

# Problem Set 2

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```
library(data.table)
library(sandwich)
library(lmtest)

library(ggplot2)
library(knitr)
```

## 1. What happens when pilgrims attend the Hajj pilgrimage to Mecca?

What happens when a diverse set of people are brought together toward a common purpose? Maybe it brings people together, or maybe instead it highlights the differences between groups. Clingingsmith, Khwaja and Kremer (2009) (<https://dash.harvard.edu/handle/1/3659699>) investigate the question. by asking Pakistani nationals to provide information about their views about people from other nations.

The random assignment and data is collected in the following way (detailed in the paper):

- Pakistani nationals apply for a chance to attend the Hajj at a domestic bank. Saudi Arabia agreed in the time period of the study (2006) to grant 150,000 visas.
- Of the 135,000 people who applied for a visa, 59% of those who applied were successful.
- The remainder of the visas were granted under a different allocation method that was not randomly assigned, and so this experiment cannot provide causal evidence about other allocation mechanisms.
- Among the 135,000 who apply, the authors conduct a random sample and survey about these respondents views about others.

Using the data collected by the authors, test, using randomization inference, whether there is a change in beliefs about others as a result of attending the Hajj.

- Use, as your primary outcome the `views` variable. This variable is a column-sum of each respondent's views toward members of other countries.
- Use, as your treatment feature `success`. This variable encodes whether the respondent successfully attended the Hajj.

```
d <- fread("../data/clingingsmith_2009.csv")
```

1. State the sharp-null hypothesis that you will be testing.

**Answer: The sharp-null hypothesis is that there is no change in belief for those who attend Hajj compared to those who do not attend Hajj**

2. Using `data.table`, group the data by `success` and report whether views toward others are generally more positive among lottery winners or lottery non-winners. This answer should be of the form `d[, .(mean_views = ...), keyby = ...]` where you have filled in the `...` with the appropriate functions and variables.

```
hajj_group_mean <- d[, .(mean_views = mean(views)), keyby = .(success)] # the result s
should be a data.table with two colums and two rows
hajj_group_mean
```

```
##      success mean_views
## 1:         0    1.868304
## 2:         1    2.343137
```

```
hajj_ate      <- hajj_group_mean[, mean(mean_views), keyby = .(success)][, diff(V1)]
# from the `hajj_group_mean` produce a single, numeric vector that is the ate. check tha
t it is numeric using `class(hajj_ate)`
hajj_ate
```

```
## [1] 0.4748337
```

But is this a “meaningful” difference? Or, could a difference of this size have arisen from an “unlucky” randomization? Conduct 10,000 simulated random assignments under the sharp null hypothesis to find out. (Don’t just copy the code from the async, think about how to write this yourself.)

```
## do your work to conduct the randomiation inference here.
## as a reminder, RI will randomly permute / assign the treatment variable
## and recompute the test-statistic (i.e. the mean difference) under each permutation
randomization <- function(units) {
  assignments <- rep(c(0, 1), each = units)
  sample(assignments)
}
ri <- function(num, simulations=10000) {
  results <- NA
  for(simulation in 1:simulations) {
    results[simulation] <- d[, .(group_mean = mean(views)), keyby = .(randomization(num))][, diff(group_mean)]
  }
  return(results)
}
hajj_ri_distribution <- ri(d[, .N]/2) # this should be a numeric vector that has a length
equal to the number of RI permutations you ran
hajj_ri_distribution
```

```

##      [1] -0.167014614  0.029227557 -0.112734864  0.054279749 -0.037578288
##      [6]  0.058455115 -0.530271399  0.233820459 -0.187891441  0.008350731
##     [11] -0.096033403  0.676409186  0.141962422  0.250521921  0.129436326
##     [16] -0.083507307  0.208768267  0.167014614  0.196242171  0.070981211
##     [21]  0.175365344  0.167014614  0.037578288 -0.125260960 -0.200417537
##     [26]  0.112734864  0.108559499 -0.079331942  0.004175365 -0.129436326
##     [31]  0.029227557 -0.242171190 -0.096033403 -0.004175365  0.112734864
##     [36] -0.008350731 -0.137787056  0.041753653 -0.037578288  0.016701461
##     [41]  0.116910230 -0.104384134 -0.079331942  0.045929019 -0.133611691
##     [46]  0.066805846  0.187891441  0.045929019  0.338204593 -0.079331942
##     [51] -0.104384134 -0.033402923  0.137787056  0.133611691  0.212943633
##     [56]  0.296450939  0.070981211  0.058455115  0.108559499 -0.137787056
##     [61] -0.288100209  0.317327766  0.100208768  0.066805846  0.054279749
##     [66] -0.179540710 -0.075156576  0.087682672  0.175365344 -0.334029228
##     [71]  0.045929019  0.179540710 -0.041753653  0.020876827 -0.041753653
##     [76] -0.037578288 -0.096033403  0.058455115  0.375782881 -0.175365344
##     [81] -0.079331942  0.025052192 -0.167014614  0.100208768 -0.158663883
##     [86] -0.146137787 -0.325678497  0.133611691  0.016701461 -0.054279749
##     [91] -0.116910230  0.054279749  0.154488518 -0.212943633 -0.175365344
##     [96]  0.325678497 -0.146137787 -0.020876827  0.141962422  0.196242171
##    [101] -0.012526096  0.200417537  0.087682672  0.020876827 -0.045929019
##    [106] -0.058455115 -0.150313152  0.070981211 -0.104384134  0.087682672
##    [111]  0.100208768 -0.225469729  0.171189979  0.008350731  0.196242171
##    [116]  0.279749478 -0.033402923  0.075156576  0.037578288 -0.204592902
##    [121] -0.012526096  0.041753653 -0.054279749 -0.083507307  0.150313152
##    [126]  0.083507307 -0.008350731 -0.016701461 -0.112734864 -0.012526096
##    [131]  0.083507307  0.129436326  0.242171190  0.058455115 -0.179540710
##    [136] -0.004175365 -0.125260960  0.066805846 -0.367432150 -0.045929019
##    [141] -0.154488518  0.116910230  0.137787056  0.100208768  0.087682672
##    [146]  0.250521921  0.254697286  0.004175365 -0.263048017  0.020876827
##    [151] -0.104384134  0.121085595  0.204592902 -0.037578288  0.062630480
##    [156]  0.037578288  0.020876827 -0.171189979 -0.338204593 -0.263048017
##    [161]  0.125260960  0.091858038  0.141962422 -0.045929019  0.150313152
##    [166]  0.091858038  0.079331942  0.208768267  0.004175365 -0.020876827
##    [171] -0.179540710 -0.012526096 -0.091858038 -0.070981211  0.121085595
##    [176] -0.050104384  0.300626305  0.267223382 -0.016701461  0.350730689
##    [181] -0.192066806 -0.033402923 -0.129436326 -0.079331942  0.146137787
##    [186]  0.296450939 -0.041753653 -0.004175365 -0.062630480  0.146137787
##    [191] -0.246346555 -0.237995825 -0.154488518  0.162839248  0.279749478
##    [196]  0.183716075 -0.062630480 -0.141962422 -0.108559499  0.091858038
##    [201]  0.029227557  0.158663883  0.083507307  0.087682672 -0.096033403
##    [206] -0.254697286  0.083507307  0.129436326 -0.025052192  0.075156576
##    [211]  0.062630480  0.096033403 -0.066805846  0.221294363 -0.187891441
##    [216]  0.020876827  0.045929019 -0.012526096  0.208768267  0.125260960
##    [221] -0.070981211  0.221294363  0.150313152 -0.087682672 -0.096033403
##    [226] -0.250521921  0.146137787 -0.020876827 -0.108559499 -0.154488518
##    [231]  0.087682672 -0.020876827  0.091858038  0.167014614 -0.029227557
##    [236]  0.204592902  0.050104384  0.041753653  0.317327766 -0.029227557
##    [241] -0.012526096  0.279749478  0.288100209  0.434237996  0.004175365
##    [246] -0.200417537 -0.100208768  0.016701461  0.050104384 -0.029227557
##    [251]  0.254697286  0.237995825  0.054279749  0.045929019  0.000000000
##    [256]  0.079331942  0.133611691 -0.062630480 -0.054279749  0.146137787
##    [261] -0.070981211 -0.141962422 -0.192066806 -0.221294363  0.079331942

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## [266] 0.108559499 -0.029227557 -0.108559499 -0.083507307 -0.141962422
## [271] 0.058455115 0.037578288 0.079331942 -0.116910230 -0.221294363
## [276] -0.137787056 -0.033402923 0.075156576 0.075156576 -0.133611691
## [281] -0.171189979 0.121085595 -0.083507307 0.175365344 0.062630480
## [286] -0.033402923 -0.016701461 -0.192066806 0.183716075 0.041753653
## [291] -0.070981211 0.041753653 -0.196242171 -0.137787056 -0.354906054
## [296] 0.204592902 0.129436326 -0.108559499 -0.304801670 0.192066806
## [301] 0.112734864 -0.258872651 0.012526096 0.091858038 -0.062630480
## [306] -0.029227557 0.150313152 0.116910230 -0.125260960 -0.066805846
## [311] -0.112734864 -0.121085595 -0.091858038 0.137787056 0.212943633
## [316] -0.083507307 -0.083507307 0.254697286 -0.121085595 0.379958246
## [321] -0.187891441 -0.008350731 0.196242171 -0.129436326 0.162839248
## [326] 0.150313152 -0.087682672 -0.033402923 0.367432150 -0.208768267
## [331] 0.020876827 0.029227557 0.020876827 -0.008350731 0.121085595
## [336] 0.258872651 0.079331942 -0.008350731 0.045929019 -0.020876827
## [341] 0.004175365 0.359081420 -0.137787056 -0.187891441 0.096033403
## [346] 0.338204593 -0.012526096 0.066805846 -0.308977035 0.091858038
## [351] -0.104384134 -0.129436326 -0.125260960 0.146137787 0.146137787
## [356] 0.070981211 0.062630480 -0.208768267 0.062630480 -0.016701461
## [361] 0.108559499 -0.263048017 0.054279749 -0.237995825 0.175365344
## [366] -0.371607516 0.225469729 -0.070981211 -0.204592902 0.271398747
## [371] 0.221294363 -0.083507307 0.196242171 0.062630480 -0.129436326
## [376] 0.033402923 0.346555324 -0.087682672 0.075156576 0.070981211
## [381] -0.033402923 -0.062630480 -0.008350731 -0.070981211 0.133611691
## [386] 0.300626305 -0.250521921 -0.171189979 0.112734864 -0.338204593
## [391] 0.020876827 -0.167014614 0.112734864 0.158663883 -0.116910230
## [396] -0.233820459 -0.150313152 -0.342379958 0.033402923 0.075156576
## [401] 0.116910230 -0.150313152 -0.175365344 0.083507307 -0.079331942
## [406] 0.041753653 0.050104384 -0.025052192 -0.070981211 0.187891441
## [411] -0.116910230 -0.004175365 0.175365344 -0.041753653 -0.271398747
## [416] -0.087682672 0.304801670 0.162839248 0.112734864 0.104384134
## [421] -0.096033403 0.346555324 -0.020876827 0.150313152 -0.133611691
## [426] 0.321503132 0.087682672 -0.020876827 -0.004175365 -0.137787056
## [431] 0.167014614 -0.025052192 -0.175365344 -0.066805846 -0.058455115
## [436] 0.129436326 0.066805846 -0.208768267 -0.054279749 -0.321503132
## [441] -0.254697286 -0.091858038 -0.212943633 -0.283924843 -0.037578288
## [446] 0.025052192 -0.192066806 0.183716075 -0.141962422 -0.050104384
## [451] -0.020876827 -0.338204593 0.091858038 0.108559499 0.275574113
## [456] -0.058455115 -0.321503132 -0.116910230 -0.187891441 0.225469729
## [461] 0.129436326 0.004175365 -0.008350731 -0.133611691 -0.041753653
## [466] -0.029227557 0.050104384 -0.162839248 -0.058455115 -0.037578288
## [471] -0.116910230 0.125260960 -0.150313152 -0.200417537 -0.050104384
## [476] -0.367432150 0.300626305 0.096033403 -0.129436326 0.388308977
## [481] -0.204592902 -0.200417537 0.267223382 0.062630480 -0.116910230
## [486] -0.275574113 -0.012526096 -0.016701461 0.008350731 0.329853862
## [491] 0.129436326 0.116910230 -0.363256785 -0.050104384 0.296450939
## [496] 0.225469729 0.192066806 0.000000000 0.004175365 0.158663883
## [501] -0.029227557 -0.192066806 0.112734864 -0.125260960 0.405010438
## [506] -0.037578288 0.162839248 -0.025052192 -0.129436326 -0.070981211
## [511] 0.054279749 0.000000000 0.187891441 0.141962422 -0.045929019
## [516] -0.183716075 0.058455115 -0.125260960 -0.146137787 0.150313152
## [521] -0.025052192 -0.100208768 -0.037578288 -0.087682672 -0.167014614
## [526] -0.283924843 0.116910230 -0.233820459 -0.062630480 -0.066805846
## [531] -0.100208768 -0.050104384 -0.204592902 0.171189979 0.221294363

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```

## [536] -0.033402923 -0.162839248 0.045929019 -0.225469729 0.083507307
## [541] 0.083507307 0.104384134 0.029227557 -0.175365344 0.183716075
## [546] 0.029227557 -0.208768267 -0.196242171 0.037578288 0.179540710
## [551] -0.212943633 -0.079331942 -0.112734864 0.237995825 -0.083507307
## [556] -0.025052192 0.233820459 0.167014614 -0.104384134 0.125260960
## [561] -0.108559499 -0.079331942 0.158663883 -0.070981211 0.066805846
## [566] 0.104384134 0.091858038 -0.167014614 0.025052192 0.250521921
## [571] 0.062630480 -0.258872651 0.154488518 -0.041753653 0.125260960
## [576] 0.091858038 0.192066806 0.187891441 -0.008350731 -0.204592902
## [581] -0.045929019 0.079331942 -0.087682672 0.158663883 0.108559499
## [586] 0.045929019 -0.087682672 -0.062630480 -0.020876827 -0.083507307
## [591] -0.070981211 0.020876827 0.116910230 0.179540710 0.037578288
## [596] 0.167014614 0.250521921 0.221294363 0.020876827 0.083507307
## [601] 0.167014614 0.204592902 -0.108559499 0.233820459 -0.137787056
## [606] 0.121085595 -0.087682672 -0.388308977 -0.091858038 -0.012526096
## [611] -0.254697286 0.150313152 -0.204592902 0.037578288 0.020876827
## [616] -0.187891441 0.308977035 -0.271398747 0.217118998 -0.012526096
## [621] 0.313152401 0.062630480 -0.096033403 0.141962422 0.137787056
## [626] -0.179540710 0.112734864 -0.079331942 0.104384134 -0.334029228
## [631] -0.029227557 0.121085595 0.054279749 0.321503132 -0.062630480
## [636] -0.100208768 -0.129436326 -0.054279749 -0.129436326 0.000000000
## [641] 0.116910230 0.279749478 0.058455115 -0.208768267 0.271398747
## [646] 0.104384134 -0.045929019 0.070981211 -0.167014614 0.192066806
## [651] -0.208768267 0.079331942 -0.154488518 0.141962422 0.087682672
## [656] -0.096033403 -0.129436326 0.045929019 -0.104384134 -0.096033403
## [661] 0.254697286 -0.200417537 -0.363256785 -0.062630480 -0.004175365
## [666] 0.083507307 -0.029227557 -0.187891441 -0.012526096 0.012526096
## [671] -0.229645094 0.016701461 -0.033402923 -0.162839248 -0.033402923
## [676] -0.045929019 0.200417537 -0.196242171 -0.079331942 0.066805846
## [681] -0.096033403 0.054279749 -0.167014614 -0.208768267 -0.112734864
## [686] 0.137787056 0.037578288 0.146137787 -0.116910230 -0.288100209
## [691] 0.100208768 -0.100208768 -0.108559499 -0.275574113 -0.100208768
## [696] -0.129436326 0.146137787 0.079331942 0.133611691 0.100208768
## [701] -0.158663883 -0.258872651 -0.538622129 -0.112734864 -0.154488518
## [706] 0.133611691 -0.137787056 0.313152401 -0.121085595 0.162839248
## [711] -0.187891441 -0.045929019 -0.208768267 0.087682672 -0.033402923
## [716] 0.091858038 0.070981211 0.116910230 0.008350731 0.054279749
## [721] -0.070981211 -0.137787056 -0.116910230 -0.100208768 -0.016701461
## [726] 0.012526096 0.062630480 -0.141962422 -0.116910230 -0.075156576
## [731] 0.263048017 0.045929019 -0.292275574 -0.258872651 0.020876827
## [736] 0.058455115 0.020876827 -0.371607516 -0.317327766 0.133611691
## [741] -0.246346555 0.096033403 -0.229645094 -0.141962422 -0.162839248
## [746] -0.158663883 -0.250521921 -0.229645094 0.058455115 -0.141962422
## [751] 0.020876827 -0.212943633 0.037578288 0.141962422 0.116910230
## [756] 0.225469729 0.070981211 0.250521921 -0.037578288 -0.192066806
## [761] -0.350730689 -0.033402923 0.070981211 -0.179540710 0.075156576
## [766] 0.116910230 0.162839248 -0.283924843 0.025052192 -0.179540710
## [771] 0.041753653 0.229645094 0.062630480 0.325678497 -0.083507307
## [776] -0.004175365 0.096033403 -0.187891441 -0.187891441 0.100208768
## [781] 0.329853862 0.271398747 -0.158663883 -0.304801670 -0.112734864
## [786] -0.045929019 0.221294363 -0.045929019 0.167014614 0.012526096
## [791] 0.091858038 -0.041753653 0.004175365 0.020876827 0.175365344
## [796] -0.296450939 -0.087682672 0.066805846 0.217118998 0.087682672
## [801] 0.008350731 0.070981211 0.217118998 -0.008350731 0.058455115

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## [806] -0.359081420 0.150313152 0.037578288 0.329853862 0.075156576
## [811] -0.204592902 -0.129436326 0.116910230 -0.100208768 -0.100208768
## [816] 0.150313152 0.041753653 -0.058455115 0.029227557 0.025052192
## [821] -0.150313152 0.083507307 -0.066805846 -0.045929019 0.004175365
## [826] -0.112734864 0.237995825 -0.033402923 0.292275574 -0.033402923
## [831] -0.041753653 0.079331942 0.192066806 0.175365344 -0.208768267
## [836] -0.167014614 -0.112734864 -0.062630480 -0.066805846 -0.225469729
## [841] 0.121085595 -0.096033403 -0.037578288 0.237995825 -0.137787056
## [846] -0.075156576 -0.041753653 0.192066806 -0.025052192 0.204592902
## [851] -0.250521921 0.025052192 0.087682672 -0.079331942 -0.050104384
## [856] 0.004175365 0.062630480 0.037578288 0.016701461 -0.054279749
## [861] 0.112734864 0.037578288 0.150313152 -0.037578288 -0.020876827
## [866] 0.212943633 0.033402923 -0.137787056 -0.037578288 -0.075156576
## [871] 0.125260960 0.083507307 0.146137787 0.129436326 0.150313152
## [876] 0.087682672 -0.050104384 0.091858038 -0.100208768 -0.137787056
## [881] 0.183716075 -0.233820459 0.175365344 0.296450939 -0.020876827
## [886] 0.129436326 -0.087682672 0.016701461 -0.096033403 -0.066805846
## [891] 0.033402923 0.175365344 -0.020876827 0.409185804 0.204592902
## [896] -0.129436326 0.058455115 0.258872651 0.033402923 -0.050104384
## [901] -0.020876827 -0.121085595 0.096033403 -0.025052192 0.025052192
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## [911] 0.054279749 -0.108559499 0.187891441 -0.154488518 -0.125260960
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## [9331] -0.146137787 -0.075156576 0.050104384 -0.187891441 0.020876827
## [9336] 0.054279749 0.000000000 -0.125260960 0.146137787 -0.012526096
## [9341] 0.012526096 0.137787056 0.012526096 0.125260960 -0.300626305
## [9346] -0.104384134 -0.150313152 0.012526096 -0.096033403 0.192066806
## [9351] 0.183716075 0.100208768 0.112734864 0.054279749 0.200417537
## [9356] -0.087682672 -0.096033403 0.016701461 0.087682672 0.133611691
## [9361] -0.175365344 0.004175365 -0.100208768 -0.187891441 -0.141962422
## [9366] 0.137787056 -0.279749478 -0.125260960 0.183716075 0.254697286
## [9371] -0.212943633 0.096033403 0.116910230 0.146137787 0.146137787
## [9376] 0.237995825 0.242171190 -0.066805846 -0.125260960 -0.025052192
## [9381] 0.062630480 -0.058455115 -0.016701461 -0.179540710 -0.062630480
## [9386] 0.000000000 0.100208768 -0.313152401 -0.137787056 -0.058455115
## [9391] 0.237995825 0.154488518 0.179540710 0.212943633 0.070981211
## [9396] 0.154488518 -0.154488518 0.012526096 -0.025052192 0.400835073
## [9401] -0.112734864 0.091858038 -0.405010438 0.012526096 -0.033402923
## [9406] -0.150313152 0.442588727 -0.200417537 -0.204592902 0.317327766
## [9411] -0.212943633 -0.029227557 0.183716075 0.062630480 0.079331942
## [9416] -0.237995825 0.104384134 0.083507307 -0.075156576 -0.104384134
## [9421] -0.555323591 0.050104384 -0.212943633 -0.167014614 0.100208768
## [9426] 0.263048017 0.137787056 0.146137787 -0.070981211 0.171189979
## [9431] 0.100208768 0.075156576 0.212943633 0.066805846 -0.196242171
## [9436] 0.217118998 -0.054279749 0.070981211 -0.129436326 -0.104384134
## [9441] -0.154488518 0.242171190 0.062630480 0.029227557 0.158663883

```

```

## [9446] -0.225469729 0.133611691 -0.150313152 0.221294363 -0.096033403
## [9451] -0.141962422 -0.288100209 -0.129436326 0.012526096 -0.196242171
## [9456] 0.158663883 -0.179540710 0.091858038 -0.033402923 -0.200417537
## [9461] -0.079331942 0.050104384 -0.079331942 0.346555324 -0.100208768
## [9466] 0.208768267 -0.112734864 -0.054279749 -0.296450939 0.179540710
## [9471] 0.229645094 -0.137787056 -0.121085595 -0.292275574 0.300626305
## [9476] -0.091858038 0.083507307 0.183716075 0.096033403 -0.025052192
## [9481] -0.004175365 -0.096033403 -0.050104384 0.029227557 -0.096033403
## [9486] -0.041753653 0.087682672 -0.104384134 -0.129436326 -0.183716075
## [9491] -0.012526096 0.087682672 -0.100208768 -0.016701461 0.283924843
## [9496] 0.041753653 0.233820459 -0.045929019 -0.267223382 0.004175365
## [9501] -0.066805846 0.058455115 0.308977035 -0.288100209 0.037578288
## [9506] 0.020876827 -0.146137787 0.263048017 0.196242171 0.221294363
## [9511] -0.317327766 -0.321503132 -0.054279749 -0.125260960 -0.054279749
## [9516] -0.367432150 0.020876827 0.129436326 0.162839248 -0.066805846
## [9521] 0.229645094 -0.091858038 -0.154488518 0.100208768 0.146137787
## [9526] -0.070981211 -0.025052192 -0.062630480 -0.020876827 0.112734864
## [9531] 0.083507307 -0.146137787 -0.075156576 -0.004175365 0.075156576
## [9536] -0.104384134 0.016701461 -0.033402923 0.050104384 0.004175365
## [9541] -0.020876827 0.375782881 -0.121085595 -0.121085595 0.129436326
## [9546] -0.217118998 0.162839248 -0.050104384 0.108559499 -0.020876827
## [9551] 0.125260960 -0.045929019 0.116910230 -0.045929019 0.000000000
## [9556] -0.630480167 0.020876827 0.070981211 0.020876827 -0.041753653
## [9561] 0.121085595 0.204592902 -0.070981211 -0.083507307 0.087682672
## [9566] 0.054279749 0.158663883 0.000000000 0.033402923 -0.367432150
## [9571] -0.050104384 0.070981211 -0.125260960 0.183716075 0.121085595
## [9576] 0.125260960 0.388308977 0.058455115 -0.008350731 0.350730689
## [9581] 0.058455115 -0.029227557 -0.288100209 -0.045929019 0.158663883
## [9586] -0.058455115 -0.196242171 0.133611691 0.267223382 0.158663883
## [9591] -0.079331942 0.108559499 0.162839248 -0.121085595 -0.108559499
## [9596] 0.016701461 -0.116910230 0.058455115 0.400835073 -0.217118998
## [9601] 0.066805846 -0.004175365 -0.167014614 -0.146137787 -0.054279749
## [9606] 0.179540710 0.229645094 0.054279749 0.183716075 -0.179540710
## [9611] 0.116910230 -0.129436326 0.237995825 0.183716075 -0.204592902
## [9616] -0.079331942 0.058455115 -0.162839248 0.112734864 -0.012526096
## [9621] -0.083507307 0.029227557 0.029227557 0.058455115 -0.070981211
## [9626] 0.158663883 0.187891441 0.150313152 -0.033402923 0.167014614
## [9631] -0.083507307 0.300626305 0.012526096 -0.179540710 0.000000000
## [9636] -0.004175365 -0.250521921 0.196242171 -0.037578288 -0.008350731
## [9641] -0.204592902 0.137787056 -0.004175365 -0.091858038 0.070981211
## [9646] -0.141962422 -0.054279749 0.079331942 0.175365344 -0.045929019
## [9651] 0.091858038 -0.321503132 0.029227557 0.162839248 0.066805846
## [9656] 0.070981211 -0.112734864 -0.029227557 0.171189979 -0.388308977
## [9661] 0.137787056 -0.342379958 0.012526096 -0.104384134 0.162839248
## [9666] -0.104384134 -0.020876827 0.087682672 -0.025052192 0.221294363
## [9671] 0.054279749 0.300626305 0.016701461 0.058455115 -0.104384134
## [9676] 0.066805846 0.292275574 -0.016701461 0.158663883 0.146137787
## [9681] -0.137787056 0.045929019 -0.020876827 -0.041753653 0.066805846
## [9686] -0.004175365 0.242171190 0.237995825 0.033402923 0.204592902
## [9691] -0.258872651 0.016701461 -0.083507307 -0.275574113 -0.129436326
## [9696] 0.212943633 0.183716075 -0.179540710 -0.133611691 -0.091858038
## [9701] -0.045929019 -0.208768267 -0.242171190 0.016701461 -0.020876827
## [9706] -0.133611691 0.104384134 0.062630480 0.137787056 0.087682672
## [9711] -0.300626305 0.200417537 -0.154488518 -0.096033403 0.029227557

```

```

## [9716] 0.104384134 0.037578288 -0.392484342 -0.075156576 -0.196242171
## [9721] 0.233820459 0.029227557 0.096033403 0.242171190 -0.025052192
## [9726] -0.271398747 0.033402923 0.233820459 -0.233820459 -0.004175365
## [9731] 0.008350731 -0.029227557 -0.058455115 -0.304801670 0.045929019
## [9736] 0.125260960 0.150313152 -0.125260960 -0.025052192 0.083507307
## [9741] -0.154488518 -0.062630480 -0.409185804 -0.179540710 -0.212943633
## [9746] 0.050104384 0.104384134 -0.016701461 -0.275574113 0.125260960
## [9751] 0.058455115 -0.304801670 -0.167014614 0.020876827 -0.091858038
## [9756] 0.012526096 0.075156576 -0.079331942 -0.037578288 -0.083507307
## [9761] -0.112734864 0.275574113 -0.054279749 -0.066805846 0.062630480
## [9766] 0.271398747 -0.012526096 0.020876827 0.183716075 0.083507307
## [9771] -0.225469729 -0.171189979 0.250521921 0.016701461 -0.288100209
## [9776] 0.217118998 0.029227557 0.208768267 -0.112734864 -0.313152401
## [9781] 0.050104384 0.108559499 -0.196242171 -0.133611691 -0.363256785
## [9786] 0.179540710 -0.208768267 -0.004175365 0.041753653 -0.012526096
## [9791] 0.012526096 -0.025052192 0.020876827 0.079331942 -0.438413361
## [9796] -0.083507307 -0.075156576 0.225469729 -0.096033403 0.125260960
## [9801] -0.012526096 -0.125260960 0.079331942 0.029227557 0.183716075
## [9806] -0.066805846 -0.054279749 0.020876827 -0.116910230 0.045929019
## [9811] 0.037578288 -0.108559499 -0.446764092 -0.004175365 0.000000000
## [9816] -0.317327766 0.171189979 -0.104384134 0.129436326 0.288100209
## [9821] -0.342379958 -0.058455115 0.045929019 -0.054279749 -0.091858038
## [9826] 0.016701461 0.158663883 -0.058455115 0.129436326 0.104384134
## [9831] -0.129436326 0.054279749 -0.025052192 -0.125260960 -0.175365344
## [9836] 0.079331942 -0.058455115 -0.112734864 -0.121085595 0.212943633
## [9841] -0.075156576 -0.091858038 0.446764092 0.279749478 -0.045929019
## [9846] 0.171189979 -0.029227557 -0.050104384 0.054279749 0.100208768
## [9851] -0.108559499 0.054279749 -0.242171190 -0.087682672 -0.112734864
## [9856] 0.334029228 -0.025052192 0.079331942 0.025052192 0.263048017
## [9861] 0.325678497 0.129436326 -0.158663883 0.116910230 0.417536534
## [9866] 0.200417537 -0.192066806 0.008350731 -0.125260960 -0.091858038
## [9871] -0.204592902 0.150313152 0.058455115 0.321503132 -0.167014614
## [9876] 0.087682672 -0.171189979 0.104384134 0.329853862 0.125260960
## [9881] -0.070981211 -0.183716075 -0.087682672 0.121085595 -0.292275574
## [9886] -0.121085595 0.129436326 0.158663883 0.041753653 0.096033403
## [9891] 0.012526096 0.058455115 -0.108559499 0.229645094 0.137787056
## [9896] 0.296450939 -0.488517745 0.121085595 -0.079331942 -0.116910230
## [9901] -0.033402923 0.275574113 -0.045929019 0.041753653 -0.283924843
## [9906] 0.066805846 0.187891441 -0.167014614 -0.288100209 -0.037578288
## [9911] 0.062630480 0.104384134 -0.033402923 0.133611691 -0.221294363
## [9916] 0.288100209 -0.154488518 -0.033402923 -0.066805846 -0.104384134
## [9921] 0.162839248 -0.162839248 0.008350731 0.237995825 -0.096033403
## [9926] 0.062630480 0.329853862 -0.154488518 -0.225469729 -0.029227557
## [9931] 0.208768267 0.029227557 -0.029227557 0.062630480 0.329853862
## [9936] 0.008350731 -0.221294363 0.112734864 -0.133611691 0.283924843
## [9941] -0.129436326 0.000000000 -0.187891441 -0.384133612 0.029227557
## [9946] -0.041753653 -0.242171190 -0.091858038 -0.016701461 -0.100208768
## [9951] 0.192066806 0.375782881 0.121085595 -0.050104384 -0.192066806
## [9956] -0.212943633 -0.141962422 -0.150313152 -0.405010438 0.183716075
## [9961] 0.075156576 0.225469729 0.045929019 0.308977035 0.091858038
## [9966] -0.083507307 0.179540710 -0.083507307 -0.225469729 0.029227557
## [9971] -0.116910230 0.271398747 -0.121085595 -0.058455115 0.025052192
## [9976] 0.066805846 0.342379958 -0.263048017 0.141962422 -0.204592902
## [9981] 0.329853862 0.070981211 -0.062630480 -0.041753653 -0.338204593

```

```
## [9986] -0.183716075  0.121085595  0.288100209 -0.016701461 -0.062630480
## [9991] -0.070981211  0.037578288  0.083507307 -0.162839248 -0.045929019
## [9996]  0.087682672 -0.229645094  0.020876827  0.000000000 -0.066805846
```

3. How many of the simulated random assignments generate an estimated ATE that is at least as large as the actual estimate of the ATE? Conduct your work in the code chunk below, saving the results into `hajj_count_larger`, but also support your coding with a narrative description. In that narrative description (and throughout), use R's "inline code chunks" to write your answer consistent with each time you run your code.

```
hajj_count_larger <- sum(hajj_ri_distribution >= hajj_ate) # length 1 numeric vector from comparison of `hajj_ate` and `hajj_ri_distribution`
hajj_count_larger
```

```
## [1] 28
```

```
# There are 23 simulated random assignments that have an estimated ATE that is at least as large as the actual estimated ATE
```

4. If there are `hajj_count_larger` randomizations that are larger than `hajj_ate`, what is the implied *one-tailed* p-value? Both write the code in the following chunk, and include a narrative description of the result following your code.

```
hajj_one_tailed_p_value <- mean(hajj_ri_distribution > hajj_ate) # length 1 numeric vector
hajj_one_tailed_p_value
```

```
## [1] 0.0028
```

```
# The one tailed p-value is 0.0023
```

5. Now, conduct a similar test, but for a two-sided p-value. You can either use two tests, one for larger than and another for smaller than; or, you can use an absolute value (`abs`). Both write the code in the following chunk, and include a narrative description of the result following your code.

```
hajj_two_tailed_p_value <- mean(abs(hajj_ri_distribution) > abs(hajj_ate)) # length 1 numeric vector
hajj_two_tailed_p_value
```

```
## [1] 0.0049
```

```
#The two-tailed p-value of 0.0041. This means that if the sharp null hypothesis were true, then it would be possible to see a treatment effect larger than that what is in our experiment in roughly 0.0041 of the possible randomization vectors.
```

## 2. Sports Cards



In this experiment, the experimenters invited consumers at a sports card trading show to bid against one other bidder for a pair trading cards. We abstract from the multi-unit-auction details here, and simply state that the treatment auction format was theoretically predicted to produce lower bids than the control auction format. We provide you a relevant subset of data from the experiment.

In this question, we are asking you to produce p-values and confidence intervals in three different ways:

1. Using a `t.test`;
2. Using a regression; and,
3. Using randomization inference.

```
d <- fread('../data/list_data_2019.csv')
```

1. Using a `t.test`, compute a 95% confidence interval for the difference between the treatment mean and the control mean. After you conduct your test, write a narrative statement, using inline code evaluation that describes what your tests find, and how you interpret these results. (You should be able to look into `str(t_test_cards)` to find the pieces that you want to pull to include in your written results.)

```
t_test_cards <- t.test(d[uniform_price_auction==0,bid], d[uniform_price_auction==1,bid])
# this should be the t.test object. Extract pieces from this object in-text below the code chunk.
str(t_test_cards)
```

```
## List of 10
## $ statistic : Named num 2.82
## .. attr(*, "names")= chr "t"
## $ parameter : Named num 62
## .. attr(*, "names")= chr "df"
## $ p.value : num 0.00642
## $ conf.int : num [1:2] 3.56 20.85
## .. attr(*, "conf.level")= num 0.95
## $ estimate : Named num [1:2] 28.8 16.6
## .. attr(*, "names")= chr [1:2] "mean of x" "mean of y"
## $ null.value : Named num 0
## .. attr(*, "names")= chr "difference in means"
## $ stderr : num 4.33
## $ alternative: chr "two.sided"
## $ method : chr "Welch Two Sample t-test"
## $ data.name : chr "d[uniform_price_auction == 0, bid] and d[uniform_price_auction = 1, bid]"
## - attr(*, "class")= chr "htest"
```

```
# The 95% confidence interval is between 3.56 and 20.85. And we have the p-value of 0.006421, which is small enough to reject the null hypothesis that the bid price for treatment auction format is equal to the control auction format
```

2. In plain language, what does this confidence interval mean?

**Answer: Confidence interval gives a range of values for an unknown parameter (for example, a population mean). For a given estimation in a given sample, using a higher confidence level generates a wider (i.e., less precise) confidence interval. In general terms, a confidence interval for an unknown parameter is based on sampling the distribution of a corresponding estimator. It means were this procedure to be repeated on numerous samples, the fraction of calculated confidence intervals (which would differ for each sample) that encompass the true population parameter would tend toward 95%**

3. Conduct a randomization inference process, with `n_ri_loops = 1000`, using an estimator that you write by hand (i.e. in the same way as earlier questions). On the sharp-null distribution that this process creates, compute the 2.5% quantile and the 97.5% quantile using the function `quantile` with the appropriate vector passed to the `probs` argument. This is the randomization-based uncertainty that is generated by your design. After you conduct your test, write a narrative statement of your test results.

```
## first, do you work for the randomization inference

simulation_q3 <- function(d, num_simulations) {
  simulated_ate_list <- c()
  for (i in 1:num_simulations){
    d[ , simulation := sample(c(0,1), replace=TRUE, size=.N) ]
    simulated_ate <- d[ , .(mean_group = mean(bid)), keyby=simulation][ , diff(mean_group)]
    simulated_ate_list <- c(simulated_ate_list, simulated_ate)
  }
  return(simulated_ate_list)
}

n_ri_loops <- 1000

cards_ate <- d[ , .(mean_group = mean(bid)), keyby=uniform_price_auction][ , diff(mean_group)]
cards_ri_distribution <- simulation_q3(d, n_ri_loops) # numeric vector of length equal
# to your number of RI permutations
cards_ri_quantiles <- quantile(cards_ri_distribution, probs=c(2.5/100, 97.5/100)) #
# there's a built-in to pull these.
cards_ri_p_value <- mean(abs(cards_ri_distribution)>= abs(cards_ate))
cards_ate
```

```
## [1] -12.20588
```

```
cards_ri_quantiles
```

```
##      2.5%      97.5%
## -8.328953  8.791304
```

```
cards_ri_p_value
```

```
## [1] 0.004
```

*# Because p-value of 0.007 is less than 0.05. We reject the Sharp Null Hypothesis that the treatment effect is zero for all subjects or observations. Thus, with a 95% confidence, the experiment's ATE of `r cards\_ate` is not likely to be a random result, and it is likely to be different from zero.*

4. Do you learn anything different if you regress the outcome on a binary treatment variable? To answer this question, regress `bid` on a binary variable equal to 0 for the control auction and 1 for the treatment auction and then calculate the 95% confidence interval using *classical standard errors* (in a moment you will calculate with *robust standard errors*). There are two ways to do this – you can code them by hand; or use a built-in, `confint`. After you conduct your test, write a narrative statement of your test results.

```
mod <- lm(bid ~ uniform_price_auction, data = d) # this should be a model object, class = 'lm'.
confint(mod, level=0.95)
```

```
##                2.5 %    97.5 %
## (Intercept)    22.71534 34.931716
## uniform_price_auction -20.84416 -3.567603
```

*# The OLS based confidence interval produces the same values of confidence interval. Since zero is not included in the confidence interval, we can say that with 95% confidence the true ATE is located within this range (confidence interval).*

5. Calculate the 95% confidence interval using robust standard errors, using the `sandwich` package. There is a function in `lmtest` called `coefci` that can help with this. It is also possible to do this work by hand. After you conduct your test, write a narrative statement of your test results.

```
library(sandwich)
library(lmtest)

m <- lm(bid ~ uniform_price_auction, data = d)
cards_robust_ci <- coefci(mod, devel = 0.95, vcov = vcovHC)
#Using the sandwich package, we also see that the robust standard errors is very close to what we had calculated using other prior methods.
```

6. Characterize what you learn from each of these different methods – are the results contingent on the method of analysis that you choose?

*#Compared to part 3 above, there is a slight deviation in confidence interval around zero when using a randomization inference based method. However, the overall approach does not lead to any material difference in test results.*

## Power Analysis

(Because there are a *lot* of ways to write this code, we're not going to write a tight testing suite against this question.)

Understanding whether your experiment design and data collection strategy are able to reject the null hypothesis *when they should* is valuable! And, this isn't theoretical value. If your design and data collection cannot reject the null hypothesis, why even run the experiment in the first place?

The classical formulation of power asks, "Given a test procedure and data, what proportion of the tests I *could* conduct would reject the null hypothesis?"

Imagine that you and David Reiley are going to revive the sports card experiment from the previous question. However, because it is for a class project, and because you've already spent all your money on a shiny new data science degree :raised\_hands: :money\_with\_wings: , you're not going to be able to afford to recruit as many participants as before.

1. Describe a t-test based testing procedure that you might conduct for this experiment. What is your null hypothesis, and what would it take for you to reject this null hypothesis? (This second statement could either be in terms of p-values, or critical values.)

**Answer: A t-test experiment for this hypothesis would test if the treatment mean is different than the control mean. In this case, I would split my subjects into a control and treatment group. The null hypothesis is that there is no difference in the means between control group and treatment group. If p value is smaller than 0.05, we can reject the null hypothesis at 5% significance level.**

2. Suppose that you are only able to recruit 10 people to be a part of your experiment – 5 in treatment and another 5 in control. Simulate “re-conducting” the sports card experiment once by sampling from the data you previously collected, and conducting the test that you've written down in part 1 above. Given the results of this 10 person simulation, would your test reject the null hypothesis?

```
d <- fread('../data/list_data_2019.csv')
t_test_ten_people <- d[, .SD[sample(.N, 5, replace = T)], by = uniform_price_auction][,
  t.test(bid ~ uniform_price_auction)] # this should be a test object
t_test_ten_people
```

```
##
## Welch Two Sample t-test
##
## data: bid by uniform_price_auction
## t = 2.0246, df = 7.433, p-value = 0.0802
## alternative hypothesis: true difference in means is not equal to 0
## 95 percent confidence interval:
## -2.437466 34.037466
## sample estimates:
## mean in group 0 mean in group 1
## 25.6 9.8
```

```
# Because p value is greater than 0.05, we cannot reject the null hypothesis
```

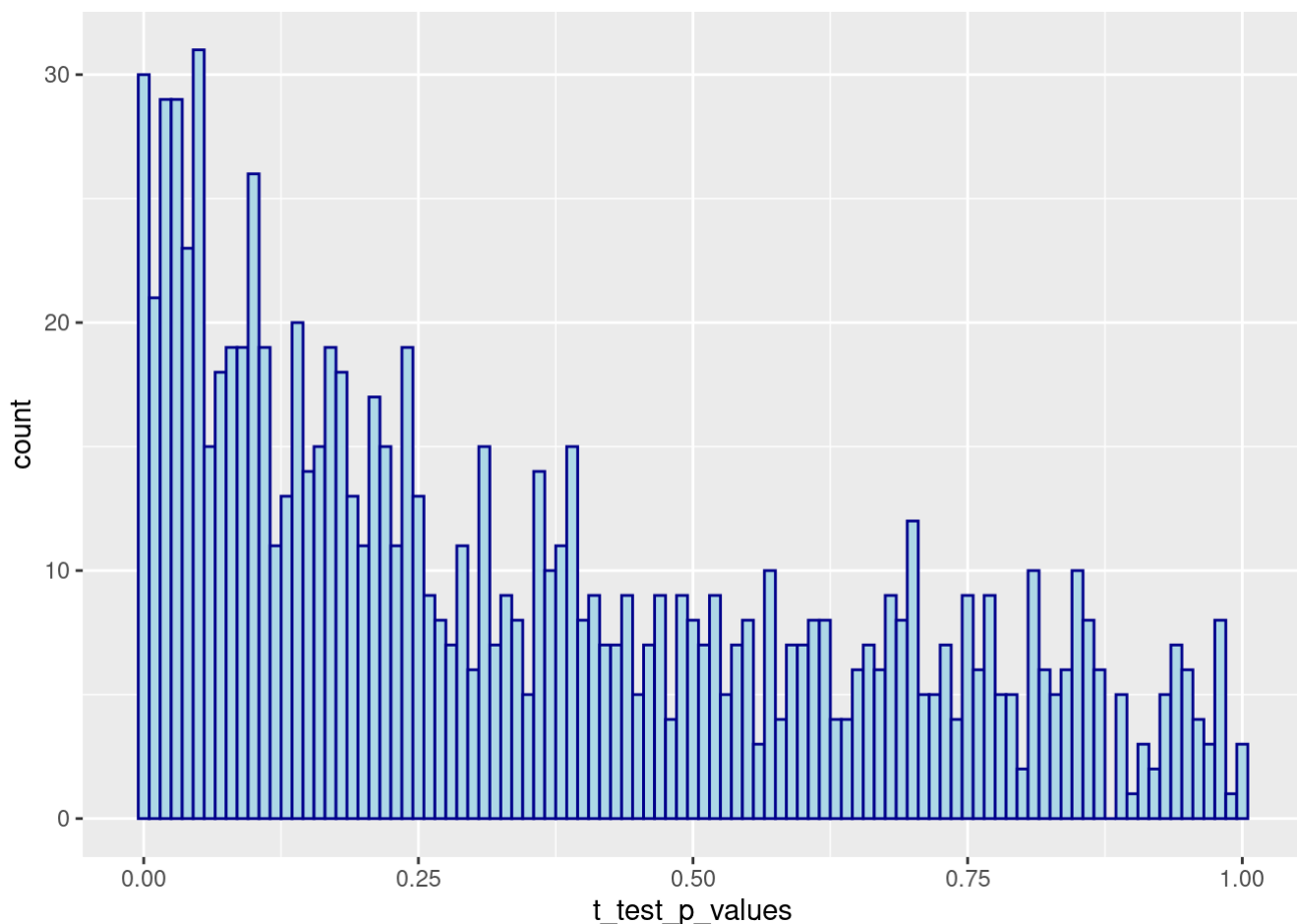
3. Now, repeat this process – sampling 10 people from your existing data and conducting the appropriate test – one-thousand times. Each time that you conduct this sample and test, pull the p-value from your t-test and store it in an object for later use. Consider whether your sampling process should sample with or without replacement.

```
t_test_p_values <- rep(NA, 1000) # fill this in with the p-values from your power analysis
is
sample_t <- function(data, size) {
  data[, .SD[sample(.N, size, replace = T)], by = uniform_price_auction][, t.test(bid ~
    uniform_price_auction)$p.value]
}

t_test_p_values <- replicate(1000, sample_t(d, 5))
## you can either write a for loop, use an apply method, or use replicate (which is an e
asy-of-use wrapper to an apply method)
```

4. Use `ggplot` and either `geom_hist()` or `geom_density()` to produce a distribution of your p-values, and describe what you see. What impression does this leave you with about the power of your test?

```
library(ggplot2)
ggplot(as.data.frame(t_test_p_values), aes(x=t_test_p_values)) +
  geom_histogram(color="darkblue", fill="lightblue", binwidth = 0.01)
```



*# We can see the distribution is right skewed with more smaller number of p-values. The more heavier right-skewed the distribution is, the higher the power of the test.*

5. Suppose that you and David were to actually run this experiment and design – sample 10 people, conduct a t-test, and draw a conclusion. **And** suppose that when you get the data back, **lo and behold** it happens to reject the null hypothesis. Given the power that your design possesses, does the result seem reliable? Or, does it seem like it might be a false-positive result?

**Answer: it might be false positive. Because based on the distribution, it is likely the result randomly happened due to chances.**

6. Apply the decision rule that you wrote down in part 1 above to each of the simulations you have conducted. What proportion of your simulations have rejected your null hypothesis? This is the p-value that this design and testing procedure generates. After you write and execute your code, include a narrative sentence or two about what you see.

```
t_test_rejects <- sum(t_test_p_values < 0.05)/1000
t_test_rejects
```

```
## [1] 0.143
```

```
# 0.148 of the simulations could reject the null hypothesis.
```

7. Does buying more sample increase the power of your test? Apply the algorithm you have just written onto different sizes of data. Namely, conduct the exact same process that you have for 10 people, but now conduct the process for every 10% of recruitment size of the original data: Conduct a power analysis with a 10%, 20%, 30%, ... 200% sample of the original data. (You could be more granular if you like, perhaps running this task for every 1% of the data).

```
percentages_to_sample <- 0.1
counter <- 1
sample_size <- NA
power_analysis <- NA

while (percentages_to_sample < 2.1) {
  sample_size[counter] <- percentages_to_sample * nrow(d)
  p_vals <- replicate(1000, t.test(
    sample(d[uniform_price_auction==1, (bid)], sample_size[counter]/2, replace=T),
    sample(d[uniform_price_auction==0, (bid)], sample_size[counter]/2, replace=T)
  )$p.value)
  power_analysis[counter] <- mean(p_vals < 0.05)
  cat(sprintf('Sample size: %.2f, Power: %.3f\n', sample_size[counter], power_analysis[counter]))
  percentages_to_sample <- percentages_to_sample + 0.1
  counter <- counter + 1
}
```

```
## Sample size: 6.80, Power: 0.063
## Sample size: 13.60, Power: 0.180
## Sample size: 20.40, Power: 0.321
## Sample size: 27.20, Power: 0.436
## Sample size: 34.00, Power: 0.516
## Sample size: 40.80, Power: 0.587
## Sample size: 47.60, Power: 0.645
## Sample size: 54.40, Power: 0.719
## Sample size: 61.20, Power: 0.746
## Sample size: 68.00, Power: 0.787
## Sample size: 74.80, Power: 0.836
## Sample size: 81.60, Power: 0.863
## Sample size: 88.40, Power: 0.903
## Sample size: 95.20, Power: 0.905
## Sample size: 102.00, Power: 0.930
## Sample size: 108.80, Power: 0.940
## Sample size: 115.60, Power: 0.959
## Sample size: 122.40, Power: 0.967
## Sample size: 129.20, Power: 0.964
## Sample size: 136.00, Power: 0.974
```

*# From the results, we can see buying more sample does increase the power of our test.*