CEE 260/MIE 273: Probability and Statistics in Civil Engineering
Lecture 5A: Inference for Single Proportion

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Outline

1 Test for normality

2 CI for proportion

3 Hypothesis testing

4 Using p-values

5 Outlook

Module objectives

Inference refers to various ways in which we obtain information and make decisions based on data. In this module, we consider: (a) **point estimates**, (b) **confidence intervals** and (c) **hypothesis tests** for

- Single proportions
- Difference of two proportions
- Contingency tables

Today's objectives

- Test for normality
- Compute CIs (confidence intervals)
- Conduct hypothesis tests
- Calculate sample size

Success-failure condition

Given a sample proportion $\hat{p}$ of size n whose observations are independent. We can assume the distribution for p is normal if

- $np \geq 10$ and
- $n(1 - p) \geq 10$

Example 1

A simple random sample of 826 payday loan borrowers was surveyed to better understand their interests around regulation and costs. 70% of the responses supported new regulations on payday lenders. Is it reasonable to model $\hat{p} = 0.70$ using a normal distribution?

CI for proportion

The confidence interval (CI) for a proportion is given by:

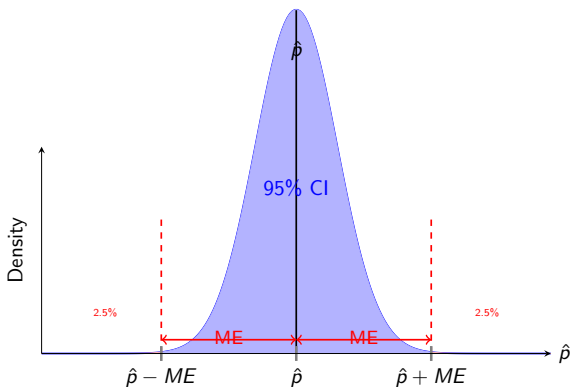$$\hat{p} \pm z^* \times SE \equiv \hat{p} \pm ME \qquad (1)$$

where:

$$z^* = \Phi\left(1 - \frac{\alpha}{2}\right) \quad \textbf{critical value} \qquad (2)$$

$$SE = \sqrt{\frac{p(1-p)}{n}} \quad \textbf{standard error} \qquad (3)$$

$$ME = z^* \times SE \quad \textbf{margin of error} \qquad (4)$$

Note that p is unknown, so we use $\hat{p}$ in its place when computing the standard error.

Confidence interval (visualization)

- The confidence interval is symmetric around $\hat{p}$
- Margin of error (ME) extends equally in both directions
- CI $= [\hat{p} - ME, \hat{p} + ME]$

Example 1: Elderly drivers

The Marist Poll published a report stating that 66% of adults nationally think licensed drivers should be required to retake their road test once they reach 65 years of age. It was also reported that interviews were conducted on 1,018 American adults.

(a) Verify that the success-failure condition is met.

(b) Find the standard error for the sample proportion.

(c) Find the critical value for a 95% confidence interval.

(d) Find the margin of error for the confidence interval.

(e) Construct a 95% confidence interval for p, the proportion of adults

Example 1 (cont.)

(a) Success-failure condition:

$$
\begin{aligned}
np &= 1018 \times 0.66 = 671.88 \geq 10 \quad \checkmark \\
n(1-p) &= 1018 \times (1-0.66) = 346.12 \geq 10 \quad \checkmark
\end{aligned}
$$

(b) Standard error:

$$
SE = \sqrt{\frac{p(1-p)}{n}} = \sqrt{\frac{0.66(1-0.66)}{1018}} = 0.0149
$$

(c) Critical value for 95% CI:

$$
z^* = \Phi\left(1 - \frac{0.05}{2}\right) = \Phi(0.975) = 1.96 \quad \texttt{norm.cdf(0.975)}
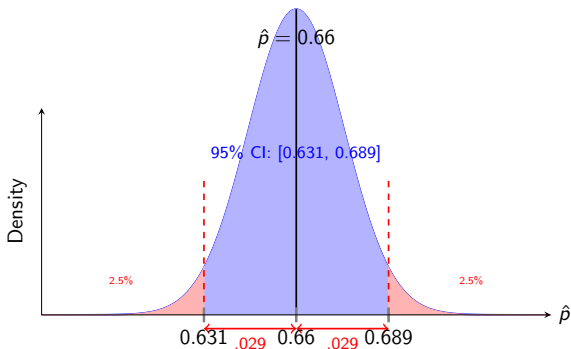$$

(d) Margin of error:

$$
ME = z^* \times SE = 1.96 \times 0.0149 = 0.0292 \approx 3\%
$$

(e) Confidence interval:

$$
CI = [\hat{p} - ME, \hat{p} + ME] = [0.66 - 0.0292, 0.66 + 0.0292] = [0.6308, 0.6892]
$$

Example 1 (cont.)

Conclusion: We are 95% confident that between 63.1% and 68.9% of American adults think licensed drivers should be required to retake their road test once they reach 65 years of age.

Summary of hypothesis testing approach

1. *Define* the **null** (H_0) and **alternative** (H_1) hypotheses
2. *Determine* the appropriate **test statistic** (and distribution)
3. *Estimate* the test statistic z from the sample data
4. *Specify* or *identify* the **level of significance** (α)
5. *Define* the **region of rejection/critical region** of the null hypothesis by choosing the **critical value** z^*
6. *Decide.* If the test statistic is in the critical region (i.e. $|z| > z^*$), reject H_0. If not, do not reject H_0 (fail to reject it)

Distribution of the test statistic

In this lecture, the test statistic is the **sample proportion**.
We will assume the normal distribution is the success-failure condition holds.

The sample proportion is **normally** distributed and its variance is :

$$\mathbb{V}(p) = \frac{p(1-p)}{n} \tag{5}$$

And thus, the standard error is:

$$SE_{\hat{p}} = \sqrt{\frac{p_0(1-p_0)}{n}} \tag{6}$$

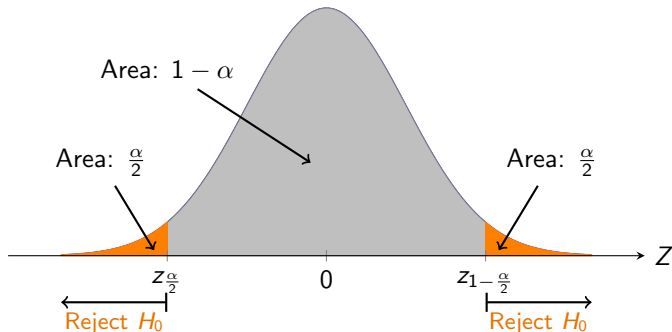Thus, to compute the probability (area under curve) of the test statistic, we use the z-score:

$$z = \frac{\hat{p} - p_0}{SE_p} \tag{7}$$

which is normally distributed.

Two-sided tests

Case A: both tails

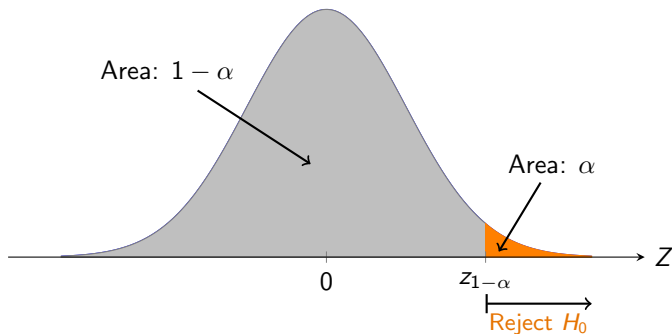- $H_0 : p = p_0$
- $H_1 : p \neq p_0$

$$z^* = z_{1 - \frac{\alpha}{2}} = \left| z_{\frac{\alpha}{2}} \right| \tag{8}$$

One-sided tests

Case B: upper tail

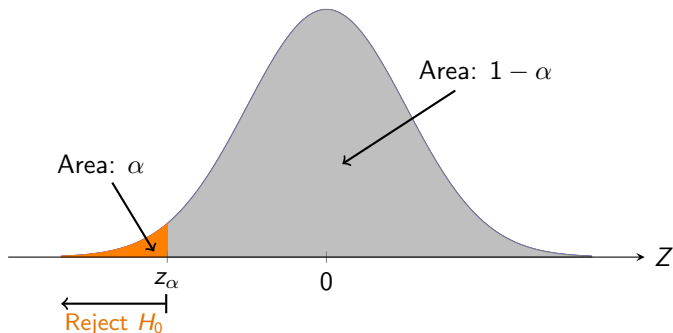- $H_0 : p = p_0$
- $H_1 : p > p_0$

$$z^* = z_{1-\alpha} 2 \qquad (9)$$

One-sided tests (cont.)

Case C: lower tail

- $H_0 : p = p_0$
- $H_1 : p < p_0$

$$z^* = |z_\alpha| \tag{10}$$

Example 2: Getting enough sleep (OS 5.21)

400 students were randomly sampled from a large university, and 289 said they did not get enough sleep. Conduct a hypothesis test to check whether this represents a statistically significant difference from 50%, and use a significance level of 0.01

Step 1. Parameter of interest: p (proportion of students not getting enough sleep)

Step 2. Null hypothesis: $H_0 : p = p_0 = .5$.

Step 3. Alternative hypothesis: $H_1 : p \neq p_0$.

Step 4. Formula for test statistic value: $z = \frac{\hat{p} - p_0}{SE_p}$

$$\hat{p} = \frac{289}{400} = .723 \tag{11}$$

Example 2: Getting enough sleep (cont.)

Step 5. Calculate test statistic value:

$$z = \frac{.723 - .5}{\sqrt{.5(.5)/400}} = 8.92$$

Step 6. Compute critical value at $\alpha = 0.01$:

$$z_{\alpha/2} = \Phi^{-1}(1 - \alpha/2) = \Phi^{-1}(0.995) = 2.576 \quad \texttt{norm.ppf(0.995)}$$
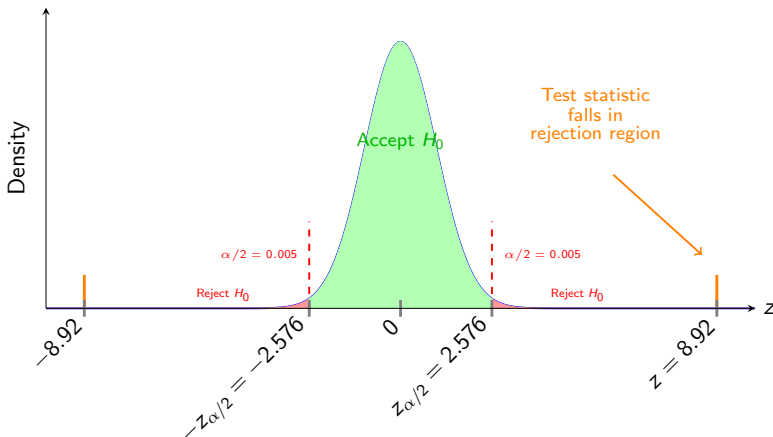
Step 7. Compare test statistic to critical value:

$$|z| = 8.92 > 2.576 = z_{\alpha/2}$$

Step 8. Conclude:
Using a significance level of 0.01, we reject H_0 since $8.92 > 2.576$. Thus, at the 1% significance level, there is sufficient evidence to conclude that true proportion differs from the target value of 0.5.

Test for normality
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CI for proportion
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Hypothesis testing
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Using p-values
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Outlook
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Example 2: Getting enough sleep (cont.)

Decision: Since $|z| = 8.92 > 2.576 = z_{\alpha/2}$, we **reject** H_0 at $\alpha = 0.01$ significance level.

Example 3: Equipment quality

A car manufacturer is considering switching to a new, higher quality piece of equipment that constructs vehicle door hinges. They figure that they will save money in the long run if this new machine produces hinges that have flaws no more than 0.2% of the time. A random sample of 800 hinges produced by the new machine shows that 4 are flawed. At the 0.05 significance level, is there enough evidence to conclude that the new machine produces hinges with a flaw rate greater than 0.2%?

Example 3 (cont.)

This is a one-sided test (upper-tailed)
Hypotheses:

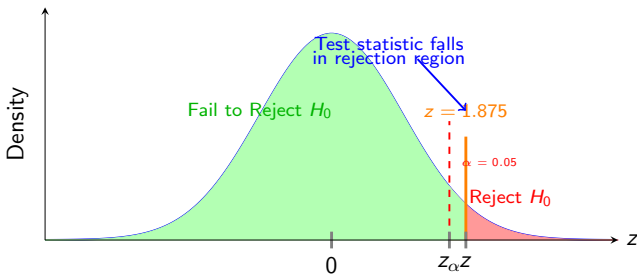- $H_0 : p = 0.002$
- $H_a : p > 0.002$

Test Statistic:

$$
\begin{aligned}
\hat{p} &= \frac{4}{800} = 0.005 \\
SE &= \sqrt{\frac{0.002(1 - 0.002)}{800}} \approx 0.0016 \\
z &= \frac{\hat{p} - 0.002}{SE} \approx 1.875
\end{aligned}
$$

Critical Value: For $\alpha = 0.05$, the critical value is:

$$
z_\alpha = \Phi^{-1}(1 - \alpha) = \Phi^{-1}(0.95) = 1.645 \quad \texttt{norm.ppf(0.95)}
$$

Example 3 (cont.)

Decision: Since $z = 1.875 > 1.645 = z_\alpha$, we **reject** H_0 at $\alpha = 0.05$ significance level.

p-value

The p-value is the probability of obtaining a test statistic value at least as contradictory to H_0 as the value that actually resulted. The smaller the p-value, the more contradictory are the data to H_0.

Usefulness of p-value

- Provides more information about the strength of a test
- Indicates the smallest level at which the data is significant
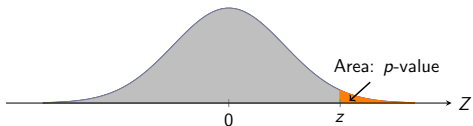- Can be compared with α irrespective of which type of test was used

Step 1. Formulate your hypotheses

Step 2. Determine the p-value from the test statistic

Step 3. Conclude the test based on a chosen level of significance:
  ① p-value $\leq \alpha \implies$ reject H_0 at level α.
  ② p-value $> \alpha \implies$ do not reject H_0 at level α.
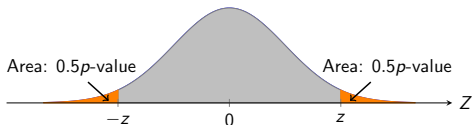
p-value for z tests

p-value: area in upper tail

$$p = 1 - \Phi(z) \qquad (12)$$

p-value: area in lower tail

$$p = \Phi(z) \qquad (13)$$

p-value: sum of area in both tails

$$p = 2(1 - \Phi(|z|)) \qquad (14)$$

Hypothesis testing using *p*-value approach

Example 4: Getting enough sleep (OS 5.21)

400 students were randomly sampled from a large university, and 289 said they did not get enough sleep. Conduct a hypothesis test to check whether this represents a statistically significant difference from 50%, and use a significance level of 0.01

Step 1. Parameter of interest: p (proportion of students not getting enough sleep)

Step 2. Null hypothesis: $H_0 : p = p_0$.

Step 3. Alternative hypothesis: $H_1 : p \neq p_0$.

Step 4. Formula for test statistic value: $z = \frac{\hat{p} - p_0}{SE_p}$

Notes:

$$
\begin{aligned}
p_0 &= 0.50 \quad \text{(expected value)} \\
\hat{p} &= \frac{289}{400} = .723 \quad \text{(observed value—from sample)}
\end{aligned}
$$

Hypothesis testing using *p*-value approach

Example 4: Getting enough sleep (cont.)

Step 5. Calculate test statistic value:

$$z = \frac{.723 - .5}{\sqrt{.5(.5)/400}} = 8.92$$

Step 6. Determine *p*-value (two-tailed test):

$$p\text{-value} = 2(1 - \Phi(8.92)) = 0.0$$

Step 7. Compare *p*-value to $\alpha = 0.01$:

$$0.0 \leq 0.01$$

Step 8. Conclude:
Using a significance level of 0.01, we reject H_0 since $0.0 < 0.01$.

Example 5: Equipment quality (p-value approach)

A car manufacturer is considering switching to a new, higher quality piece of equipment that con- structs vehicle door hinges. They figure that they will save money in the long run if this new machine produces hinges that have flaws no more than 0.2% of the time. A random sample of 800 hinges produced by the new machine shows that 4 are flawed. At the 0.05 significance level, is there enough evidence to conclude that the new machine produces hinges with a flaw rate greater than 0.2%?

Example 5 (cont.)

This is a one-sided test
Hypotheses:

- $H_0 : p = 0.002$
- $H_a : p > 0.002$

Test Statistic:

$$
\begin{aligned}
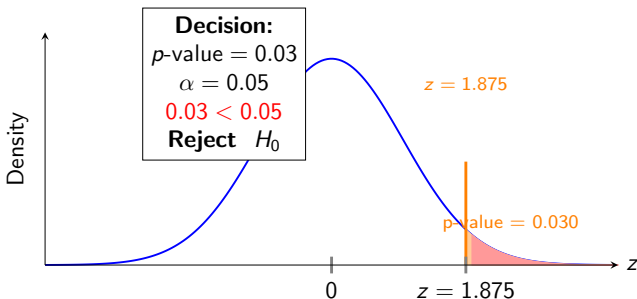\hat{p} &= \frac{4}{800} = 0.005 \\
SE &= \sqrt{\frac{0.002(1 - 0.002)}{800}} \approx 0.0016 \\
z &= \frac{\hat{p} - 0.002}{SE} \approx 1.875
\end{aligned}
$$

p-value: For $z = 1.875$, the *p*-value is:

$$
p\text{-value} = 1 - \Phi(1.875) \approx 0.0304 \quad \texttt{1 - norm.cdf(1.875)}
$$

Example 5 (cont.)

Decision: Since the p-value $= 0.03 < \alpha = 0.05$, we **reject** H_0 at the 5% significance level.
Conclusion: There is sufficient evidence to conclude that the new machine produces hinges with a flaw rate greater than 0.2%.

Recap of this lecture

- Definition of hypothesis testing
  - Null hypothesis (default/expected outcome) H_0
  - Alternate hypothesis (what we want to test/support; research hypothesis) H_1 or H_A
  - One-tailed or two-tailed
- Types of errors:
  - Type I: false positive
  - Type II: false negative
- Test statistic:
  - Sample proportion with independent observations and large enough sample size (normal distribution); Z-statistic:

$$z = \frac{\hat{p} - p_0}{\sqrt{\frac{p_0(1-p_0)}{n}}} \tag{15}$$

- The p-value is the minimum probability of a Type I error.
  - Upper-tailed test: p-value$= 1 - \Phi(z)$; Python: `norm.sf(z)`
  - Lower-tailed test: p-value $= \Phi(z)$; Python: `norm.cdf(z)`
  - Two-tailed test: p-value $= 2(1 - \Phi(|z|))$;
    Python: `2 * norm.cdf(np.abs(z))`