BS2280 - Econometrics 1

Lecture 4 - Part 2: Hypothesis Testing

Dr. Yichen Zhu

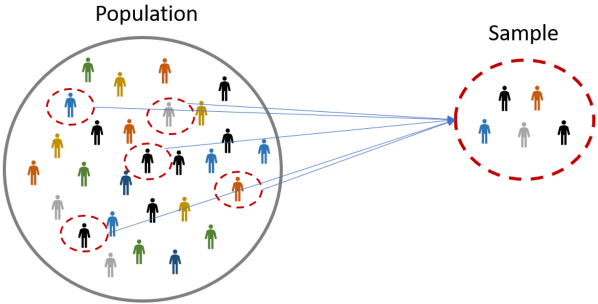
Structure of today's lecture

1. Hypothesis Testing in Econometrics
2. Hypothesis Testing in Econometrics: Regression Coefficients
3. Hypothesis Testing in Econometrics: Goodness of Fit R^2

Intended Learning Outcomes

- Undertaking hypothesis tests for regression coefficients β_1, β_2
- Testing the statistical significance of Goodness of fit R^2

Review: Hypothesis Testing in Statistics



	Population Parameters	**Inference**	**Sample Coefficients**
Statistics:	μ, σ^2	$\longleftarrow$	$\bar{x}, s^2$
Econometrics:	β_1, β_2	$\longleftarrow$	$\hat{\beta}_1, \hat{\beta}_2$

Example: Two-Tail Test (σ unknown)

The average cost of a hotel room in New York is said to be \$168 per night. A random sample of 25 hotels resulted in $\bar{x} = \$172.50$ and $s = \$15.40$. Test at the $\alpha = 0.05$ level. Assume the population distribution is normal.

- $H_0 : \mu = 168$
- $H_1 : \mu \neq 168$

Steps for hypothesis testing:

1. State the null and alternative hypotheses
2. Select the significance level
3. Select and calculate the test statistics
4. Set the decision rule
5. Make statistical decisions

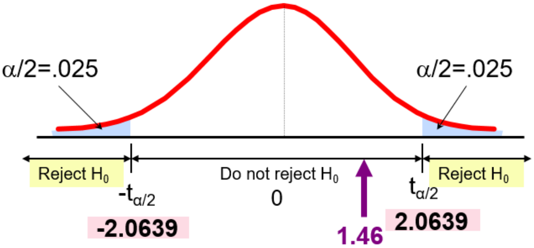
Example Solution: Two-Tail Test

$H_0: \mu = 168$
$H_A: \mu \neq 168$

- $\alpha = 0.05$
- $n = 25$
- σ is unknown, so use a **t statistic**
- **Critical Value:**

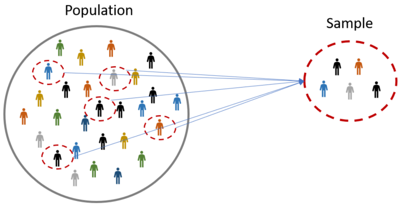
$t_{24} = \pm 2.0639$

$$t_{n-1} = \frac{\bar{x} - \mu}{\frac{s}{\sqrt{n}}} = \frac{172.50 - 168}{\frac{15.40}{\sqrt{25}}} = 1.46$$



Do not reject H_0: not sufficient evidence that true mean cost is different than \$168

Estimation Background: Hypothesis Testing in Econometrics



What is Estimation?

Estimation is the process of using sample data to draw inferences about the population. For example, we use OLS estimator to estimate β_1 and β_2

	Population Parameters	**Inference**	**Sample Coefficients**
Statistics:	μ, σ^2	$\longleftarrow$	$\bar{x}, s^2$
Econometrics:	β_1, β_2	$\longleftarrow$	$\hat{\beta}_1, \hat{\beta}_2$

What about hypothesis testing for regressions?

	Statistics	**Econometrics**
Model	X, unknown μ, σ^2	$Y = \beta_1 + \beta_2 X + u$
Estimator	$\bar{X}$ and s^2	$\hat{\beta}_1$ and $\hat{\beta}_2$
Null Hypothesis **Alternative Hypothesis**	$H_0 : \mu = \mu_0$ $H_1 : \mu \neq \mu_0$	$H_0 : \beta_1 = \beta_1^0 \quad H_0 : \beta_2 = \beta_2^0$ $H_1 : \beta_1 \neq \beta_1^0 \quad H_1 : \beta_2 \neq \beta_2^0$
Test statistic	$t = \dfrac{\bar{X} - \mu_0}{s.e.(\bar{X})}$	$t = \dfrac{\hat{\beta}_1 - \beta_1^0}{s.e.(\hat{\beta}_1)} \quad t = \dfrac{\hat{\beta}_2 - \beta_2^0}{s.e.(\hat{\beta}_2)}$
Reject H_0 if	$\lvert t \rvert > t_{crit}$	$\lvert t \rvert > t_{crit}$
Degrees of Freedom	$n - 1$	$n - k = n - 2$

Hypothesis Testing for β_2

Example

Impact of wage inflation (w) on price inflation (p); both measured in % annual growth rate. Sample size $n = 20$

Population regression model:

$$p = \beta_1 + \beta_2 w + u$$

Sample estimated regression model:

$$\hat{p} = \underset{(0.05)}{1.21} + \underset{(0.10)}{0.82}\ w \tag{1}$$

Note: Standard Errors (s.e.) in brackets

Null Hypothesis	$H_0 : \beta_2 = 1.0$
Alternative Hypothesis	$H_1 : \beta_2 \neq 1.0$

Hypothesis Testing for β_2

$$\hat{p} = \underset{(0.05)}{1.21} + \underset{(0.10)}{0.82}\, w \tag{2}$$

Note: Standard Errors (s.e.) in brackets

1. State the null and alternative hypotheses

Null Hypothesis	$H_0 : \beta_2 = 1.0$
Alternative Hypothesis	$H_1 : \beta_2 \neq 1.0$

2. Select the significance level. Significance level $\alpha = 5\%$
3. Select and calculate the test statistics

   Do not know the population variance σ^2, so use t statistic: $t = \dfrac{\hat{\beta}_2 - \beta_2^0}{s.e.(\hat{\beta}_2)} = \dfrac{0.82 - 1.0}{0.10} = -1.80$
4. Set the decision rule. $n = 20$, degree of freedom $= n - k = 20 - 2 = 18$, $t_{crit,5\%} = 2.101$
5. Make statistical decisions. $|t| = 1.80 < t_{crit,5\%} = 2.101$, cannot reject the null $H_0 : \beta_2 = 1.0$

Hypothesis Testing for β_2

$$\hat{p} = \underset{(0.05)}{1.21} + \underset{(0.10)}{0.82}\, w \tag{2}$$

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$$\hat{p} = \underset{(0.05)}{1.21} + \underset{(0.10)}{0.82}\ w \tag{2}$$

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Hypothesis Testing for β_2

$$\hat{p} = \underset{(0.05)}{1.21} + \underset{(0.10)}{0.82}\, w \tag{2}$$

Note: Standard Errors (s.e.) in brackets

1. State the null and alternative hypotheses

Null Hypothesis	$H_0 : \beta_2 = 1.0$
Alternative Hypothesis	$H_1 : \beta_2 \neq 1.0$

2. Select the significance level. Significance level $\alpha = 5\%$
3. Select and calculate the test statistics

   Do not know the population variance σ^2, so use t statistic: $t = \dfrac{\hat{\beta}_2 - \beta_2^0}{s.e.(\hat{\beta}_2)} = \dfrac{0.82 - 1.0}{0.10} = -1.80$
4. Set the decision rule. $n = 20$, degree of freedom = $n - k = 20 - 2 = 18$, $t_{crit,5\%} = 2.101$
5. Make statistical decisions. $|t| = 1.80 < t_{crit,5\%} = 2.101$, cannot reject the null $H_0 : \beta_2 = 1.0$

Hypothesis Testing for β_2

- Usually, we do not have a feeling for the actual value of the coefficients.
- We do not have any prior notion on how big the actual relationship is!!!!
- **Often or Always**, we just want to demonstrate that Y is influenced by X, therefore:

Null Hypothesis	$H_0 : \beta_2 = 0$
Alternative Hypothesis	$H_1 : \beta_2 \neq 0$

Population regression model:

$$p = \beta_1 + \beta_2 w + u$$

Sample estimated regression model:

$$\hat{p} = \underset{(0.05)}{1.21} + \underset{(0.10)}{0.82}\, w \tag{3}$$

Note: Standard Errors (s.e.) in brackets

Hypothesis Testing for β_2

$$\hat{p} = \underset{(0.05)}{1.21} + \underset{(0.10)}{0.82}\, w \tag{4}$$

Note: Standard Errors (s.e.) in brackets

1. State the null and alternative hypotheses

Null Hypothesis	$H_0 : \beta_2 = 0$
Alternative Hypothesis	$H_1 : \beta_2 \neq 0$

2. Select the significance level. Significance level $\alpha = 5\%$
3. Select and calculate the test statistics

   Do not know the population variance σ^2, so use t statistic: $t = \dfrac{\hat{\beta}_2 - \beta_2^0}{s.e.(\hat{\beta}_2)} = \dfrac{\hat{\beta}_2}{s.e.(\hat{\beta}_2)} = \dfrac{0.82 - 0}{0.10} = 8.2$
4. Set the decision rule. $n = 20$, degree of freedom = $n - k = 20 - 2 = 18$, $t_{crit,5\%} = 2.101$
5. Make statistical decisions. $|t| = 8.2 > t_{crit,5\%} = 2.101$, reject the null $H_0 : \beta_2 = 0$.
   Wage inflation (w) will affect price inflation (p).

Student Task

We estimated in previous lectures the relationship between hourly earnings ($) and years of schooling. Sample size $n = 500$

$$\widehat{EARNINGS} = \underset{(2.804)}{0.765} + \underset{(0.185)}{1.266}\; S \tag{5}$$

Note: Standard Errors (s.e.) in brackets

1. State the null and alternative hypotheses

Null Hypothesis	$H_0 : \beta_2 = 0$
Alternative Hypothesis	$H_1 : \beta_2 \neq 0$

2. Select the significance level. Significance level $\alpha = 5\%$
3. Select and calculate the test statistics

   Do not know the population variance σ^2, so use t statistic: $t = \dfrac{\hat{\beta}_2 - \beta_2^0}{s.e.(\hat{\beta}_2)} = ?$
4. Set the decision rule. $n = 50$, degree of freedom = $n - k = ?$, $t_{crit,5\%} = 1.96$
5. Make statistical decisions. ?

Hypothesis Testing for β_1 and β_2 with R

$$\widehat{EARNINGS} = \underset{(2.804)}{0.765} + \underset{(0.185)}{1.266}\ S \tag{6}$$

```
> summary(earnfit)

Call:
lm(formula = EARNINGS ~ S, data = EAWE21.simple)

Residuals:
    Min      1Q  Median      3Q     Max
-20.079  -6.726  -2.203   3.451  79.037

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)   0.7647     2.8038
S             1.2657     0.1855
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 11.36 on 498 degrees of freedom
Multiple R-squared:  0.08551, Adjusted R-squared:  0.08368
F-statistic: 46.57 on 1 and 498 DF,  p-value: 2.579e-11
```

Hypothesis Testing for β_1 and β_2 with R

$$\widehat{EARNINGS} = \underset{(2.804)}{0.765} + \underset{(0.185)}{1.266}\ S \tag{7}$$

- ***p*-values**: probability of obtaining the corresponding t statistic as a matter of chance, if the null hypothesis $H_0 : \beta = 0$ is true.
- *p*-values < α, reject the null hypothesis $H_0 : \beta = 0$

```
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Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)   0.7647     2.8038            0.785
S             1.2657     0.1855         2.58e-11 ***
---
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```

Review: Goodness of Fit R^2

- How good is our regression model?
- Good: variations in Y can be explained by variations in X

$$\underset{\substack{\text{Total variations, variations in } Y \\ \text{Total Sum of Squares, TSS} \\ TSS = \sum(Y_i - \bar{Y})^2}}{Y_i} = \beta_1 + \beta_2 \underset{\substack{\text{Explained variations, variations in } X \\ \text{Explained sum of squares, ESS} \\ ESS = \sum(\hat{Y}_i - \bar{Y})^2}}{X_i} + \underset{\substack{\text{Residual variations, variations in } u_i \\ \text{Residual sum of squares, RSS} \\ RSS = \sum(Y_i - \hat{Y}_i)^2 = \sum u_i^2}}{u_i} \tag{8}$$

$$TSS = ESS + RSS \tag{9}$$

- Total variation in Y can be decomposed into variations arising from the X variable and variations arising from the residuals u_i

$$R^2 = \frac{Explained\ Varations\ in\ X}{Total\ Varations\ in\ Y} = \frac{ESS}{TSS} = \frac{\sum_{i=1}^{n}(\hat{Y}_i - \bar{Y})^2}{\sum_{i=1}^{n}(Y_i - \bar{Y})^2}$$

Review: Goodness of Fit R^2

- Create a measure of the proportion of ESS in TSS: the R^2 - the coefficient of determination

$$R^2 = \frac{\textit{Explained Varations in X}}{\textit{Total Varations in Y}} = \frac{ESS}{TSS} = \frac{\sum_{i=1}^{n}(\hat{Y}_i - \bar{Y})^2}{\sum_{i=1}^{n}(Y_i - \bar{Y})^2}$$

- $0 \leq R^2 \leq 1$: The R^2 is bound between 0 and 1
- $R^2 = 0$: variations in X cannot explain any variations in Y
- $R^2 = 1$: variations in X can fully explain variations in Y
- A high R^2 means that the independent variable X is good at predicting Y

- **Example**: $R^2 = 0.75$, it means that 75% of the variations in Y can be explained by variations in the X variable.
- Remaining 25% comes from unobservables through the residual term

```
> summary(earnfit)
Call:
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-20.079  -6.726  -2.203   3.451  79.037

Coefficients:
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S             1.2657     0.1855   6.824 2.58e-11 ***
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Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 11.36 on 498 degrees of freedom
Multiple R-squared:  0.08551, Adjusted R-squared:  0.08368
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```

$R^2 = 0.0855$, only 8.55% of the **variations in earnings** can be explained by **variations in schooling.** 91.45% of the variations in earnings is left unexplained.

Hypothesis Testing for Goodness of Fit R^2: F statistic

$$Y_i = \beta_1 + \beta_2 X_i + u_i \tag{10}$$

$$R^2 = \frac{\textit{Explained Varations in X}}{\textit{Total Varations in Y}} = \frac{ESS}{TSS} = \frac{\sum_{i=1}^{n}(\hat{Y}_i - \bar{Y})^2}{\sum_{i=1}^{n}(Y_i - \bar{Y})^2}$$

Null Hypothesis	$H_0 : R^2 = 0$
Alternative Hypothesis	$H_1 : R^2 \neq 0$

Test the entire regression model, cannot use t statistic, we need F statistic.

$$F(k-1, n-k) = \frac{ESS/(k-1)}{RSS/(n-k)} = \frac{\frac{ESS}{TSS}/(k-1)}{\frac{RSS}{TSS}/(n-k)} \tag{11}$$

Make use of $TSS = ESS + RSS$, F statistic will change to

$$F(k-1, n-k) = \frac{ESS/(k-1)}{RSS/(n-k)} = \frac{\frac{ESS}{TSS}/(k-1)}{\frac{RSS}{TSS}/(n-k)} = \frac{R^2/(k-1)}{(1-R^2)/(n-k)} \tag{12}$$

Hypothesis Testing for Goodness of Fit R^2

$$\widehat{EARNINGS} = \underset{(2.804)}{0.765} + \underset{(0.185)}{1.266}\ S \tag{13}$$

1. State the null and alternative hypotheses

Null Hypothesis	$H_0 : R^2 = 0$
Alternative Hypothesis	$H_1 : R^2 \neq 0$

2. Select the significance level. Significance level $\alpha = 5\%$
3. Select and calculate the test statistics

Test the entire regression model, so use F statistic. Two ways:

Option 1. $F(k-1, n-k) = \dfrac{ESS/(k-1)}{RSS/(n-k)} = \dfrac{\frac{ESS}{TSS}/(k-1)}{\frac{RSS}{TSS}/(n-k)}$

Using ESS and RSS we get by using anova() command in R

Option 2. $F(k-1, n-k) = \dfrac{ESS/(k-1)}{RSS/(n-k)} = \dfrac{\frac{ESS}{TSS}/(k-1)}{\frac{RSS}{TSS}/(n-k)} = \dfrac{R^2/(k-1)}{(1-R^2)/(n-k)}$

Using R^2 from when using summary() command in R

Hypothesis Testing for Goodness of Fit R^2

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   Option 2. $F(k-1, n-k) = \dfrac{ESS/(k-1)}{RSS/(n-k)} = \dfrac{\frac{ESS}{TSS}/(k-1)}{\frac{RSS}{TSS}/(n-k)} = \dfrac{R^2/(k-1)}{(1-R^2)/(n-k)}$

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Hypothesis Testing for Goodness of Fit R^2

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1. State the null and alternative hypotheses

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   Test the entire regression model, so use F statistic. Two ways:
   Option 1. $F(k-1, n-k) = \dfrac{ESS/(k-1)}{RSS/(n-k)} = \dfrac{\frac{ESS}{TSS}/(k-1)}{\frac{RSS}{TSS}/(n-k)}$
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Hypothesis Testing for Goodness of Fit R^2

$$\widehat{EARNINGS} = \underset{(2.804)}{0.765} + \underset{(0.185)}{1.266}\ S \tag{14}$$

Select and calculate the test statistics

Test the entire regression model, so use F statistic. Two ways:

Option 1. $F(k-1, n-k) = \dfrac{ESS/(k-1)}{RSS/(n-k)} = \dfrac{\frac{ESS}{TSS}/(k-1)}{\frac{RSS}{TSS}/(n-k)}$

Using ESS and RSS we get by using anova() command in R

```
Analysis of Variance Table

Response: EARNINGS
           Df Sum Sq Mean Sq F value    Pr(>F)
S           1   6014  6014.0  46.568 2.579e-11 ***
Residuals 498  64315   129.1
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

$$F(1, n-2) = \frac{ESS}{RSS/(n-2)} = \frac{6014}{64315/(500-2)} = \frac{6014}{129.15} = 46.57$$

Hypothesis Testing for Goodness of Fit R^2

$$\widehat{EARNINGS} = \underset{(2.804)}{0.765} + \underset{(0.185)}{1.266}\ S \tag{15}$$

Select and calculate the test statistics

Option 2. $F(k-1, n-k) = \dfrac{ESS/(k-1)}{RSS/(n-k)} = \dfrac{\frac{ESS}{TSS}/(k-1)}{\frac{RSS}{TSS}/(n-k)} = \dfrac{R^2/(k-1)}{(1-R^2)/(n-k)}$

Using R^2 from when using summary() command in R

```
Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)   0.7647     2.8038   0.273    0.785
S             1.2657     0.1855   6.824 2.58e-11 ***
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Residual standard error: 11.36 on 498 degrees of freedom
Multiple R-squared:  0.08551,    Adjusted R-squared:  0.08368
F-statistic: 46.57 on 1 and 498 DF,  p-value: 2.579e-11
```

$$F(1, n-2) = \frac{R^2}{(1-R^2)/(n-2)} = \frac{0.0855}{(1-0.0855)/(500-2)} = 46.56$$

Hypothesis Testing for Goodness of Fit R^2

$$\widehat{EARNINGS} = \underset{(2.804)}{0.765} + \underset{(0.185)}{1.266}\ S \tag{16}$$

1. State the null and alternative hypotheses

Null Hypothesis	$H_0 : R^2 = 0$
Alternative Hypothesis	$H_1 : R^2 \neq 0$

2. Select the significance level. Significance level $\alpha = 5\%$
3. Select and calculate the test statistics
   Test the entire regression model, so use F statistic. Calculate in two ways and F statistics is 46.57.
4. Set the decision rule. $k = 2, n = 500$. $F_{crit,5\%}(k-1, n-k) = F_{crit,5\%}(1, 498) = 3.84$
5. Make statistical decisions. $F = 46.57 > F_{crit,5\%}(1, 498) = 3.84$, can reject the null $H_0 : R^2 = 0$.
   Our model is statistically significant at 5% level.

Student Task

Use the F-test to check if the model is statistically significant
$F_{crit,5\%}(1, 24) = 4.26$

```
> anova(efit)
Analysis of Variance Table

Response: EMPLOY
          Df Sum Sq Mean Sq F value    Pr(>F)
GDP        1 14.060
Residuals 24 23.994
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

$$F(k-1, n-k) = \frac{ESS/(k-1)}{RSS/(n-k)} = ?$$

What to do next:

- Attempt homework 4
- Revise basic R commands from R Workshop 1
- Read chapter 2.8 - 2.11 of Dougherty