

# IDS 702: MODULE 8.2

## BOOTSTRAP

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# INTRODUCTION

- When building statistical models, we often need to quantify the uncertainty around the estimated parameters we are interested in.
- So far in this class, we have been doing so using standard errors and confidence intervals.
- Computing standard errors is often straightforward when we have closed forms.
- For example, the standard error for  $\bar{X}$  is  $\sigma/\sqrt{n}$ .
- When  $\sigma$  is unknown, replace with  $s = \hat{\sigma}$ .
- What to do when we do not have closed forms?

# INTRODUCTION

- Setting confidence intervals and conducting hypotheses testing often requires us to know the distribution of the parameter of interest.
- A key tool for doing this is the central limit theorem.
- Recall that according to CLT, for large samples, averages and sums are approximately normally distributed.
- With some work, the CLT allows confidence intervals and hypotheses testing on means, proportions, sums, intercepts, slopes, and so on.
- But...what if we want to set confidence intervals on a correlation or an sd or a ratio?

# INTRODUCTION

- Once neat solution is to approximate whatever distribution you have in mind via re-sampling from the true population.
- For example, suppose I would like to estimate the average income of Durham residents and quantify uncertainty around my estimate.
- First I need a sample (of course!).
- Suppose I sample 1000 residents and record their income as  $X_1, \dots, X_{1000}$ . Then, my estimate of average income is  $\bar{X}$ .
- Next, I should quantify my uncertainty around that number. I can do so using the standard error  $\sigma/\sqrt{n}$  mentioned earlier, which relies on the CLT.

# BOOTSTRAP

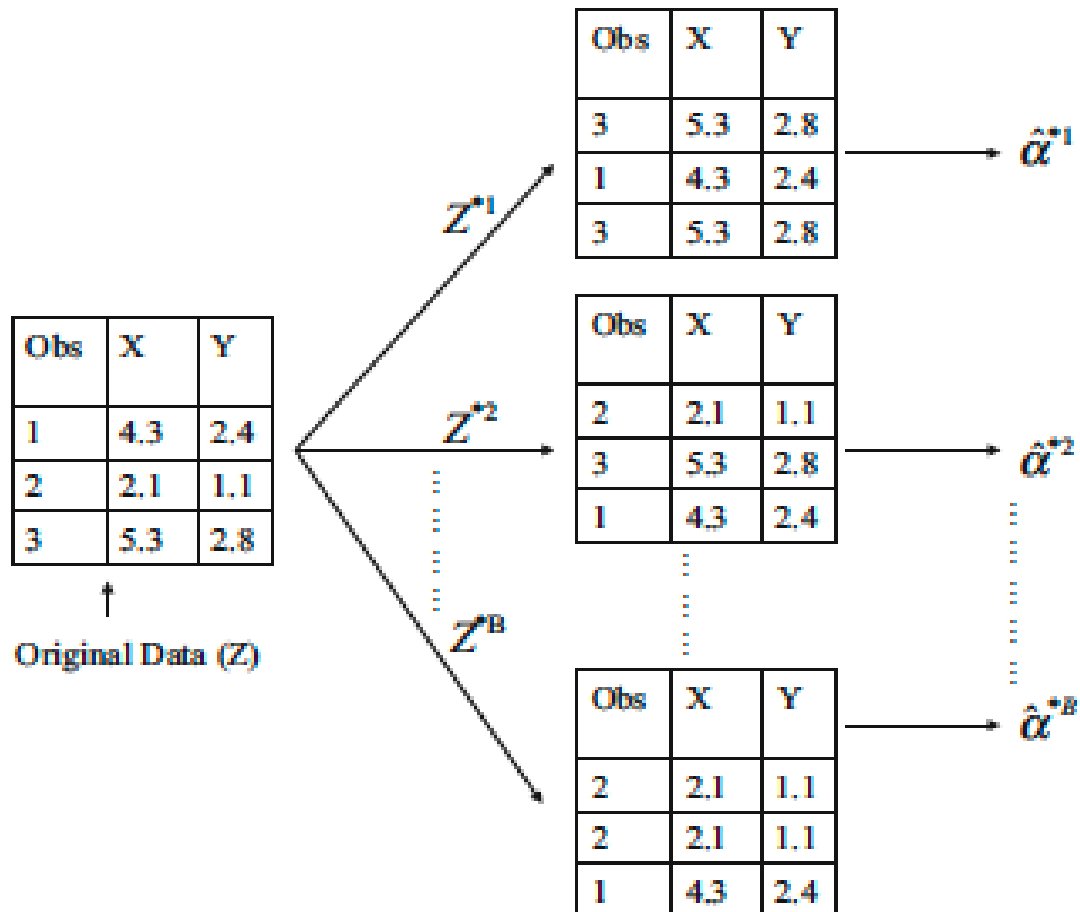
- Alternatively, I could approximate the entire distribution of average income myself as follows:
  1. Generate  $B = 100$  different samples of 1000 Durham residents.
  2. For each set  $b = 1, \dots, B$  of 1000 residents, compute  $\bar{X}^b$ .
  3. Make a histogram of all  $\bar{X}^1, \dots, \bar{X}^{100}$  values. This approximates the distribution of average income of Durham residents.
- Point estimate of average income is thus the mean of  $\bar{X}^1, \dots, \bar{X}^{100}$ .
- To quantify uncertainty, can use the standard deviation of  $\bar{X}^1, \dots, \bar{X}^{100}$ .
- For confidence intervals, use the quantiles of the histogram.
- In practice, however, the procedure above cannot be applied, because we usually cannot generate many samples from the original population.
- What to do then? **Bootstrap!**

# BOOTSTRAP

- **Bootstrap** is a very powerful statistical tool.
- It can be used to "approximate" the distribution of almost any parameter of interest.
- Bootstrap allows us to mimic the process of obtaining new sample sets by repeatedly sampling observations from the original data set.
- That is, replace step 1 of the previously outlined approach with
  1. Generate  $B = 100$  different samples of 1000 Durham residents by re-sampling from the original observed sample with replacement.
- Can then follow the remaining steps to approximate the distribution of the parameter of interest.
- Ideally, the sample you start with should be representative of the entire population. Bootstrap relies on the original sample!

# BOOTSTRAP

Here's a figure from the ISL book illustrating the approach.



# WHAT'S NEXT?

MOVE ON TO THE READINGS FOR THE NEXT MODULE!