Forecasting of Sumatera Andaman Earthquake (1973-2012)

MATH1307 – Forecasting Project

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1 Introduction

Sumatra region in Indonesia is prone to earthquakes because it lies at the boundary of two of Earth's tectonic plates. However, there was no indication that this region will have large earthquake until December 26, 2004, when the magnitude 9.1 earthquake struck this area and killed over 200,000 people. Since then, scientists tried to estimate when the next big earthquake will occur in Sumatra and similar regions previously thought to be at low risk for large earthquakes, such as in China, Java, Japan, and Peru. [1]

This report tried to forecast earthquake magnitudes in Sumatera Andaman area based on its earthquakes' historical data from January 1973 to March 2012, using 9,573 earthquake observations. The earthquake dataset is obtained from United States Geological Survey (USGS) website. [2]

The challenge of this forecasting is to find the pattern of earthquakes in this area, and use this pattern to predict next big earthquakes. To make things more complicated, most of earthquake data will contained small magnitudes earthquake, and we have to predict the next big earthquakes using this small earthquakes data, explained by histogram below:

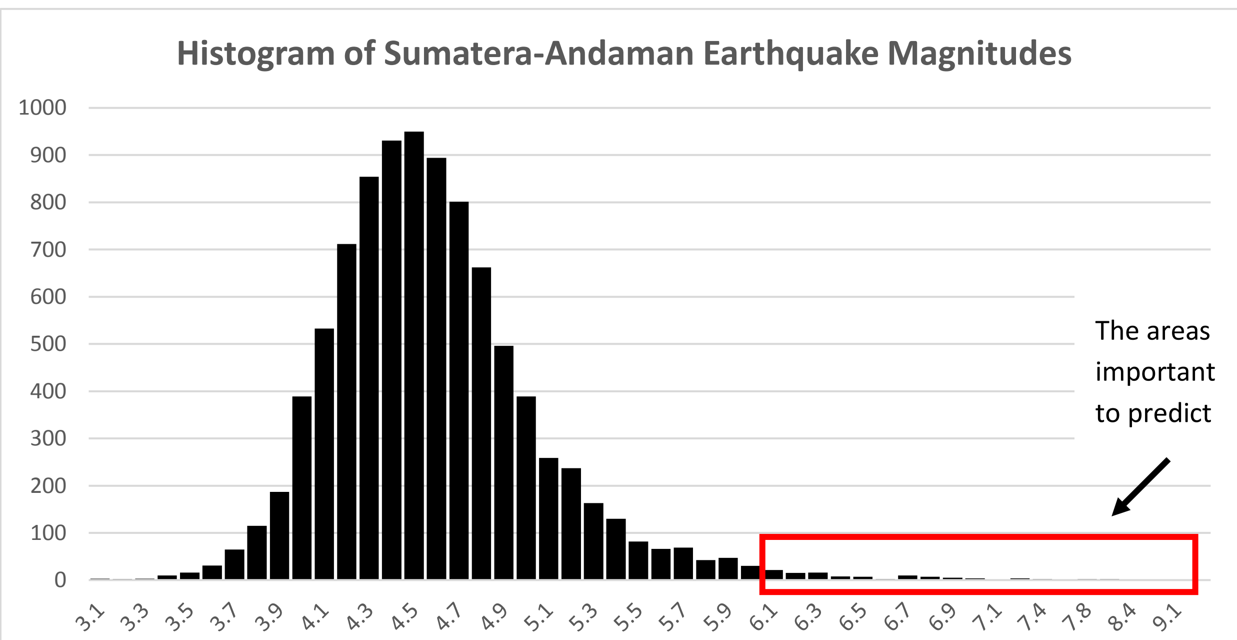

Figure 1: Histogram of Sumatera Andaman Earthquakes Jan 1973-March 2012

To answer the challenge, we will categorize the earthquakes data into three parts: foreshock, mainshock, and aftershock, and see if we can find the pattern and correlation between these three variables. When the correlations are found, we will model these three variables and use the best model to forecast the next earthquake magnitudes. In this report, **Autoregressive Distributed Lag Model** (AR-DLagM) and **Dynamic Linear Model** (DYNLM) approaches are being used for modelling and forecasting the data.

2 Method

The challenge of natural disaster forecasting lies to its' randomness of occurrence. Hence, we need to find a pattern to tackle this randomness nature. Some previous research tried to find this pattern. Özel (2010) [4], for instance, try to find the sequence of earthquake by using stochastic process (especially Poisson process) using covariate information, such as the number of foreshock and aftershock. The result of the research is the probability of total number of foreshock and aftershock for the next periods of time.

In this report, we will do different things. Instead of predicting the probability of total number of foreshock and aftershock, we will use total number of foreshock and aftershock to predict the magnitude of mainshock. This idea is based on the initial observations that higher mainshock magnitude usually accompanied by higher number of foreshocks and aftershocks. However, this approach will have one big challenge: until now, researchers still have no clue to precisely categorize the foreshock, mainshock, and aftershock. Hence, for this research, we will categorize them using our own term below:

- Due to earthquakes randomness, there are no specific time used in this research (hence no daily, weekly, monthly, or yearly data). The time that used in this report, is refers to one specific time step.
- In every particular time step when earthquake happened, the biggest magnitude in that time is categorized as **mainshock**.
- Earthquakes happened before mainshock in that day is categorized as **foreshock**.
- Earthquakes happened after mainshock in that day is categorized as **aftershock**.
- The number of foreshock and aftershock is being summed and being used as independent variables to predict mainshock magnitude.

Using this rules, from the initial 9,573 earthquake observations, we now have **3,803 mainshock**. The rest of them are categorized as foreshock and aftershock, and already being summed.

Next, after the earthquakes data is being categorized, we will do four regression experiments using AR-DLagM and DYNLM, which is:

- Regressing the number of foreshock to mainshock magnitude
- Regressing the number of aftershock to mainshock magnitude
- Regressing the combination of number of foreshock and aftershock to mainshock magnitude
- Regressing the number of aftershock (as X variable) and the number of foreshock (as Z variable) to mainshock magnitude.

Due to limitations of DLagM model, amongst all of the approach that available in that model, we only use AR-DLagM model in this research. Also, because we cannot use Z variable in AR-DLagM model, the fourth approach mentioned above is not implemented with this model. Hence, in total, we have 7 experiments in this research with detailed process and results explained below.

3 Discussions and Results

First, let's see the time series plots of foreshock, mainshock, and aftershock below:

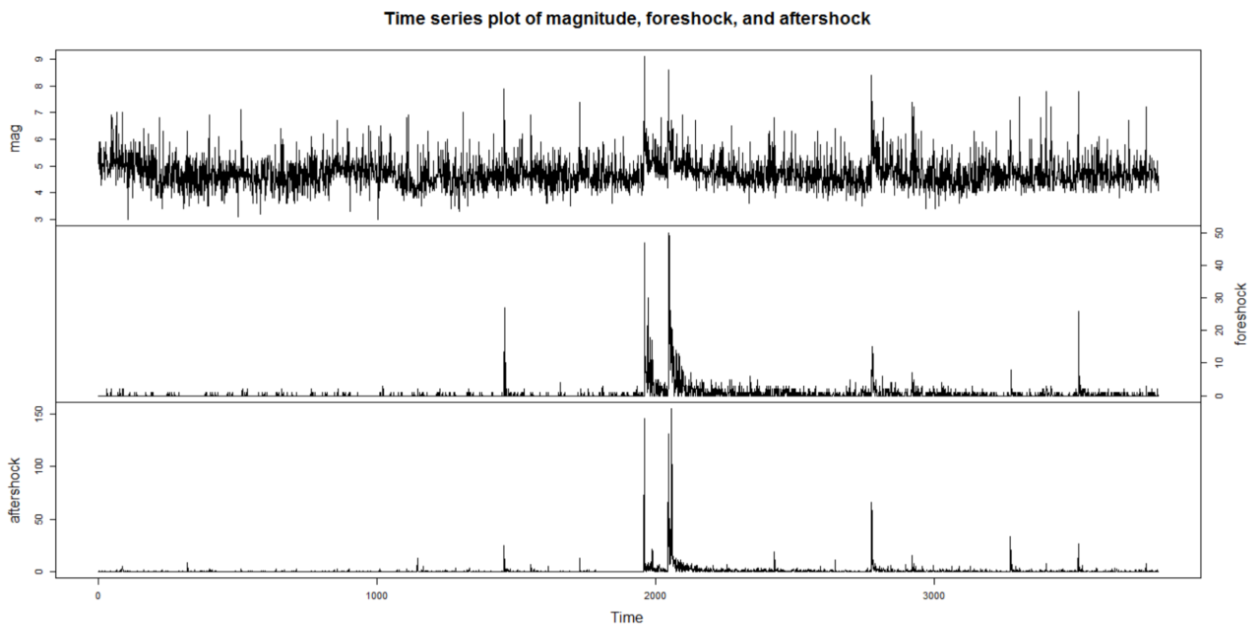

Figure 2: Time series plot of mainshock magnitude, number of foreshock, and number of aftershock

The plot shows that the magnitude series are bouncing around the mean. Changing variance, intervention, and trend are often appeared when magnitude is increase (like in time step 2000). These pattern in magnitude series are mimicked by foreshock and aftershock series plot. Changing variance in magnitude series usually followed by changing variance in foreshock and aftershock series, like what happened in time step 2000. When the earthquake magnitude increase to above 9, the number of foreshock and aftershock also increase. This is confirm the initial hypothesis, that there are correlation between mainshock and the number of foreshock and aftershock.

To prove this hypothesis, correlation test is being done, resulting 24% correlation between mainshock magnitude and the number of foreshock; 32% correlation between mainshock magnitude and the number of foreshock; and 45% correlation between foreshock and aftershock. Even though this is not a high correlation, we still can say these series are positively correlated: means the increase of mainshock magnitude resulting in increase of foreshock and aftershock numbers; also, the increase of foreshock numbers resulting in the increase of aftershock numbers (for R-code, please see **Appendix 1**).

Because the correlation is proven, hence we can start to fit the model and find the best model to forecast.

3.1 AR-DLagM Model

3.1.1 Regressing Number of Foreshock to the Mainshock Magnitude

There are 8 models built using this approach, with model specifications, adjusted R-squared values, and MASE result below:

Model	P	Q	Adjusted R-Squared	MASE
Eq1	1	1	0.068	0.7356
Eq2	1	2	0.073	0.7315
Eq3	1	3	0.079	0.7275
Eq4	2	1	0.068	0.7355
Eq5	2	2	0.073	0.7316
Eq6	2	3	0.079	0.7275
Eq7	3	1	0.068	0.7352
Eq8	3	2	0.073	0.7312
Eq9	**3**	**3**	**0.079**	**0.7274**

Table 1: Modelling result of regressing number of foreshock to mainshock magnitude using AR-DLagM approach

The test result (please refers to **Appendix 2**) shows all the models are significant, but the value of adjusted R-squared are very low, and overall only explaining 7% of the variation of the models. However, this is still acceptable because earthquakes are fairly unpredictable, hence when the p-value said the models are significant, it means the relationships in the model is still reliable [3]. Here, model "Eq9" with p=q=3 has the lowest MASE value.

Now we will examine multicollinearity and residuals of "eq9" model:

X.t	L(X.t, 1)	L(X.t, 2)	L(X.t, 3)	L(y.t, 1)	L(y.t, 2)	L(y.t, 3)
1.668252	1.710201	1.708744	1.638480	1.113575	1.117046	1.114082

Here, we have a very low VIF values, means multicollinearity of this model is very low. However, the model has significant residuals left in this models as shown below:

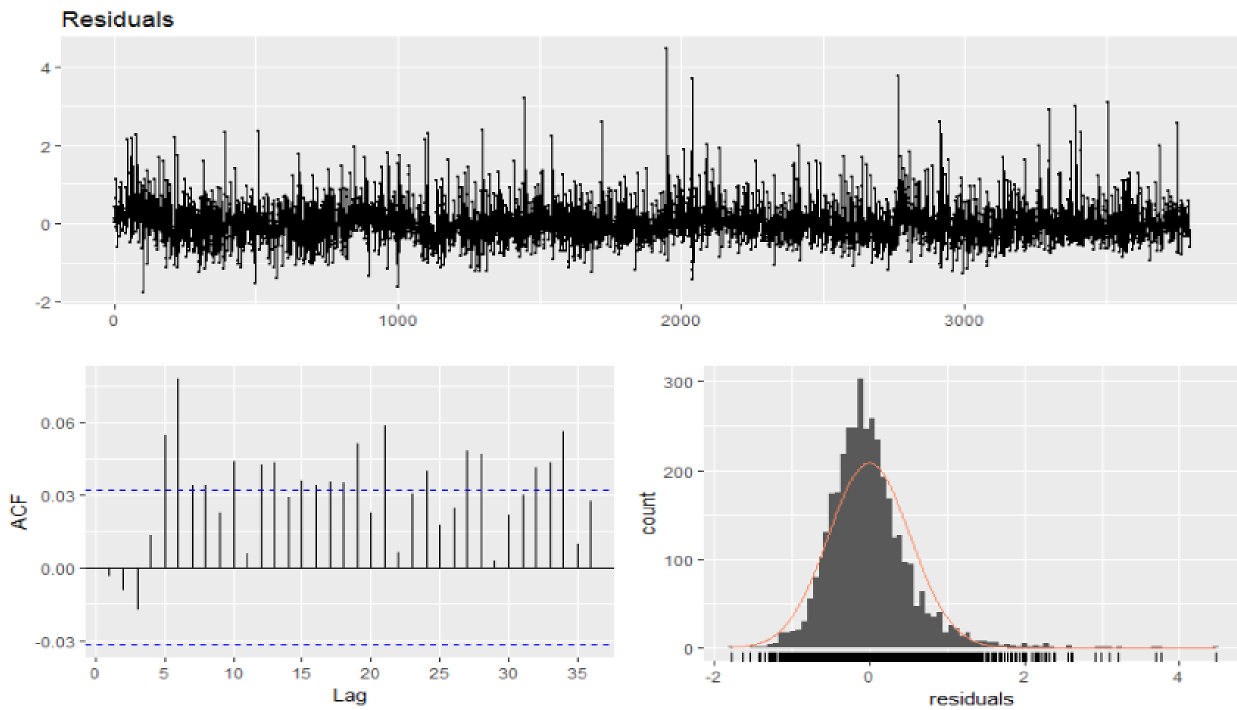

Figure 3: Residuals plot of best model, model "eq9"

There are some visible changing variance in the model, also several significant correlations in ACF plot. The histogram also seems left skewed. It is confirmed by BG-test that indicates these residuals are significant.

The first candidate model seems not convincing enough, hence we will regress the number of aftershock to mainshock magnitude, and see whether this model will gives better performance.

3.1.2 Regressing Number of Aftershock to the Mainshock Magnitude

Here, 7 models built using this approach, with model specifications, adjusted R-squared values, and MASE result below:

Model	P	Q	Adjusted R-Squared	MASE
Eq10	1	1	0.116	0.7310
Eq11	1	2	0.125	0.7265
Eq12	1	3	0.132	0.7216
Eq13	2	1	0.119	0.7297
Eq14	2	2	0.125	0.7261
Eq15	2	3	0.132	0.7214
Eq16	3	1	0.120	0.7290
Eq17	3	2	0.126	0.7253
Eq18	**3**	**3**	**0.132**	**0.7215**

Table 2: Modelling result of regressing number of aftershock to mainshock magnitude using AR-DLagM approach

The table shows regressing number of aftershock to mainshock magnitude gives better results, shown by the increase of adjusted R-squared values and the decrease of MASE values. It is understandable because aftershock series have more earthquake numbers than foreshock series, hence it assumed will be better explaining the variability of the models. Using this approach, model “eq18” with p=q=3 has the lowest MASE value. Please refer to **Appendix 3** for R-code and modelling results.

Multicollinearity and residuals check for model “eq18” is being done again, with the result below:

X.t	L(X.t, 1)	L(X.t, 2)	L(X.t, 3)	L(y.t, 1)	L(y.t, 2)	L(y.t, 3)
1.312354	1.704412	1.707498	1.424848	1.144901	1.149366	1.141896

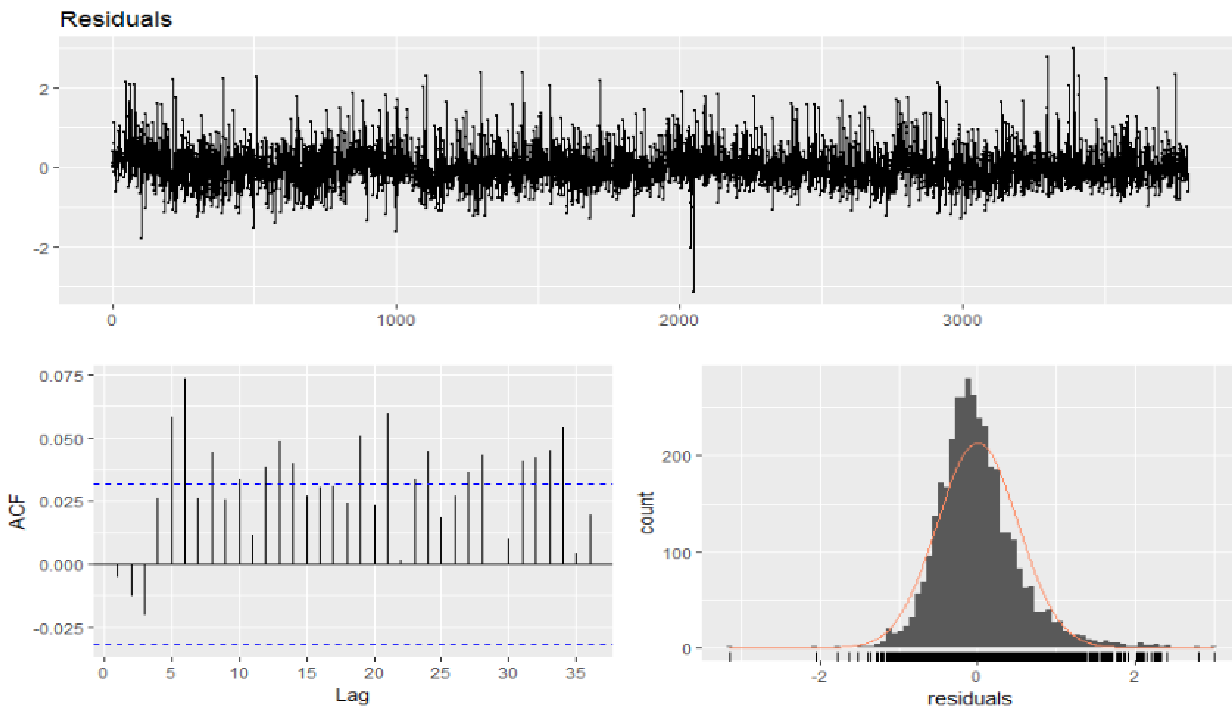

Figure 4: Residuals plot of best model, model “eq18”

Again, VIF shows a very good result indicating low multicollinearity, but BG-test result indicates the residuals are still significant. However, the residuals are getting better here, shown by lesser changing variance, and better histogram.

Hence, using AR-DLagM model, we have 2 best models candidates even though the residuals are still significant. Now we will use DYNLM and find the best candidate model from this approach.

3.2 DYNLM Model

In this model, we will taking account the trend and the intervention. As shown at previous time series plot, the most visible intervention appeared at time step 2000, when the earthquake magnitude increase to above 9.
As we did in the ARDLM modelling, we will regress mainshock to foreshock, mainshock to aftershock, and mainshock to both foreshock and aftershock, and chose the best fit model based on its MASE value.

There are 22 models built using this approach, with model specifications and MASE result below:

Foreshock															
Model	Y.t	X.t	Z.t	P.t	P.t.1	L(X.t), k=1	L(X.t), k=2	L(X.t), k=3	L(X.t), k=4	L(Z,t), k=1	L(Z,t), k=2	L(Z,t), k=3	L(Z,t), k=4	trend	MASE
Eqa	✓	✓		✓										✓	0.7398
Eqb	✓	✓		✓	✓	✓								✓	0.7387
Eqc	✓	✓		✓			✓							✓	0.7391
Eqd	✓	✓		✓	✓	✓	✓							✓	Too low
Eqe	✓	✓		✓	✓				✓					✓	Too low
Aftershock															
Eqf	✓	✓		✓										✓	0.7396
Combining aftershock & foreshock in 1 dataset															
Eqg	✓	✓		✓										✓	0.7303
Eqi	✓	✓		✓		✓								✓	0.7238
Eqj	✓	✓		✓		✓	✓							✓	0.7241
Eqk	✓	✓		✓			✓							✓	0.7249
Eql	✓	✓		✓	✓		✓							✓	0.7245
Eqm	✓	✓		✓	✓	✓	✓							✓	0.7238
Eqn	✓	✓		✓	✓			✓						✓	0.7241
Eqo	✓	✓		✓	✓	✓		✓						✓	0.7230
Eqp	✓	✓		✓	✓	✓	✓	✓						✓	0.7233
Using aftershock as Z variable and foreshock as X variable															
Eqs	✓	✓	✓	✓	✓									✓	0.7283
Eqt	✓	✓	✓	✓	✓	✓				✓				✓	0.7284
Equ	✓	✓	✓	✓	✓		✓				✓			✓	0.7287
Eqv	✓	✓	✓	✓	✓	✓	✓			✓	✓			✓	0.7287
Eqw	✓	✓	✓	✓	✓			✓				✓		✓	0.7282
Eqx	✓	✓	✓	✓	✓				✓				✓	✓	0.7280
Eqz	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	0.7279

Table 3: Modelling result of time series regression using DYNLM approach, by taking account the trend and intervention.

It seems that using both the number of foreshock and aftershock together resulting the lowest MASE amongst all models. However, here, we will still take three best models from each approaches just to see if one of them has better forecasting results. As a side note, in aftershock regression, there is only 1 model shown because unfortunately, adding the lag in this regression only resulting NAs in the lag coefficients, hence it gives same MASE value for all models (no progress for the models). All of R-codes and detailed modelling results can be found on **Appendix 4**.

Now we will check multicollinearity and residuals of three best candidate models: model “eqb”, “eqf”, and “eqo”.

VIF of model “eqb”

X.t	L(X.t, k = 1)	P.t	P.t.1	trend(Y.ta)
1.658386	1.656064	1.160750	1.139218	1.008724

VIF of model “eqf”

X.tb	P.t	trend(Y.ta)
1.035595	1.032703	1.002877

VIF of model “eqo”

X.tc	L(X.tc, k = 3)	L(X.tc, k = 1)	L(X.tc, k = 2)	P.t	P.t.1	trend(Y.ta)
1.822856	1.965131	2.974067	3.115745	1.270911	1.295177	1.008244

Again, similar as models before, multicollinearity is very low, which is good. Now we will check the residuals for these models.

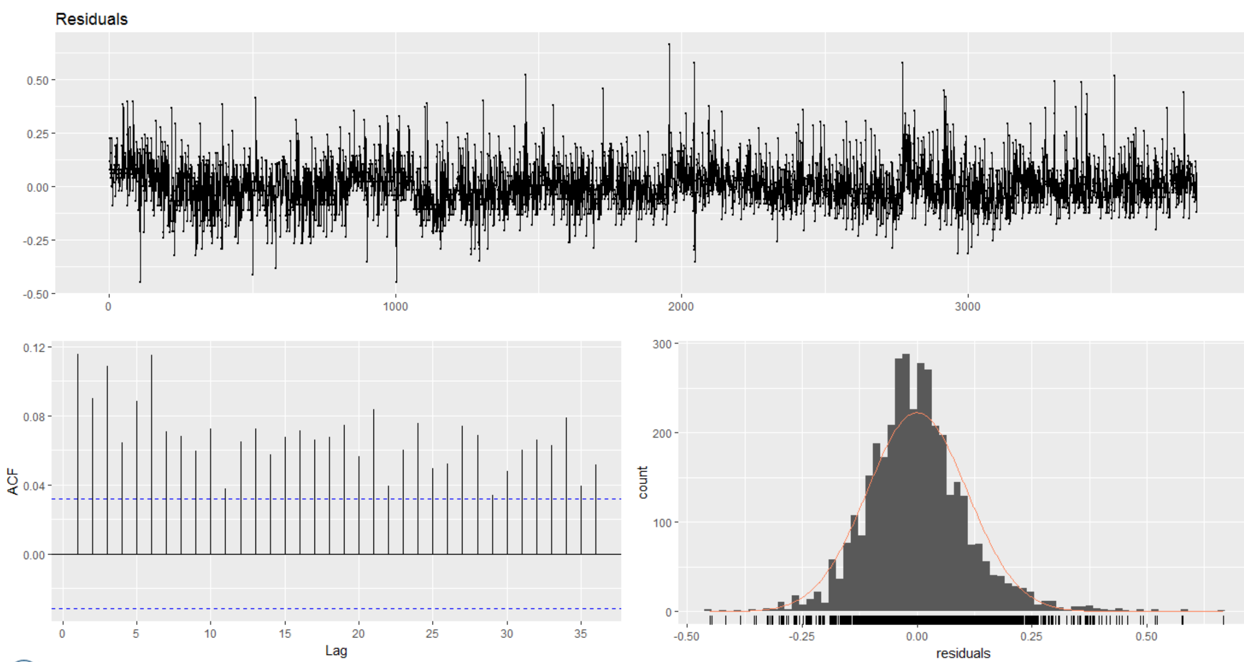

Figure 5: Residuals plot of best model, model “eqb”

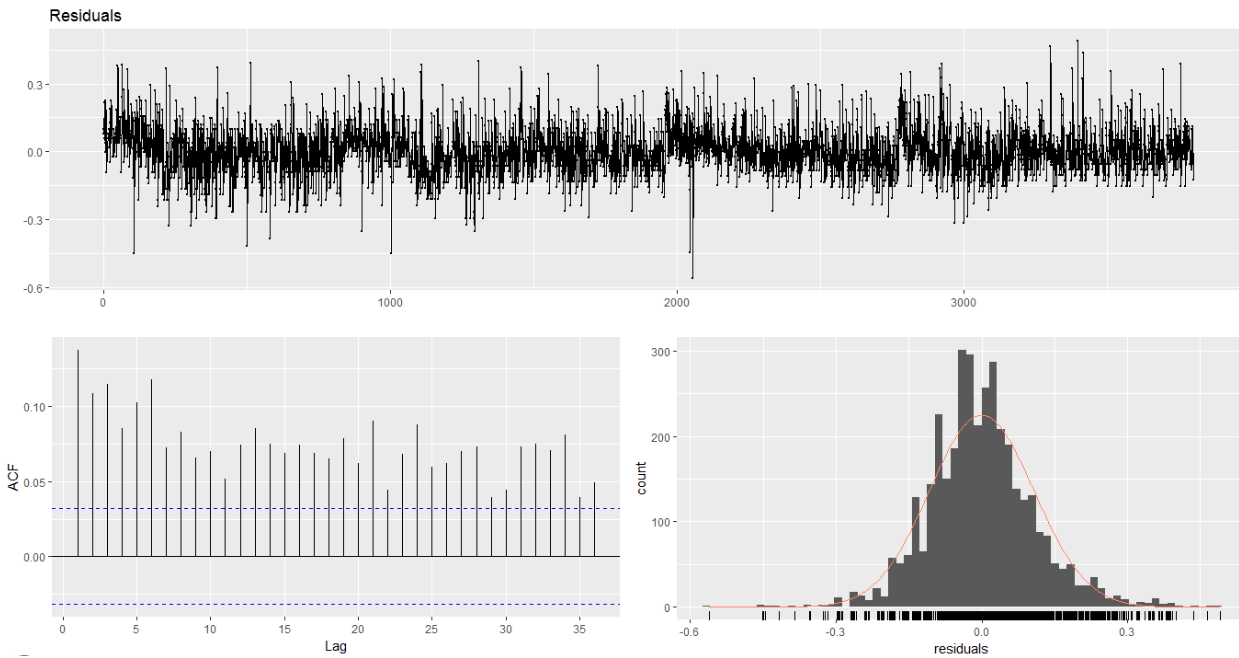

Figure 6: Residuals plot of best model, model "eqf"

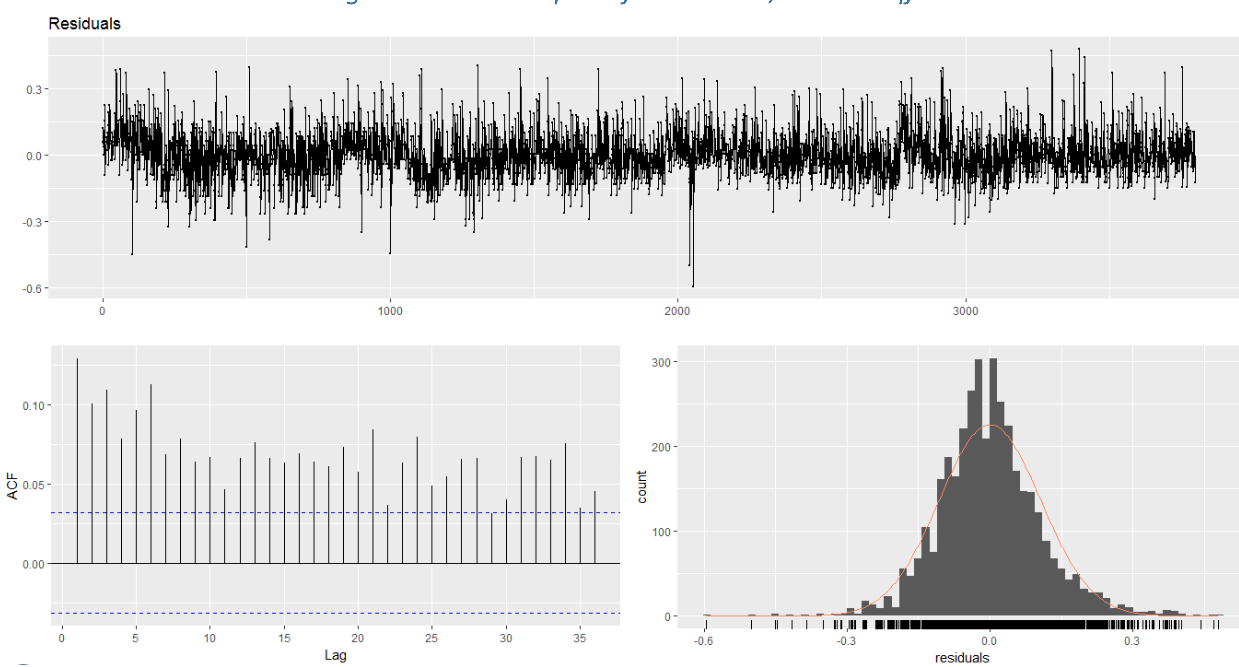

Figure 7: Residuals plot of best model, model "eqr"

Here, BG-Test states that all of the residuals for these three models are still significant, and confirmed by all of residuals plots above.

Now we have 5 best model candidates that share similar characteristics: they have low VIF and MASE values, but all of them also have significant residuals.
Due to scope limitation of this project, even though these models are still not perfect, we will forecast the earthquake magnitudes using these models and compare the results.

3.3 Forecasting

The forecast will be done for the next 14 earthquakes. We already have test dataset contained earthquakes from April-June 2012 that will be compared with forecasting results. This period is chosen because it contains earthquake with high magnitude (8.6) and we will see whether our model able to capture it. Time series plot of the forecasting is shown below:

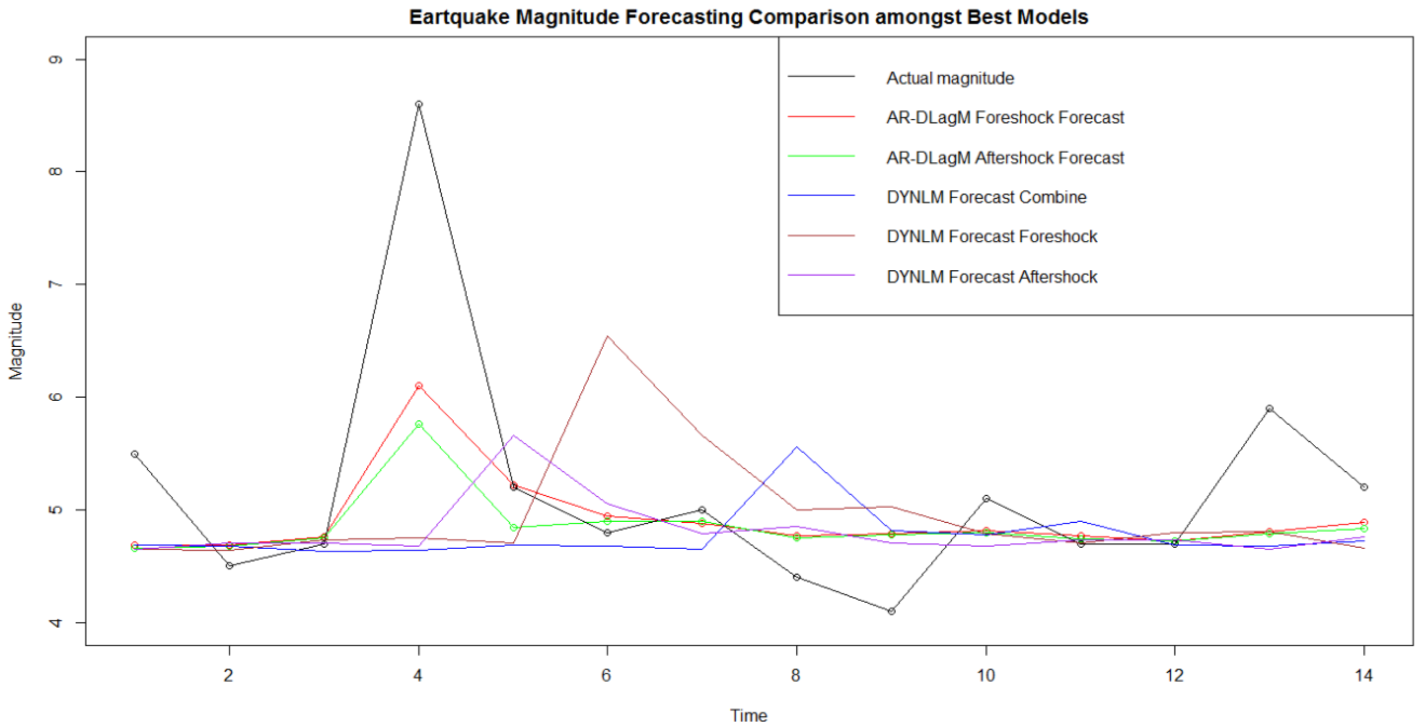

Figure 8 : Forecasting results' comparison of 5 models from AR-DLagM and DYNLM approach

The most obvious thing we can see in this graph is all of the models tried to catch the spike, however, AR-DLag M did a better job here than DYNLM approach. Both of AR-DLagM best model understand that there will be a spike at time step 4, even though their spike is not as high as actual earthquake magnitude. All of DYNLM models also catch the spike, but they missed 1-4 time step ahead. As a side note, even though there are interventions in this data, the intervention (using pulse function) coefficients in DYNLM approach actually are insignificant in their modelling result.

Hence, from this forecasting result, we can conclude that AR-DlagM approach works better than DYNLM approach in this project. Also, regressing only the number of foreshock to mainshock magnitude works better than regressing the number of aftershock to mainshock magnitude, or than regressing both foreshock and aftershock's numbers to mainshock magnitude. For R-code of this forecasting, please refer to **Appendix 5**.

4 Conclusions

This report shows that in a random event like natural disasters, there are still some pattern that we can catch. In this report, that pattern is being catch by using the number of foreshock and aftershock (to determine the mainshock magnitude). This pattern can be catch even when we just create simple own term to define foreshock and aftershock (and not following more scientific way like using Omori law to define aftershock). However, using the number of foreshock and aftershock only, still gives several limitations. Hence we need to add another variable to provide better forecasting.

5 Any Other Issues

As mentioned before, there are still some limitations in implementing this method:

1. This approach tried to predict the earthquake magnitude for the next 14 earthquakes, but it did not specify the time (or place). Hence, further analysis that includes these parts is needed.

2. Even though the model can capture the spike and capture the variance in the series, the magnitude that being captured still not high enough. Also, all of the models still have significant residuals.

3. In DYNLM models, every time we add lag Y.t, the adjusted R-squared values always gives perfect result (100%), also the residuals is 99% not significant. This impossible results has made the lag of Y.t is not included in modelling part, which maybe resulting in less option in creating better forecast with this model.

6 References

[1] Earthquakes and Tsunamis in Sumatra: What we have recently learned, 2008<http://www.tectonics.caltech.edu/outreach/highlights/sumatra/> retrieved on 1st Oct 2017.

[2] https://earthquake.usgs.gov/earthquakes/search/

[3] Can a Regression Model with a Small R-squared Be Useful?, 2012, <http://www.theanalysisfactor.com/small-r-squared/> retrieved on 2nd Oct 2017.

[4] Özel, G, 2010, 'A bivariate compound Poisson model for the occurrence of foreshock and aftershock sequences in Turkey', Environmetrics 2011, vol.22, pp.847-856

7 Appendix

7.1 Appendix 1

Time series plot code and correlation test between number of foreshock, mainshock magnitude, and the number of aftershock.

```
eq<- read.csv("edit.csv")
#eq[eq == 0] <- NA
#eq <- na.omit(eq)

eq.ts<- ts(eq[,3:5])
mag<- ts(eq$mag)
foreshock<- ts(eq$foreshock)
aftershock<- ts(eq$aftershock)
combine <- ts(eq$combine)

cor(mag.all[,1:2], use = "complete.obs")

##                  mag foreshock
## mag        1.0000000 0.2359117
## foreshock 0.2359117 1.0000000

cor(mag.all[,c(1,3)], use = "complete.obs")

##                   mag aftershock
## mag         1.0000000  0.3176264
## aftershock 0.3176264  1.0000000

cor(mag.all[,1:3], use = "complete.obs")

##                   mag foreshock aftershock
## mag         1.0000000 0.2359117  0.3176264
## foreshock   0.2359117 1.0000000  0.4475426
## aftershock 0.3176264 0.4475426  1.0000000
```

7.2 Appendix 2

Models building and summary of AR-DLagM approach by regressing number of foreshock to mainshock magnitude.

```
mag<-as.vector(mag)
foreshock<-as.vector(foreshock)
aftershock<-as.vector(aftershock)
combine<-as.vector(combine)

eq1 = ardlDlm(x = foreshock, y = mag, p = 1 , q = 1, show.summary = TRUE)

##
## Time series regression with "zooreg" data:
## Start = 2, End = 3802
```

```
##
## Call:
## dynlm(formula = formula(model.text))
##
## Residuals:
##     Min      1Q  Median      3Q     Max
## -1.7160 -0.3271 -0.0604  0.2507  4.4396
##
## Coefficients:
##             Estimate Std. Error t value Pr(>|t|)
## (Intercept) 4.182429   0.077259  54.135  < 2e-16 ***
## X.t         0.043022   0.004252  10.119  < 2e-16 ***
## L(X.t, 1)   0.007222   0.004214   1.714   0.0867 .
## L(y.t, 1)   0.111158   0.016342   6.802 1.19e-11 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.5331 on 3795 degrees of freedom
##   (2 observations deleted due to missingness)
## Multiple R-squared:  0.0689, Adjusted R-squared:  0.06816
## F-statistic: 93.61 on 3 and 3795 DF,  p-value: < 2.2e-16
```

```
eq2 = ardlDlm(x = foreshock, y = mag, p = 1 , q = 2, show.summary = TRUE)
```

```
##
## Time series regression with "zooreg" data:
## Start = 3, End = 3802
##
## Call:
## dynlm(formula = formula(model.text))
##
## Residuals:
##     Min      1Q  Median      3Q     Max
## -1.7145 -0.3284 -0.0563  0.2454  4.4596
##
## Coefficients:
##             Estimate Std. Error t value Pr(>|t|)
## (Intercept) 3.858657   0.103236  37.377  < 2e-16 ***
## X.t         0.042493   0.004240  10.021  < 2e-16 ***
## L(X.t, 1)   0.003254   0.004282   0.760    0.447
## L(y.t, 1)   0.100416   0.016417   6.117 1.05e-09 ***
## L(y.t, 2)   0.079540   0.016331   4.870 1.16e-06 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.5313 on 3792 degrees of freedom
##   (3 observations deleted due to missingness)
## Multiple R-squared:  0.07438,    Adjusted R-squared:  0.07341
## F-statistic: 76.18 on 4 and 3792 DF,  p-value: < 2.2e-16
```

```r
eq3 = ardlDlm(x = foreshock, y = mag, p = 1 , q = 3, show.summary = TRUE)

##
## Time series regression with "zooreg" data:
## Start = 4, End = 3802
##
## Call:
## dynlm(formula = formula(model.text))
##
## Residuals:
##     Min      1Q  Median      3Q     Max
## -1.7803 -0.3269 -0.0585  0.2472  4.4803
##
## Coefficients:
##             Estimate Std. Error t value Pr(>|t|)
## (Intercept) 3.540412   0.119699  29.578  < 2e-16 ***
## X.t         0.041555   0.004228   9.828  < 2e-16 ***
## L(X.t, 1)   0.001236   0.004284   0.288    0.773
## L(y.t, 1)   0.093708   0.016409   5.711 1.21e-08 ***
## L(y.t, 2)   0.069214   0.016411   4.218 2.53e-05 ***
## L(y.t, 3)   0.084498   0.016028   5.272 1.43e-07 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.5293 on 3789 degrees of freedom
##   (4 observations deleted due to missingness)
## Multiple R-squared:  0.0811, Adjusted R-squared:  0.07989
## F-statistic: 66.89 on 5 and 3789 DF,  p-value: < 2.2e-16

eq4 = ardlDlm(x = foreshock, y = mag, p = 2 , q = 1, show.summary = TRUE)

##
## Time series regression with "zooreg" data:
## Start = 3, End = 3802
##
## Call:
## dynlm(formula = formula(model.text))
##
## Residuals:
##     Min      1Q  Median      3Q     Max
## -1.7147 -0.3266 -0.0591  0.2520  4.4409
##
## Coefficients:
##             Estimate Std. Error t value Pr(>|t|)
## (Intercept) 4.181497   0.077272  54.114  < 2e-16 ***
## X.t         0.041545   0.004387   9.469  < 2e-16 ***
## L(X.t, 1)   0.004863   0.004552   1.068    0.285
## L(X.t, 2)   0.005951   0.004323   1.377    0.169
## L(y.t, 1)   0.111078   0.016343   6.796 1.24e-11 ***
## ---
```

```
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.5331 on 3793 degrees of freedom
##   (2 observations deleted due to missingness)
## Multiple R-squared:  0.06936,    Adjusted R-squared:  0.06838
## F-statistic: 70.67 on 4 and 3793 DF,  p-value: < 2.2e-16
```

```r
eq5 = ardlDlm(x = foreshock, y = mag, p = 2 , q = 2 , show.summary = TRUE)
```

```
##
## Time series regression with "zooreg" data:
## Start = 3, End = 3802
##
## Call:
## dynlm(formula = formula(model.text))
##
## Residuals:
##     Min      1Q  Median      3Q     Max
## -1.7137 -0.3289 -0.0569  0.2454  4.4600
##
## Coefficients:
##             Estimate Std. Error t value Pr(>|t|)
## (Intercept) 3.864046   0.103425  37.361  < 2e-16 ***
## X.t         0.041561   0.004374   9.503  < 2e-16 ***
## L(X.t, 1)   0.001830   0.004584   0.399    0.690
## L(X.t, 2)   0.003772   0.004334   0.870    0.384
## L(y.t, 1)   0.100628   0.016419   6.129 9.76e-10 ***
## L(y.t, 2)   0.078018   0.016425   4.750 2.11e-06 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.5314 on 3791 degrees of freedom
##   (3 observations deleted due to missingness)
## Multiple R-squared:  0.07457,    Adjusted R-squared:  0.07335
## F-statistic: 61.09 on 5 and 3791 DF,  p-value: < 2.2e-16
```

```r
eq6 = ardlDlm(x = foreshock, y = mag, p = 2 , q = 3 , show.summary = TRUE)
```

```
##
## Time series regression with "zooreg" data:
## Start = 4, End = 3802
##
## Call:
## dynlm(formula = formula(model.text))
##
## Residuals:
##     Min      1Q  Median      3Q     Max
## -1.7806 -0.3271 -0.0589  0.2474  4.4803
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
```

```
## (Intercept)  3.538332   0.121060  29.228  < 2e-16 ***
## X.t           0.041676   0.004357   9.565  < 2e-16 ***
## L(X.t, 1)     0.001419   0.004568   0.311    0.756
## L(X.t, 2)    -0.000508   0.004397  -0.116    0.908
## L(y.t, 1)     0.093653   0.016418   5.704 1.26e-08 ***
## L(y.t, 2)     0.069378   0.016474   4.211 2.60e-05 ***
## L(y.t, 3)     0.084853   0.016322   5.199 2.11e-07 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.5294 on 3788 degrees of freedom
##   (4 observations deleted due to missingness)
## Multiple R-squared:  0.08111,    Adjusted R-squared:  0.07965
## F-statistic: 55.73 on 6 and 3788 DF,  p-value: < 2.2e-16
```

```
eq7 = ardlDlm(x = foreshock, y = mag, p = 3 , q = 1 , show.summary = TRUE)
```

```
##
## Time series regression with "zooreg" data:
## Start = 4, End = 3802
##
## Call:
## dynlm(formula = formula(model.text))
##
## Residuals:
##     Min      1Q  Median      3Q     Max
## -1.7142 -0.3268 -0.0588  0.2522  4.4412
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept) 4.1827840  0.0773012  54.110  < 2e-16 ***
## X.t         0.0413771  0.0045801   9.034  < 2e-16 ***
## L(X.t, 1)   0.0047931  0.0045929   1.044    0.297
## L(X.t, 2)   0.0057399  0.0045650   1.257    0.209
## L(X.t, 3)   0.0006953  0.0045144   0.154    0.878
## L(y.t, 1)   0.1107121  0.0163456   6.773 1.45e-11 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.5329 on 3791 degrees of freedom
##   (2 observations deleted due to missingness)
## Multiple R-squared:  0.06943,    Adjusted R-squared:  0.0682
## F-statistic: 56.57 on 5 and 3791 DF,  p-value: < 2.2e-16
```

```
eq8 = ardlDlm(x = foreshock, y = mag, p = 3 , q = 2 , show.summary = TRUE)
```

```
##
## Time series regression with "zooreg" data:
## Start = 4, End = 3802
##
## Call:
```

```
## dynlm(formula = formula(model.text))
##
## Residuals:
##     Min      1Q  Median      3Q     Max
## -1.7133 -0.3294 -0.0569  0.2450  4.4602
##
## Coefficients:
##             Estimate Std. Error t value Pr(>|t|)
## (Intercept) 3.867168   0.103462  37.378  < 2e-16 ***
## X.t         0.041348   0.004566   9.056  < 2e-16 ***
## L(X.t, 1)   0.001757   0.004626   0.380    0.704
## L(X.t, 2)   0.003523   0.004575   0.770    0.441
## L(X.t, 3)   0.000849   0.004500   0.189    0.850
## L(y.t, 1)   0.100339   0.016421   6.110 1.09e-09 ***
## L(y.t, 2)   0.077547   0.016422   4.722 2.42e-06 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.5312 on 3789 degrees of freedom
##   (3 observations deleted due to missingness)
## Multiple R-squared:  0.07457,    Adjusted R-squared:  0.07311
## F-statistic: 50.89 on 6 and 3789 DF,  p-value: < 2.2e-16
```

```
eq9 = ardlDlm(x = foreshock, y = mag, p = 3 , q = 3 , show.summary = TRUE)
```

```
##
## Time series regression with "zooreg" data:
## Start = 4, End = 3802
##
## Call:
## dynlm(formula = formula(model.text))
##
## Residuals:
##     Min      1Q  Median      3Q     Max
## -1.7814 -0.3271 -0.0580  0.2455  4.4802
##
## Coefficients:
##               Estimate Std. Error t value Pr(>|t|)
## (Intercept)  3.537e+00  1.211e-01  29.200  < 2e-16 ***
## X.t          4.219e-02  4.554e-03   9.265  < 2e-16 ***
## L(X.t, 1)    1.660e-03  4.611e-03   0.360    0.719
## L(X.t, 2)    2.928e-05  4.609e-03   0.006    0.995
## L(X.t, 3)   -1.756e-03  4.513e-03  -0.389    0.697
## L(y.t, 1)    9.342e-02  1.643e-02   5.686 1.40e-08 ***
## L(y.t, 2)    6.926e-02  1.648e-02   4.203 2.69e-05 ***
## L(y.t, 3)    8.556e-02  1.643e-02   5.209 2.00e-07 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.5294 on 3787 degrees of freedom
```

```
##   (4 observations deleted due to missingness)
## Multiple R-squared:  0.08114,    Adjusted R-squared:  0.07945
## F-statistic: 47.78 on 7 and 3787 DF,  p-value: < 2.2e-16
```

7.3 Appendix 3

Models building and summary of AR-DLagM approach by regressing number of aftershock to mainshock magnitude.

```
eq10 = ardlDlm(x = aftershock, y = mag, p = 1 , q = 1, show.summary = TRUE)

##
## Time series regression with "zooreg" data:
## Start = 2, End = 3802
##
## Call:
## dynlm(formula = formula(model.text))
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -3.08963 -0.32463 -0.05512  0.25812  3.01312
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept)  4.085601   0.076116  53.676   <2e-16 ***
## X.t          0.032938   0.001812  18.182   <2e-16 ***
## L(X.t, 1)   -0.004096   0.001887  -2.171     0.03 *
## L(y.t, 1)    0.132447   0.016057   8.248   <2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.5191 on 3795 degrees of freedom
##   (2 observations deleted due to missingness)
## Multiple R-squared:  0.1172, Adjusted R-squared:  0.1165
## F-statistic:   168 on 3 and 3795 DF,  p-value: < 2.2e-16

eq11 = ardlDlm(x = aftershock, y = mag, p = 1 , q = 2, show.summary = TRUE)

##
## Time series regression with "zooreg" data:
## Start = 3, End = 3802
##
## Call:
## dynlm(formula = formula(model.text))
##
## Residuals:
##     Min      1Q  Median      3Q     Max
## -3.1746 -0.3208 -0.0549  0.2488  3.0197
##
## Coefficients:
```

```
##               Estimate Std. Error t value Pr(>|t|)
## (Intercept)  3.702840   0.098950  37.421  < 2e-16 ***
## X.t          0.032829   0.001802  18.214  < 2e-16 ***
## L(X.t, 1)   -0.005109   0.001886  -2.709  0.00678 **
## L(y.t, 1)    0.117526   0.016142   7.281 4.01e-13 ***
## L(y.t, 2)    0.095828   0.015498   6.183 6.94e-10 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.5164 on 3792 degrees of freedom
##   (3 observations deleted due to missingness)
## Multiple R-squared:  0.1257, Adjusted R-squared:  0.1248
## F-statistic: 136.3 on 4 and 3792 DF,  p-value: < 2.2e-16
```

```
eq12 = ardlDlm(x = aftershock, y = mag, p = 1 , q = 3, show.summary = TRUE)
```

```
##
## Time series regression with "zooreg" data:
## Start = 4, End = 3802
##
## Call:
## dynlm(formula = formula(model.text))
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -3.15742 -0.31959 -0.05728  0.24872  3.00131
##
## Coefficients:
##               Estimate Std. Error t value Pr(>|t|)
## (Intercept)  3.391290   0.112990  30.014  < 2e-16 ***
## X.t          0.032376   0.001796  18.026  < 2e-16 ***
## L(X.t, 1)   -0.005151   0.001878  -2.743  0.00611 **
## L(y.t, 1)    0.108486   0.016154   6.716 2.15e-11 ***
## L(y.t, 2)    0.082683   0.015624   5.292 1.28e-07 ***
## L(y.t, 3)    0.087972   0.015448   5.695 1.33e-08 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.5141 on 3789 degrees of freedom
##   (4 observations deleted due to missingness)
## Multiple R-squared:  0.1331, Adjusted R-squared:  0.132
## F-statistic: 116.4 on 5 and 3789 DF,  p-value: < 2.2e-16
```

```
eq13 = ardlDlm(x = aftershock, y = mag, p = 2 , q = 1, show.summary = TRUE)
```

```
##
## Time series regression with "zooreg" data:
## Start = 3, End = 3802
##
## Call:
## dynlm(formula = formula(model.text))
```

```
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -3.09573 -0.32444 -0.05584  0.25519  3.01669
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept)  4.083929   0.076010  53.729  < 2e-16 ***
## X.t          0.032755   0.001810  18.101  < 2e-16 ***
## L(X.t, 1)   -0.007160   0.002066  -3.466 0.000534 ***
## L(X.t, 2)    0.006558   0.001810   3.624 0.000294 ***
## L(y.t, 1)    0.132177   0.016035   8.243 2.29e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.5183 on 3793 degrees of freedom
##   (2 observations deleted due to missingness)
## Multiple R-squared:  0.1203, Adjusted R-squared:  0.1193
## F-statistic: 129.6 on 4 and 3793 DF,  p-value: < 2.2e-16
```

```
eq14 = ardlDlm(x = aftershock, y = mag, p = 2 , q = 2 , show.summary = TRUE)
```

```
##
## Time series regression with "zooreg" data:
## Start = 3, End = 3802
##
## Call:
## dynlm(formula = formula(model.text))
##
## Residuals:
##     Min      1Q  Median      3Q     Max
## -3.1701 -0.3220 -0.0547  0.2491  3.0210
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept)  3.738467   0.100540  37.184  < 2e-16 ***
## X.t          0.032736   0.001802  18.163  < 2e-16 ***
## L(X.t, 1)   -0.006746   0.002059  -3.276  0.00106 **
## L(X.t, 2)    0.003715   0.001879   1.977  0.04808 *
## L(y.t, 1)    0.118653   0.016145   7.349 2.43e-13 ***
## L(y.t, 2)    0.086820   0.016148   5.377 8.05e-08 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.5162 on 3791 degrees of freedom
##   (3 observations deleted due to missingness)
## Multiple R-squared:  0.1266, Adjusted R-squared:  0.1255
## F-statistic: 109.9 on 5 and 3791 DF,  p-value: < 2.2e-16
```

```
eq15 = ardlDlm(x = aftershock, y = mag, p = 2 , q = 3 , show.summary = TRUE)
```

```
##
## Time series regression with "zooreg" data:
## Start = 4, End = 3802
##
## Call:
## dynlm(formula = formula(model.text))
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -3.15448 -0.31917 -0.05624  0.24759  3.00274
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept)  3.425317   0.115387  29.685  < 2e-16 ***
## X.t          0.032319   0.001796  17.992  < 2e-16 ***
## L(X.t, 1)   -0.006349   0.002051  -3.095  0.00198 **
## L(X.t, 2)    0.002724   0.001880   1.449  0.14735
## L(y.t, 1)    0.109515   0.016168   6.774 1.45e-11 ***
## L(y.t, 2)    0.076372   0.016217   4.709 2.57e-06 ***
## L(y.t, 3)    0.085804   0.015518   5.529 3.43e-08 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.514 on 3788 degrees of freedom
##   (4 observations deleted due to missingness)
## Multiple R-squared:  0.1336, Adjusted R-squared:  0.1322
## F-statistic: 97.34 on 6 and 3788 DF,  p-value: < 2.2e-16
```

```
eq16 = ardlDlm(x = aftershock, y = mag, p = 3 , q = 1 , show.summary = TRUE)
```

```
##
## Time series regression with "zooreg" data:
## Start = 4, End = 3802
##
## Call:
## dynlm(formula = formula(model.text))
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -3.08155 -0.32258 -0.05567  0.25616  3.01839
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept)  4.091936   0.076046  53.809  < 2e-16 ***
## X.t          0.032513   0.001813  17.930  < 2e-16 ***
## L(X.t, 1)   -0.007062   0.002065  -3.420 0.000632 ***
## L(X.t, 2)    0.005094   0.001997   2.551 0.010781 *
## L(X.t, 3)    0.003151   0.001816   1.735 0.082903 .
## L(y.t, 1)    0.130144   0.016051   8.108 6.88e-16 ***
## ---
```

```
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.5179 on 3791 degrees of freedom
##   (2 observations deleted due to missingness)
## Multiple R-squared:  0.121,  Adjusted R-squared:  0.1198
## F-statistic: 104.4 on 5 and 3791 DF,  p-value: < 2.2e-16
```

```
eq17 = ardlDlm(x = aftershock, y = mag, p = 3 , q = 2 , show.summary = TRUE)
```

```
##
## Time series regression with "zooreg" data:
## Start = 4, End = 3802
##
## Call:
## dynlm(formula = formula(model.text))
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -3.15541 -0.32202 -0.05366  0.24967  3.02273
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept)  3.747817   0.100535  37.279  < 2e-16 ***
## X.t          0.032488   0.001806  17.988  < 2e-16 ***
## L(X.t, 1)   -0.006647   0.002058  -3.230  0.00125 **
## L(X.t, 2)    0.002225   0.002060   1.080  0.28011
## L(X.t, 3)    0.003226   0.001809   1.783  0.07462 .
## L(y.t, 1)    0.116622   0.016162   7.216 6.45e-13 ***
## L(y.t, 2)    0.086528   0.016138   5.362 8.73e-08 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.5158 on 3789 degrees of freedom
##   (3 observations deleted due to missingness)
## Multiple R-squared:  0.1273, Adjusted R-squared:  0.1259
## F-statistic: 92.14 on 6 and 3789 DF,  p-value: < 2.2e-16
```

```
eq18 = ardlDlm(x = aftershock, y = mag, p = 3 , q = 3 , show.summary = TRUE)
```

```
##
## Time series regression with "zooreg" data:
## Start = 4, End = 3802
##
## Call:
## dynlm(formula = formula(model.text))
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -3.15257 -0.31909 -0.05599  0.24762  3.00326
##
## Coefficients:
```

```
##               Estimate Std. Error t value Pr(>|t|)
## (Intercept)  3.430717   0.117085  29.301  < 2e-16 ***
## X.t          0.032286   0.001800  17.933  < 2e-16 ***
## L(X.t, 1)   -0.006342   0.002052  -3.091  0.00201 **
## L(X.t, 2)    0.002499   0.002054   1.217  0.22378
## L(X.t, 3)    0.000512   0.001876   0.273  0.78491
## L(y.t, 1)    0.109373   0.016178   6.761 1.59e-11 ***
## L(y.t, 2)    0.076543   0.016231   4.716 2.49e-06 ***
## L(y.t, 3)    0.084587   0.016147   5.238 1.71e-07 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.5141 on 3787 degrees of freedom
##   (4 observations deleted due to missingness)
## Multiple R-squared:  0.1336, Adjusted R-squared:  0.132
## F-statistic: 83.42 on 7 and 3787 DF,  p-value: < 2.2e-16
```

7.4 Appendix 4

Models building and summary of modelling using DYNLM approach

```
na.ma(mag,weighting = "simple", k =3)

mag<- ts(eq$mag)
foreshock<- ts(eq$foreshock)
aftershock<- ts(eq$aftershock)
Y.t=mag
X.t <- foreshock


Y.ta = log(mag)
T=1959
P.t=1*(seq(Y.ta)==T)
P.t.1=Lag(P.t,+1)

eqa <- dynlm (Y.ta ~  X.t + P.t + trend(Y.ta))
summary(eqa)

##
## Time series regression with "zooreg" data:
## Start = 1, End = 3802
##
## Call:
## dynlm(formula = Y.ta ~ X.t + P.t + trend(Y.ta))
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -0.45157 -0.06510 -0.00525  0.05929  0.66560
##
## Coefficients:
##                Estimate Std. Error t value Pr(>|t|)
```

```
## (Intercept)  1.551e+00  3.539e-03 438.182   <2e-16 ***
## X.t           1.135e-02  7.650e-04  14.839   <2e-16 ***
## P.t          -2.679e-01  1.145e-01  -2.339   0.0194 *
## trend(Y.ta) -4.064e-06  1.615e-06  -2.516   0.0119 *
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.1089 on 3797 degrees of freedom
##   (1 observation deleted due to missingness)
## Multiple R-squared:  0.05654,    Adjusted R-squared:  0.05579
## F-statistic: 75.84 on 3 and 3797 DF,  p-value: < 2.2e-16
```

```
eqb<- dynlm (Y.ta ~  X.t + L(X.t, k=1) + P.t + P.t.1 + trend(Y.ta))
summary(eqb)
```

```
##
## Time series regression with "zooreg" data:
## Start = 2, End = 3802
##
## Call:
## dynlm(formula = Y.ta ~ X.t + L(X.t, k = 1) + P.t + P.t.1 + trend(Y.ta))
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -0.45127 -0.06508 -0.00428  0.05947  0.66605
##
## Coefficients:
##                   Estimate Std. Error t value Pr(>|t|)
## (Intercept)    1.550e+00  3.541e-03 437.866   <2e-16 ***
## X.t            1.038e-02  9.334e-04  11.119   <2e-16 ***
## L(X.t, k = 1)  1.633e-03  9.328e-04   1.750   0.0801 .
## P.t           -2.217e-01  1.173e-01  -1.891   0.0587 .
## P.t.1          7.663e-02  1.162e-01   0.660   0.5096
## trend(Y.ta)   -4.140e-06  1.617e-06  -2.561   0.0105 *
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.1088 on 3794 degrees of freedom
##   (1 observation deleted due to missingness)
## Multiple R-squared:  0.05776,    Adjusted R-squared:  0.05652
## F-statistic: 46.51 on 5 and 3794 DF,  p-value: < 2.2e-16
```

```
eqc<- dynlm (Y.ta ~  X.t + L(X.t, k=2) + P.t + trend(Y.ta) )
summary(eqc)
```

```
##
## Time series regression with "zooreg" data:
## Start = 3, End = 3802
##
## Call:
## dynlm(formula = Y.ta ~ X.t + L(X.t, k = 2) + P.t + trend(Y.ta))
```

```
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -0.45116 -0.06527 -0.00502  0.05948  0.66616
##
## Coefficients:
##                 Estimate Std. Error t value Pr(>|t|)
## (Intercept)    1.550e+00  3.543e-03 437.574   <2e-16 ***
## X.t            1.047e-02  8.729e-04  11.999   <2e-16 ***
## L(X.t, k = 2)  1.736e-03  8.299e-04   2.092   0.0365 *
## P.t           -2.261e-01  1.162e-01  -1.945   0.0518 .
## trend(Y.ta)   -4.142e-06  1.617e-06  -2.561   0.0105 *
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.1088 on 3794 degrees of freedom
##   (1 observation deleted due to missingness)
## Multiple R-squared:  0.05763,    Adjusted R-squared:  0.05664
## F-statistic: 58.01 on 4 and 3794 DF,  p-value: < 2.2e-16
```

```
eqd<- dynlm (Y.ta ~  X.t + L(X.t, k=1)+L(X.t, k=2) + P.t + trend(Y.ta) )
summary(eqd)
```

```
##
## Time series regression with "zooreg" data:
## Start = 3, End = 3802
##
## Call:
## dynlm(formula = Y.ta ~ X.t + L(X.t, k = 1) + L(X.t, k = 2) +
##     P.t + trend(Y.ta))
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -0.45106 -0.06523 -0.00444  0.05957  0.66637
##
## Coefficients:
##                 Estimate Std. Error t value Pr(>|t|)
## (Intercept)    1.550e+00  3.543e-03 437.549  < 2e-16 ***
## X.t            9.908e-03  9.546e-04  10.379  < 2e-16 ***
## L(X.t, k = 1)  1.370e-03  9.356e-04   1.464  0.14331
## L(X.t, k = 2)  1.273e-03  8.879e-04   1.434  0.15158
## P.t           -1.993e-01  1.177e-01  -1.694  0.09037 .
## trend(Y.ta)   -4.202e-06  1.618e-06  -2.598  0.00942 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.1088 on 3793 degrees of freedom
##   (1 observation deleted due to missingness)
## Multiple R-squared:  0.05817,    Adjusted R-squared:  0.05692
## F-statistic: 46.85 on 5 and 3793 DF,  p-value: < 2.2e-16
```

```r
eqe<- dynlm (Y.ta ~  X.t +L(X.t, k=4) +P.t + P.t.1 + trend(Y.ta) )
summary(eqe)
```

```
##
## Time series regression with "zooreg" data:
## Start = 5, End = 3802
##
## Call:
## dynlm(formula = Y.ta ~ X.t + L(X.t, k = 4) + P.t + P.t.1 + trend(Y.ta))
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -0.45060 -0.06514 -0.00431  0.05994  0.66668
##
## Coefficients:
##                 Estimate Std. Error t value Pr(>|t|)
## (Intercept)    1.550e+00  3.541e-03 437.614  < 2e-16 ***
## X.t            1.010e-02  8.401e-04  12.020  < 2e-16 ***
## L(X.t, k = 4)  2.790e-03  7.983e-04   3.495  0.00048 ***
## P.t           -2.079e-01  1.155e-01  -1.800  0.07200 .
## P.t.1          1.557e-01  1.088e-01   1.431  0.15250
## trend(Y.ta)   -4.122e-06  1.616e-06  -2.550  0.01080 *
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.1087 on 3791 degrees of freedom
##   (1 observation deleted due to missingness)
## Multiple R-squared:  0.06009,    Adjusted R-squared:  0.05885
## F-statistic: 48.48 on 5 and 3791 DF,  p-value: < 2.2e-16
```

THE RESULT IS STILL SHIT UNTIL NOW. NOW USING AFTERSHOCK

```r
X.tb<-aftershock
eqf<- dynlm (Y.ta ~  X.tb + P.t + trend(Y.ta))
summary(eqf)
```

```
##
## Time series regression with "zooreg" data:
## Start = 1, End = 3802
##
## Call:
## dynlm(formula = Y.ta ~ X.tb + P.t + trend(Y.ta))
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -0.56145 -0.06476 -0.00253  0.06094  0.49150
##
## Coefficients:
##               Estimate Std. Error t value Pr(>|t|)
## (Intercept)  1.551e+00  3.496e-03 443.712   <2e-16 ***
## X.tb         5.934e-03  3.348e-04  17.723   <2e-16 ***
```

```
## P.t         -8.591e-02  1.094e-01  -0.785   0.4323
## trend(Y.ta) -3.599e-06  1.593e-06  -2.259   0.0239 *
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.1076 on 3797 degrees of freedom
##   (1 observation deleted due to missingness)
## Multiple R-squared:  0.07809,    Adjusted R-squared:  0.07736
## F-statistic: 107.2 on 3 and 3797 DF,  p-value: < 2.2e-16
```

```
X.tc<-combine
eqg<- dynlm (Y.ta ~  X.tc + P.t + trend(Y.ta))
summary(eqg)
```

```
##
## Time series regression with "zooreg" data:
## Start = 1, End = 3802
##
## Call:
## dynlm(formula = Y.ta ~ X.tc + P.t + trend(Y.ta))
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -0.61605 -0.06394 -0.00365  0.05994  0.48217
##
## Coefficients:
##               Estimate Std. Error t value Pr(>|t|)
## (Intercept)  1.550e+00  3.467e-03 447.103  < 2e-16 ***
## X.tc         5.213e-03  2.653e-04  19.648  < 2e-16 ***
## P.t         -2.860e-01  1.103e-01  -2.593  0.00954 **
## trend(Y.ta) -4.323e-06  1.581e-06  -2.734  0.00629 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.1067 on 3797 degrees of freedom
##   (1 observation deleted due to missingness)
## Multiple R-squared:  0.09394,    Adjusted R-squared:  0.09322
## F-statistic: 131.2 on 3 and 3797 DF,  p-value: < 2.2e-16
```

```
eqh<- dynlm (Y.t ~  X.tc + P.t + trend(Y.t))
summary(eqh)
```

```
##
## Time series regression with "zooreg" data:
## Start = 1, End = 3802
##
## Call:
## dynlm(formula = Y.t ~ X.tc + P.t + trend(Y.t))
##
## Residuals:
##     Min      1Q  Median      3Q     Max
```

```
## -3.4629 -0.3192 -0.0492  0.2593  2.9381
##
## Coefficients:
##                Estimate Std. Error t value Pr(>|t|)
## (Intercept)  4.744e+00  1.690e-02 280.679  < 2e-16 ***
## X.tc         2.864e-02  1.294e-03  22.142  < 2e-16 ***
## P.t         -1.633e+00  5.376e-01  -3.037  0.00241 **
## trend(Y.t)  -2.443e-05  7.710e-06  -3.169  0.00154 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.5202 on 3797 degrees of freedom
##   (1 observation deleted due to missingness)
## Multiple R-squared:  0.1163, Adjusted R-squared:  0.1156
## F-statistic: 166.5 on 3 and 3797 DF,  p-value: < 2.2e-16
```

```r
eqi<- dynlm (Y.t ~  X.tc + L(X.tc, k=1) +P.t + trend(Y.t))
summary(eqi)
```

```
##
## Time series regression with "zooreg" data:
## Start = 1, End = 3802
##
## Call:
## dynlm(formula = Y.t ~ X.tc + L(X.tc, k = 1) + P.t + trend(Y.t))
##
## Residuals:
##     Min      1Q  Median      3Q     Max
## -3.4629 -0.3192 -0.0492  0.2593  2.9381
##
## Coefficients: (1 not defined because of singularities)
##                   Estimate Std. Error t value Pr(>|t|)
## (Intercept)     4.744e+00  1.690e-02 280.679  < 2e-16 ***
## X.tc            2.864e-02  1.294e-03  22.142  < 2e-16 ***
## L(X.tc, k = 1)         NA         NA      NA       NA
## P.t            -1.633e+00  5.376e-01  -3.037  0.00241 **
## trend(Y.t)     -2.443e-05  7.710e-06  -3.169  0.00154 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.5202 on 3797 degrees of freedom
##   (1 observation deleted due to missingness)
## Multiple R-squared:  0.1163, Adjusted R-squared:  0.1156
## F-statistic: 166.5 on 3 and 3797 DF,  p-value: < 2.2e-16
```

```r
eqj<- dynlm (Y.t ~  X.tc + L(X.tc, k=1) + L(X.tc, k=2)+P.t + trend(Y.t))
summary(eqj)
```

```
##
## Time series regression with "zooreg" data:
## Start = 1, End = 3802
```

```
##
## Call:
## dynlm(formula = Y.t ~ X.tc + L(X.tc, k = 1) + L(X.tc, k = 2) +
##     P.t + trend(Y.t))
##
## Residuals:
##     Min      1Q  Median      3Q     Max
## -3.4629 -0.3192 -0.0492  0.2593  2.9381
##
## Coefficients: (2 not defined because of singularities)
##                  Estimate Std. Error t value Pr(>|t|)
## (Intercept)     4.744e+00  1.690e-02 280.679  < 2e-16 ***
## X.tc            2.864e-02  1.294e-03  22.142  < 2e-16 ***
## L(X.tc, k = 1)         NA         NA      NA       NA
## L(X.tc, k = 2)         NA         NA      NA       NA
## P.t            -1.633e+00  5.376e-01  -3.037  0.00241 **
## trend(Y.t)     -2.443e-05  7.710e-06  -3.169  0.00154 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.5202 on 3797 degrees of freedom
##   (1 observation deleted due to missingness)
## Multiple R-squared:  0.1163, Adjusted R-squared:  0.1156
## F-statistic: 166.5 on 3 and 3797 DF,  p-value: < 2.2e-16
```

```r
eqk<- dynlm (Y.t ~  X.tc + L(X.tc, k=2)+P.t + trend(Y.t))
summary(eqk)
```

```
##
## Time series regression with "zooreg" data:
## Start = 1, End = 3802
##
## Call:
## dynlm(formula = Y.t ~ X.tc + L(X.tc, k = 2) + P.t + trend(Y.t))
##
## Residuals:
##     Min      1Q  Median      3Q     Max
## -3.4629 -0.3192 -0.0492  0.2593  2.9381
##
## Coefficients: (1 not defined because of singularities)
##                  Estimate Std. Error t value Pr(>|t|)
## (Intercept)     4.744e+00  1.690e-02 280.679  < 2e-16 ***
## X.tc            2.864e-02  1.294e-03  22.142  < 2e-16 ***
## L(X.tc, k = 2)         NA         NA      NA       NA
## P.t            -1.633e+00  5.376e-01  -3.037  0.00241 **
## trend(Y.t)     -2.443e-05  7.710e-06  -3.169  0.00154 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.5202 on 3797 degrees of freedom
```

```
##   (1 observation deleted due to missingness)
## Multiple R-squared:  0.1163, Adjusted R-squared:  0.1156
## F-statistic: 166.5 on 3 and 3797 DF,  p-value: < 2.2e-16
```

```r
eql<- dynlm (Y.t ~  X.tc + L(X.tc, k=2)+P.t +P.t.1 + trend(Y.t))
summary(eql)
```

```
##
## Time series regression with "zooreg" data:
## Start = 2, End = 3802
##
## Call:
## dynlm(formula = Y.t ~ X.tc + L(X.tc, k = 2) + P.t + P.t.1 + trend(Y.t))
##
## Residuals:
##     Min      1Q  Median      3Q     Max
## -3.4538 -0.3189 -0.0489  0.2595  2.9384
##
## Coefficients: (1 not defined because of singularities)
##                  Estimate Std. Error t value Pr(>|t|)
## (Intercept)     4.744e+00  1.691e-02 280.507  < 2e-16 ***
## X.tc            2.859e-02  1.294e-03  22.088  < 2e-16 ***
## L(X.tc, k = 2)         NA         NA      NA       NA
## P.t            -1.626e+00  5.376e-01  -3.026  0.00250 **
## P.t.1           6.748e-01  5.205e-01   1.296  0.19492
## trend(Y.t)     -2.423e-05  7.712e-06  -3.142  0.00169 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.5202 on 3795 degrees of freedom
##   (2 observations deleted due to missingness)
## Multiple R-squared:  0.1167, Adjusted R-squared:  0.1158
## F-statistic: 125.3 on 4 and 3795 DF,  p-value: < 2.2e-16
```

```r
eqm<- dynlm (Y.t ~  X.tc + L(X.tc, k=1)+L(X.tc, k=2)+P.t +P.t.1 + trend(Y.t))
summary(eqm)
```

```
##
## Time series regression with "zooreg" data:
## Start = 2, End = 3802
##
## Call:
## dynlm(formula = Y.t ~ X.tc + L(X.tc, k = 1) + L(X.tc, k = 2) +
##     P.t + P.t.1 + trend(Y.t))
##
## Residuals:
##     Min      1Q  Median      3Q     Max
## -3.4538 -0.3189 -0.0489  0.2595  2.9384
##
## Coefficients: (2 not defined because of singularities)
##                  Estimate Std. Error t value Pr(>|t|)
```

```
## (Intercept)     4.744e+00  1.691e-02 280.507  < 2e-16 ***
## X.tc            2.859e-02  1.294e-03  22.088  < 2e-16 ***
## L(X.tc, k = 1)         NA         NA      NA       NA
## L(X.tc, k = 2)         NA         NA      NA       NA
## P.t            -1.626e+00  5.376e-01  -3.026  0.00250 **
## P.t.1           6.748e-01  5.205e-01   1.296  0.19492
## trend(Y.t)     -2.423e-05  7.712e-06  -3.142  0.00169 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.5202 on 3795 degrees of freedom
##   (2 observations deleted due to missingness)
## Multiple R-squared:  0.1167, Adjusted R-squared:  0.1158
## F-statistic: 125.3 on 4 and 3795 DF,  p-value: < 2.2e-16
```

```
eqn<- dynlm (Y.t ~  X.tc + L(X.tc, k=3)+P.t +P.t.1 + trend(Y.t))
summary(eqn)
```

```
##
## Time series regression with "zooreg" data:
## Start = 2, End = 3802
##
## Call:
## dynlm(formula = Y.t ~ X.tc + L(X.tc, k = 3) + P.t + P.t.1 + trend(Y.t))
##
## Residuals:
##     Min      1Q  Median      3Q     Max
## -3.4538 -0.3189 -0.0489  0.2595  2.9384
##
## Coefficients: (1 not defined because of singularities)
##                  Estimate Std. Error t value Pr(>|t|)
## (Intercept)     4.744e+00  1.691e-02 280.507  < 2e-16 ***
## X.tc            2.859e-02  1.294e-03  22.088  < 2e-16 ***
## L(X.tc, k = 3)         NA         NA      NA       NA
## P.t            -1.626e+00  5.376e-01  -3.026  0.00250 **
## P.t.1           6.748e-01  5.205e-01   1.296  0.19492
## trend(Y.t)     -2.423e-05  7.712e-06  -3.142  0.00169 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.5202 on 3795 degrees of freedom
##   (2 observations deleted due to missingness)
## Multiple R-squared:  0.1167, Adjusted R-squared:  0.1158
## F-statistic: 125.3 on 4 and 3795 DF,  p-value: < 2.2e-16
```

```
eqo<- dynlm (Y.t ~  X.tc + L(X.tc, k=3)+ L(X.tc, k=1)+P.t +P.t.1 + trend(Y.t)
)
summary(eqo)
```

```
##
## Time series regression with "zooreg" data:
```

```
## Start = 2, End = 3802
##
## Call:
## dynlm(formula = Y.t ~ X.tc + L(X.tc, k = 3) + L(X.tc, k = 1) +
##     P.t + P.t.1 + trend(Y.t))
##
## Residuals:
##     Min      1Q  Median      3Q     Max
## -3.4538 -0.3189 -0.0489  0.2595  2.9384
##
## Coefficients: (2 not defined because of singularities)
##                  Estimate Std. Error t value Pr(>|t|)
## (Intercept)     4.744e+00  1.691e-02 280.507  < 2e-16 ***
## X.tc            2.859e-02  1.294e-03  22.088  < 2e-16 ***
## L(X.tc, k = 3)         NA         NA      NA       NA
## L(X.tc, k = 1)         NA         NA      NA       NA
## P.t            -1.626e+00  5.376e-01  -3.026  0.00250 **
## P.t.1           6.748e-01  5.205e-01   1.296  0.19492
## trend(Y.t)     -2.423e-05  7.712e-06  -3.142  0.00169 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.5202 on 3795 degrees of freedom
##   (2 observations deleted due to missingness)
## Multiple R-squared:  0.1167, Adjusted R-squared:  0.1158
## F-statistic: 125.3 on 4 and 3795 DF,  p-value: < 2.2e-16
```

```
eqp<- dynlm (Y.t ~  X.tc + L(X.tc, k=3)+ L(X.tc, k=1)+L(X.tc, k=2)+P.t +P.t.1
+ trend(Y.t))
summary(eqp)
```

```
##
## Time series regression with "zooreg" data:
## Start = 2, End = 3802
##
## Call:
## dynlm(formula = Y.t ~ X.tc + L(X.tc, k = 3) + L(X.tc, k = 1) +
##     L(X.tc, k = 2) + P.t + P.t.1 + trend(Y.t))
##
## Residuals:
##     Min      1Q  Median      3Q     Max
## -3.4538 -0.3189 -0.0489  0.2595  2.9384
##
## Coefficients: (3 not defined because of singularities)
##                  Estimate Std. Error t value Pr(>|t|)
## (Intercept)     4.744e+00  1.691e-02 280.507  < 2e-16 ***
## X.tc            2.859e-02  1.294e-03  22.088  < 2e-16 ***
## L(X.tc, k = 3)         NA         NA      NA       NA
## L(X.tc, k = 1)         NA         NA      NA       NA
## L(X.tc, k = 2)         NA         NA      NA       NA
```

```
## P.t            -1.626e+00  5.376e-01  -3.026  0.00250 **
## P.t.1           6.748e-01  5.205e-01   1.296  0.19492
## trend(Y.t)     -2.423e-05  7.712e-06  -3.142  0.00169 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.5202 on 3795 degrees of freedom
##   (2 observations deleted due to missingness)
## Multiple R-squared:  0.1167, Adjusted R-squared:  0.1158
## F-statistic: 125.3 on 4 and 3795 DF,  p-value: < 2.2e-16
```

```
eqr<- dynlm (Y.ta ~  X.tc + L(X.tc, k=3)+ L(X.tc, k=1)+L(X.tc, k=2)+P.t +P.t.1
+ trend(Y.ta))
```

```
X.td<- aftershock
Z.td<- foreshock
eqs<- dynlm (Y.ta ~  X.td + Z.td+P.t +P.t.1 + trend(Y.ta))
summary(eqs)
```

```
##
## Time series regression with "zooreg" data:
## Start = 2, End = 3802
##
## Call:
## dynlm(formula = Y.ta ~ X.td + Z.td + P.t + P.t.1 + trend(Y.ta))
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -0.63527 -0.06367 -0.00488  0.05999  0.47998
##
## Coefficients:
##               Estimate Std. Error t value Pr(>|t|)
## (Intercept)  1.550e+00  3.468e-03 446.877  < 2e-16 ***
## X.td         4.642e-03  3.650e-04  12.716  < 2e-16 ***
## Z.td         6.945e-03  8.248e-04   8.420  < 2e-16 ***
## P.t         -3.331e-01  1.123e-01  -2.966  0.00304 **
## P.t.1        1.333e-01  1.067e-01   1.249  0.21185
## trend(Y.ta) -4.440e-06  1.583e-06  -2.805  0.00505 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.1066 on 3794 degrees of freedom
##   (2 observations deleted due to missingness)
## Multiple R-squared:  0.09554,    Adjusted R-squared:  0.09435
## F-statistic: 80.16 on 5 and 3794 DF,  p-value: < 2.2e-16
```

```
eqt<- dynlm (Y.ta ~  X.td + Z.td+L(Z.td, k=1)+L(X.td, k=1)+P.t +P.t.1 + trend
(Y.ta))
summary(eqt)
```

```
##
## Time series regression with "zooreg" data:
## Start = 2, End = 3802
##
## Call:
## dynlm(formula = Y.ta ~ X.td + Z.td + L(Z.td, k = 1) + L(X.td,
##     k = 1) + P.t + P.t.1 + trend(Y.ta))
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -0.56499 -0.06371 -0.00448  0.05985  0.47301
##
## Coefficients:
##                  Estimate Std. Error t value Pr(>|t|)
## (Intercept)     1.550e+00  3.463e-03 447.509  < 2e-16 ***
## X.td            5.026e-03  3.809e-04  13.198  < 2e-16 ***
## Z.td            8.837e-03  1.074e-03   8.228 2.59e-16 ***
## L(Z.td, k = 1)  5.630e-04  9.286e-04   0.606  0.54439
## L(X.td, k = 1) -1.990e-03  5.081e-04  -3.918 9.09e-05 ***
## P.t            -1.540e-01  1.236e-01  -1.246  0.21268
## P.t.1           2.095e-01  1.155e-01   1.814  0.06978 .
## trend(Y.ta)    -4.460e-06  1.581e-06  -2.821  0.00482 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.1065 on 3792 degrees of freedom
##   (1 observation deleted due to missingness)
## Multiple R-squared:  0.09919,    Adjusted R-squared:  0.09753
## F-statistic: 59.65 on 7 and 3792 DF,  p-value: < 2.2e-16
```

```
equ<- dynlm (Y.ta ~  X.td + Z.td+L(Z.td, k=2)+L(X.td, k=2)+P.t +P.t.1 + trend
(Y.ta))
summary(equ)
```

```
##
## Time series regression with "zooreg" data:
## Start = 3, End = 3802
##
## Call:
## dynlm(formula = Y.ta ~ X.td + Z.td + L(Z.td, k = 2) + L(X.td,
##     k = 2) + P.t + P.t.1 + trend(Y.ta))
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -0.62067 -0.06375 -0.00520  0.06014  0.48111
##
## Coefficients:
##                  Estimate Std. Error t value Pr(>|t|)
## (Intercept)     1.550e+00  3.472e-03 446.335  < 2e-16 ***
## X.td            4.617e-03  3.674e-04  12.569  < 2e-16 ***
```

```
## Z.td              6.694e-03  9.531e-04   7.024 2.55e-12 ***
## L(Z.td, k = 2)  9.239e-04  8.679e-04   1.064  0.28719
## L(X.td, k = 2) -1.911e-04  4.469e-04  -0.428  0.66891
## P.t             -3.196e-01  1.151e-01  -2.777  0.00551 **
## P.t.1            1.631e-01  1.241e-01   1.314  0.18888
## trend(Y.ta)     -4.470e-06  1.585e-06  -2.820  0.00482 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.1067 on 3791 degrees of freedom
##   (1 observation deleted due to missingness)
## Multiple R-squared:  0.09583,    Adjusted R-squared:  0.09416
## F-statistic:  57.4 on 7 and 3791 DF,  p-value: < 2.2e-16
```

```
eqv<- dynlm (Y.ta ~  X.td + Z.td+L(Z.td, k=1)+L(X.td, k=1)+L(Z.td, k=2)+L(X.t
d, k=2)+P.t +P.t.1 + trend(Y.ta))
summary(eqv)
```

```
##
## Time series regression with "zooreg" data:
## Start = 3, End = 3802
##
## Call:
## dynlm(formula = Y.ta ~ X.td + Z.td + L(Z.td, k = 1) + L(X.td,
##     k = 1) + L(Z.td, k = 2) + L(X.td, k = 2) + P.t + P.t.1 +
##     trend(Y.ta))
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -0.56740 -0.06376 -0.00470  0.05995  0.47382
##
## Coefficients:
##                   Estimate Std. Error t value Pr(>|t|)
## (Intercept)      1.550e+00  3.466e-03 447.087  < 2e-16 ***
## X.td             5.023e-03  3.817e-04  13.160  < 2e-16 ***
## Z.td             8.595e-03  1.094e-03   7.858 5.03e-15 ***
## L(Z.td, k = 1) -1.506e-04  1.095e-03  -0.138  0.89060
## L(X.td, k = 1) -2.091e-03  5.251e-04  -3.982 6.95e-05 ***
## L(Z.td, k = 2)  8.531e-04  8.985e-04   0.949  0.34247
## L(X.td, k = 2)  3.452e-04  5.067e-04   0.681  0.49571
## P.t             -1.276e-01  1.257e-01  -1.016  0.30985
## P.t.1            2.003e-01  1.258e-01   1.592  0.11138
## trend(Y.ta)     -4.472e-06  1.583e-06  -2.826  0.00474 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.1065 on 3789 degrees of freedom
##   (1 observation deleted due to missingness)
## Multiple R-squared:  0.0996, Adjusted R-squared:  0.09746
## F-statistic: 46.57 on 9 and 3789 DF,  p-value: < 2.2e-16
```

```
eqw<- dynlm (Y.ta ~  X.td + Z.td+L(Z.td, k=3)+L(X.td, k=3)+P.t +P.t.1 + trend
(Y.ta))
##  Breusch-Godfrey test for serial correlation of order up to 11
##
## data:  object
## LM test = 181.99, df = 11, p-value < 2.2e-16
```

```
eqx<- dynlm (Y.ta ~  X.td + Z.td+L(Z.td, k=4)+L(X.td, k=4)+P.t +P.t.1 + trend
(Y.ta))
summary(eqx)
```

```
##
## Time series regression with "zooreg" data:
## Start = 5, End = 3802
##
## Call:
## dynlm(formula = Y.ta ~ X.td + Z.td + L(Z.td, k = 4) + L(X.td,
##     k = 4) + P.t + P.t.1 + trend(Y.ta))
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -0.60029 -0.06335 -0.00421  0.06042  0.48234
##
## Coefficients:
##                  Estimate Std. Error t value Pr(>|t|)
## (Intercept)     1.549e+00  3.472e-03 446.145  < 2e-16 ***
## X.td            4.538e-03  3.676e-04  12.343  < 2e-16 ***
## Z.td            6.508e-03  9.473e-04   6.870 7.49e-12 ***
## L(Z.td, k = 4)  1.895e-03  8.280e-04   2.288  0.02217 *
## L(X.td, k = 4) -2.565e-04  3.937e-04  -0.652  0.51469
## P.t            -3.058e-01  1.145e-01  -2.670  0.00762 **
## P.t.1           1.375e-01  1.067e-01   1.289  0.19759
## trend(Y.ta)    -4.430e-06  1.585e-06  -2.795  0.00521 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.1065 on 3789 degrees of freedom
##   (1 observation deleted due to missingness)
## Multiple R-squared:  0.09689,    Adjusted R-squared:  0.09522
## F-statistic: 58.07 on 7 and 3789 DF,  p-value: < 2.2e-16
```

```
eqz<- dynlm (Y.ta ~  X.td + Z.td+L(Z.td, k=1)+L(X.td, k=1)+L(Z.td, k=2)+L(X.t
d, k=2)+L(Z.td, k=3)+L(X.td, k=3)+L(Z.td, k=4)+L(X.td, k=4)+P.t +P.t.1 + tren
d(Y.ta))
summary(eqz)
```

```
##
## Time series regression with "zooreg" data:
## Start = 5, End = 3802
##
## Call:
```

```
## dynlm(formula = Y.ta ~ X.td + Z.td + L(Z.td, k = 1) + L(X.td,
##     k = 1) + L(Z.td, k = 2) + L(X.td, k = 2) + L(Z.td, k = 3) +
##     L(X.td, k = 3) + L(Z.td, k = 4) + L(X.td, k = 4) + P.t +
##     P.t.1 + trend(Y.ta))
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -0.57603 -0.06355 -0.00506  0.05986  0.47367
##
## Coefficients:
##                  Estimate Std. Error t value Pr(>|t|)
## (Intercept)     1.549e+00  3.468e-03 446.700  < 2e-16 ***
## X.td            4.961e-03  3.825e-04  12.969  < 2e-16 ***
## Z.td            8.889e-03  1.179e-03   7.541 5.82e-14 ***
## L(Z.td, k = 1) -7.938e-04  1.162e-03  -0.683  0.49460
## L(X.td, k = 1) -2.142e-03  5.333e-04  -4.016 6.05e-05 ***
## L(Z.td, k = 2)  3.887e-04  1.097e-03   0.354  0.72318
## L(X.td, k = 2)  3.555e-04  5.360e-04   0.663  0.50722
## L(Z.td, k = 3) -1.735e-04  1.091e-03  -0.159  0.87366
## L(X.td, k = 3)  2.952e-04  4.906e-04   0.602  0.54734
## L(Z.td, k = 4)  2.064e-03  9.227e-04   2.237  0.02534 *
## L(X.td, k = 4) -5.829e-04  4.792e-04  -1.216  0.22393
## P.t            -1.300e-01  1.260e-01  -1.031  0.30238
## P.t.1           2.312e-01  1.276e-01   1.811  0.07014 .
## trend(Y.ta)    -4.420e-06  1.584e-06  -2.791  0.00529 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.1064 on 3783 degrees of freedom
##   (1 observation deleted due to missingness)
## Multiple R-squared:  0.1011, Adjusted R-squared:  0.09806
## F-statistic: 32.75 on 13 and 3783 DF,  p-value: < 2.2e-16
```

7.5 Appendix 5

Forecasting using 5 best models

```
training<- c(5.5, 4.5, 4.7, 8.6, 5.2, 4.8, 5, 4.4, 4.1, 5.1, 4.7, 4.7, 5.9, 5
.2)

eq.fc = ardlDlmForecast(model = eq18, x = c(1,0,1,33,8,2,1,0,1,2,1,0,2,4), h=
14)$forecast
eq.fc2 = ardlDlmForecast(model = eq9, x = c(1,0,1,33,8,2,1,0,1,2,1,0,2,4), h=
14)$forecast

q = 14
n = nrow(eqr$model)
s.rad = array(NA , (n + q))
d<-c(2,2,1,33,14,5,7,2,1,3,3,0,4,6)
X.t.new <- c(combine, d)
```

```r
X.t.new <- ts(X.t.new)
s.rad[1:n] = Y.ta[4:length(Y.ta)]
trend=array(NA,q)
trend.start=eqr$model[n,"trend(Y.ta)"]
trend=seq(trend.start, trend.start+q, 1)
#i=6
for (i in 1:q){
  data.new = c(1,X.t.new[n+i],X.t.new[n-3+i],X.t.new[n-1 + i],X.t.new[n-2 + i
], P.t[n],P.t.1[n],trend[i])
          s.rad[n+i] = as.vector(eqr$coefficients) %*% data.new
}

result<-s.rad[(n+1):(n+q)]
result<-exp(result)

eqb<- dynlm (Y.ta ~  X.t + L(X.t, k=1) + P.t + P.t.1 + trend(Y.ta))
q = 14
n = nrow(eqb$model)
s.rad = array(NA , (n + q))
d<-c(2,2,1,33,14,5,7,2,1,3,3,0,4,6)
X.t.new <- c(X.t, d)
X.t.new <- ts(X.t.new)
s.rad[1:n] = Y.ta[4:length(Y.ta)]
trend=array(NA,q)
trend.start=eqb$model[n,"trend(Y.ta)"]
trend=seq(trend.start, trend.start+q, 1)
#i=6
for (i in 1:q){
  data.new = c(1,X.t.new[n+i],X.t.new[n-1+i], P.t[n],P.t.1[n],trend[i])
          s.rad[n+i] = as.vector(eqb$coefficients) %*% data.new
}

result2<-s.rad[(n+1):(n+q)]
result2<-exp(result2)

X.tb<-aftershock
eqf<- dynlm (Y.ta ~  X.tb + P.t + trend(Y.ta))
q = 14
n = nrow(eqf$model)
s.rad = array(NA , (n + q))
d<-c(2,2,1,33,14,5,7,2,1,3,3,0,4,6)
X.t.new3 <- c(X.tb, d)
X.t.new3 <- ts(X.t.new3)
s.rad[1:n] = Y.ta[4:length(Y.ta)]
trend=array(NA,q)
trend.start=eqf$model[n,"trend(Y.ta)"]
trend=seq(trend.start, trend.start+q, 1)
#i=6
for (i in 1:q){
  data.new = c(1,X.t.new3[n+i], P.t[n],trend[i])
```

```
          s.rad[n+i] = as.vector(eqf$coefficients) %*% data.new
}

result3<-s.rad[(n+1):(n+q)]
result3<-exp(result3)

{plot(eq.fc2, type="o", ylim=c(4,9),ylab = "Magnitude", xlab = "Time", main="
Eartquake Magnitude Forecasting Comparison amongst Best Models", col="Red")
lines(ts(eq.fc),col="green",type="o")
lines(ts(training),col="black",type="o")
lines(ts(result),col="blue")
lines(ts(result2),col="brown")
lines(ts(result3),col="purple")
legend("topright", lty=1, pch=-1,col=c("black", "red","green", "blue","brown"
, "purple"),c("Actual magnitude", "AR-DLagM Foreshock Forecast", "AR-DLagM Af
tershock Forecast","DYNLM Forecast Combine", "DYNLM Forecast Foreshock", "DYN
LM Forecast Aftershock"))}
```