar1    -0.769609    0.164321 -4.68357 0.000003
ar2    -0.805024    0.182349 -4.41475 0.000010
ar3    -0.936952    0.241740 -3.87586 0.000106
ar4    -0.701793    0.193678 -3.62350 0.000291
ar5    -0.783418    0.237986 -3.29187 0.000995
ar6    -0.708759    0.246722 -2.87271 0.004070
ma1     0.784796    0.172843  4.54052 0.000006
ma2     0.769085    0.205348  3.74527 0.000180
ma3     0.926814    0.228924  4.04857 0.000052
ma4     0.704351    0.183261  3.84343 0.000121
ma5     0.759659    0.211222  3.59650 0.000323
ma6     0.805573    0.167924  4.79723 0.000002
omega   0.000026    0.000031  0.85998 0.389797
alpha1  0.119977    0.053977  2.22275 0.026232
alpha2  0.000000    0.118744  0.00000 1.000000
beta1   0.879023    0.081010 10.85075 0.000000

LogLikelihood : 2129.722

Information Criteria
------------------------------------

Akaike       -3.7444
Bayes        -3.6731
```

```
Shibata      -3.7448
Hannan-Quinn -3.7175

Weighted Ljung-Box Test on Standardized Residuals
------------------------------------
                         statistic   p-value
Lag[1]                       1.641 2.002e-01
Lag[2*(p+q)+(p+q)-1][35]    20.804 2.421e-06
Lag[4*(p+q)+(p+q)-1][59]    31.607 3.316e-01
d.o.f=12
H0 : No serial correlation

Weighted Ljung-Box Test on Standardized Squared Residuals
------------------------------------
                         statistic p-value
Lag[1]                      0.7853  0.3755
Lag[2*(p+q)+(p+q)-1][8]     1.9187  0.8712
Lag[4*(p+q)+(p+q)-1][14]    3.9420  0.8857
d.o.f=3

Weighted ARCH LM Tests
------------------------------------
            Statistic Shape Scale P-Value
ARCH Lag[4]     1.255 0.500 2.000  0.2626
ARCH Lag[6]     1.580 1.461 1.711  0.5902
ARCH Lag[8]     1.774 2.368 1.583  0.7867

Nyblom stability test
------------------------------------
Joint Statistic:  4.4252
Individual Statistics:
ar1    0.18704
ar2    0.75860
ar3    0.81175
ar4    0.03179
ar5    0.05396
ar6    0.05139
ma1    0.36196
ma2    0.28853
ma3    0.78526
ma4    0.07324
ma5    0.04344
ma6    0.05224
omega  0.18453
alpha1 0.10100
alpha2 0.07612
beta1  0.12876

Asymptotic Critical Values (10% 5% 1%)
Joint Statistic:         3.46 3.75 4.3
Individual Statistic:    0.35 0.47 0.75

Sign Bias Test
------------------------------------
```

	t-value	prob	sig
	<dbl>	<dbl>	<chr>

	t-value	prob	sig
	<dbl>	<dbl>	<chr>
Sign Bias	0.7734887	0.4393958	
Negative Sign Bias	0.8789021	0.3796422	
Positive Sign Bias	0.3472325	0.7284816	
Joint Effect	0.9959176	0.8022398	

4 rows

```
Adjusted Pearson Goodness-of-Fit Test:
------------------------------------
  group statistic p-value(g-1)
1    20     162.6    7.901e-25
2    30     181.7    4.812e-24
3    40     197.9    3.911e-23
4    50     209.8    8.858e-22


Elapsed time : 0.6239369
```

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```
#AIC -3.7517
```

```
Even though GARCH (2, 2) has the lowest AIC value, however, we chose GARCH (1, 1) bas
ed on the significance of all its parameters.
```

Overfitting

```
Similiarly, we use GARCH (1, 2) and GARCH (2, 1)  to overfit.
```

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```
model8<-ugarchspec(variance.model = list(model = "sGARCH", garchOrder = c(1, 2)),
                   mean.model = list(armaOrder = c(6, 6), include.mean = FALSE),
                   distribution.model = "norm")
m.66_13<-ugarchfit(spec = model8, data = diff_bitcoin, out.sample = 1000)
m.66_13
```

```
*---------------------------------*
*          GARCH Model Fit        *
*---------------------------------*

Conditional Variance Dynamics
-----------------------------------
GARCH Model : sGARCH(1,2)
Mean Model  : ARFIMA(6,0,6)
Distribution    : norm

Optimal Parameters
------------------------------------
        Estimate  Std. Error   t value Pr(>|t|)
ar1    -0.333821    0.058358  -5.72021 0.000000
ar2     0.050457    0.070118   0.71959 0.471774
ar3     0.090716    0.046409   1.95469 0.050619
ar4     0.124574    0.071918   1.73217 0.083244
ar5    -0.471900    0.046744 -10.09546 0.000000
ar6    -0.764002    0.077053  -9.91526 0.000000
ma1     0.386062    0.050792   7.60081 0.000000
ma2    -0.047505    0.060552  -0.78454 0.432723
ma3    -0.059903    0.041583  -1.44057 0.149705
ma4    -0.089944    0.055956  -1.60741 0.107965
ma5     0.442196    0.040412  10.94222 0.000000
ma6     0.853907    0.059315  14.39604 0.000000
omega   0.000042    0.000016   2.59798 0.009377
alpha1  0.196870    0.031952   6.16149 0.000000
beta1   0.142627    0.049467   2.88328 0.003936
beta2   0.659503    0.049641  13.28549 0.000000

Robust Standard Errors:
        Estimate  Std. Error  t value Pr(>|t|)
ar1    -0.333821    0.088964 -3.75231 0.000175
ar2     0.050457    0.170555  0.29584 0.767354
ar3     0.090716    0.059753  1.51819 0.128966
ar4     0.124574    0.195678  0.63663 0.524369
ar5    -0.471900    0.060818 -7.75916 0.000000
ar6    -0.764002    0.224469 -3.40360 0.000665
ma1     0.386062    0.107796  3.58140 0.000342
ma2    -0.047505    0.149951 -0.31680 0.751392
ma3    -0.059903    0.071717 -0.83527 0.403566
ma4    -0.089944    0.155232 -0.57942 0.562309
ma5     0.442196    0.090260  4.89916 0.000001
ma6     0.853907    0.177987  4.79759 0.000002
omega   0.000042    0.000041  1.01717 0.309074
alpha1  0.196870    0.072661  2.70943 0.006740
beta1   0.142627    0.065933  2.16320 0.030526
beta2   0.659503    0.076761  8.59168 0.000000

LogLikelihood : 2133.842

Information Criteria
------------------------------------

Akaike       -3.7517
Bayes        -3.6804
```

```
Shibata      -3.7521
Hannan-Quinn -3.7248

Weighted Ljung-Box Test on Standardized Residuals
------------------------------------
                         statistic   p-value
Lag[1]                      0.2838 5.942e-01
Lag[2*(p+q)+(p+q)-1][35]   20.6790 6.021e-06
Lag[4*(p+q)+(p+q)-1][59]   31.2161 3.663e-01
d.o.f=12
H0 : No serial correlation

Weighted Ljung-Box Test on Standardized Squared Residuals
------------------------------------
                         statistic p-value
Lag[1]                     0.09979  0.7521
Lag[2*(p+q)+(p+q)-1][8]    1.05598  0.9700
Lag[4*(p+q)+(p+q)-1][14]   2.96482  0.9574
d.o.f=3

Weighted ARCH LM Tests
------------------------------------
            Statistic Shape Scale P-Value
ARCH Lag[4]     1.031 0.500 2.000  0.3099
ARCH Lag[6]     1.232 1.461 1.711  0.6823
ARCH Lag[8]     1.312 2.368 1.583  0.8738

Nyblom stability test
------------------------------------
Joint Statistic:  4.7147
Individual Statistics:
ar1    0.03381
ar2    0.22122
ar3    0.98676
ar4    0.03899
ar5    0.13478
ar6    0.08756
ma1    0.05367
ma2    0.18470
ma3    0.88098
ma4    0.06433
ma5    0.05057
ma6    0.05586
omega  0.21371
alpha1 0.11905
beta1  0.13338
beta2  0.15329

Asymptotic Critical Values (10% 5% 1%)
Joint Statistic:         3.46 3.75 4.3
Individual Statistic:    0.35 0.47 0.75

Sign Bias Test
------------------------------------
```

	t-value	prob	sig
	<dbl>	<dbl>	<chr>

	t-value <dbl>	prob <dbl>	sig <chr>
Sign Bias	2.2719700	0.02327663	**
Negative Sign Bias	0.6867412	0.49238748	
Positive Sign Bias	0.6174351	0.53707283	
Joint Effect	5.5009410	0.13858234	

4 rows

```


Adjusted Pearson Goodness-of-Fit Test:
------------------------------------
  group statistic p-value(g-1)
1    20     174.2    4.362e-27
2    30     202.9    5.336e-28
3    40     200.6    1.303e-23
4    50     212.5    3.036e-22


Elapsed time : 0.6053879
```

Hide

```
#AIC -3.7517
```

```
 We chose GARCH (1,1) based on the significance of all the parameters.
```

Residuals analysis of ARIMA(6,1,6) x GARCH(1,1)

Hide

```
plot(m.66_11)
```

```


Make a plot selection (or 0 to exit):

 1:   Series with 2 Conditional SD Superimposed
 2:   Series with 1% VaR Limits
 3:   Conditional SD (vs |returns|)
 4:   ACF of Observations
 5:   ACF of Squared Observations
 6:   ACF of Absolute Observations
 7:   Cross Correlation
 8:   Empirical Density of Standardized Residuals
 9:   QQ-Plot of Standardized Residuals
10:   ACF of Standardized Residuals
11:   ACF of Squared Standardized Residuals
12:   News-Impact Curve
```

Hide

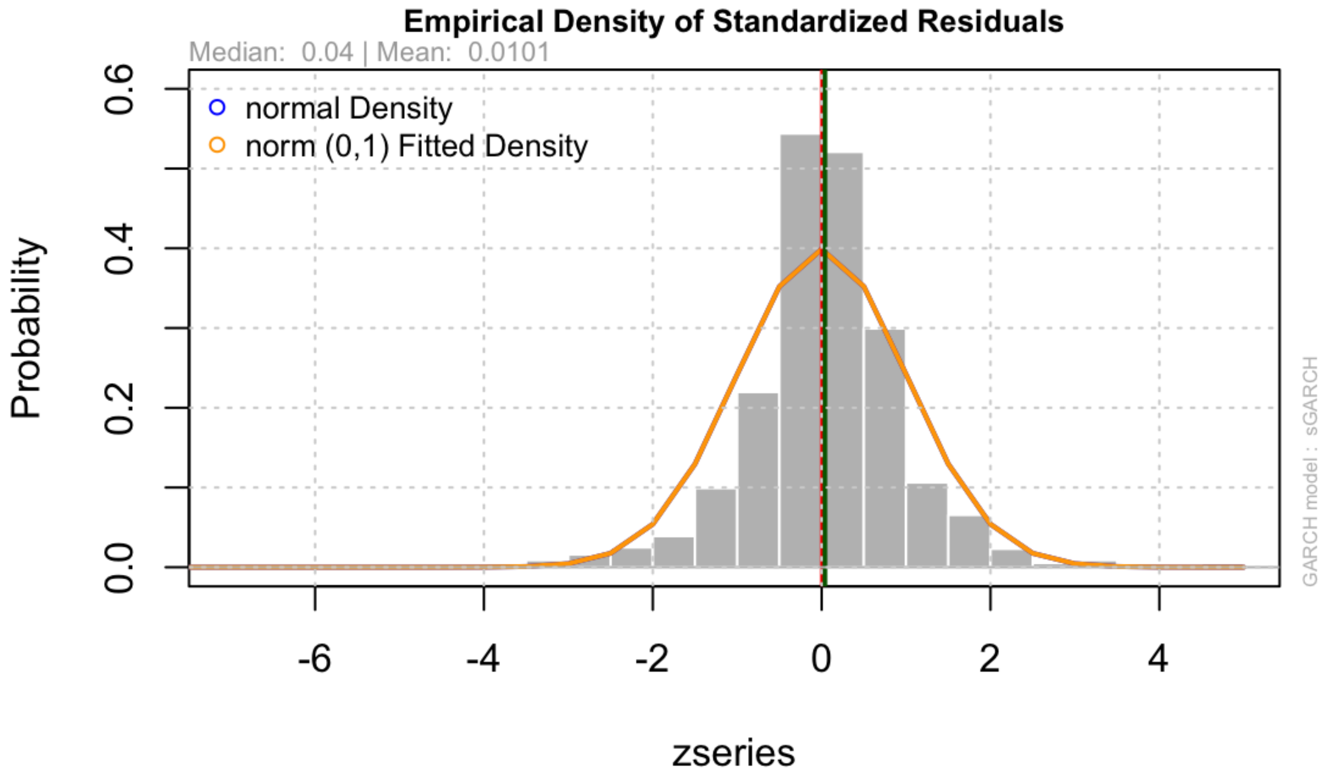
```
8
```

```
Make a plot selection (or 0 to exit):

 1:   Series with 2 Conditional SD Superimposed
 2:   Series with 1% VaR Limits
 3:   Conditional SD (vs |returns|)
 4:   ACF of Observations
 5:   ACF of Squared Observations
 6:   ACF of Absolute Observations
 7:   Cross Correlation
 8:   Empirical Density of Standardized Residuals
 9:   QQ-Plot of Standardized Residuals
10:   ACF of Standardized Residuals
11:   ACF of Squared Standardized Residuals
12:   News-Impact Curve
```

Hide

```
9
```



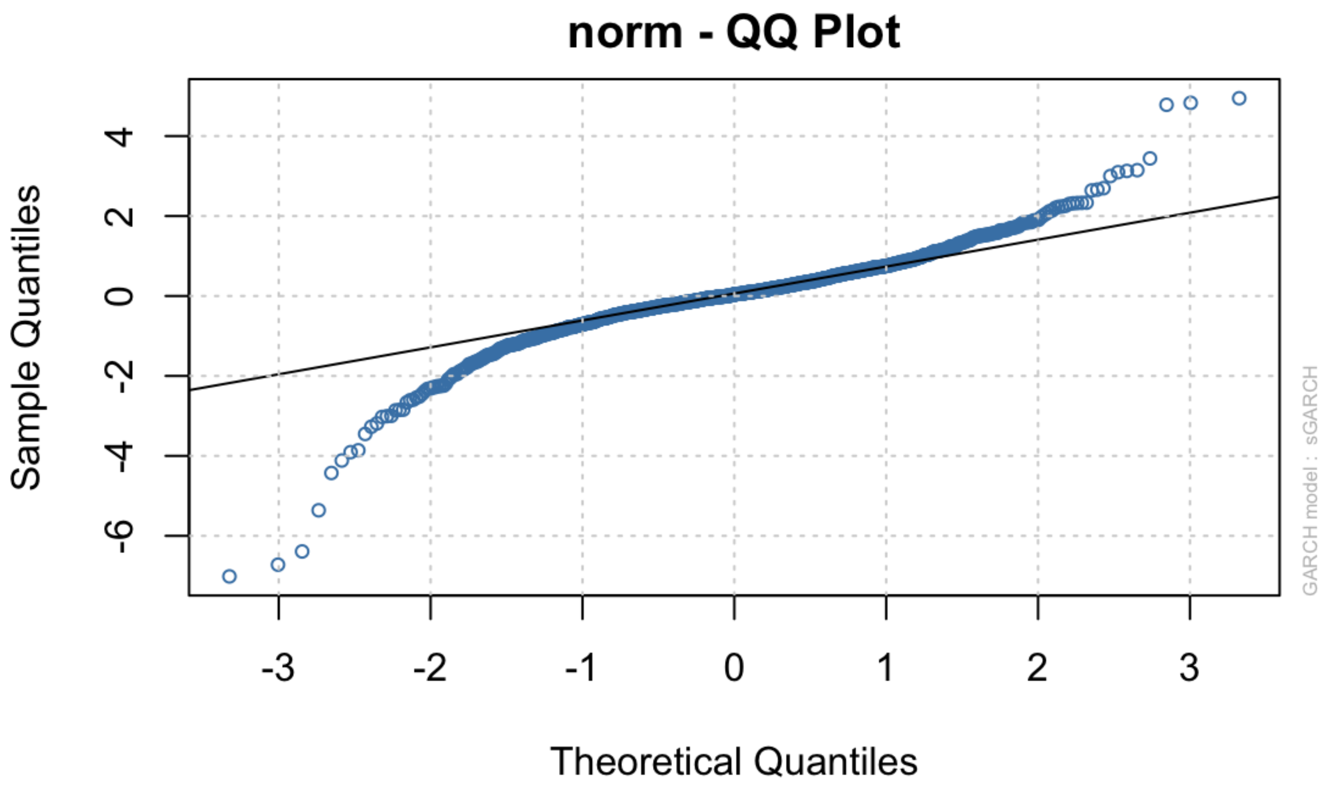
```

Make a plot selection (or 0 to exit):

 1:   Series with 2 Conditional SD Superimposed
 2:   Series with 1% VaR Limits
 3:   Conditional SD (vs |returns|)
 4:   ACF of Observations
 5:   ACF of Squared Observations
 6:   ACF of Absolute Observations
 7:   Cross Correlation
 8:   Empirical Density of Standardized Residuals
 9:   QQ-Plot of Standardized Residuals
10:   ACF of Standardized Residuals
11:   ACF of Squared Standardized Residuals
12:   News-Impact Curve
```

Hide

```
10
```



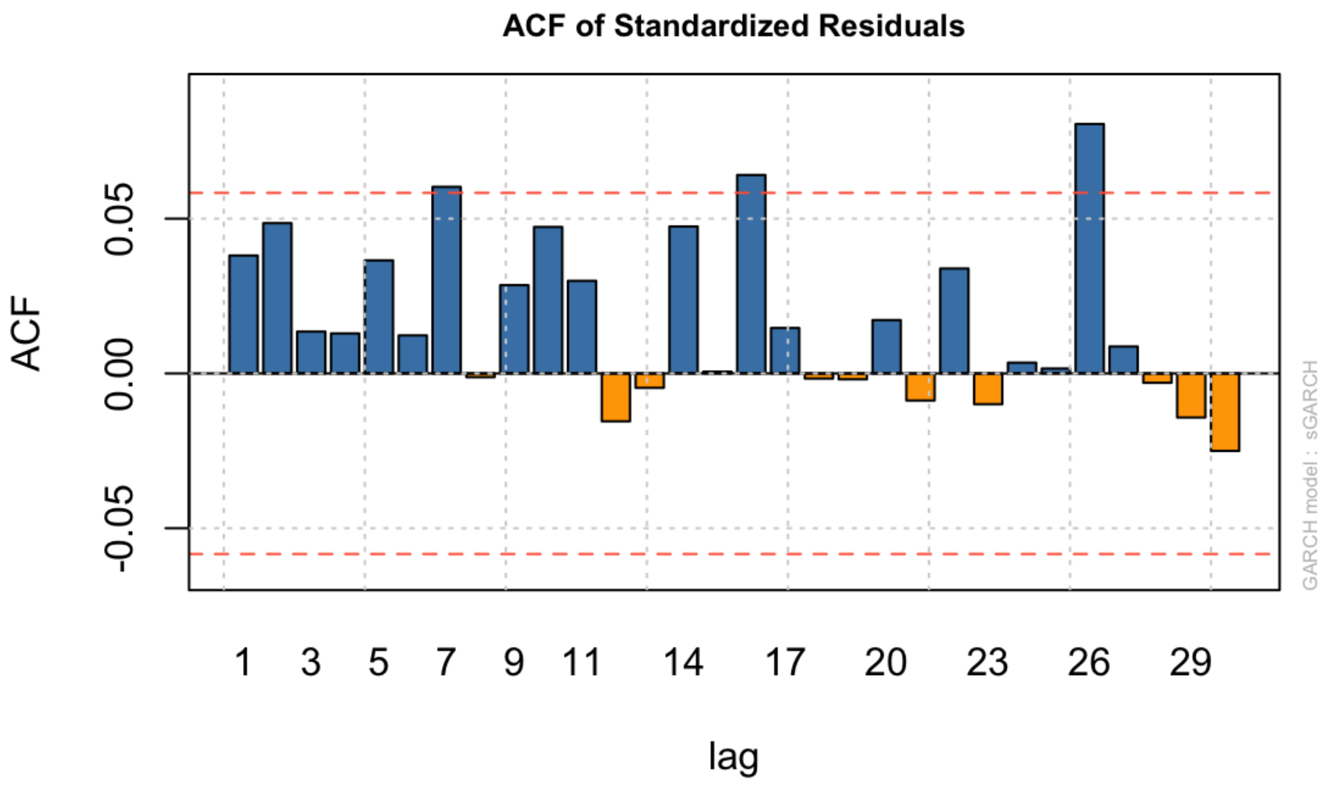
```

Make a plot selection (or 0 to exit):

 1:   Series with 2 Conditional SD Superimposed
 2:   Series with 1% VaR Limits
 3:   Conditional SD (vs |returns|)
 4:   ACF of Observations
 5:   ACF of Squared Observations
 6:   ACF of Absolute Observations
 7:   Cross Correlation
 8:   Empirical Density of Standardized Residuals
 9:   QQ-Plot of Standardized Residuals
10:   ACF of Standardized Residuals
11:   ACF of Squared Standardized Residuals
12:   News-Impact Curve
```

Hide

```
11
```



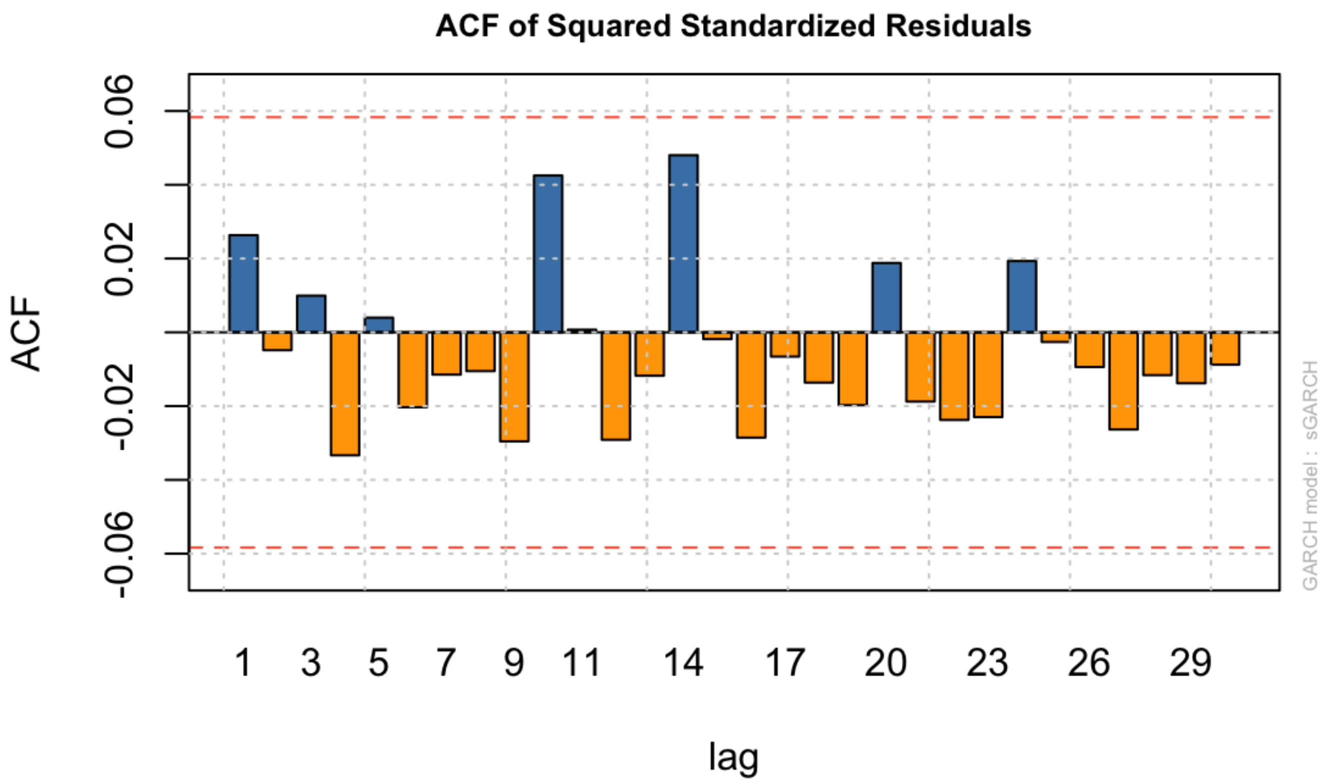
```

Make a plot selection (or 0 to exit):

 1:   Series with 2 Conditional SD Superimposed
 2:   Series with 1% VaR Limits
 3:   Conditional SD (vs |returns|)
 4:   ACF of Observations
 5:   ACF of Squared Observations
 6:   ACF of Absolute Observations
 7:   Cross Correlation
 8:   Empirical Density of Standardized Residuals
 9:   QQ-Plot of Standardized Residuals
10:   ACF of Standardized Residuals
11:   ACF of Squared Standardized Residuals
12:   News-Impact Curve
```

Hide

```
12
```



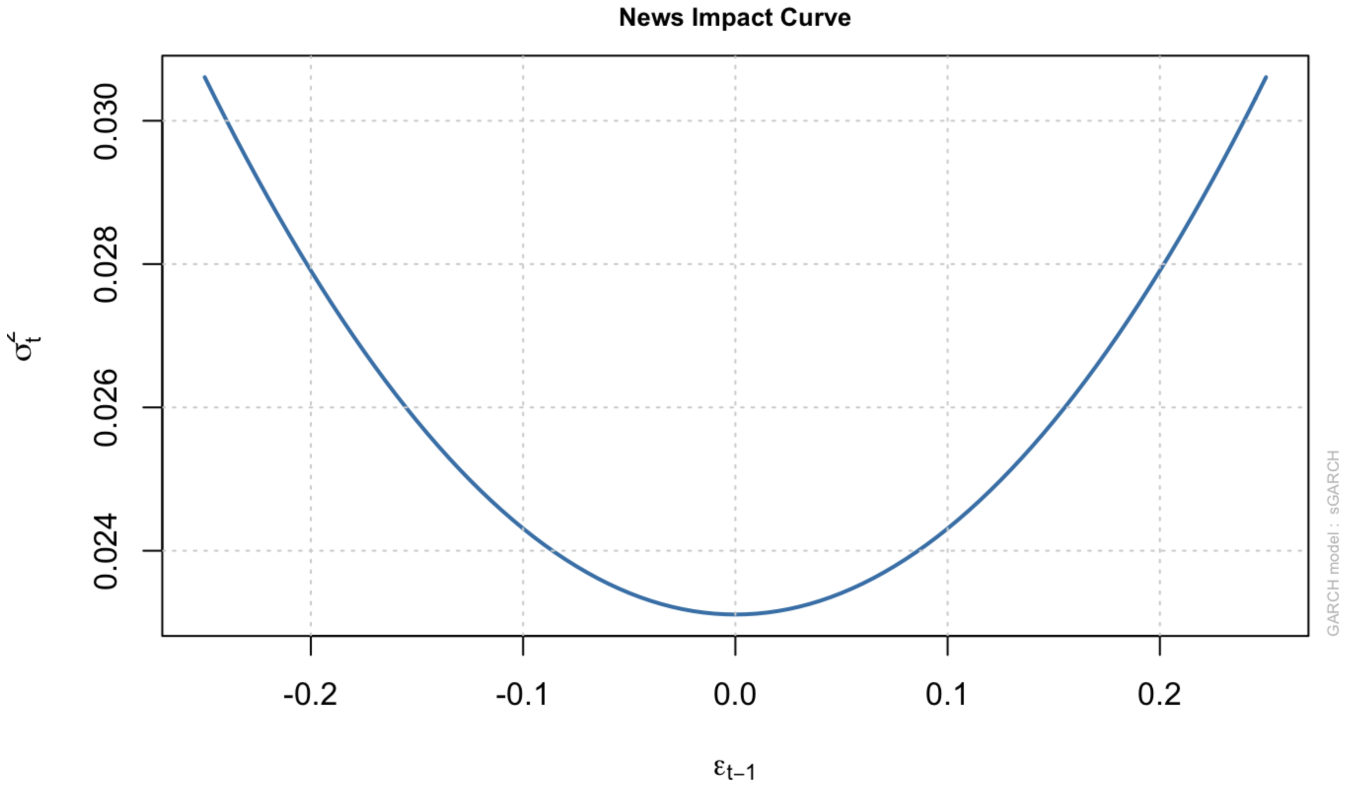
```

Make a plot selection (or 0 to exit):

 1:   Series with 2 Conditional SD Superimposed
 2:   Series with 1% VaR Limits
 3:   Conditional SD (vs |returns|)
 4:   ACF of Observations
 5:   ACF of Squared Observations
 6:   ACF of Absolute Observations
 7:   Cross Correlation
 8:   Empirical Density of Standardized Residuals
 9:   QQ-Plot of Standardized Residuals
10:   ACF of Standardized Residuals
11:   ACF of Squared Standardized Residuals
12:   News-Impact Curve
```

Hide

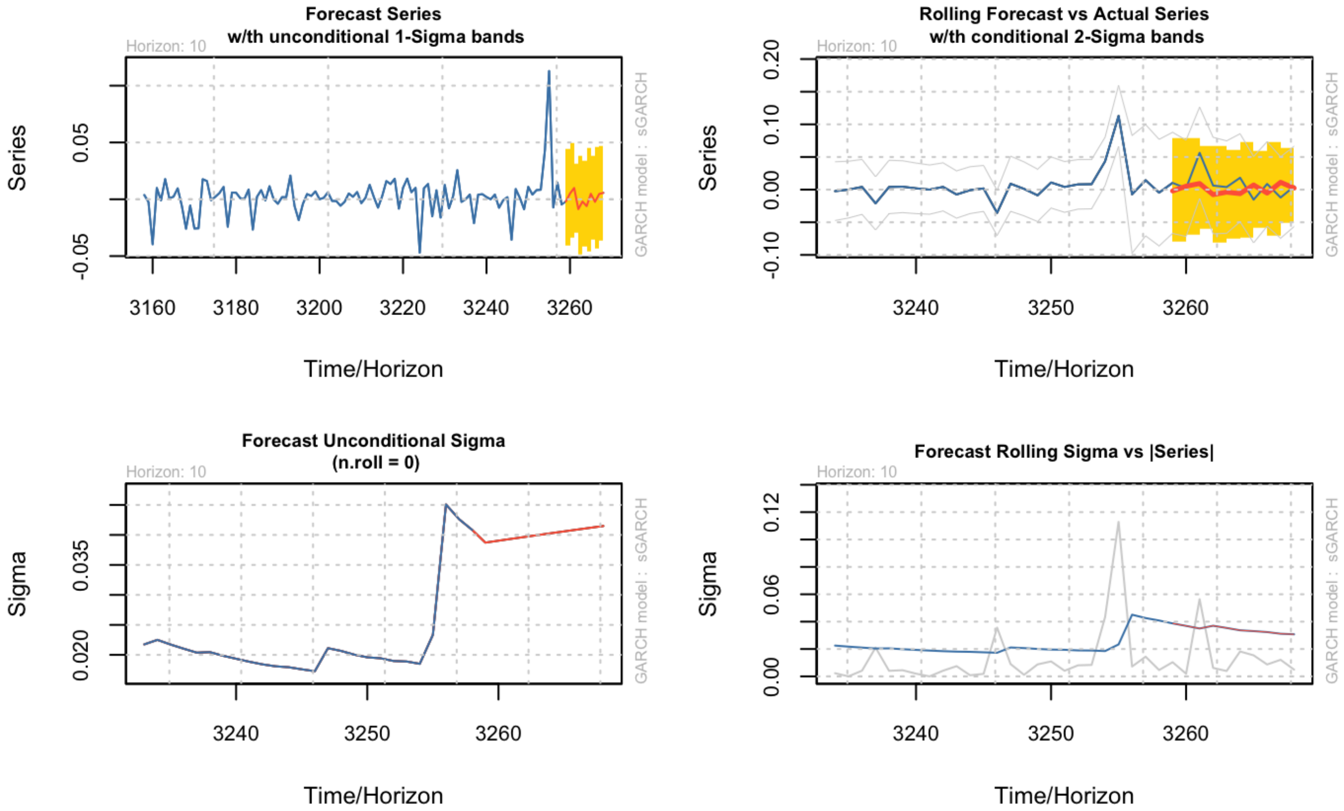
```
0
```



```
  In conclusion we chose ARIMA(6,1,6) x GARCH(1,1) for forcasting since it seems to p
ass most of the residuals tests. However, we can still observe the thick tails in QQ-
plot, this could be a result of some othe factors that we have missed; this can also
be the result of using the entire life time price of BitCoins for modelling when it w
hen through various stages since its conception.
```

Hide

```
forc.66_11 = ugarchforecast(m.66_11, data = diff_bitcoin, n.ahead = 10, n.roll = 10)
plot(forc.66_11, which = "all")
```



Hide

```
forc.66_11
```

```


*------------------------------------*
*       GARCH Model Forecast         *
*------------------------------------*
Model: sGARCH
Horizon: 10
Roll Steps: 10
Out of Sample: 10

0-roll forecast [T0=3258-01-01]:
        Series   Sigma
T+1  -0.001988 0.03872
T+2   0.005052 0.03904
T+3   0.009965 0.03935
T+4  -0.008676 0.03966
T+5  -0.001993 0.03997
T+6  -0.006047 0.04028
T+7   0.004846 0.04059
T+8  -0.002293 0.04089
T+9   0.004662 0.04119
T+10  0.005672 0.04149
```

After taking the values back from the differcing and log tranform, these are our predictions side by side with the observed values.

price	price_observed
<dbl>	<dbl>

price <dbl>	price_observed <dbl>
3818.011	3882.70
3798.771	3854.36
3761.105	3851.05
3793.878	3854.79
3801.447	3859.58
3824.504	3864.42
3806.015	3847.18
3814.752	3761.56
3797.009	3896.38
3775.534	3903.94

1-10 of 10 rows

Hide

```
MASE = function(observed , fitted ){
  # observed: Observed series on the forecast period
  # fitted: Forecast values by your model
  Y.t = observed
  n = length(fitted)
  e.t = Y.t - fitted
  sum = 0
  for (i in 2:n){
    sum = sum + abs(Y.t[i] - Y.t[i-1] )
  }
  q.t = e.t / (sum/(n-1))
  MASE = data.frame( MASE = mean(abs(q.t)))
  return(list(MASE = MASE))
}
```

Hide

```
mase_value<-MASE(preditions11$price_observed,preditions11$price)
```

```
$MASE
```

MASE <dbl>
2.143548

1 row

```
NA
```

Summary

```
The analysis of BitCoins Price concludes that the best model for the Time Series is A
RIMA(6,1,6) x GARCH(1,1). The model produced price predictions with the MASE value of
2.143548.
```