

# Lecture 18

## Inference for Proportions

Text: Chapter 10

STAT 8010 Statistical Methods I  
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### Inference for Categorical Data

In the next few lectures we will focus on **categorical data analysis**, i.e., statistical inference for categorical data

- Inference for a single proportion  $p$
- Comparison of two proportions  $p_1$  and  $p_2$
- Inference for multi-category data and multivariate category data



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### Inference for a single proportion: Motivated Example

Researchers in the development of new treatments for cancer patients often evaluate the effectiveness of new therapies by reporting the **proportion** of patients who survive for a specified period of time after completion of the treatment. A new genetic treatment of 870 patients with a particular type of cancer resulted in 330 patients surviving at least 5 years after treatment. **Estimate** the proportion of all patients with the specified type of cancer who would survive at least 5 years after being administered this treatment.

- Binary (two-category) outcomes: "success" & "failure"
- Similar to the inferential problem for  $\mu$ , we would like to infer  $p$ , the population proportion of success  $\Rightarrow$  **point estimate, interval estimate, hypothesis testing**



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## Point/Interval Estimation

- Point estimate:

$$\hat{p} = \frac{X(\text{\# of "successes"})}{n}$$

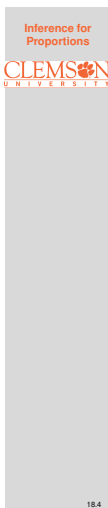
**Recall:**  $X \sim \text{Bin}(n, p) \Rightarrow \mathbb{E}[\hat{p}] = \mathbb{E}\left[\frac{X}{n}\right] = \frac{1}{n}\mathbb{E}[X] = \frac{np}{n} = p$

- 100(1 -  $\alpha$ )% CI for  $p$ :

$$\hat{p} \pm z_{\alpha/2} \sqrt{\frac{(\hat{p})(1 - \hat{p})}{n}}$$

Why?

- CLT approximation:  $\hat{p} \approx N(p, \sigma_{\hat{p}}^2)$  where  $n$  "sufficiently large"  $\Rightarrow \min(np, n(1-p)) \geq 5$
- $\sigma_{\hat{p}}^2 = \text{Var}\left(\frac{X}{n}\right) = \frac{1}{n^2} \text{Var}(X) = \frac{1}{n^2} n(p)(1-p) = \frac{p(1-p)}{n}$



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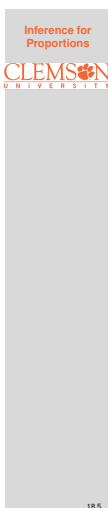
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## Motivated Example Revisited

A new genetic treatment of 870 patients with a particular type of cancer resulted in 330 patients surviving at least 5 years after treatment.

- Estimate the proportion of all patients who would survive at least 5 years after being administered this treatment.
- Construct a 95% CI for  $p$



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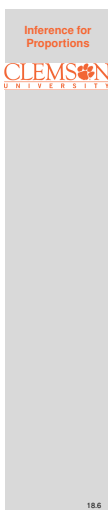
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## Another Example

Among 900 randomly selected registered voters nationwide, 63% of them are somewhat or very concerned about the spread of bird flu in the United States.

- What is the point estimate for  $p$ , the proportion of U.S. voters who are concerned about the spread of bird flu?
- Construct a 95% CI for  $p$



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## Margin of error & Sample Size Calculation

- Margin of error (ME):

$$z_{\alpha/2} \sqrt{\frac{n\hat{p}(1-\hat{p})}{n}}$$

$\Rightarrow$  CI for  $p = \hat{p} \pm \text{ME}$

- Sample size determination:

$$n = \frac{\tilde{p}(1-\tilde{p}) \times z_{\alpha/2}^2}{\text{ME}^2},$$

What value of  $\tilde{p}$  to use?

- An educated guess
- A value from previous research
- Use a pilot study
- The "most conservative" choice is to use  $\tilde{p} = 0.5$



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## Example

A researcher wants to estimate the proportion of voters who will vote for candidate A. She wants to estimate to within 0.05 with 90% confidence.

- 1 How large a sample does she need if she thinks the true proportion is about .9?
- 2 How large a sample does she need if she thinks the true proportion is about .6?
- 3 How large a sample does she need if she wants to use the most conservative estimate?



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## Hypothesis Testing for $p$

- 1 State the null and alternative hypotheses:

$$H_0 : p = p_0 \text{ vs. } H_a : p > \text{ or } \neq \text{ or } < p_0$$

- 2 Compute the test statistic:

$$z_{obs} = \frac{\hat{p} - p_0}{\sqrt{\frac{p_0(1-p_0)}{n}}}$$

- 3 Make the decision of the test:

Rejection Region/ P-Value Methods

- 4 Draw the conclusion of the test:

We (do/do not) have enough statistical evidence to conclude that ( $H_a$  in words) at  $\alpha\%$  significant level.



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## Bird Flu Example Revisited

Among 900 randomly selected registered voters nationwide, 63% of them are somewhat or very concerned about the spread of bird flu in the United States. Conduct a hypothesis test at .01 level to assess the research hypothesis:  $p > .6$ .



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## Recap: Inference for $p$

- Point estimate:

$$\hat{p} = \frac{X}{n}$$

where  $X$  is the number of “successes” in the sample with sample size  $n$ , and the probability of success,  $p$ , is the parameter of interest

- $100(1 - \alpha)\%$  confidence interval:

$$\hat{p} \pm z_{\alpha/2} \sqrt{\frac{(\hat{p})(1 - \hat{p})}{n}}$$

- Hypothesis Testing:

$H_0 : p = p_0$  vs.  $H_a : p >$  or  $\neq$  or  $< p_0$

$$z^* = \frac{\hat{p} - p_0}{\sqrt{\frac{p_0(1 - p_0)}{n}}}$$

Under  $H_0 : p = p_0$ ,  $z^* \sim N(0, 1)$



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## Another CI for $p$ : Wilson Score Confidence Interval

- The actual coverage probability of  $100(1 - \alpha)\%$  CI  $\hat{p} \pm z_{\alpha/2} \sqrt{\frac{(\hat{p})(1 - \hat{p})}{n}}$  is usually **falls below**  $(1 - \alpha)$  😞

- E.B. Wilson proposed one solution in 1927

**Idea:** Solving  $\frac{p - \hat{p}}{\sqrt{\frac{p(1 - p)}{n}}} = \pm z_{\alpha/2}$  for  $p$

$$\Rightarrow (p - \hat{p})^2 = z_{\alpha/2}^2 \frac{p(1 - p)}{n}$$

$100(1 - \alpha)\%$  Wilson Score Confidence Interval:

$$\frac{X + \frac{z_{\alpha/2}^2}{2}}{n + z_{\alpha/2}^2} \pm \frac{z_{\alpha/2}}{n + z_{\alpha/2}^2} \sqrt{\frac{X(n - X)}{n} + \frac{z_{\alpha/2}^2}{4}}$$



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## Example

Suppose we would like to estimate  $p$ , the probability of being vegetarian (for all the CU student). We take a sample with sample size  $n = 25$  and none of them are vegetarian (i.e.,  $X = 0$ ). Construct a 95% CI for  $p$ .



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## Rule of Three: An Approximate 95% CI for $p$ When $\hat{p} = 0$ or 1

When  $\hat{p} = 0$ , we have

$$\hat{p} \pm z_{\alpha/2} \sqrt{\frac{(\hat{p})(1-\hat{p})}{n}} = 0 \pm z_{\alpha/2} \times 0 = (0, 0)$$

Similarly, when  $\hat{p} = 1$ , we have

$$\hat{p} \pm z_{\alpha/2} \sqrt{\frac{(\hat{p})(1-\hat{p})}{n}} = 1 \pm z_{\alpha/2} \times 0 = (1, 1)$$

These Wald CIs degenerate to a point, which do not reflect the estimation uncertainty. Here we could apply the **rule of three** to approximate 95% CI:

$$\begin{aligned} (0, 3/n), & \quad \text{if } \hat{p} = 0 \\ (1 - 3/n, 1), & \quad \text{if } \hat{p} = 1 \end{aligned}$$



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## Comparing Two Population Proportions $p_1$ and $p_2$

- We often interested in comparing two groups, e.g., does a particular treatment increase the survival probability for cancer patients ?
- We would like to infer  $p_1 - p_2$ , the difference between two population proportions  $\Rightarrow$  **point estimate, interval estimate, hypothesis testing**



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## Notation

- Parameters
  - $p_1, p_2$ : population proportions
  - $p_1 - p_2$ : the difference between two population proportions
- Sample Statistics
  - $n_1, n_2$ : sample sizes
  - $\hat{p}_1 = \frac{X_1}{n_1}, \hat{p}_2 = \frac{X_2}{n_2}$ : sample proportions



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## Point/Interval Estimation for $p_1 - p_2$

- Point estimate:

$$\hat{p}_1 - \hat{p}_2 = \frac{X_1}{n_1} - \frac{X_2}{n_2}$$

- $100(1 - \alpha)\%$  CI based on CLT:

$$\hat{p}_1 - \hat{p}_2 \pm z_{\alpha/2} \sqrt{\frac{(\hat{p}_1)(1 - \hat{p}_1)}{n_1} + \frac{(\hat{p}_2)(1 - \hat{p}_2)}{n_2}}$$



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## Hypothesis Testing for $p_1 - p_2$

- State the null and alternative hypotheses:

$$H_0 : p_1 - p_2 = 0 \text{ vs. } H_a : p_1 - p_2 > \text{ or } \neq \text{ or } < 0$$

- Compute the test statistic:

$$z_{obs} = \frac{\hat{p} - p_0}{\sqrt{\frac{\bar{p}(1-\bar{p})}{n_1} + \frac{\bar{p}(1-\bar{p})}{n_2}}}$$

$$\text{where } \bar{p} = \frac{X_1 + X_2}{n_1 + n_2}$$

- Make the decision of the test:

Rejection Region/ P-Value Methods

- Draw the conclusion of the test:

We (do/do not) have enough statistical evidence to conclude that ( $H_a$  in words) at  $\alpha\%$  significant level.



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Example

A Simple Random Sample of 100 CU graduate students is taken and it is found that 79 “strongly agree” that they would recommend their current graduate program. A Simple Random Sample of 85 USC graduate students is taken and it is found that 52 “strongly agree” that they would recommend their current graduate program. At 5 % level, can we conclude that the proportion of “strongly agree” is higher at CU?

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Summary

In this lecture, we learned statistical inference for population proportion  $p$ :

- Point estimate
- Interval estimate
- Hypothesis testing

In next lecture we will learn statistical inference for multi-category data and bivariate categorical data

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