R Event Study

David Zimmermann

2018-01-31

Contents

1 Introduction

The following script provides an application of an event study. The data and and the script itself can be found here: https://github.com/DavZim/Classes/tree/master/Advanced%20Corporate%20Finance/Event%20Study

To run this notebook, make sure that you have at least RStudio version 1.0.44 installed and run R version 3.3.2.

The general outline for this document is to first load the data, merge the necessary data, inspect the data both visually and via tables, estimate a CMRM (constant-mean-return model), calculate the ARs (abnormal returns), and CARs (cumulative abnormal returns) and then test for significance using a t-test.

2 Preparation

2.1 Load libraries

```
library(dplyr)     # for data manipulation
library(ggplot2)   # for plotting
library(lubridate) # for dates
library(readr)     # for data loading
library(scales)    # for plotting
library(tidyr)     # for tidy data
```

2.2 Load data

```
mar_wide <- read_csv("data/market.csv")
ret_wide <- read_csv("data/returns.csv")
events <- read_csv("data/events.csv")

# reshape returns and market to long format
returns <- gather(ret_wide, key = company,
              value = ret, -date)
market <- gather(mar_wide, key = country,
                  value = mret, -date)

# date formatting
returns <- returns %>% mutate(date = dmy(date))
market <- market %>% mutate(date = dmy(date))
events <- events %>% mutate(event = dmy(event))
```

2.3 Inspect data

```
returns
```

```
## # A tibble: 26,604 x 3
##    date       company       ret
##    <date>     <chr>       <dbl>
##  1 1997-01-02 Chrysler  0.0341
##  2 1997-01-03 Chrysler  0.0146
##  3 1997-01-06 Chrysler  0.0289
```

```
##  4 1997-01-07 Chrysler  0
##  5 1997-01-08 Chrysler -0.00702
##  6 1997-01-09 Chrysler  0
##  7 1997-01-10 Chrysler  0.0106
##  8 1997-01-13 Chrysler -0.0210
##  9 1997-01-14 Chrysler  0.00714
## 10 1997-01-15 Chrysler  0
## # ... with 26,594 more rows
```

```
market
```

```
## # A tibble: 17,736 x 3
##    date       country      mret
##    <date>     <chr>       <dbl>
##  1 1997-01-02 us      -0.00751
##  2 1997-01-03 us       0.0149
##  3 1997-01-06 us       0.000372
##  4 1997-01-07 us       0.00791
##  5 1997-01-08 us      -0.00519
##  6 1997-01-09 us       0.00820
##  7 1997-01-10 us       0.00613
##  8 1997-01-13 us      -0.000457
##  9 1997-01-14 us       0.0122
## 10 1997-01-15 us      -0.00269
## # ... with 17,726 more rows
```

```
events
```

```
## # A tibble: 6 x 2
##   company     event
##   <chr>       <date>
## 1 Chrysler    1998-05-06
## 2 BellSouth   2006-03-06
## 3 Engelhard   2006-01-03
## 4 Norsk Hydro 2006-12-18
## 5 Pilkington  2005-10-31
## 6 INA         1999-09-14
```

2.4 Merge Data

```
comps <- c("Chrysler", "BellSouth", "Engelhard", "Norsk Hydro", "Pilkington", "INA")
counts <- c("us", "us", "us", "norway", "uk", "italy")
countries <- data_frame(company = comps, country = counts)

# merge into one dataset
merged <- left_join(returns, countries, by = "company")
merged <- left_join(merged, market, by = c("date", "country"))
merged <- left_join(merged, events, by = "company")
merged
```

```
## # A tibble: 26,604 x 6
##    date       company       ret country      mret event
##    <date>     <chr>       <dbl> <chr>       <dbl> <date>
##  1 1997-01-02 Chrysler  0.0341  us      -0.00751  1998-05-06
##  2 1997-01-03 Chrysler  0.0146  us       0.0149   1998-05-06
```

```
##  3 1997-01-06 Chrysler  0.0289  us       0.000372 1998-05-06
##  4 1997-01-07 Chrysler  0       us       0.00791  1998-05-06
##  5 1997-01-08 Chrysler -0.00702 us      -0.00519  1998-05-06
##  6 1997-01-09 Chrysler  0       us       0.00820  1998-05-06
##  7 1997-01-10 Chrysler  0.0106  us       0.00613  1998-05-06
##  8 1997-01-13 Chrysler -0.0210  us      -0.000457 1998-05-06
##  9 1997-01-14 Chrysler  0.00714 us       0.0122   1998-05-06
## 10 1997-01-15 Chrysler  0       us      -0.00269  1998-05-06
## # ... with 26,594 more rows
```

2.5 Estimation and Events

```
# calculate the event-time as the difference in days to the event
merged <- merged %>% group_by(company) %>%
  mutate(date_index = 1:n(),
         event_index = max(ifelse(event == date, date_index, 0)),
         event_time = date_index - event_index)

merged
```

```
## # A tibble: 26,604 x 9
## # Groups:   company [6]
##    date       company       ret country      mret event      date_index
##    <date>     <chr>       <dbl> <chr>       <dbl> <date>          <int>
##  1 1997-01-02 Chrysler  0.0341  us      -0.00751  1998-05-06          1
##  2 1997-01-03 Chrysler  0.0146  us       0.0149   1998-05-06          2
##  3 1997-01-06 Chrysler  0.0289  us       0.000372 1998-05-06          3
##  4 1997-01-07 Chrysler  0       us       0.00791  1998-05-06          4
##  5 1997-01-08 Chrysler -0.00702 us      -0.00519  1998-05-06          5
##  6 1997-01-09 Chrysler  0       us       0.00820  1998-05-06          6
##  7 1997-01-10 Chrysler  0.0106  us       0.00613  1998-05-06          7
##  8 1997-01-13 Chrysler -0.0210  us      -0.000457 1998-05-06          8
##  9 1997-01-14 Chrysler  0.00714 us       0.0122   1998-05-06          9
## 10 1997-01-15 Chrysler  0       us      -0.00269  1998-05-06         10
## # ... with 26,594 more rows, and 2 more variables: event_index <dbl>,
## #   event_time <dbl>
```

Now we want to split our sample into estimation-sample ($[-230, -31]$) and event-sample ($[-30, +30]$). We also want to have a quick visualization of the return correlations to the market.

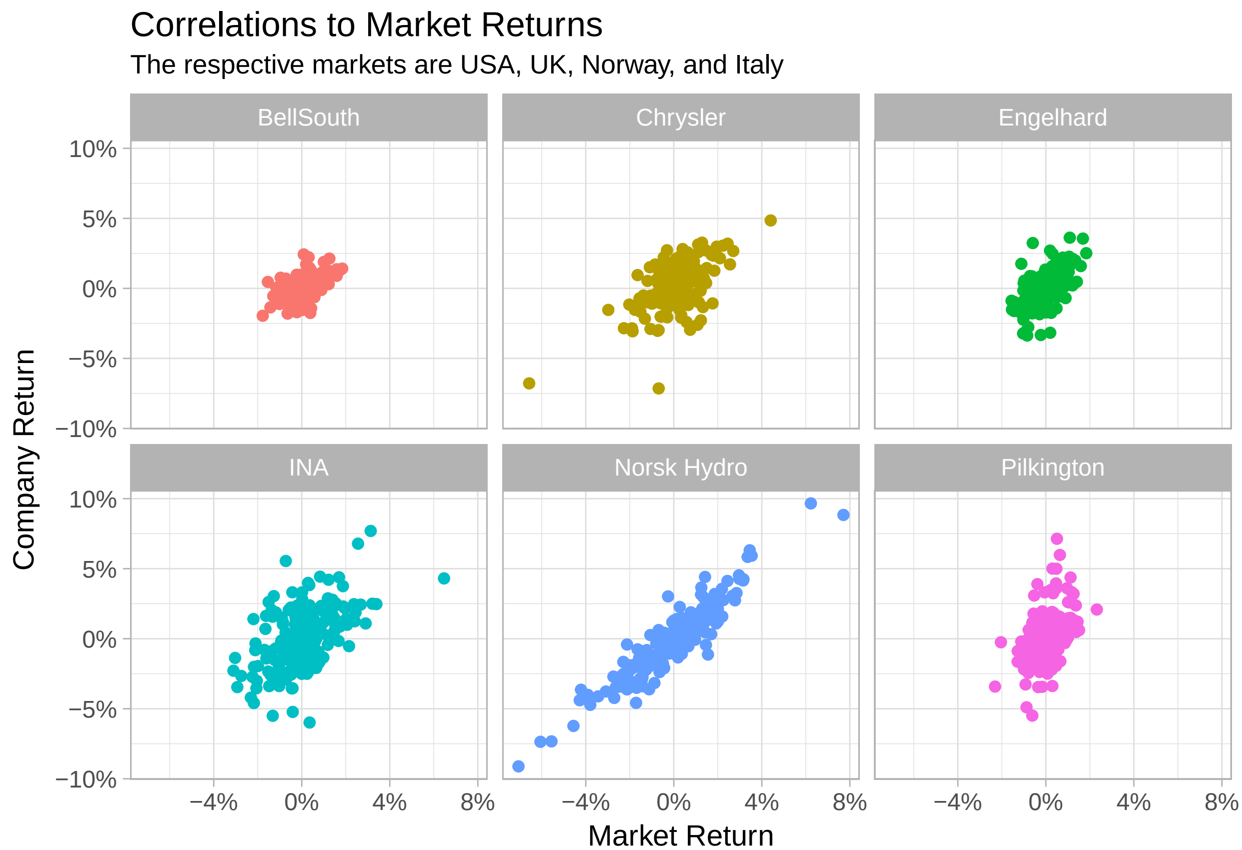
```
# windows
estimation_window <- c(-230, -31)
event_window <- c(-30, 30)

# filter returns
estimation <- merged %>% filter(event_time >= estimation_window[1] &
                                   event_time <= estimation_window[2])

event <- merged %>% filter(event_time >= event_window[1] &
                              event_time <= event_window[2])

# have a look at the data
estimation
```

```
## # A tibble: 1,200 x 9
## # Groups:   company [6]
##    date       company       ret country      mret event      date_index
##    <date>     <chr>       <dbl> <chr>       <dbl> <date>          <int>
##  1 1997-06-18 Chrysler  0.00384 us      -0.00462  1998-05-06        120
##  2 1997-06-19 Chrysler -0.00382 us       0.00995  1998-05-06        121
##  3 1997-06-20 Chrysler  0       us       0.000297 1998-05-06        122
##  4 1997-06-23 Chrysler -0.0115  us      -0.0202   1998-05-06        123
##  5 1997-06-24 Chrysler  0.0234  us       0.0180   1998-05-06        124
##  6 1997-06-25 Chrysler -0.00381 us      -0.00757  1998-05-06        125
##  7 1997-06-26 Chrysler  0.0114  us      -0.00573  1998-05-06        126
##  8 1997-06-27 Chrysler -0.0113  us       0.00388  1998-05-06        127
##  9 1997-06-30 Chrysler  0.00382 us      -0.00263  1998-05-06        128
## 10 1997-07-01 Chrysler -0.00951 us       0.00659  1998-05-06        129
## # ... with 1,190 more rows, and 2 more variables: event_index <dbl>,
## #   event_time <dbl>
```

```
event
```

```
## # A tibble: 366 x 9
## # Groups:   company [6]
##    date       company       ret country      mret event      date_index
##    <date>     <chr>       <dbl> <chr>       <dbl> <date>          <int>
##  1 1998-03-25 Chrysler -0.0173  us      -0.00222  1998-05-06        320
##  2 1998-03-26 Chrysler -0.0132  us      -0.000497 1998-05-06        321
##  3 1998-03-27 Chrysler  0.00149 us      -0.00467  1998-05-06        322
##  4 1998-03-30 Chrysler -0.00593 us      -0.00151  1998-05-06        323
##  5 1998-03-31 Chrysler -0.00598 us       0.00787  1998-05-06        324
##  6 1998-04-01 Chrysler  0.00601 us       0.00625  1998-05-06        325
##  7 1998-04-02 Chrysler -0.0209  us       0.00974  1998-05-06        326
##  8 1998-04-03 Chrysler -0.00305 us       0.00218  1998-05-06        327
##  9 1998-04-06 Chrysler  0.0214  us      -0.00387  1998-05-06        328
## 10 1998-04-07 Chrysler  0.00300 us      -0.00971  1998-05-06        329
## # ... with 356 more rows, and 2 more variables: event_index <dbl>,
## #   event_time <dbl>
```

```
# Graph data
theme_set(theme_light())
ggplot(estimation %>% filter(ret != 0), aes(x = mret, y = ret, color = company)) +
  geom_point() +
  facet_wrap(~company) +
  scale_x_continuous(labels = percent) +
  scale_y_continuous(labels = percent) +
   theme(legend.position = "none") +
  labs(title = "Correlations to Market Returns",
       subtitle = "The respective markets are USA, UK, Norway, and Italy",
       x = "Market Return", y = "Company Return")
```



3 Estimation

3.1 Calculate the CMRM

Although we have many options, this script uses the constant-mean-return model to calculate expected returns (for simplicity reasons mainy).

The expected return is given by

$$E\left[R_{i,t}|X_t\right]$$

using the CMRM (constant mean return model), we get

$$E[R_{i,t}|X_t] = \overline{R_{i,t}}$$

```
cmrm <- estimation %>% group_by(company) %>% summarise(cmrm = mean(ret))
cmrm
```

```
## # A tibble: 6 x 2
##   company          cmrm
##   <chr>           <dbl>
## 1 BellSouth    0.000395
## 2 Chrysler     0.00173
## 3 Engelhard   -0.0000261
## 4 INA          0.000112
```

```
## 5 Norsk Hydro  0.000419
## 6 Pilkington   0.00147
```

3.2 CAPM

To calculate the capm we can use the simplified market-model (estimates the intercept (risk-free rate) instead of imposing it) which uses a linear regression of the form $return \sim marketreturn$, using the `broom`-library we can do the following:

```
capm <- estimation %>%
  group_by(company) %>%
  # "do" a regression using do() from the broom-package (tidyverse)
  # see https://github.com/tidyverse/broom
  do(fit = lm(ret ~ mret, data = .)) %>%
  # get the coefficients: intercept and slope (alpha and beta)
  # and discard the model itself (fit)
  mutate(alpha = coefficients(fit)[1],
         beta = coefficients(fit)[2],
         fit = NULL)
capm
```

```
## Source: local data frame [6 x 3]
## Groups: <by row>
##
## # A tibble: 6 x 3
##   company           alpha  beta
##   <chr>             <dbl> <dbl>
## 1 BellSouth   -0.00000498 0.681
## 2 Chrysler     0.000699   0.851
## 3 Engelhard   -0.000335   1.06
## 4 INA         -0.000117   0.870
## 5 Norsk Hydro -0.000616   1.27
## 6 Pilkington   0.000906   1.22
```

```
event_capm <- left_join(event, capm, by = "company") %>%
  # compute the expected return
  mutate(capm = alpha + mret * beta,
         alpha = NULL,
         beta = NULL)
event_capm
```

```
## # A tibble: 366 x 10
## # Groups:   company [6]
##    date       company       ret country      mret event      date_index
##    <date>     <chr>       <dbl> <chr>       <dbl> <date>          <int>
##  1 1998-03-25 Chrysler -0.0173  us      -0.00222  1998-05-06        320
##  2 1998-03-26 Chrysler -0.0132  us      -0.000497 1998-05-06        321
##  3 1998-03-27 Chrysler  0.00149 us      -0.00467  1998-05-06        322
##  4 1998-03-30 Chrysler -0.00593 us      -0.00151  1998-05-06        323
##  5 1998-03-31 Chrysler -0.00598 us       0.00787  1998-05-06        324
##  6 1998-04-01 Chrysler  0.00601 us       0.00625  1998-05-06        325
##  7 1998-04-02 Chrysler -0.0209  us       0.00974  1998-05-06        326
##  8 1998-04-03 Chrysler -0.00305 us       0.00218  1998-05-06        327
##  9 1998-04-06 Chrysler  0.0214  us      -0.00387  1998-05-06        328
## 10 1998-04-07 Chrysler  0.00300 us      -0.00971  1998-05-06        329
```

```
## # ... with 356 more rows, and 3 more variables: event_index <dbl>,
## #   event_time <dbl>, capm <dbl>
```

Nonetheless, we will continue the tests using the CMRM and leave the testing of the CAPM to the interested reader.

3.3 Merge Returns

Next, we want to merge the expected returns into the event-dataset to be able to calculate the next steps.

```
# select only necessary variables
event <- event %>% select(company, ret, event_time)
event <- left_join(event, cmrm, by = "company")
event
```

```
## # A tibble: 366 x 4
## # Groups:   company [?]
##    company       ret event_time    cmrm
##    <chr>       <dbl>      <dbl>   <dbl>
##  1 Chrysler -0.0173       -30.0 0.00173
##  2 Chrysler -0.0132       -29.0 0.00173
##  3 Chrysler  0.00149      -28.0 0.00173
##  4 Chrysler -0.00593      -27.0 0.00173
##  5 Chrysler -0.00598      -26.0 0.00173
##  6 Chrysler  0.00601      -25.0 0.00173
##  7 Chrysler -0.0209       -24.0 0.00173
##  8 Chrysler -0.00305      -23.0 0.00173
##  9 Chrysler  0.0214       -22.0 0.00173
## 10 Chrysler  0.00300      -21.0 0.00173
## # ... with 356 more rows
```

3.4 Calculate the Abnormal Returns

The abnormal return in period t for company i is given by

$$AR_{i,t} = R_{i,t} - E\left[R_{i,t}\right]$$

which we can calculate in R like this

```
event <- event %>% mutate(ar = ret - cmrm)
event
```

```
## # A tibble: 366 x 5
## # Groups:   company [6]
##    company       ret event_time    cmrm        ar
##    <chr>       <dbl>      <dbl>   <dbl>     <dbl>
##  1 Chrysler -0.0173       -30.0 0.00173 -0.0190
##  2 Chrysler -0.0132       -29.0 0.00173 -0.0149
##  3 Chrysler  0.00149      -28.0 0.00173 -0.000245
##  4 Chrysler -0.00593      -27.0 0.00173 -0.00766
##  5 Chrysler -0.00598      -26.0 0.00173 -0.00771
##  6 Chrysler  0.00601      -25.0 0.00173  0.00428
##  7 Chrysler -0.0209       -24.0 0.00173 -0.0226
##  8 Chrysler -0.00305      -23.0 0.00173 -0.00478
##  9 Chrysler  0.0214       -22.0 0.00173  0.0197
```

```
## 10 Chrysler  0.00300      -21.0 0.00173  0.00126
## # ... with 356 more rows
```

3.5 Calculate the Cumulative Abnormal Returns

The CARs are given by

$$CAR_{i,t} = \sum_{k=1}^{t} AR_{i,t-k}$$

with a known distribution of

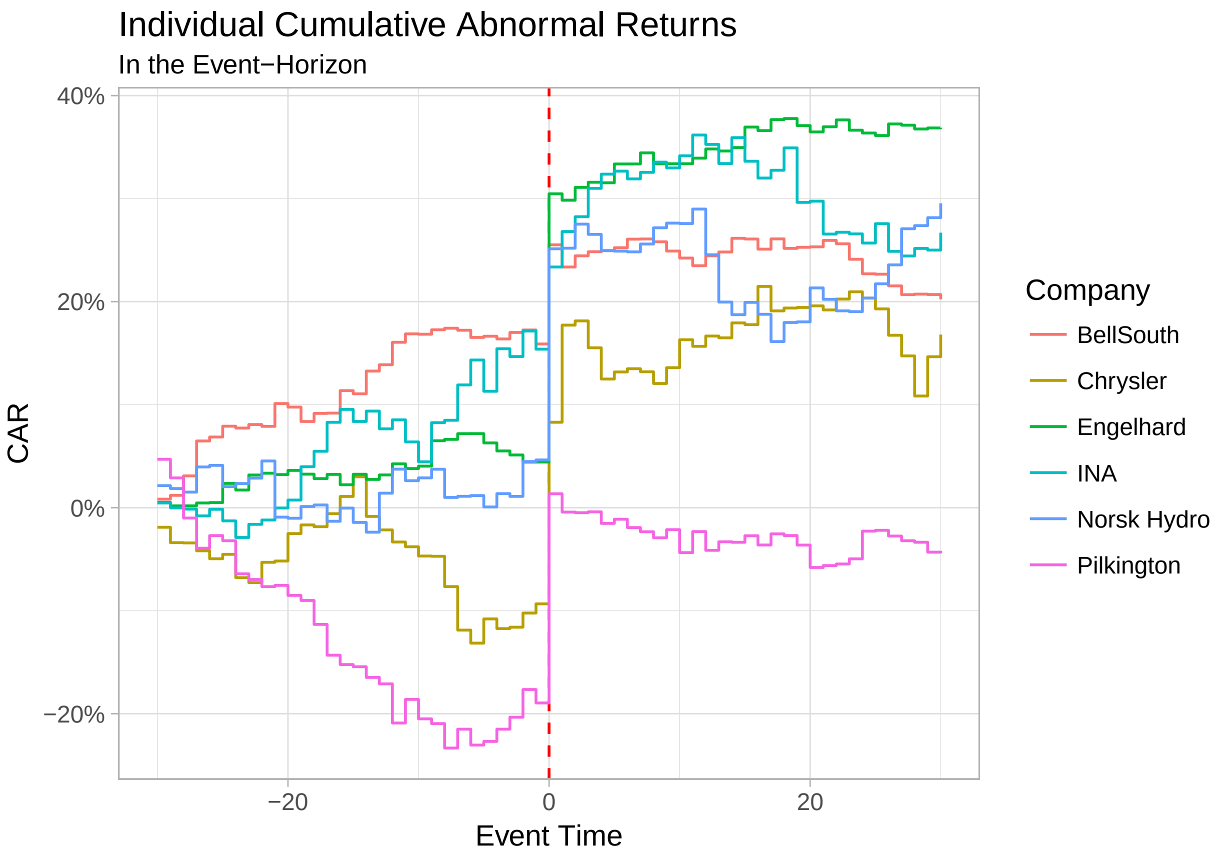
$$CAR_{i,t} \sim N(0, \sigma^2_{i,t})$$

In R we can calculate the CARs like this

```
indiv_event <-  event %>% group_by(company) %>% mutate(car = cumsum(ar))
indiv_event
```

```
## # A tibble: 366 x 6
## # Groups:   company [6]
##    company       ret event_time    cmrm        ar     car
##    <chr>       <dbl>      <dbl>   <dbl>     <dbl>   <dbl>
##  1 Chrysler -0.0173       -30.0 0.00173 -0.0190   -0.0190
##  2 Chrysler -0.0132       -29.0 0.00173 -0.0149   -0.0340
##  3 Chrysler  0.00149      -28.0 0.00173 -0.000245 -0.0342
##  4 Chrysler -0.00593      -27.0 0.00173 -0.00766  -0.0419
##  5 Chrysler -0.00598      -26.0 0.00173 -0.00771  -0.0496
##  6 Chrysler  0.00601      -25.0 0.00173  0.00428  -0.0453
##  7 Chrysler -0.0209       -24.0 0.00173 -0.0226   -0.0679
##  8 Chrysler -0.00305      -23.0 0.00173 -0.00478  -0.0727
##  9 Chrysler  0.0214       -22.0 0.00173  0.0197   -0.0530
## 10 Chrysler  0.00300      -21.0 0.00173  0.00126  -0.0518
## # ... with 356 more rows
```

```
ggplot(indiv_event, aes(x = event_time, y = car, color = company)) +
  geom_vline(xintercept = 0, color = "red", linetype = "dashed") +
  geom_step() +
  scale_y_continuous(labels = percent) +
  labs(title = "Individual Cumulative Abnormal Returns", subtitle = "In the Event-Horizon",
       x = "Event Time", y = "CAR", color = "Company")
```



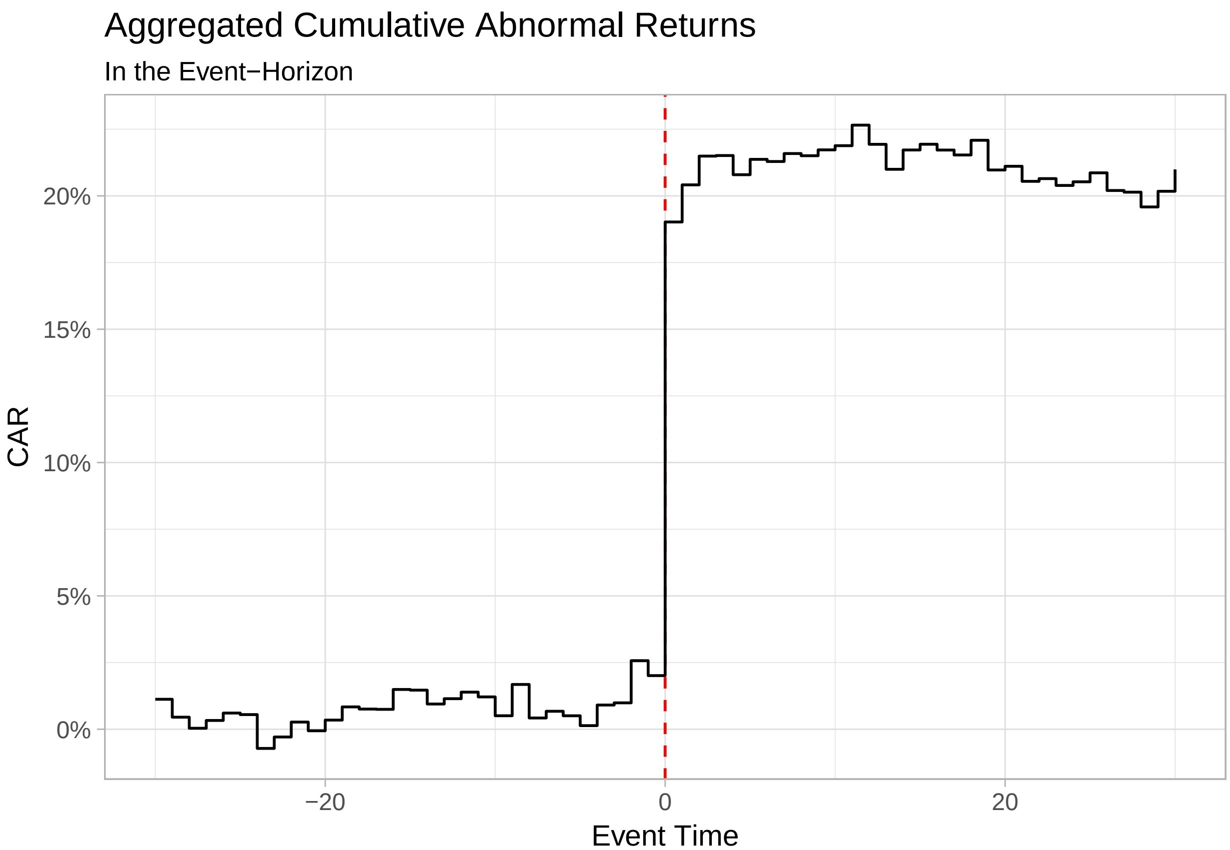
We can also calculate aggregated values (AAR as the average abnormal return) per day, which is handy, for example for ploting

```
# aggregated
agg_event <- event %>% group_by(event_time) %>% summarise(aar = mean(ar))
agg_event <- agg_event %>% mutate(car = cumsum(aar))
agg_event
```

```
## # A tibble: 61 x 3
##    event_time       aar       car
##         <dbl>     <dbl>     <dbl>
##  1      -30.0  0.0112    0.0112
##  2      -29.0 -0.00671   0.00452
##  3      -28.0 -0.00415   0.000364
##  4      -27.0  0.00292   0.00329
##  5      -26.0  0.00278   0.00607
##  6      -25.0 -0.000583  0.00549
##  7      -24.0 -0.0127   -0.00719
##  8      -23.0  0.00429  -0.00291
##  9      -22.0  0.00559   0.00269
## 10      -21.0 -0.00326  -0.000577
## # ... with 51 more rows
```

```
ggplot(agg_event, aes(x = event_time, y = car)) +
  geom_vline(xintercept = 0, color = "red", linetype = "dashed") +
  geom_step() +
  scale_y_continuous(labels = percent) +
  labs(title = "Aggregated Cumulative Abnormal Returns", subtitle = "In the Event-Horizon",
```

```
       x = "Event Time", y = "CAR")
```



4 Testing

To test for signifance, we mainly use t-test in this script, other tests include Boehmer et al. (1991) and Corrado (1989), among others.

The variance of the $CARs$, are known to be distributed with a variance of

$$\sigma^2_{i,t} = \frac{1}{N(N-1)} \sum_{j=1}^{N} \left(CAR_{j,t} - \overline{CAR_{j,t}}\right)^2$$

4.1 T-test

The first chunk uses a t-test to test the individual ARs (the question we are trying to answer: Is the abnormal return in time-period t different from zero?).

```
test1 <- indiv_event %>%
  group_by(event_time) %>%
  summarise(mean_ar = mean(ar),
         var_ar = 1/(n()*(n() - 1)) * sum((ar - mean_ar)^2),
         t_value = mean_ar / sqrt(var_ar),
         p_value = pt(abs(t_value), df = n(), lower.tail = F)*2)

test1
```

```
## # A tibble: 61 x 5
##    event_time   mean_ar     var_ar t_value p_value
##         <dbl>     <dbl>      <dbl>   <dbl>   <dbl>
##  1      -30.0  0.0112   0.0000795   1.26    0.255
##  2      -29.0 -0.00671  0.0000111  -2.01    0.0907
##  3      -28.0 -0.00415  0.0000596  -0.538   0.610
##  4      -27.0  0.00292  0.0000887   0.311   0.767
##  5      -26.0  0.00278  0.00000740  1.02    0.346
##  6      -25.0 -0.000583 0.0000349  -0.0988  0.924
##  7      -24.0 -0.0127   0.0000297  -2.33    0.0589
##  8      -23.0  0.00429  0.0000120   1.24    0.262
##  9      -22.0  0.00559  0.0000183   1.31    0.239
## 10      -21.0 -0.00326  0.000118   -0.301   0.774
## # ... with 51 more rows
```

The following chunk uses CARs to see if the price-development (which is represented by the CARs) is different from zero, instead of a snapshot of a single day as we did in the example above.

```r
# test2 with CARs
stars <- function(p) {
  ifelse(p < 0.001, "***",
         ifelse(p < 0.01, "**",
                ifelse(p < 0.05, "*", " ")))
}

test2 <- indiv_event %>%
  group_by(event_time) %>%
  summarise(mean_car = mean(car),
         var_car = 1/(n()*(n() - 1)) * sum((car - mean_car)^2),
         t_value = mean_car / sqrt(var_car),
         p_value = pt(abs(t_value), df = n(), lower.tail = F)*2)

test2 %>% mutate(sign = stars(p_value),
                car = cumsum(mean_car)) %>%
  select(event_time, car, t_value, sign) %>%
  filter(event_time %in% -3:6) # look only at the frame [-3, 6], to have less output
```

```
## # A tibble: 10 x 4
##    event_time   car t_value sign
##         <dbl> <dbl>   <dbl> <chr>
##  1      -3.00 0.184   0.165 " "
##  2      -2.00 0.210   0.444 " "
##  3      -1.00 0.230   0.357 " "
##  4       0    0.421   4.07  **
##  5       1.00 0.625   4.55  **
##  6       2.00 0.840   4.52  **
##  7       3.00 1.05    4.32  **
##  8       4.00 1.26    3.90  **
##  9       5.00 1.48    3.96  **
## 10       6.00 1.69    3.90  **
```

4.2 Testing over Aggregated Times

In the next step we want to look not at a single time-point, but at aggregated times, in this example, we want to see if the price in the time-horizon $[-3, +3]$ is different from zero.

```
time_window <- c(-3, 3)
test3 <- indiv_event %>% filter(event_time >= time_window[1] &
                                  event_time <= time_window[2]) %>%
  select(company, ar) %>%
  group_by(company) %>% summarise(car = sum(ar))

# using the same logic as before
test3 %>% summarise(mean_car = mean(car),
                    var_car = 1/(n()*(n() - 1)) * sum((car - mean_car)^2),
                    t_value = mean_car / sqrt(var_car),
                    p_value = pt(abs(t_value), df = n(), lower.tail = F)*2,
                    sign = stars(p_value))
```

```
## # A tibble: 1 x 5
##   mean_car  var_car t_value  p_value sign
##      <dbl>    <dbl>   <dbl>    <dbl> <chr>
## 1    0.206 0.000893    6.89 0.000460 ***
```

So we can see, that we have detected highly significant returns in the time-period $[-3, +3]$. If we want to test multiple time-periods we can do it like this.

4.3 Multiple Time Windows

It may seem a bit more complicated, but we are essentially doing the same thing as before, but use a lapply-function to loop over the row-numbers and repeat the process.

```
time_windows <- data_frame(min = c(-1, 0, -1, -3),
                           max = c(0, 1, 1, 3))

list_events <- lapply(1:nrow(time_windows), function(i) {
  tmp <- indiv_event %>% filter(event_time >= time_windows$min[i] &
                                event_time <= time_windows$max[i]) %>%
    select(company, ar) %>%
    group_by(company) %>%
    summarise(car = sum(ar)) %>%
    summarise(mean_car = mean(car),
              var_car = 1/(n()*(n() - 1)) * sum((car - mean_car)^2),
              t_value = mean_car / sqrt(var_car),
              p_value = pt(abs(t_value), df = n(), lower.tail = F)*2,
              sign = stars(p_value)) %>%
    mutate(range = paste0("[", time_windows$min[i], ", ",
                          time_windows$max[i], "]"))
  return(tmp %>% select(range, car = mean_car, t_value, p_value, sign))
})
# lapply returns a list of data_frames, to bind them into a single df, we use
# do.call in combination with rbind.
mult_events <- do.call(rbind, list_events)
mult_events
```

```
## # A tibble: 4 x 5
```

```
##   range      car t_value  p_value sign
##   <chr>   <dbl>   <dbl>    <dbl> <chr>
## 1 [-1, 0] 0.164    5.27 0.00188  **
## 2 [0, 1]  0.184    5.85 0.00110  **
## 3 [-1, 1] 0.178    5.06 0.00231  **
## 4 [-3, 3] 0.206    6.89 0.000460 ***
```