MATH 450: Mathematical statistics

September 24th, 2020

Lecture 8: Method of moments

Topics

Week 2	*Chapter 6: Statistics and Sampling Distributions*
Week 4	Chapter 7: Point Estimation
Week 6	*Chapter 8: Confidence Intervals*
Week 9	*Chapter 9: Test of Hypothesis*
Week 11	Chapter 10: Two-sample inference
Week 12	Regression

Chapter 7: Overview

7.1 Point estimate

- unbiased estimator
- mean squared error

7.2 Methods of point estimation

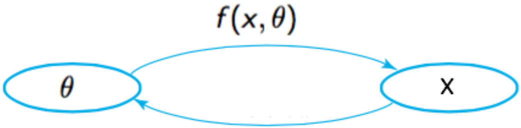
- method of moments
- method of maximum likelihood.

7.3 Sufficient statistic

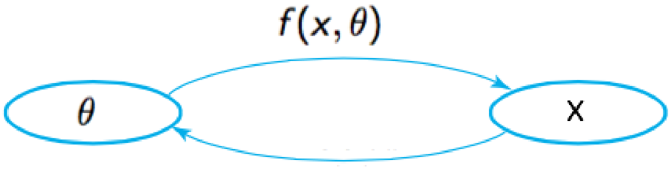
7.4 Information and Efficiency

- Large sample properties of the maximum likelihood estimator

- Given a random sample $X_1, \ldots, X_n$ from a distribution with pmf/pdf $f(x, \theta)$ parameterized by a parameter θ
- Goal: Estimate θ



Point estimate



Definition

A point estimate $\hat{\theta}$ of a parameter θ is a single number that can be regarded as a sensible value for θ.

$$\begin{array}{ccccc} \text{population parameter} & \Longrightarrow & \textit{sample} & \Longrightarrow & \textit{estimator} \\ \theta & \Longrightarrow & X_1, X_2, \ldots, X_n & \Longrightarrow & \hat{\theta} \end{array}$$

Estimate vs estimator

$$\begin{aligned} \textit{sample} &\implies \textit{estimator} \\ X_1, X_2, \ldots, X_n &\implies \hat{\theta} \end{aligned}$$

$$\begin{aligned} \textit{observed data} &\implies \textit{estimate} \\ x_1, x_2, \ldots, x_n &\implies \hat{\theta} \end{aligned}$$

Mean Squared Error

- Measuring error of estimation

$$|\hat{\theta} - \theta| \quad \text{or} \quad (\hat{\theta} - \theta)^2$$

- The error of estimation is random

Definition

The mean squared error of an estimator $\hat{\theta}$ is

$$E[(\hat{\theta} - \theta)^2]$$

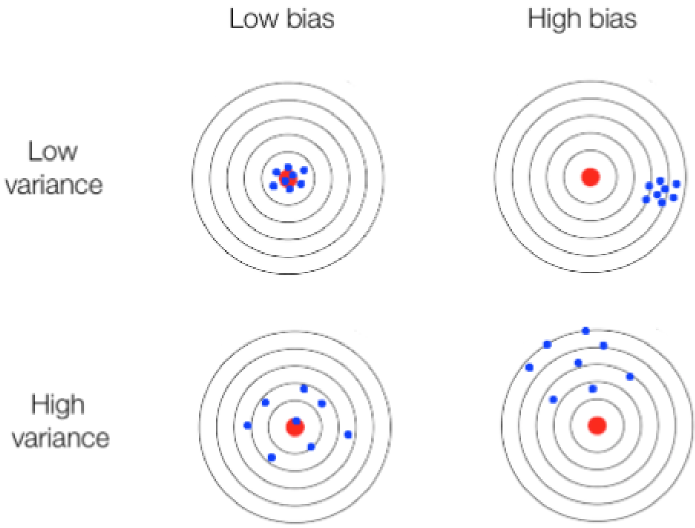
Theorem

$$MSE(\hat{\theta}) = E[(\hat{\theta} - \theta)^2] = V(\hat{\theta}) + \left(E(\hat{\theta}) - \theta\right)^2$$

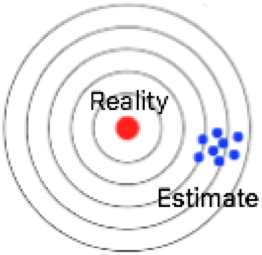
Bias-variance decomposition

Mean squared error = variance of estimator + $(bias)^2$

Bias-variance decomposition



Statistical bias vs. social bias



Unbiased estimators

Definition

A point estimator $\hat{\theta}$ is said to be an unbiased estimator of θ if

$$E(\hat{\theta}) = \theta$$

for every possible value of θ.

Unbiased estimator

$\Leftrightarrow$ Bias $= 0$

$\Leftrightarrow$ Mean squared error $=$ variance of estimator

Example: sample proportion

Problem

Let $X_1, X_2, \ldots, X_n$ be a random sample of size n from a Bernoulli distribution with probability of success p

x	0	1
p(x)	1-p	p

Assume that we estimate p by using the sample mean

$$\bar{X} = \frac{X_1 + X_2 + \ldots X_n}{n}$$

What are the bias and the variance of this estimator?

Example: sample proportion

Problem

Let $X_1, X_2, \ldots, X_n$ be a random sample of size n from a Bernoulli distribution with probability of success p

x	0	1
p(x)	1-p	p

Assume that we estimate p by using the sample mean

$$\bar{X} = \frac{X_1 + X_2 + \ldots X_n}{n}$$

Compute the MSE of this estimator.

Example: sample proportion

Problem

Let $X_1, X_2, \ldots, X_n$ be a random sample of size n from a Bernoulli distribution with probability of success p

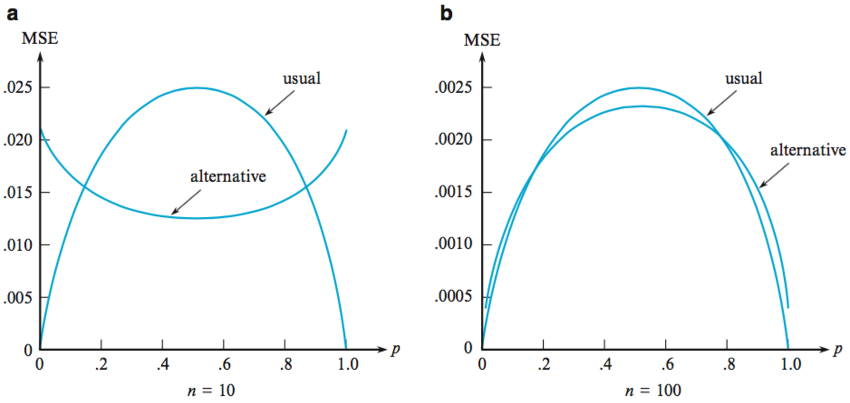
x	0	1
$p(x)$	1-p	p

Assume that we estimate p by using

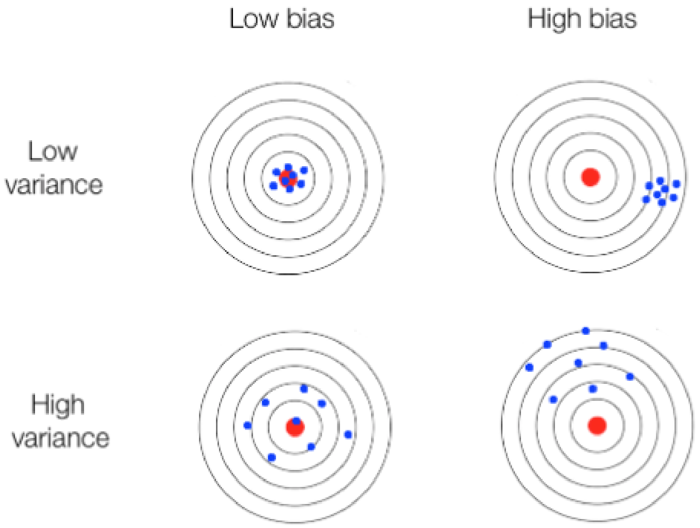
$$\tilde{p} = \frac{X_1 + X_2 + \ldots + X_n + 2}{n+4}$$

Compute the MSE of this estimator.

Example 7.1 and 7.4



Bias-variance decomposition



Method of moments

Example

Problem

Let $X_1, \ldots, X_{10}$ be a random sample from a distribution with pdf

$$f(x) = \begin{cases} (\theta+1)x^{\theta} & \text{if } 0 \leq x \leq 1 \\ 0 & \text{otherwise} \end{cases}$$

A random sample of ten students yields data

$$x_1 = .92,\ x_2 = .79,\ x_3 = .90,\ x_4 = .65,\ x_5 = .86,$$

$$x_6 = .47,\ x_7 = .73,\ x_8 = .97,\ x_9 = .94,\ x_{10} = .77$$

Provide an estimate of θ.

Idea

- We can compute $E(X) \rightarrow$ the answer will be a function of θ
- For large n, we have

$$\bar{X} = \frac{X_1 + X_2 + \ldots + X_n}{n}$$

  is close to $E[X]$
- We can compute $\bar{x}$ from the data $\rightarrow$ approximate θ

Example 1: Step 1

Problem

Let $X_1, \ldots, X_{10}$ be a random sample from a distribution with pdf

$$f(x) = \begin{cases} (\theta + 1)x^{\theta} & \text{if } 0 \leq x \leq 1 \\ 0 & \text{otherwise} \end{cases}$$

Compute $E[X]$.

Example 1

Problem

A random sample of ten students yields data

$$x_1 = .92,\ x_2 = .79,\ x_3 = .90,\ x_4 = .65,\ x_5 = .86,$$

$$x_6 = .47,\ x_7 = .73,\ x_8 = .97,\ x_9 = .94,\ x_{10} = .77$$

Compute $\bar{x}$.

Example 1

Problem

Let $X_1, \ldots, X_{10}$ *be a random sample from a distribution with pdf*

$$f(x) = \begin{cases} (\theta+1)x^{\theta} & \text{if } 0 \le x \le 1 \\ 0 & \text{otherwise} \end{cases}$$

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Provide an estimate of θ *by the method of moments.*

Method of moments: Example 2

Problem

Suppose that for a parameter $0 \leq \theta \leq 1$, X is the outcome of the roll of a four-sided tetrahedral die

x	1	2	3	4
$p(x)$	$\frac{3\theta}{4}$	$\frac{\theta}{4}$	$\frac{3(1-\theta)}{4}$	$\frac{(1-\theta)}{4}$

Suppose the die is rolled 10 times with outcomes

$$4, 1, 2, 3, 1, 2, 3, 4, 2, 3$$

Use the method of moments to obtain an estimate of θ.

Moments

- Let $X_1, \dots, X_n$ be a random sample from a normal distribution with pmf or pdf $f(x)$.
- For $k = 1, 2, 3, \dots$, the k^{th} population moment, or k^{th} moment of the distribution $f(x)$, is

$$E(X^k)$$

  - First moment: the mean
  - Second moment: $E(X^2)$

Sample moments

- Let $X_1, \ldots, X_n$ be a random sample from a distribution with pmf or pdf $f(x)$.
- For $k = 1, 2, 3, \ldots,$ the k^{th} sample moment is

$$\frac{X_1^k + X_2^k + \ldots + X_n^k}{n}$$

The law of large numbers provides that when $n \to \infty$

$$\frac{X_1^k + X_2^k + \ldots + X_n^k}{n} \to E(X^k)$$

Method of moments: ideas

- Let $X_1, \ldots, X_n$ be a random sample from a distribution with pmf or pdf

$$f(x; \theta_1, \theta_2, \ldots, \theta_m)$$

- Assume that for $k = 1, \ldots, m$

$$\hat{u}_k = \frac{X_1^k + X_2^k + \ldots + X_n^k}{n} = E(X^k)$$

- Solve the system of equations for $\theta_1, \theta_2, \ldots, \theta_m$

Method of moments: Example 3

Problem

Let $\beta > 1$ *and* $X_1, \ldots, X_n$ *be a random sample from a distribution with pdf*

$$f(x) = \begin{cases} \frac{\beta}{x^{\beta+1}} & \text{if } x > 1 \\ 0 & \text{otherwise} \end{cases}$$

Use the method of moments to obtain an estimator of β.

Problem

Let $X_1, \ldots, X_n$ be a random sample from the normal distribution $\mathcal{N}(0, \sigma^2)$.
Use the method of moments to obtain an estimator of σ.