

Working with CRSP/COMPUSTAT in R: Reproducible Empirical Asset Pricing

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Abstract It is common to come across SAS or Stata manuals while working on academic empirical finance research. Nonetheless, given the popularity of open-source programming languages such as R, there are fewer resources in R covering popular databases such as CRSP and COMPUSTAT. The aim of this article is to bridge the gap and illustrate how to leverage R in working with both datasets. As an application, we illustrate how to form size-value portfolios with respect to Fama and French (1993) and study the sensitivity of the results with respect to different inputs. Ultimately, the purpose of the article is to advocate reproducible finance research and contribute to the recent idea of “Open Source Cross-Sectional Asset Pricing”, proposed by Chen and Zimmermann (2020).

Overall edit: - Add caption to each plot. Hence, the cross-reference to the plot could be applied (i.e., using, for example, “Figure 2”, instead of “the figure below”).

Overview

Typically the CRSP and COMPUSTAT databases are viewed as the cornerstones of academic empirical finance research. The former corresponds to security-related information for publicly listed companies, such as closing prices and returns. The latter covers financial statements disclosed by public firms, such as income statement, balance sheet, and cash flow-related items. We begin our discussion by demonstrating how to clean, manipulate, and merge both datasets. After doing so, we conduct the main analysis from the perspective of empirical asset pricing research based on Fama and French (1993).

The undertaken analysis constitutes a typical portfolio formation procedure to investigate how investors are compensated for taking certain types of risk/style. By grouping firms (stocks) with respect to pre-specified attributes, the researcher can study the implications of these characteristics (risks) in association with future returns. Such analysis is known as the cross-section of expected return (see, e.g., Harvey et al. (2016)) since the relationship is investigated on the firm/portfolio level. Consistent with Harvey et al. (2016), we find that the results of the cross-section of expected returns are sensitive to the research design. In particular, the exclusion of small stocks in the sample has a significant economic impact. Small stocks tend to trade less frequently and to be less liquid. Hence, in order to better understand the cross-section of expected returns, one needs to take into consideration the underlying limits of arbitrage facing investors (Li et al. (2014)).

We hope this article would further contribute to reproducible finance research and to our understandings of the cross-sectional of expected returns. The article proceeds as follows. In Section 2.2, we discuss how to load each dataset along with the pre-analysis needed in order to merge the data altogether. Section 2.3 is devoted to the replication of Fama and French (1993) size and value premiums. The analysis is conducted using raw and risk-adjusted returns. Section 2.4 then proceeds to investigate the sensitivity of the cross-section of returns with respect to the research design. Finally, Section 2.6 concludes.

Data

The discussion assumes that the user has already downloaded the CRSP and the COMPUSTAT datasets in two separate files, both in csv formats.¹ The article will rely on different libraries to perform the analysis. The core packages of interest are `data.table` (Dowle and Srinivasan (2019)) and `lubridate` (Grolemund and Wickham (2011)). We also refer to `ggplot2` (Wickham (2016)) to produce figures and `parallel` (R Core Team (2020)) to perform parallel processing. In a few cases, we refer to `plyr` (Wickham (2011)) and `dplyr` (Wickham et al. (2020)) for additional data manipulation. Nonetheless, the main analysis is conducted in the `data.table` environment.

```
library(data.table)
library(lubridate)
library(ggplot2)
library(plyr)
library(parallel)
rm(list = ls())
```

¹Note that users can work with the database directly using the WRDS API.

CRSP

While there are a lot of pros⁶ working **data.table**, one good functionality is the option that allows the user to easily specify a subset of variables while reading the whole data. Mostly, after downloading the full dataset, we focus on a subset of variables of interest. We refer to its main function `fread`, rather than the base command `read.csv`. The `fread` is similar to the base command; however, it provides faster and more convenient data manipulation. It is highly relevant when it comes to large data. Additionally, it allows users to easily utilize multi-threads using the `nThread` argument.

```
file.i <- "CRSP_1960_2019.csv"
select.var <- c("PERMCO", "date", "COMNAM", "SHROUT", "SHRCD", "DLRET",
               "DLSTCD", "DLPDT", "EXCHCD", "RET", "PRC", "CUSIP")
DT <- fread(file.i, select = select.var)
```

The above commands load the monthly CRSP dataset with pre-specified variables. Those are the permanent identifier of the security (PERMCO), date, shares outstanding in thousands (SHROUT), share code (SHRCD), exchange code (EXCHCD), security return RET, price PRC, and the CUSIP identifier. Note that the CUSIP is the key link between the CRSP and COMPUSTAT data. Additionally, we consider delisting-related variables denoted by DL, which are discussed later.

Filters and Cleaning

After loading the data, we perform a few filters and cleaning procedures. In particular, we keep common shares, those with 10 or 11 codes. We drop missing values for prices. There are also certain flags for prices denoted by -44, -55, -66, -77, -88, and -99. We drop these from the data as well. Additionally, we keep securities listed on major exchanges (NYSE, AMEX, or NASDAQ). Given these filters, we compute the market cap for each stock-month in the data.

```
DT <- DT[DT$SHRCD %in% 10:11,]
DT <- DT[!is.na(DT$PRC),]
DT <- DT[!DT$PRC %in% -(4:9)*11,]
DT$RET <- as.numeric(DT$RET)
DT <- DT[!is.na(DT$RET),]
DT$PRC <- abs(DT$PRC)
DT$MKT CAP <- DT$PRC*DT$SHROUT
DT <- DT[DT$EXCHCD %in% 1:3,]
```

There may be duplicates in the data depending on the identifier of interest. To control for this, consider the following commands⁷

```
DT <- unique(DT)
DT <- DT[order(DT$PERMCO, DT$date),]
DT[, `:=`( duplicate_N = .N ), by= list(PERMCO, date)]
table(DT$duplicate_N)/nrow(DT)*100


#>           1           2           3           4           6           7
#> 98.014830993  1.902150108  0.044272559  0.018337003  0.010738451  0.009670885
```

Note that the `:=` command creates a new variable to the already existing **data.table**, where `.N` denotes the data length. By grouping the data based on the stock identifier and month, we can count whether there are multiple observations within each case. As we observe from the above table, about 2% of the observations are duplicates, i.e., multiple observations for the same stock-month. For instance, the table below illustrates the case in which we have 7 duplicates:

```
head(DT[DT$duplicate_N == 7,], 7)

#>   PERMCO    date                                COMNAM SHROUT SHRCD DLRET DLSTCD DLPDT
#> 1: 54311 20160531 LIBERTY MEDIA CORP 3RD NEW 25569 11          NA    NA
#> 2: 54311 20160531 LIBERTY MEDIA CORP 3RD NEW 55684 11          NA    NA
#> 3: 54311 20160531 LIBERTY MEDIA CORP 3RD NEW 10228 11          NA    NA
#> 4: 54311 20160531 LIBERTY MEDIA CORP 3RD NEW 22284 11          NA    NA
#> 5: 54311 20160531 LIBERTY MEDIA CORP 3RD NEW 102277 11          NA    NA
#> 6: 54311 20160531 LIBERTY MEDIA CORP 3RD NEW 9871 11          NA    NA
#> 7: 54311 20160531 LIBERTY MEDIA CORP 3RD NEW 222735 11          NA    NA
#>   EXCHCD    RET    PRC    CUSIP    MKTCAP duplicate_N
#> 1:      3 0.064481 19.48 53122987 498084.1          7
```

```
#> 2:      3  0.052778 18.95 53122985 1055211.8      7
#> 3:      3  0.081873 15.56 53122970 159147.7      7
#> 4:      3  0.095723 15.00 53122988 334260.0      7
#> 5:      3 -0.026854 31.89 53122940 3261613.5     7
#> 6:      3 -0.026292 32.59 53122950 321695.9     7
#> 7:      3 -0.017801 31.45 53122960 7005015.8     7
```

Note that the duplicates arise due to different CUSIP identifiers. Since we are planning to link the data with the COMPUSTAT using CUSIP, we check whether there are duplicates for the same **cusip**-month 

```
DT[, `:=`( duplicate_N = .N ), by= list(CUSIP,date)]
table(DT$duplicate_N)/nrow(DT)*100
```

```
#> 1
#> 100
```

```
DT$duplicate_N <- NULL
```

In all cases, observe that there is a unique **cusip**-date observation. However, if one is working with CRSP alone, it is common to aggregate duplicates by value-weighting the observations based on market cap to yield a unique **permco**-month observation. Additionally, note that the first 6 CUSIP characters result in the same unique identifier.

In terms of date formatting, we utilize the **lubridate** library to manipulate dates:


```
DT$date <- ymd(DT$date)
DT$date <- ceiling_date(DT$date,"m") - 1
```

It is common to require a minimum history of each security in the data. For instance, a researcher may need to estimate the market beta on a rolling window using an initial sample of 2 years. For the sake of illustration, we require that each security should have at least two months of data (2 observations). Nonetheless, dropping observations in the following manner could have major implications in terms data-snooping and survivor-ship bias. In Section 2.4, we discuss the sensitivity of the portfolio results to this input.

```
crsp_keep <- 2
DT[, `:=`( N_obs = .N ), by= list(CUSIP)]
DT <- DT[DT$N_obs >= crsp_keep,]
DT$N_obs <- NULL
```

Finally, we have 24,581 unique securities, 720 months, and a total of 3,184,762 security-month observations.

Delisted Returns

An important characteristic of the CRSP database is that it includes historical companies that were delisted in the past. Not controlling for such delisting creates a survivor-ship bias, especially when it comes to researching the cross-section of stock returns - see, e.g., [Beaver et al. \(2007\)](#) for further information. To control for delisted returns, we follow the methodology recommended by [Bali et al. \(2016\)](#). We demonstrate these steps below. Before we do so, we take a quick look ^{at} the summary statistics of the current monthly returns 

```
summary(DT$RET)
```

```
#>      Min.   1st Qu.   Median     Mean   3rd Qu.    Max.
#> -0.99360 -0.06667  0.00000  0.01155  0.07143 24.00000
```

```
DT$DLRET <- as.numeric(DT$DLRET)
DT <- DT[order(DT$CUSIP,DT$date),]
DT[, `:=`( last_date = date[.N]), by= list(CUSIP) ]
DT[DT$DLSTCD %in% 100, "DLSTCD"] <- NA
cusip_delist <- unique(DT[!is.na(DT$DLSTCD),]$CUSIP)

DT_delist <- DT[DT$CUSIP %in% cusip_delist,]
DT_delist_last <- DT_delist[, .SD[.N], by= list(CUSIP)]
rm(DT_delist)
DT_delist_last$date <- ceiling_date(DT_delist_last$date + 1,"m") - 1
```

```

DT_delist_last$RET <- DT_delist_last$DLRET

na_dlret_index <- is.na(DT_delist_last$RET)
DT_delist_last_na <- DT_delist_last[na_dlret_index,]
DT_delist_last <-DT_delist_last[!na_dlret_index,]

select_code <- c(500,520:551,573,574,580,584)
DT_delist_last_na[DT_delist_last_na$DLSTCD %in% select_code,"RET"] <- -0.3
DT_delist_last_na[!DT_delist_last_na$DLSTCD %in% select_code,"RET"] <- -1

DT_delist_last <- rbind(DT_delist_last,DT_delist_last_na)
DT_delist_last$MKTCAP <- DT_delist_last$MKTCAP*(1 + DT_delist_last$RET)
DT_delist_last$PRC <- DT_delist_last$PRC*(1 + DT_delist_last$RET)

DT <- rbind(DT,DT_delist_last)
DT <- DT[order(DT$CUSIP,DT$date),]
summary(DT$RET) %$

#>      Min.   1st Qu.    Median      Mean   3rd Qu.      Max.
#> -1.00000 -0.06667   0.00000   0.01151   0.07143  24.00000

```

The above steps adjust for delisted returns. When available, it takes into consideration the delisting returns provided by CRSP. Otherwise, we use an arbitrary return^{US} according to the suggestion by [Bali et al. \(2016\)](#). We can see that the minimum return becomes -100%. However, at the same time, we observe that the mean return stays roughly the same due to the large sample size. It is also worth mentioning that dropping stocks below a certain price level potentially eliminates outliers and penny stocks that are more likely to get delisted.

Simple Portfolio Formation

Before we merge CRSP with COMPUSTAT, let's^{US} perform some basic analysis. For instance, we can easily aggregate the security return on the monthly level to create either a value-weighted or equally weighted portfolios. To do so, consider the following commands:

```

PORT_RET <- DT[,list(EW_RET = lapply(.SD,mean,na.rm = TRUE)),
                  by = list(date), .SDcols = "RET"]
PORT_RET2 <- DT[,list(VW_RET = lapply(.SD,
                                     function(x) sum(x*MKTCAP/sum(MKTCAP,na.rm = TRUE),na.rm = TRUE))),
                by = list(date), .SDcols = "RET"]
PORT_RET <- merge(PORT_RET,PORT_RET2)
rm(PORT_RET2)
PORT_RET <- PORT_RET[order(PORT_RET$date),]

```

To summarize the returns over time, consider the time series of cumulative returns for each portfolio. We refer to the **ggplot2** library and the National Bureau of Economic Research (NBER) recession periods to do so:

```

bar.col <- "gray"
ggplot_recession0 <- geom_rect(fill = bar.col,col = bar.col,
                              aes(xmin=date("1973-11-30"),
                                  xmax=date("1975-03-31"),
                                  ymin=-Inf, ymax=Inf))
ggplot_recession1 <- geom_rect(fill = bar.col,col = bar.col,
                              aes(xmin=date("1980-01-31"),
                                  xmax=date("1980-07-31"),
                                  ymin=-Inf, ymax=Inf))
ggplot_recession2 <- geom_rect(fill = bar.col,col = bar.col,
                              aes(xmin=date("1981-07-31"),
                                  xmax=date("1982-11-30"),
                                  ymin=-Inf, ymax=Inf))
ggplot_recession3 <- geom_rect(fill = bar.col,col = bar.col,
                              aes(xmin=date("1990-07-31"),
                                  xmax=date("1991-03-31"),
                                  ymin=-Inf, ymax=Inf))
ggplot_recession4 <- geom_rect(fill = bar.col,col = bar.col,

```

```

aes(xmin=date("2001-03-31"),
    xmax=date("2001-11-30"),
    ymin=-Inf, ymax=Inf))
ggplot_recession5 <- geom_rect(fill = bar.col,col = bar.col,
    aes(xmin=date("2007-12-31"),
    xmax=date("2009-06-30"),
    ymin=-Inf, ymax=Inf))

ds.plot1 <- data.frame(date = PORT_RET$date, CumRet = cumsum(PORT_RET$EW_RET),
    Type = "Equally-Weighted" )
ds.plot2 <- data.frame(date = PORT_RET$date, CumRet = cumsum(PORT_RET$VW_RET),
    Type = "Value-Weighted" )
ds.plot <- rbind(ds.plot1,ds.plot2)
ds.plot$Type <- as.factor(ds.plot$Type)

p <- ggplot(ds.plot, aes(date, CumRet,colour = Type))
p <- p + ggplot_recession0 + ggplot_recession1 +
    ggplot_recession2 + ggplot_recession3 +
    ggplot_recession4 + ggplot_recession5
p <- p + geom_line(alpha = 0.4)
p <- p + xlab("Date") + ylab("Cumulative Return")
p <- p + geom_abline(intercept = 0, slope = 0, color="black", linetype="dashed", size=0.2)
p

```



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plot.

We note that, overall, the equally-weighted portfolio under-performs the value-weighted one. The equally-weighted portfolio attributes greater weight to small-cap stocks. Contrary to [Fama and French \(1993\)](#), interestingly, we observe that the value-weighted stocks outperform the small-cap stocks. Nonetheless, the pattern became evident beginning in the late 80s. To take a closer look into the above, we group securities into size portfolios. At each month, we group securities into 5 groups based on the market cap cut-off.² To perform the cut-off, we refer to the `ntile` function from the `dplyr` library. In the following analysis, we proceed with equal-weighting for the sake of brevity.

```

library(dplyr)
cut.n <- 5
DT <- DT[,`:=` (Group_Size = ntile(MKTCAP,cut.n)), by = list(date)]
N_G <- DT[,.N, by = list(date,Group_Size) ]
N_G[,mean(N), by = list(Group_Size)]

#>   Group_Size    V1
#> 1:         2 885.3694
#> 2:         1 885.7667

```

²Note that in empirical asset pricing studies, when forming portfolios based on a single characteristic (i.e., single-sort), the common practice is to choose $G = 10$. On the other hand, for double-sorting it is common to choose $G = 5$. This, however, depends on data availability. In our case, we choose $G = 5$ for both brevity and consistency (see, e.g., [Fama and French \(1993\)](#)).

```
#> 3:      3 885.3875
#> 4:      4 885.3694
#> 5:      5 884.9500
```

We observe that, on average, each group contains 885 firms over the sample period. In addition to the group size, we consider the next one month return on each security. We use the shift function from **data.table** and apply it ^{to} on each security as follows ☹

```
DT <- DT[order(DT$CUSIP,DT$date),]
DT <- DT[,`:=`(RET_1 = shift(RET,-1)), by = list(CUSIP)]
```

Given the above, we report summary statistics on the size group level:

```
DT_size <- DT[,lapply(.SD,mean,na.rm = TRUE),by = list(Group_Size),
  .SDcols = c("RET","RET_1","PRC","SHROUT","MKTCAP","EXCHCD")]
DT_size <- DT_size[order(DT_size$Group_Size),]
DT_size$RET_1 <- DT_size$RET_1*12
DT_size$RET <- DT_size$RET*12
DT_size
```

#>	Group_Size	RET	RET_1	PRC	SHROUT	MKTCAP	EXCHCD
#> 1:	1	-0.1047989	0.2177438	4.265575	7569.757	13946.99	2.704329
#> 2:	2	0.1463509	0.1069973	9.280118	11101.177	56211.45	2.592039
#> 3:	3	0.2047528	0.1200868	15.410881	15797.729	168506.54	2.396027
#> 4:	4	0.2313902	0.1266713	25.020412	26814.684	538252.87	2.039177
#> 5:	5	0.2132456	0.1225963	105.854839	167534.402	7505924.35	1.457429

Clearly, securities ranked in the 5th largest size group have a higher market-cap, which is associated with both higher prices and shares outstanding. Additionally, note that the large stocks are more likely to be listed on NYSE (EXCHCD = 1), whereas the small cap stocks are listed on NASDAQ (EXCHCD = 3). In terms of returns, the results are sensitive with respect to whether we consider in-sample return or next month's return. In the in-sample, we observe that large caps outperform small cap. Nonetheless, the more relevant case in practice is the out-of-sample return. In the latter case, we observe that small cap stocks outperform large cap stocks. In annual terms, the small cap stocks return 10% higher mean return than large cap stocks. Ignoring transaction cost and assuming that investors rebalance their portfolios on a monthly basis, this evidence is consistent ^{with} Fama and French (1993) size premium. That is, investors expect higher return for investing in small cap stocks.

COMPUSTAT

The above discussion relates to the CRSP data alone. In the following, ^{we} focus on the COMPUSTAT data, which contains accounting-related information for public firms. Similar to the above, we focus on a subset of variables. For identification, we look into the CUSIP and the CIK number. The latter is relevant to identify firms via the SEC EDGAR system - for those interested in merging the data with SEC filings and perform textual analysis. The FYEARQ and FQTR are the fiscal year and quarter of the data point. For accounting variables, we consider total assets (atq), net income (niq), and common equity ceqq.

```
file.j <- "COMPUSTAT_1960_2020.csv"
select.var2 <- tolower(c("FYEARQ","FQTR","cusip","cik","sic","niq","atq","ceqq"))
DT2 <- unique(fread(file.j,select = select.var2))
```

Filters and Cleaning


To link between COMPUSTAT and CRSP, we need to make a small adjustment for the CUSIP identifiers. In CRSP, the number of characters is 8, whereas in COMPUSTAT, it is 9.

```
table(nchar(DT$CUSIP))

#>
#>      8
#> 3187327

table(nchar(DT2$cusip))
```

```
#>
#>      0      9
#>    130 1806228
```


Note that there are a few cases in which the CUSIP is unavailable in COMPUSTAT. The adjustments are described below .

```
DT2 <- DT2[!nchar(DT2$cusip) == 0,]
DT2$CUSIP <- substr(DT2$cusip,0,8)
DT2$cusip <- NULL
DT2 <- unique(DT2[DT2$CUSIP %in% DT2$CUSIP,])
```

In order to merge with the CRSP data, which corresponds to calendar dates, we adjust the fiscal dates in COMPUSTAT. It is common to use 6 months lags to allow the financial disclosures to become publicly available. To do so, we perform the following adjustments:

```
DT2$date <- ymd(DT2$yearq*10000 + DT2$fqtr*3*100 + 1)
DT2$date <- DT2$date + months(6)
DT2$date <- ceiling_date(DT2$date, "q") - 1
DT2 <- DT2[month(DT2$date) == 6,]
DT2$yearq <- DT2$fqtr <- NULL
```

Additionally, we keep the annual data rather than the quarterly one and consider portfolio formation on an annual basis.³ In particular, we keep the June data for the portfolio formation process.

Same as before, let's ^{us} check for duplicates .

```
DT2 <- unique(DT2)
DT2[, `:=`( duplicate_N = .N ), by= list(CUSIP,date)]
table(DT2$duplicate_N)
```

```
#>
#>      1
#> 247903
```

```
DT2$duplicate_N <- NULL
```

The COMPUSTAT dataset have unique cusip-date observations. ^{uppercase}

Summary Statistics

Given the final COMPUSTAT data, we consider a few summary statistics for each industry, which is defined using the 4th digit of the SIC code.

```
DT2 <- na.omit(DT2)
DT2$ROA <- DT2$niq/DT2$atq
DT2$ROE <- DT2$niq/DT2$ceqq
DT2$BL <- DT2$atq/DT2$ceqq
DT2$Industry <- floor(DT2$sic/1000)

DT2_sum <- DT2[,lapply(.SD,median,na.rm = TRUE), by = list(Industry),
  .SDcols = c("atq", "ROA", "ROE", "BL")]
DT2_sum <- DT2_sum[order(DT2_sum$Industry),]
DT2_sum
```

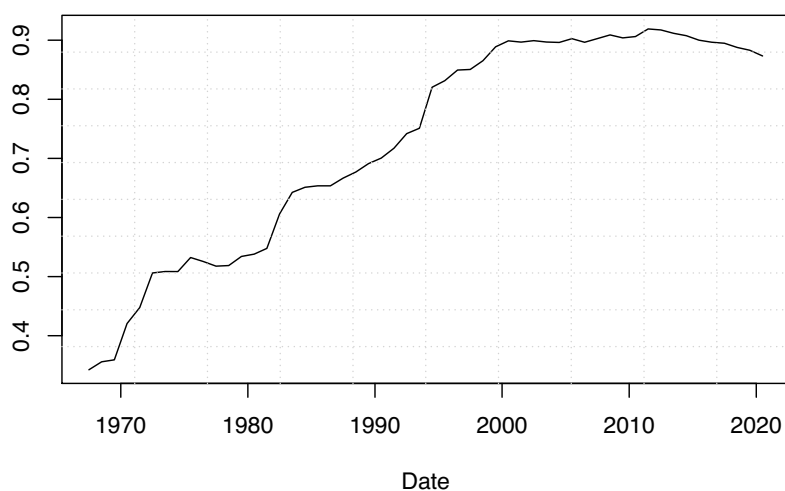
```
#>      Industry      atq      ROA      ROE      BL
#> 1:      0  97.9455 -0.005973224 -0.007163557  2.005072
#> 2:      1 152.8265  0.003908058  0.015030814  2.031069
#> 3:      2 112.5905  0.006157001  0.023091766  1.761200
#> 4:      3  85.0685  0.010216054  0.024022369  1.736357
#> 5:      4 540.3000  0.006908974  0.024877318  2.914309
#> 6:      5 148.0990  0.011941449  0.030180501  2.155898
#> 7:      6 893.6370  0.002491525  0.026317412  8.965721
#> 8:      7  88.5455  0.004830920  0.018396345  1.736342
#> 9:      8  73.5180  0.006937877  0.020926220  1.904278
#> 10:     9  37.3550 -0.003438435  0.006888589  1.562943
```

³Clearly, it all depends on the purpose of the investigation.

We observe that financial firms are associated with ^{the} highest book leverage, given the business nature of financial institutions. Also, we note that the financial industry is associated with the largest total assets. This is not surprising given the concentration of the financial industry over time, in which a few entities hold the majority of assets. To relate to the last point, consider the total assets of the top 10% firms with respect to the total assets in the industry as a whole.

```
DT2_Fin <- DT2[DT2$Industry == 6,]
DT2_Fin <- DT2_Fin[, `:=` (Group_Size = ntile(atq,10)), by = list(date)]
DT2_Fin <- DT2_Fin[, `:=` (Total_Assets = sum(atq)), by = list(date)]
DT2_Fin <- DT2_Fin[, lapply(.SD, function(x) sum(x/Total_Assets)),
                        by = list(date, Group_Size), .SDcols = "atq"]
DT2_Fin_Top <- DT2_Fin[DT2_Fin$Group_Size == 10,]
DT2_Fin_Top <- DT2_Fin_Top[order(DT2_Fin_Top$date),]
plot(atq~date, data = DT2_Fin_Top, type = "l",
     main = "Proportion of Assets held by Top 10% in Financial Industry",
     ylab = "", xlab = "Date")
grid(10)
```

Proportion of Assets held by Top 10% in Financial Industry



add caption
to the plot.

According to the above plot, we discern that the top 10% increased their share of total assets from 34% in the late 60s up to 90% more recently.

CRSP-COMPUSTAT

Note that the COMPUSTAT dataset is annual, while the CRSP is monthly. If we seek to form portfolios based on book-to-market (BM) ratio, such as the case for Fama-French, we need to create an annual BM variable in the COMPUSTAT dataset. Before we merge the data together, let's ^{we} add the market value of equity (ME) to the COMPUSTAT dataset. Additionally, ^{we} add the stock prices which would be useful for small ^{cap} stocks from the portfolio formation later on.

```
BM <- DT[, c("date", "CUSIP", "MKTCAP", "PRC")]
DT2 <- merge(DT2, BM, by = c("CUSIP", "date"), all = F)
DT2$BM_ratio <- DT2$ceqq / (DT2$MKTCAP / 1000)
DT2$ME <- DT2$MKTCAP
DT2$PRC_LAST <- DT2$PRC
DT2$MKTCAP <- DT2$PRC <- NULL
DT2 <- DT2[order(DT2$CUSIP, DT2$date),]
DT2[, `:=` (N_years = 1:.N), by = list(CUSIP)]
rm(BM); gc()

#>      used   (Mb) gc trigger   (Mb) max used   (Mb)
#> Ncells 1024743 54.8   2730065 145.9  2730065 145.9
#> Vcells 63598437 485.3 149041274 1137.1 148737297 1134.8
```

The above commands link the COMPUSTAT and the CRSP datasets to determine the market equity of the firms and, hence, the book-to-market ratio. Also, we denote the stock price as PRC_LAST to refer to the recent stock price in the annual data.

Before we finally merge the data altogether, we need to do one small trick with the CRSP data. The ultimate goal of this illustration is to attribute the next 12 months' returns with respect to the BM ratio from the previous June. To do so, consider the following:

```
prev_june_f <- function(x) floor_date(floor_date(x,"m") + months(6),"y") - months(6) - 1
DT$date_june <- prev_june_f(DT$date)
DT2$date_june <- DT2$date
DT2$date <- NULL
```

While the `prev_june_f` seems obscure, one should break the function into different components in order to understand how it works. Consider the special case where we have ☹️

```
x <- DT$date[1:13]
x
#> [1] "1970-12-31" "1971-01-31" "1971-02-28" "1971-03-31" "1971-04-30"
#> [6] "1971-05-31" "1971-06-30" "1971-07-31" "1971-08-31" "1971-09-30"
#> [11] "1971-10-31" "1971-11-30" "1971-12-31"
```

The first command of the function shifts the dates six months ahead:

```
floor_date(x,"m") + months(6)
#> [1] "1971-06-01" "1971-07-01" "1971-08-01" "1971-09-01" "1971-10-01"
#> [6] "1971-11-01" "1971-12-01" "1972-01-01" "1972-02-01" "1972-03-01"
#> [11] "1972-04-01" "1972-05-01" "1972-06-01"
```

The second step identifies the floor of each date on the annual level:

```
floor_date(floor_date(x,"m") + months(6),"y")
#> [1] "1971-01-01" "1971-01-01" "1971-01-01" "1971-01-01" "1971-01-01"
#> [6] "1971-01-01" "1971-01-01" "1972-01-01" "1972-01-01" "1972-01-01"
#> [11] "1972-01-01" "1972-01-01" "1972-01-01"
```

The final step subtracts 6 months to identify the June of the previous year. The minus one is added to retrieve June 30th rather than July 1st, such that ☹️

```
floor_date(floor_date(x,"m") + months(6),"y") - months(6) - 1
#> [1] "1970-06-30" "1970-06-30" "1970-06-30" "1970-06-30" "1970-06-30"
#> [6] "1970-06-30" "1970-06-30" "1971-06-30" "1971-06-30" "1971-06-30"
#> [11] "1971-06-30" "1971-06-30" "1971-06-30"
```

Looking at returns between Dec 1970 and Mar 1971, the function traces these observations back to June 1970 for the first 7 returns. When the next June date shows up, the `date_june` variable adjusts accordingly. Finally, the merged dataset is given by ☹️

```
DT12 <- merge(DT,DT2,by = c("CUSIP", "date_june"))
```

Note: The above steps provide details on how to merge between the two data sets. In the figure below, we provide a flow chart summarizing the steps/processes undertaken to develop the final merged data set DT12.

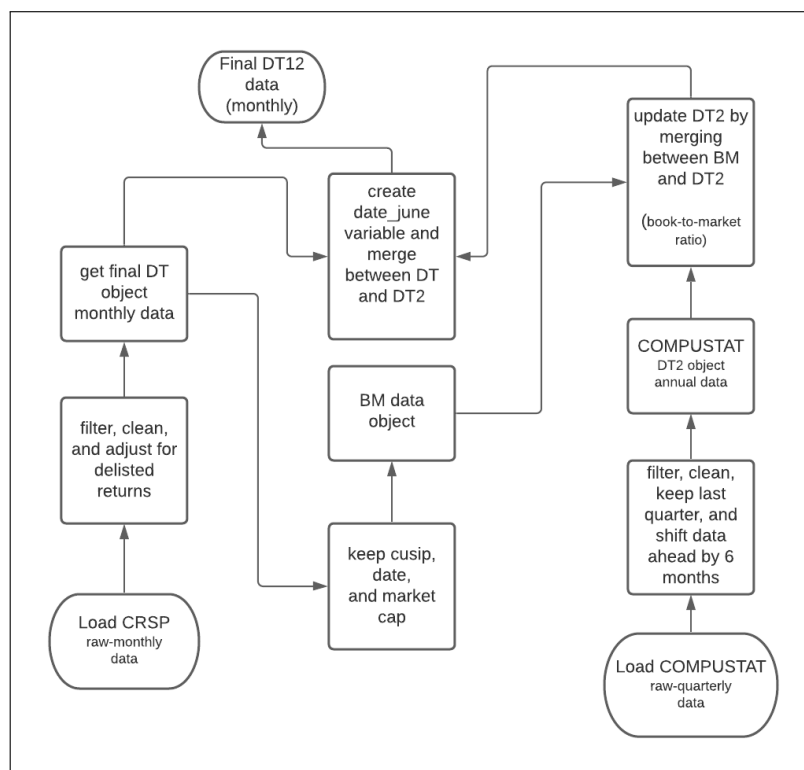
Forming Size and BM Portfolios

The DT12 object contains the final CRSP-COMPUSTAT data. The merging is conducted to allow for portfolio formation at the end of June each year, as mentioned above. Such setting allows a convenient way to form portfolios without relying on loops. Nonetheless, it would also impose that portfolio managers balance their portfolios on a monthly basis according to the market cap from the previous June.

Given the merged dataset, we form groups at the end of June-year based on market equity (size) and book-to-market ratio (value) ☹️

```
DT12 <- DT12[,`:=` (Group_ME = ntile(ME,5)), by = list(date_june)]
DT12 <- DT12[,`:=` (Group_BM = ntile(BM_ratio,5)), by = list(date_june,Group_ME)]
```

Flow Chart of the Data Merging Process



Add
caption
to this
figure.

The above two commands perform dependent portfolio sorting, in which firms are first sorted based on size and then on BM ratio. ^{We} consider value-weighting to compute the future returns on each size-value portfolio. This results in 25 value-weighted portfolios.

```

PORT_RET <- DT12[,list(VW_RET = sum(RET*ME/sum(ME)) ),
                     by = list(date,Group_ME,Group_BM)]
PORT_RET <- PORT_RET[order(PORT_RET$date,PORT_RET$Group_BM,PORT_RET$Group_ME),]
PORT_RET$VW_RET <- as.numeric(PORT_RET$VW_RET)*100

```

```

ret_matrix <- PORT_RET[,lapply(.SD,mean,na.rm = TRUE),
                          by = list(Group_ME,Group_BM), .SDcols = "VW_RET"]
ret_matrix <- ret_matrix[order(ret_matrix$Group_BM,ret_matrix$Group_ME),]
ret_matrix <- matrix(as.numeric(ret_matrix$VW_RET),5)
rownames(ret_matrix) <- 1:5
colnames(ret_matrix) <- paste("BM",1:5,sep = "_")
rownames(ret_matrix)[1] <- "Small"
rownames(ret_matrix)[5] <- "Big"
colnames(ret_matrix)[1] <- "Low"
colnames(ret_matrix)[5] <- "High"
round(data.frame(ret_matrix*12),2)

```

```

#>      Low BM_2 BM_3 BM_4 High
#> Small 12.93 14.73 18.05 20.14 23.40
#> 2      8.45 12.55 14.37 16.72 16.17
#> 3      8.04 11.79 14.30 14.24 15.99
#> 4      9.89 11.53 11.92 14.47 14.77
#> Big   9.84 11.70 10.41 13.13 12.78

```

For each column above, we observe the stock returns (raw) decrease, on average, with size. This is commonly known as the size effect. At the same time, we observe that within each size group, the mean return increases with ^{the} BM ratio. The latter denotes what is known as the value effect. In other words, investors expect higher returns from small enterprises and undervalued stocks (trading below book value). Nonetheless, recent discussions debate whether this is the case. For further information on this, see this [article](#).

Risk-Adjusted Returns using Fama-French Risk Factors

The above portfolio results compute the raw returns. In order to price these portfolios, we decompose the returns into (1) systematic components (risk-premiums) and (2) non-systematic. The latter denote the risk-adjusted returns. Additionally, we consider the excess return on each portfolio, i.e., the portfolio return minus the 1-month Treasury yield.

The Fama-French risk factors are obtained easily using the Kenneth French public library according to the commands below. Note that we focus on the three factors: market, size, and value:

```
FF_file <-
  "https://mba.tuck.dartmouth.edu/pages/faculty/ken.french/ftp/F-F_Research_Data_Factors_CSV.zip"
temp <- tempfile()
download.file(FF_file,temp)
unz_files <- unzip(temp)
ds <- read.csv(unz_files,skip = 3)
flag_obs <- grep("Annual",ds[,1],ignore.case = TRUE)
ds <- ds[1:(flag_obs-1),]
names(ds)[1] <- "date"
ds <- data.frame(apply(ds, 2, as.numeric))
ds$date <- ceiling_date(ymd(ds$date*100+ 01),"m")-1
tail(ds)

#>           date Mkt.RF  SMB   HML  RF
#> 1123 2020-01-31  -0.11 -3.11 -6.27 0.13
#> 1124 2020-02-29  -8.13  0.96 -4.01 0.12
#> 1125 2020-03-31 -13.39 -5.16 -14.12 0.12
#> 1126 2020-04-30  13.65  2.78 -1.27 0.00
#> 1127 2020-05-31   5.58  2.47 -4.95 0.01
#> 1128 2020-06-30   2.45  2.56 -2.03 0.01
```

We merge the risk factors data with the portfolios time series and regress the excess returns of each of the 25 portfolios on the three factors. To do so, we leverage some functional programming using the lapply base function along with the dply function from the **plyr** library as follows:

```
PORT_RET_RA <- merge(PORT_RET,ds)
PORT_RET_RA$RAR <- PORT_RET_RA$VW_RET - PORT_RET_RA$RF

lm_list <- dply(PORT_RET_RA,c("Group_ME","Group_BM"),
  function(x) lm( RAR ~ Mkt.RF + SMB + HML, data = x ) )
rar_matrix <- lapply(lm_list, coef)
rar_matrix <- sapply(rar_matrix,function(x) x[[1]])
rar_matrix <- matrix(rar_matrix,5,5,byrow = TRUE)

rownames(rar_matrix) <- 1:5
colnames(rar_matrix) <- paste("BM",1:5,sep = "_")
rownames(rar_matrix)[1] <- "Small"
rownames(rar_matrix)[5] <- "Big"
colnames(rar_matrix)[1] <- "Low"
colnames(rar_matrix)[5] <- "High"

rar_matrix <- round(data.frame(rar_matrix*12),2)
rar_matrix

#>      Low BM_2 BM_3 BM_4 High
#> Small -1.08 2.03 5.55 6.49 8.90
#> 2     -5.77 -0.33 0.78 2.47 1.01
#> 3     -6.51 -1.66 0.96 -0.15 -0.18
#> 4     -2.90 -1.41 -0.90 0.08 -0.10
#> Big    0.35 1.47 -0.47 0.32 -1.29
```

Note that after controlling for the three risk factors, the high-small portfolio still yields an annual return of 9%. A potential argument may be that such alpha is attributed to other risk factors that the three-factor model does not fully price. More recently, Fama-French suggest five factors model to better representation of systematic components (Fama and French, 2015).

Rendering Results

The above results are subjected to certain filtering, the time period, and the number of months each stock should include in the data. One major challenge is whether the securities in the analysis are tradable. For instance, it is common to consider stocks with a price larger than \$5. The major issue with doing so is that such a filter could cause a forward-looking bias. By the time the decision maker allocates his/her portfolio, he/she cannot ascertain whether the stocks would be above or less \$5 in the future - this is less of an issue for large-cap stocks. Hence, to keep stocks that satisfy a minimum price level, it should be done on a recurring basis. Specifically, rather than dropping all observations in which the price is less \$5, one should consider only the stocks that were qualified by the time of the portfolio formation. The same issue applies to the window length for which the data is available ~~as well as~~ other filters one may be interested in controlling for.

The following is a generalized portfolio formation function that takes four arguments. The first two correspond to the minimum price and number of years that the stock should have to be considered investable in June each year. The other two arguments set the time period during which the researcher is interested in computed the mean returns. The function returns a list containing the raw and risk-adjusted returns of the 25 portfolios along with the average number of stocks within each portfolio.

```
FF3_anomaly <- function(min_price, year_keep = 1, year1 = 1965, year2 = 2019) {
  DT12_sub <- DT12
  keep_cusip_date <- unique(DT12_sub[,list(CUSIP,date_june,N_years,PRC_LAST)])
  keep_cusip_date <- keep_cusip_date[keep_cusip_date$N_years >= year_keep,]
  keep_cusip_date <- keep_cusip_date[keep_cusip_date$PRC_LAST >= min_price ,]

  keep_cusip_date <- unique(keep_cusip_date[,list(CUSIP,date_june)])
  DT12_sub <- merge(DT12_sub,keep_cusip_date)

  DT12_sub <- DT12_sub[,`:=` (Group_ME = ntile(ME,5)), by = list(date_june)]
  DT12_sub <- DT12_sub[,`:=` (Group_BM = ntile(BM_ratio,5)), by = list(date_june,Group_ME)]
  N_G <- DT12_sub[,.N, by = list(date,Group_ME,Group_BM) ]
  N_G <- (N_G[,mean(N), by = list(Group_ME,Group_BM) ])
  N_G <- N_G[order(N_G$Group_ME,N_G$Group_BM),]
  N_G <- matrix(N_G$V1,5,5,byrow = TRUE)
  rownames(N_G) <- 1:5
  colnames(N_G) <- paste("BM",1:5,sep = "_")
  rownames(N_G)[1] <- "Small"
  rownames(N_G)[5] <- "Big"
  colnames(N_G)[1] <- "Low"
  colnames(N_G)[5] <- "High"
  N_G <- round((N_G))

  PORT_RET <- DT12_sub[,list(VW_RET = sum(RET*ME/sum(ME)) ),
    by = list(date,Group_ME,Group_BM)]
  PORT_RET <- PORT_RET[order(PORT_RET$date,PORT_RET$Group_BM,PORT_RET$Group_ME),]
  PORT_RET$VW_RET <- as.numeric(PORT_RET$VW_RET)*100

  PORT_RET_RA <- merge(PORT_RET,ds)
  PORT_RET_RA$RAR <- PORT_RET_RA$VW_RET - PORT_RET_RA$RF
  PORT_RET_RA_sub <- PORT_RET_RA
  PORT_RET_RA_sub <- PORT_RET_RA_sub[year(PORT_RET_RA_sub$date) >= year1,]
  PORT_RET_RA_sub <- PORT_RET_RA_sub[year(PORT_RET_RA_sub$date) <= year2 ,]

  ret_matrix <- PORT_RET_RA_sub[,lapply(.SD,mean,na.rm = TRUE),
    by = list(Group_ME,Group_BM), .SDcols = "VW_RET"]
  ret_matrix <- ret_matrix[order(ret_matrix$Group_BM,ret_matrix$Group_ME),]
  ret_matrix <- matrix(as.numeric(ret_matrix$VW_RET),5)
  rownames(ret_matrix) <- 1:5
  colnames(ret_matrix) <- paste("BM",1:5,sep = "_")
  rownames(ret_matrix)[1] <- "Small"
  rownames(ret_matrix)[5] <- "Big"
  colnames(ret_matrix)[1] <- "Low"
  colnames(ret_matrix)[5] <- "High"
  ret_matrix <- round(data.frame(ret_matrix*12),2)
```

```

lm_list <- dply(PORT_RET_RA_sub,c("Group_ME", "Group_BM"),
               function(x) lm( RAR ~ Mkt.RF + SMB + HML, data = x ))
rar_matrix <- lapply(lm_list, coef)
rar_matrix <- sapply(rar_matrix,function(x) x[[1]])
rar_matrix <- matrix(rar_matrix,5,5,byrow = TRUE)
rownames(rar_matrix) <- 1:5
colnames(rar_matrix) <- paste("BM",1:5,sep = "_")
rownames(rar_matrix)[1] <- "Small"
rownames(rar_matrix)[5] <- "Big"
colnames(rar_matrix)[1] <- "Low"
colnames(rar_matrix)[5] <- "High"
rar_matrix <- round(data.frame(rar_matrix*12),2)

list(N_G,ret_matrix,rar_matrix)
}

```

Control for Minimum Price

Given the above function, we test the sensitivity of the size/value premiums by including stocks with pre-specified minimum price. In particular, we run this for a sequence of prices ranging between 0 and \$50. With the **parallel** library, we can easily perform parallel computing on four cores. It takes a few seconds to run the following commands:⁴

```

p_seq <- 0:50
list_port_price <- mclapply(p_seq, function(p) FF3_anomaly(p),mc.cores = 4)

```

Given the list `list_port_price`, we extract the result of interest. In this case, we focus on the raw returns. For instance, the first item of this list corresponds to the same results from Section 2.3.

```

list_port_price[[1]][[2]]

#>      Low BM_2 BM_3 BM_4 High
#> Small 12.93 14.73 18.05 20.14 23.40
#> 2      8.45 12.55 14.37 16.72 16.17
#> 3      8.04 11.79 14.30 14.24 15.99
#> 4      9.89 11.53 11.92 14.47 14.77
#> Big   9.84 11.70 10.41 13.13 12.78

```

On the other hand, if we consider \$5 minimum price, we see that the results are tentative depending on the level of entry:

```

list_port_price[[6]][[2]]

#>      Low BM_2 BM_3 BM_4 High
#> Small 8.86 12.19 14.64 15.31 17.86
#> 2     10.35 11.94 13.51 16.18 15.08
#> 3      8.54 12.39 13.52 14.41 15.07
#> 4     10.16 11.09 11.95 14.20 15.17
#> Big   9.79 11.66 10.62 12.95 12.42

```

To capture this for each matrix of raw returns, we compute the high-minus-low (HML), i.e. column five minus column 1 for each size level. This results in 5 HML premiums for each size level. We summarize the results in the plot below:

```

RAR_list <- lapply(list_port_price,function(x) x[[2]])
RAR_list_Value <- t(sapply(RAR_list, function(x) x[,5] - x[,1] ))
colnames(RAR_list_Value) <- rownames(RAR_list[[1]])
RAR_list_Size <- t(sapply(RAR_list, function(x) x[1,] - x[5,] ))

ds.plot <- lapply(1:5, function(i) data.frame(HML = RAR_list_Value[,i],

```

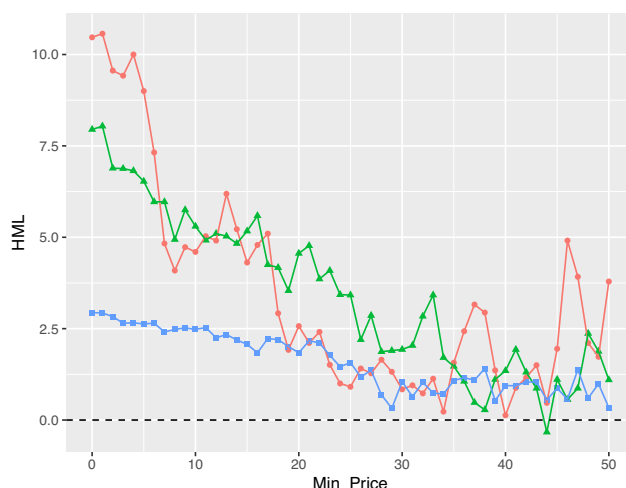
⁴Note that the `mclapply` can be easily leveraged on Linux machines.

```

Min_Price = p_seq, Size = i))

ds.plot <- Reduce(rbind,ds.plot)
ds.plot <- ds.plot[order(ds.plot$Size,ds.plot$Min_Price),]
ds.plot <- ds.plot[ds.plot$Size %in% c(1,3,5),]
ds.plot$Size <- as.factor(ds.plot$Size)
p <- ggplot(ds.plot,aes(x = Min_Price, y = HML, colour = Size, shape = Size))
p <- p + geom_point() + geom_line()
p <- p + geom_abline(intercept = 0, slope = 0, color="black", linetype="dashed")
p

```



We observe that the HML is more evident for small^{cap} stocks. However, at the same time, we note that the premium declines as we increase the minimum price entry. One argument is the following. As we increase^{the} minimum price, the size effect is mitigated and, hence, the value premium. On the other hand, this could also be attributed to whether investors can utilize such alphas for small^{cap} that tend to be less liquid.

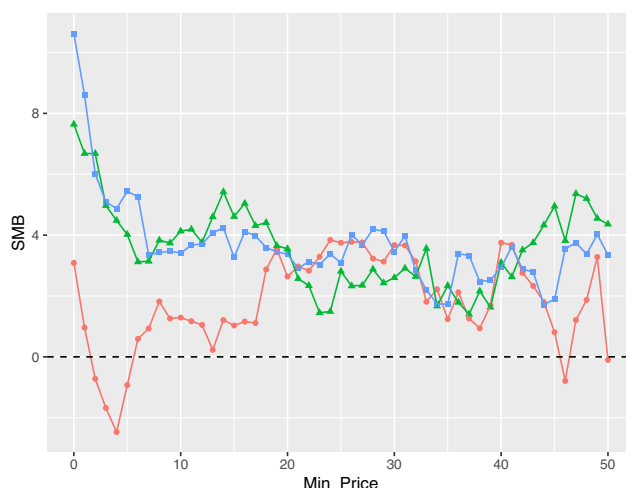
We repeat the same plot for the size premium. In particular, we compute the small-minus-big (SMB), i.e., row ~~one~~ minus row 5 for each BM level. This results in 5 SMB premiums for each BM group. Similar to the previous plot, we get the following:

```

ds.plot <- lapply(1:5, function(i) data.frame(SMB = unlist(RAR_list_Size[,i]),
Min_Price = p_seq, BM = i))

ds.plot <- Reduce(rbind,ds.plot)
ds.plot <- ds.plot[order(ds.plot$BM,ds.plot$Min_Price),]
ds.plot <- ds.plot[ds.plot$BM %in% c(1,3,5),]
ds.plot$BM <- as.factor(ds.plot$BM)
p <- ggplot(ds.plot,aes(x = Min_Price, y = SMB, colour = BM, shape = BM))
p <- p + geom_point() + geom_line()
p <- p + geom_abline(intercept = 0, slope = 0, color="black", linetype="dashed")
p

```



Consistent with the case for the HML premium, the SMB premium seems to shrink as we increase the minimum price entry. While different forces could be attributed to this, it is of great relevance for researchers/investors to understand the mechanisms behind which. Interested readers may find the work by Li et al. (2014) very relevant concerning the impact of liquidity and limits of arbitrage when it comes to the inclusion/exclusion of small-cap stocks.

Additional Results

We conduct one additional test related to the capital asset pricing model (CAPM) by Sharpe (1964) and Lintner (1965). The following analysis depends only on the CRSP database rather than the merged CRSP-COMPUSTAT data. Hence, the code is executed based on the DT data object only.

The CAPM postulates a positive linear relationship between the market beta (systematic risk) and the asset's mean return. Empirically, a large body of research shows that the relationship is flatter than the one predicted by the model (Jensen et al. (1972)) or even negative (Frazzini and Pedersen (2014)). Consistent with the literature (e.g., Bali et al. (2016)), we sort stocks into 10 portfolios based on their monthly beta. In particular, we use M months to estimate the market beta on a rolling window using the `rollRegres` (Christoffersen (2019)) library. We set M to be either 36, 60, or 120 months. For each sample size M , we estimate the market beta on a rolling basis. At the end of month t , we sort stocks into 10 groups based on their market beta and compute the value-weighted return over the next month at $t + 1$. For the next month, we repeat the same procedure until the last month of our data sample.

```
BETA <- DT[,c("date", "CUSIP", "RET")]
BETA <- merge(BETA, ds[,c("date", "Mkt.RF", "RF")], by = "date")
BETA$E_RET <- (BETA$RET - BETA$RF/100)*100
BETA$RF <- NULL
# keep stocks with at least M months
BETA[, count := (.N), by = CUSIP]
BETA <- BETA[order(BETA$CUSIP, BETA$date), ]
BETA <- BETA[BETA$count > est_window, ]

BETA <- BETA %>%
  group_by(CUSIP) %>%
  do(., mutate(., Beta = roll_regres(E_RET ~ Mkt.RF, data = ., est_window)$coef[, 2]))

BETA <- data.table(BETA)
BETA <- na.omit(BETA[, list(date, CUSIP, Beta)])

DT_capm <- merge(DT, BETA, by = c("CUSIP", "date"), all = F)
DT_capm <- DT_capm[order(DT_capm$CUSIP, DT_capm$date), ]
DT_capm <- DT_capm[, `:=` (Group_Beta = ntile(Beta, 10)), by = list(date)]
```

Note that we execute the `roll_regres` command using the `do` command in the tidy environment. This approach is the fastest solution to execute a rolling regression for panel data to the best of our knowledge. For instance, when $M = 120$, the `DT_capm` data object contains 1,287,611 observations with 9,149 unique securities. The execution takes about 10 seconds. Given the data object `DT_capm`, we compute the next month's portfolio value-weighted return as follows:

```
PORT_RET <- DT_capm[, list(VW_RET = 12*100*sum(RET_1*MKTCAP/sum(MKTCAP), na.rm = T),
  VW_BETA = sum(Beta*MKTCAP/sum(MKTCAP), na.rm = T)),
  by = list(date, Group_Beta)]
PORT_RET <- PORT_RET[order(PORT_RET$Group_Beta, PORT_RET$date), ]
```

Finally, we summarize the results using `ggplot2` in the figure below. Note that the dashed line denotes the relationship implied by the CAPM. This figure is consistent with Figure 2 from Fama and French (2004), where the slope (intercept) denotes the average annual market excess (risk-free) return. We compute the slope and intercept of the CAPM line based on the sub-sample of the Fama-French data set `ds` that corresponds to the same dates of the portfolio returns.

```
CAPM_result <- PORT_RET[, lapply(.SD, mean, na.rm = T),
  by = list(Group_Beta),
```



```

.SDcols = c("EW_RET", "VW_RET", "EW_BETA", "VW_BETA")]
CAPM_result <- CAPM_result[order(CAPM_result$Group_Beta),]
CAPM_result

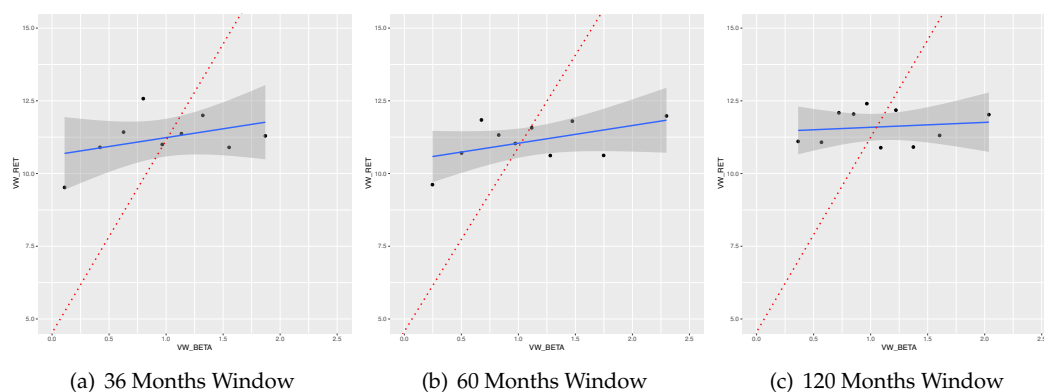
ds_sub <- ds[ds$date %in% PORT_RET$date,]

p2 <- ggplot(CAPM_result, aes(VW_BETA, VW_RET)) +
  geom_point()
p2 <- p2 + geom_smooth(method = "lm")
p2 <- p2 + ylim(c(5,15)) + xlim(c(0,2.5))
p2 <- p2 + geom_abline(intercept = mean(ds_sub$RF)*12,
  slope = mean(ds_sub$Mkt.RF)*12,
  color="red", linetype="dotted", size=1)

```

Capital Asset Pricing Model

The dots below report the average annualized monthly return (y -axis) versus market beta (x -axis) for the value-weighted portfolios. The solid line is a smoothed using a linear regression. The dashed line corresponds to the one predicted by the CAPM over the same sample period, where the slope (intercept) denotes the average annual market excess (risk-free) return. Each panel corresponds to a different estimation window needed to estimate the market beta and form beta portfolios on a rolling basis.



Consistent with Fama and French (2004), we note that the portfolio results denote a flatter line than the one suggested by the CAPM. At the same time, we note that the results are noisy and sensitive to the sample size choice. In unreported results, we find that the negative relationship suggested by Frazzini and Pedersen (2014) is only evident when the betas are estimated using daily returns and portfolios are equally weighted.

Concluding Remarks

This article provides a brief illustration of merging the CRSP (security prices/returns) data with the COMPUSTAT (financial) data. The illustration is conducted for portfolio formation using book data. The final result is combining monthly market data with annual accounting data. However, researchers interested in performing panel analysis or applying predictive models using machine learning may prefer merging the data altogether using the same frequency. We leave this for future research. Nonetheless, we hope this article would encourage further reproducible empirical asset pricing research while also helping bridge the gap between the data science community and the empirical finance literature.

Notes

An html vignette is found on https://rpubs.com/simaan84/CRSP_COMP. The Rmd source code can be retrieved using the link.

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