Prevalence of Having Contraband among Pulled-over Drives

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Background and Introduction

To be done.

Causal Roadma

Scientific Question:

What is the prevalence of having contraband if all drives are searched.

Causal Model

W_1 : age

W_2 : race: black or not

W_3 : gender : female or male

W_4 : Speed or not

$W = (W_1, W_2, W_3, W_4)$

Δ : if search is conducted

Y* : Underlying contraband status

Y : if contraband is found

- Endogenous variables: $X = (W_1, W_2, W_3, W_4, \Delta, Y)$
- Exogenous variables: $U \sim \mathbb{P}_U$ (to be determined).

Structral equation F:

$$\begin{aligned}
W_1 &= f_{W1}(U_{W1}) \\
W_2 &= f_{W2}(U_{W2}) \\
W_3 &= f_{W3}(U_{W3}) \\
W_4 &= f_{W4}(W_1, W_2, W_3, U_{W4}) \\
\Delta &= f_{\Delta}(W_1, W_2, W_3, W_4, U_{\Delta}) \\
Y^* &= f_{Y^*}(W_1, W_2, W_3, W_4, U_{Y^*}) \\
Y &= \Delta \times Y^*
\end{aligned}$$

Causal Parameter

$\Psi^*(\mathbb{P}^*) = \mathbb{P}^*(Y^* = 1) = \mathbb{P}^*(Y_{\Delta=1})$

Observed data and its link to causal model

Observed data are randomly generated from the structural causal model.

Identifiability

Lest's assume all Us are independent.

Statistical estimand

$\Psi^*(\mathbb{P}^*) = \Psi(\mathbb{P}_0) = \mathbb{E}_W\{\mathbb{P}_0(Y = 1|\Delta = 1, W)\}$

Estimate

Parametric G-computation (simple substitution estimator), IPTW, TMLE. Use super learner during the estimating procedure. Don't forget to talk about the positivity assuptions.

Present a detailed plan for statistical inference/variance estimation based on the non-parametric bootstrap and implement it.

Data preprocessing

```
# packages
library(tidyverse)
library(lubridate)
library(SuperLearner)
library(boot)
library(ltmle)
```

```
# load dataset
dat <- readRDS("data/MAStatePatrol.rds")
# take a look at the variables we have
colnames(dat)
```

```
##  [1] "raw_row_number"             "date"
##  [3] "location"                   "county_name"
##  [5] "subject_age"                "subject_race"
##  [7] "subject_sex"                "type"
##  [9] "arrest_made"                "citation_issued"
## [11] "warning_issued"             "outcome"
## [13] "contraband_found"           "contraband_drugs"
## [15] "contraband_weapons"         "contraband_alcohol"
## [17] "contraband_other"           "frisk_performed"
## [19] "search_conducted"           "search_basis"
## [21] "reason_for_stop"            "vehicle_type"
## [23] "vehicle_registration_state" "raw_Race"
```

```
table(year(dat$date)) # the dataset is balanced over years
```

```
##
##   2007   2008   2009   2010   2011   2012   2013   2014   2015
## 247357 468131 428714 388280 335974 418846 400931 384468 343537
```

```
dat_prep <- function(dat, loc, years){

  datBos <-  dat %>%
```

```r
  filter(location == loc) %>% # select location
  filter(year(date) == years) %>%  # select year
  filter(vehicle_type == 'Passenger') %>% # passenegr vehicle only
  # delete missing values
  filter(!is.na(subject_age) & !is.na(subject_sex) &
           !is.na(subject_race) & !is.na(reason_for_stop) &
           !is.na(search_conducted))  %>%
  mutate(subject_race = as.character(subject_race)) %>% # change subject_race to string
  # select following variables
  select(subject_age,
         subject_race,
         subject_sex,
         reason_for_stop,
         contraband_found,
         search_conducted)

# drop unused levels from the dataframe
datBos <- droplevels(datBos)
# subject_race represents black or not
datBos$subject_race[datBos$subject_race != 'black'] = 'others'
# reason_for_stop represents speed or not
datBos$reason_for_stop[datBos$reason_for_stop == 'Speed' &
                       datBos$reason_for_stop == 'Speed,SearBelt' &
                       datBos$reason_for_stop == 'Speed,ChildRest' &
                       datBos$reason_for_stop == 'Speed,SeatBelt,ChildRest'] = 'Speed'
datBos$reason_for_stop[datBos$reason_for_stop != 'Speed'] = 'Not Speed'
return(datBos)
}

for (i in 2007:2015){
  datBos <- dat_prep(dat, 'BOSTON', i)
  print(table(datBos$contraband_found, useNA = 'ifany'))
}
```

```
##
## FALSE  TRUE  <NA>
##   207    79 15747
##
## FALSE  TRUE  <NA>
##   159    77 28235
##
## FALSE  TRUE  <NA>
##    74    40 26541
##
## FALSE  TRUE  <NA>
##    76    62 23201
##
## FALSE  TRUE  <NA>
##    50    45 19649
##
## FALSE  TRUE  <NA>
##    75    48 22270
##
## FALSE  TRUE  <NA>
```

```
##    46    29 24071
##
## FALSE  TRUE  <NA>
##    32    27 14082
##
## FALSE  TRUE  <NA>
##    31    22 17055
```

```r
datBos <- dat_prep(dat, 'BOSTON', 2007)

# show summary and check postivity assumptions
summary(datBos$search_conducted)
```

```
##    Mode   FALSE    TRUE
## logical   15747     286
```

```r
summary(datBos$contraband_found)
```

```
##    Mode   FALSE    TRUE    NA's
## logical     207      79   15747
```

```r
summary(datBos$subject_age)
```

```
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   11.00   26.00   35.00   36.45   45.00   87.00
```

```r
summary(datBos$subject_sex)
```

```
##   male female
##  11698   4335
```

```r
table(datBos$subject_race)
```

```
##
##  black others
##   2385  13648
```

```r
table(datBos$reason_for_stop)
```

```
##
## Not Speed     Speed
##      2294     13739
```

```r
# check positivity assumption
table(datBos$subject_race, datBos$subject_sex, datBos$reason_for_stop, datBos$search_conducted)
```

```
## , ,  = Not Speed,  = FALSE
##
##
##         male female
##   black   580    141
##   others 1150    302
##
## , ,  = Speed,  = FALSE
##
##
##         male female
##   black  1134    453
##   others 8606   3381
```

```
##
## , ,  = Not Speed,  = TRUE
##
##
##          male female
##   black    35     10
##   others   58     18
##
## , ,  = Speed,  = TRUE
##
##
##          male female
##   black    27      5
##   others  108     25
```

Following are some attemps of estiamtion, I'll consider more parametric models and super learner and put all of them in R functions.

G-computation

$$\hat{\Psi}_{SS}(\hat{\mathbb{P}}) = \frac{1}{n}\sum_{i=1}^{n}\left(\hat{\mathbb{E}}\left(Y|A_i = 1, W_i\right) - \hat{\mathbb{E}}\left(Y|\Delta_i = 0, W_i\right)\right)$$

We consider following parametric models of $\mathbb{E}(Y|\Delta, W)$:

$\mathbb{E}(Y|\Delta, W) = logit^{-1}(\beta_0 + \beta_1 W_1 + \beta_2 W_2 + \beta_3 W_3 + \beta_4 W_4 + \beta_5 \Delta)$
$\mathbb{E}(Y|\Delta, W) = logit^{-1}(\beta_0 + \beta_1 W_1 + \beta_2 W_2 + \beta_3 W_3 + \beta_4 W_4 + \beta_5 \Delta + \beta_6 W1 * W4 + \beta_6 W2 * W4 + \beta_6 W3 * W4)$

```r
# G-computation
# reference: RCT_MissingData.pdf

# only drives are searched
datBos.searched <-  datBos %>% filter(search_conducted == TRUE)
datBos.intervene <- datBos %>% mutate(search_conducted = TRUE)
# 10 fold cross validation/Discrete super learner
set.seed(2019)
cv.error.1 <- cv.error.2 <- 0
for (i in 1:10){
  # model 1
  fit.g1 <- glm(contraband_found ~
                  subject_age +
                  subject_race +
                  subject_sex +
                  reason_for_stop,
                family = 'binomial', data = datBos.searched)
  cv.error.1[i] <- cv.glm(datBos.searched, fit.g1, K = 10)$delta[1]
  # model 2
  fit.g2 <- glm(contraband_found ~
                  subject_age*reason_for_stop +
                  subject_race*reason_for_stop +
                  subject_sex*reason_for_stop,
                family = 'binomial', data = datBos.searched)
```

```r
  cv.error.2[i] <- cv.glm(datBos.searched, fit.g2, K = 10)$delta[1]
}
c(mean(cv.error.1), mean(cv.error.2)) # model 1 is better
```

```
## [1] 0.1771311 0.1791976
```

```r
# model 1 function
gcomp.1 <- function(dat.s, dat.i){
  fit.gcomp.1 <- glm(contraband_found ~
                     subject_age +
                     subject_race +
                     subject_sex +
                     reason_for_stop,
                   family = 'binomial', data = dat.s)
  EY.gcomp.1 <- predict(fit.gcomp.1, newdata = dat.i, type = 'response')
  est.gcomp.1 <- mean(EY.gcomp.1)
  est.gcomp.1
}
dat.intervene <- datBos %>% mutate(search_conducted = TRUE)
est.gcomp <- gcomp.1(datBos.searched, dat.intervene) # point estimate
est.gcomp
```

```
## [1] 0.163418
```

```r
# Nonparametric bootstrap 500 times
n <- nrow(datBos)
est.g1 <- 0
for (k in 1:500){
  dat.bp <- datBos[sample(1:n, n, replace = TRUE), ]
  dat.s<-  dat.bp %>% filter(search_conducted == TRUE)
  dat.i <- dat.bp %>% mutate(search_conducted = TRUE)
  est.g1[k] <- gcomp.1(dat.s, dat.i)
}
# mean
mean(est.g1)
```

```
## [1] 0.1636413
```

```r
# standard error
sd(est.g1)
```

```
## [1] 0.0240266
```

```r
# confidence interval 5%
c(est.gcomp - 1.96*sd(est.g1), est.gcomp + 1.96*sd(est.g1))
```

```
## [1] 0.1163259 0.2105102
```

IPTW

$$\hat{\Psi}_{IPTW}(\hat{\mathbb{P}}) = \frac{1}{n}\sum_{i=1}^{n}\left(\frac{\mathbb{I}\left(\Delta_i = 1\right)}{\hat{\mathbb{P}}\left(\Delta = 1|W_i\right)} - \frac{\mathbb{I}\left(\Delta_i = 0\right)}{\hat{\mathbb{P}}\left(\Delta = 0|W_i\right)}\right)Y_i$$

Parametric models of $\mathbb{P}(A|W)$:

$\mathbb{P}(\Delta|W) = logit^{-1}(\beta_0 + \beta_1 W_1 + \beta_2 W_2 + \beta_3 W_3 + \beta_4 W_4)$

$\mathbb{E}(\Delta|W) = logit^{-1}(\beta_0 + \beta_1 W_1 + \beta_2 W_2 + \beta_3 W_3 + \beta_4 W_4 + \beta_6 W1 * W4 + \beta_6 W2 * W4 + \beta_6 W3 * W4)$

```
# IPTW # reference : RLab3.pdf

# 10 fold cross validation/Discrete super learner
set.seed(2019)
cv.error.1 <- cv.error.2 <- 0
for (i in 1:10){
  # model 1
  fit.prob.D.1 <- glm(search_conducted ~
                    subject_age +
                    subject_race +
                    subject_sex +
                    reason_for_stop,
                  family = 'binomial', data = datBos)
  cv.error.1[i] <- cv.glm(datBos, fit.prob.D.1, K = 10)$delta[1]
  # model 2
  fit.prob.D.2 <- glm(search_conducted ~
                    subject_age*reason_for_stop +
                    subject_race*reason_for_stop +
                    subject_sex*reason_for_stop,
                  family = 'binomial', data = datBos)
  cv.error.2[i] <- cv.glm(datBos, fit.prob.D.2, K = 10)$delta[1]
}
c(mean(cv.error.1), mean(cv.error.2)) # performace are close, model 1 is simpler
```

```
## [1] 0.01725586 0.01724772
```

```
# model 1 function
iptw.1 <- function(dat){
  fit.prob.D.1 <- glm(search_conducted ~
                    subject_age +
                    subject_race +
                    subject_sex +
                    reason_for_stop,
                  family = 'binomial', data = dat)
  prob.D1 <- predict(fit.prob.D.1, type = 'response')
  # calculate weights
  wt1 <- as.numeric(datBos$search_conducted == 1)/prob.D1
  # estimate
  est.IPTW.1 <- mean(wt1*dat$contraband_found, na.rm = TRUE)
  # Stabelized IPTW
  wt1.mean <- mean(wt1[!is.na(datBos$contraband_found)])
  est.sIPTW.1 <- mean(wt1*datBos$contraband_found, na.rm = TRUE)/wt1.mean
  list(est.IPTW.1, est.sIPTW.1, wt1)
}

est.IPTW <- iptw.1(datBos)
# IPTW point estimate
est.IPTW[[1]]
```

```
## [1] 9.49691
```

```r
# standardized IPTW point estimate
est.IPTW[[2]]
```

```
## [1] 0.1633454
```

```r
# distribution of weight
summary(est.IPTW[[3]]) # large variation
```

```
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   0.000   0.000   0.000   1.037   0.000 317.227
```

```r
# We adopt standardized IPTW estimator
# Nonparametric bootstrap 500 times
est.IPTW1 <- 0
for (k in 1:500){
  dat.bp <- datBos[sample(1:n, n, replace = TRUE), ]
  est.IPTW1[k] <- iptw.1(dat.bp)[[2]]
}
# mean
mean(est.IPTW1)
```

```
## [1] 0.2763022
```

```r
# standard error
sd(est.IPTW1)
```

```
## [1] 0.01743561
```

```r
# confidence interval 5%
c(est.IPTW[[2]] - 1.96*sd(est.IPTW1), est.IPTW[[2]] + 1.96*sd(est.IPTW1))
```

```
## [1] 0.1291716 0.1975192
```

TMLE

$$\Psi_{TMLE}(\hat{\mathbb{P}}) = \frac{1}{n}\sum_{i=1}^{n}\left[\hat{\mathbb{E}}^*\left(Y|A_i=1,W_i\right) - \hat{\mathbb{E}}^*\left(Y|A_i=0,W_i\right)\right]$$

Here we use super learner.

```r
# TMLE
set.seed(2019)
# specify the library
SL.library<- c("SL.mean", "SL.glm", "SL.glm.interaction")

# G-spomputation with Super Learner
# Estimate E_0(Y|A,W)
X <- subset(datBos.searched, select = c(subject_age, subject_race,
                                        subject_sex, reason_for_stop))
X1 <- subset(datBos.intervene, select = c(subject_age, subject_race,
                                        subject_sex, reason_for_stop))
fit.SL.1 <- SuperLearner(Y=as.numeric(datBos.searched$contraband_found),
                         X=X, SL.library=SL.library, family='binomial')
# performace of superlearner
CV.fit.SL.1 <- CV.SuperLearner(Y=as.numeric(datBos.searched$contraband_found),
                         X=X, SL.library=SL.library, family='binomial')
summary(CV.fit.SL.1) # superlearner is not the best!!!!!!!!!
```

```
##
## Call:
## CV.SuperLearner(Y = as.numeric(datBos.searched$contraband_found), X = X,
##     family = "binomial", SL.library = SL.library)
##
## Risk is based on: Mean Squared Error
##
## All risk estimates are based on V =  10
##
##               Algorithm     Ave       se     Min     Max
##           Super Learner 0.17976 0.011913 0.13459 0.24143
##             Discrete SL 0.17878 0.012243 0.13442 0.24354
##             SL.mean_All 0.20161 0.011942 0.15603 0.26601
##              SL.glm_All 0.17638 0.011954 0.13442 0.24354
##  SL.glm.interaction_All 0.17941 0.012501 0.13719 0.23968
```

```
EY.1W <- predict(fit.SL.1, newdata = X1)$pred
est.gcomp.SL <- mean(EY.1W)
est.gcomp.SL
```

```
## [1] 0.1689822
```

```
# IPTW with Super Learner
X <- subset(datBos, select = c(subject_age, subject_race,
                               subject_sex, reason_for_stop))
fit.SL.2 <- SuperLearner(Y=as.numeric(datBos$search_conducted),
                      X=X, SL.library=SL.library, family='binomial')
# performace of superlearner
CV.fit.SL.2 <- CV.SuperLearner(Y=as.numeric(datBos$search_conducted),
                      X=X, SL.library=SL.library, family='binomial')
summary(CV.fit.SL.2) # superlearner is not the best!!!!!!!!!
```

```
##
## Call:
## CV.SuperLearner(Y = as.numeric(datBos$search_conducted), X = X, family = "binomial",
##     SL.library = SL.library)
##
## Risk is based on: Mean Squared Error
##
## All risk estimates are based on V =  10
##
##               Algorithm      Ave         se      Min      Max
##           Super Learner 0.017257 0.00097881 0.014284 0.020591
##             Discrete SL 0.017285 0.00097900 0.014285 0.020614
##             SL.mean_All 0.017521 0.00100814 0.014157 0.020774
##              SL.glm_All 0.017254 0.00097845 0.014273 0.020614
##  SL.glm.interaction_All 0.017265 0.00097726 0.014293 0.020571
```

```
PA1.W <- fit.SL.2$SL.predict
H.AW <- as.numeric(datBos$search_conducted == 1)/PA1.W
H.AW.mean.s <- mean(H.AW[!is.na(datBos$contraband_found)])
# standardized IPTW
est.sIPTW.SL <- mean(H.AW*datBos$contraband_found, na.rm = TRUE)/H.AW.mean.s
est.sIPTW.SL
```

```
## [1] 0.1641883
```

```r
# TMLE estimate
# one-step update intial estimator of EY.AW
H.AW.std.s <- H.AW[!is.na(datBos$contraband_found)]/H.AW.mean.s
EY.1W.s <- EY.1W[!is.na(datBos$contraband_found)]
logitUpdate <- glm(datBos.searched$contraband_found ~ -1 + offset(qlogis(EY.1W.s)) + H.AW.std.s,
                   family='binomial')
epsilon <- logitUpdate$coefficients
H.1W <- 1/PA1.W
H.1W.std <- H.1W/mean(H.1W)
EY.1W.star <- plogis(qlogis(EY.1W) + epsilon*H.1W.std)
est.TLME <- mean(EY.1W.star)
est.TLME
```

```
## [1] 0.1673682
```

```r
# use ltmle package
#####################################################
# if we use dataset which only includes searched cases,
# then all search_conducted is 1, model cannot fit
# if we use dataset with all cases,
# then contraband_found has missing value, model cannot fit wither.
# Conclusion: we must update by hard coding.
########################################################

# datBos.searched.new <- datBos.searched %>%
#   mutate(search_conducted = as.numeric(search_conducted),
#          contraband_found = as.numeric(contraband_found))
# ltmle.SL<- ltmle(data=datBos.searched.new, Anodes='search_conducted',
#                  Ynodes='contraband_found', abar=1, SL.library=SL.library)
```

```r
# nonparametric bootstrap for variance estimation

# hard code function
est.all <- function(dat.bp){
  # Simple substitution
  dat.s<-  dat.bp %>% filter(search_conducted == TRUE)
  dat.i <- dat.bp %>% mutate(search_conducted = TRUE)

  X <- subset(dat.s, select = c(subject_age, subject_race,
                                         subject_sex, reason_for_stop))
  X1 <- subset(dat.i, select = c(subject_age, subject_race,
                                           subject_sex, reason_for_stop))
  fit.SL.1 <- SuperLearner(Y=as.numeric(dat.s$contraband_found),
                          X=X, SL.library=SL.library, family='binomial')
  EY.1W <- predict(fit.SL.1, newdata = X1)$pred
  est.gcomp.SL <- mean(EY.1W)

  # IPTW
  X <- subset(dat.bp, select = c(subject_age, subject_race,
                                subject_sex, reason_for_stop))
  fit.SL.2 <- SuperLearner(Y=as.numeric(dat.bp$search_conducted),
                          X=X, SL.library=SL.library, family='binomial')

  PA1.W <- fit.SL.2$SL.predict
  H.AW <- as.numeric(dat.bp$search_conducted == 1)/PA1.W
```

```r
  H.AW.mean.s <- mean(H.AW[!is.na(dat.bp$contraband_found)])
  # standardized IPTW
  est.sIPTW.SL <- mean(H.AW*dat.bp$contraband_found, na.rm = TRUE)/H.AW.mean.s

  # TMLE
  H.AW.std.s <- H.AW[!is.na(dat.bp$contraband_found)]/H.AW.mean.s
  EY.1W.s <- EY.1W[!is.na(dat.bp$contraband_found)]
  logitUpdate <- glm(dat.s$contraband_found ~ -1 + offset(qlogis(EY.1W.s)) + H.AW.std.s,
                     family='binomial')
  epsilon <- logitUpdate$coefficients
  H.1W <- 1/PA1.W
  H.1W.std <- H.1W/mean(H.1W)
  EY.1W.star <- plogis(qlogis(EY.1W) + epsilon*H.1W.std)
  est.TLME <- mean(EY.1W.star)
  c(est.gcomp.SL, est.sIPTW.SL, est.TLME)
}

# bootstrap
set.seed(2019)
est.results <- matrix(NA, ncol = 3, nrow = 500)
for (k in 1:500){
  dat.bp <- datBos[sample(1:n, n, replace = TRUE), ]
  est.results[k,] <- est.all(dat.bp)
}
```

```
## Warning: glm.fit: fitted probabilities numerically 0 or 1 occurred

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```
# plot histgrams
par(mfrow = c(1,3))
for(i in 1:3){
  print(hist(est.results[,i]))
}
```

```
## $breaks
## [1] 0.10 0.12 0.14 0.16 0.18 0.20 0.22 0.24 0.26
##
## $counts
## [1]  10  55 132 142 103  47   9   2
##
## $density
## [1]  1.0  5.5 13.2 14.2 10.3  4.7  0.9  0.2
##
## $mids
## [1] 0.11 0.13 0.15 0.17 0.19 0.21 0.23 0.25
##
## $xname
## [1] "est.results[, i]"
##
## $equidist
## [1] TRUE
##
## attr(,"class")
## [1] "histogram"

## $breaks
## [1] 0.10 0.12 0.14 0.16 0.18 0.20 0.22 0.24 0.26
##
## $counts
## [1]  20  75 144 130  88  36   6   1
##
## $density
## [1]  2.0  7.5 14.4 13.0  8.8  3.6  0.6  0.1
##
## $mids
## [1] 0.11 0.13 0.15 0.17 0.19 0.21 0.23 0.25
##
## $xname
```

```
## [1] "est.results[, i]"
##
## $equidist
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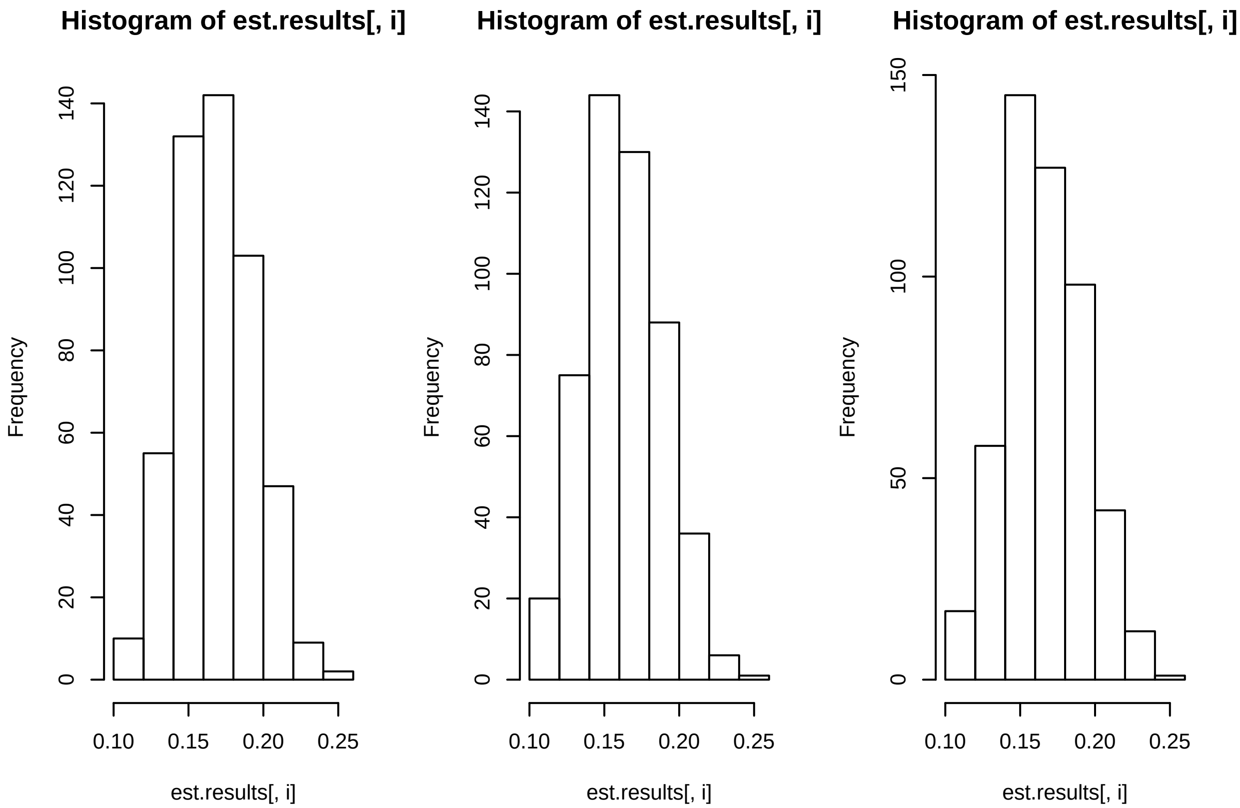
## attr(,"class")
## [1] "histogram"
```




```
## $breaks
## [1] 0.10 0.12 0.14 0.16 0.18 0.20 0.22 0.24 0.26
##
## $counts
## [1]  17  58 145 127  98  42  12   1
##
## $density
## [1]  1.7  5.8 14.5 12.7  9.8  4.2  1.2  0.1
##
## $mids
## [1] 0.11 0.13 0.15 0.17 0.19 0.21 0.23 0.25
##
## $xname
## [1] "est.results[, i]"
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## [1] TRUE
##
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## [1] "histogram"
```

```r
# point estimate
est.pt <- est.all(datBos)

# confidence interval
est.sd <- apply(est.results, 2, sd)
cbind(est.pt - 1.96*est.sd, est.pt + 1.96*est.sd)
```

```
##           [,1]      [,2]
## [1,] 0.1137243 0.2137579
## [2,] 0.1123482 0.2148759
## [3,] 0.1139156 0.2180133
```

```r
# save all results
save.image(file = "envir_1207_v1.Rdata")
```