Statistical Inference – Formula Sheet

1. Sampling Distribution of the Sample Mean

1.1 Mean — Known Variance

(Normal population or large sample, CLT)

$$\bar{X} \sim N\left(\mu, \frac{\sigma^2}{n}\right)$$

Standardized statistic:

$$Z = \frac{\bar{X} - \mu}{\sigma/\sqrt{n}} \sim N(0,1)$$

1.2 Mean — Unknown Variance

(Normal population)

$$T = \frac{\bar{X} - \mu}{S/\sqrt{n}} \sim t_{n-1}$$

Degrees of freedom:

$$\nu = n - 1$$

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2. Sampling Distribution of a Proportion

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

For large samples ($np \geq 5, n(1-p) \geq 5$):

$$\hat{p} \sim N\left(p, \frac{p(1-p)}{n}\right)$$

Important: even if population variance unknown, the sampling distribution is **Normal**, **not t-Student**.

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3. Sampling Distribution of the Variance

(Normal population)

$$\frac{(n-1)S^2}{\sigma^2} \sim \chi^2_{n-1}, \quad \nu = n - 1$$

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4. Difference of Two Means

4.1 Known Variances

$$\bar{X}_1 - \bar{X}_2 \sim N\left(\mu_1 - \mu_2, \frac{\sigma_1^2}{n_1} + \frac{\sigma_2^2}{n_2}\right)$$

$$Z = \frac{(\bar{X}_1 - \bar{X}_2) - (\mu_1 - \mu_2)}{\sqrt{\frac{\sigma_1^2}{n_1} + \frac{\sigma_2^2}{n_2}}} \sim N(0,1)$$

4.2 Unknown Variances

4.2a Unequal Variances (Welch Test)

$$T = \frac{(\bar{X}_1 - \bar{X}_2) - (\mu_1 - \mu_2)}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}} \sim t_\nu$$

$$\nu \approx \frac{\left(\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}\right)^2}{\frac{(s_1^2/n_1)^2}{n_1-1} + \frac{(s_2^2/n_2)^2}{n_2-1}}$$

4.2b Equal Variances (Pooled t-test)

$$s_p^2 = \frac{(n_1 - 1)s_1^2 + (n_2 - 1)s_2^2}{n_1 + n_2 - 2}$$

$$T = \frac{(\bar{X}_1 - \bar{X}_2) - (\mu_1 - \mu_2)}{s_p\sqrt{\frac{1}{n_1} + \frac{1}{n_2}}} \sim t_{n_1+n_2-2}$$

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5. Difference of Two Proportions

$$\hat{p}_1 - \hat{p}_2 \sim N\left(p_1 - p_2, \frac{p_1(1-p_1)}{n_1} + \frac{p_2(1-p_2)}{n_2}\right)$$

Test statistic:

$$Z = \frac{(\hat{p}_1 - \hat{p}_2) - (p_1 - p_2)}{\sqrt{\frac{p_1(1-p_1)}{n_1} + \frac{p_2(1-p_2)}{n_2}}} \sim N(0,1)$$

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6. Ratio of Two Variances

(Normal populations)

$$F = \frac{S_1^2}{S_2^2} \cdot \frac{\sigma_2^2}{\sigma_1^2} \sim F_{n_1-1,n_2-1}$$

Under $H_0 : \sigma_1^2 = \sigma_2^2$, simplifies to $F = S_1^2/S_2^2$.

Confidence Intervals

7. Mean

Known Variance

$$\bar{X} \pm z_{1-\alpha/2}\frac{\sigma}{\sqrt{n}}$$

Unknown Variance

$$\bar{X} \pm t_{1-\alpha/2,n-1}\frac{S}{\sqrt{n}}$$

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8. Proportion

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

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9. Difference of Means

Known Variances

$$(\bar{X}_1 - \bar{X}_2) \pm z_{1-\alpha/2}\sqrt{\frac{\sigma_1^2}{n_1} + \frac{\sigma_2^2}{n_2}}$$

Unknown Variances

Unequal (Welch)

$$(\bar{X}_1 - \bar{X}_2) \pm t_{1-\alpha/2,\nu}\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}$$

Equal (Pooled)

$$(\bar{X}_1 - \bar{X}_2) \pm t_{1-\alpha/2,n_1+n_2-2}\, s_p\sqrt{\frac{1}{n_1} + \frac{1}{n_2}}$$

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10. Difference of Proportions

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

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11. Variance

$$\left(\frac{(n-1)S^2}{\chi^2_{1-\alpha/2,n-1}}, \frac{(n-1)S^2}{\chi^2_{\alpha/2,n-1}}\right)$$

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12. Ratio of Variances

$$\left(\frac{S_1^2}{S_2^2}\cdot\frac{1}{F_{1-\alpha/2,n_1-1,n_2-1}},\frac{S_1^2}{S_2^2}\cdot\frac{1}{F_{\alpha/2,n_1-1,n_2-1}}\right)$$

Hypothesis Tests

13. Parametric Tests

- Mean: Z-test, t-test
- Proportion: Z-test
- Difference of means: Z-test, Welch t-test, Pooled t-test
- Difference of proportions: Z-test
- Variance: Chi-square test
- Ratio of variances: F-test

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14. Chi-Square Test of Independence

$$\chi^2=\sum_{i,j}\frac{(O_{ij}-E_{ij})^2}{E_{ij}},\quad E_{ij}=\frac{(\text{row total})(\text{column total})}{n},\quad \text{df}=(r-1)(c-1)$$

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15. Chi-Square Goodness-of-Fit Test

$$\chi^2=\sum_{i=1}^{k}\frac{(O_i-E_i)^2}{E_i},\quad \text{df}=k-1-m$$

where m = number of estimated parameters.

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16. Multiple Linear Regression

Model:

$$Y=\beta_0+\beta_1X_1+\beta_2X_2+\cdots+\beta_pX_p+\varepsilon$$

with $\varepsilon\sim N(0,\sigma^2)$, independent.

16.1 Estimation of Coefficients (OLS)

$$\hat{\beta}=(X^TX)^{-1}X^TY$$

$$\hat{\sigma}^2=\frac{\sum_{i=1}^{n}(Y_i-\hat{Y}_i)^2}{n-p-1}$$

16.2 Hypothesis Tests for Coefficients

Null hypothesis: $H_0 : \beta_j = 0$

Test statistic (t-test):

$$t_j = \frac{\hat{\beta}_j}{\mathrm{SE}(\hat{\beta}_j)} \sim t_{n-p-1}$$

where $\mathrm{SE}(\hat{\beta}_j) = \hat{\sigma}\sqrt{c_{jj}}$ and c_{jj} is the j-th diagonal element of $(\mathbf{X}^\top\mathbf{X})^{-1}$.

Confidence interval for β_j**:**

$$\hat{\beta}_j \pm t_{1-\alpha/2, n-p-1}\, \mathrm{SE}(\hat{\beta}_j)$$
