

15 Lecture 15: March 2

Last time

- Inference of MLR

Today

- HW2 posted, due March 11th
- HW1 review
- more review on probability
- Dummy-Variable regression
- Interactions

A little more background review

Reference:

- Statistical Inference, 2nd Edition, by George Casella & Roger L. Berger
- [Review of Probability Theory](#) by Arian Maleki and Tom Do

Chi-square, t-, and F-Distributions

Let $Z_1, Z_2, \dots, Z_k \stackrel{iid}{\sim} N(0, 1)$, then $X^2 \equiv Z_1^2 + Z_2^2 + \dots + Z_k^2 \sim \chi_k^2$ (with k degrees of freedom).
If $X \sim \chi_k^2$

$$\begin{aligned}\mathbf{E}(X) &= k \\ \mathbf{Var}(X) &= 2k.\end{aligned}$$

Student's t versus χ^2

If $X_1, \dots, X_n \stackrel{iid}{\sim} N(\mu, \sigma^2)$, then

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

When σ is unknown,

$$\frac{\bar{X} - \mu}{\hat{\sigma}/\sqrt{n}} \sim t_{n-1}, \quad \text{where } \hat{\sigma} = \sqrt{\frac{\sum (X_i - \bar{X})^2}{n-1}}.$$

Note that

$$\begin{aligned}\frac{\bar{X} - \mu}{\hat{\sigma}/\sqrt{n}} &= \frac{\bar{X} - \mu}{\sigma/\sqrt{n}} \cdot \frac{1}{\frac{\hat{\sigma}}{\sigma}} \\ &= Z \cdot \frac{1}{\sqrt{\frac{\sum (X_i - \bar{X})^2}{(n-1)\sigma^2}}} \\ &= \frac{Z}{\sqrt{\frac{\chi_{n-1}^2}{n-1}}}\end{aligned}$$

F versus χ^2

$$F_{ndf,ddf} \equiv \frac{\chi_{ndf}^2/ndf}{\chi_{ddf}^2/ddf}$$

t versus F

$$\begin{aligned}t_k &= \frac{Z}{\sqrt{\chi_k^2/k}} \\ &= \frac{\sqrt{\chi_1^2/1}}{\sqrt{\chi_k^2/k}} \\ &= \sqrt{F_{1,k}}\end{aligned}$$

or, in other words, $t_k^2 = F_{1,k}$

Random vectors and matrices

The cdf for random vector

$$\mathbf{Y} = \begin{bmatrix} Y_1 \\ Y_2 \\ \vdots \\ Y_n \end{bmatrix} \text{ is } F_{\mathbf{Y}}(\mathbf{y}) = \Pr(Y_1 \leq y_1, Y_2 \leq y_2, \dots, Y_n \leq y_n)$$

If a joint pdf exists, then $f_{\mathbf{Y}}(\mathbf{y}) = f_{\mathbf{Y}}(y_1, \dots, y_n)$ and

$$F_{\mathbf{Y}}(\mathbf{y}) = \int_{-\infty}^{y_1} \int_{-\infty}^{y_2} \dots \int_{-\infty}^{y_n} f_{\mathbf{Y}}(\mathbf{t}) d\mathbf{t}$$

Moments

$$\begin{aligned}\mathbf{E}(\mathbf{Y}) &= \boldsymbol{\mu}_{\mathbf{Y}} = \begin{bmatrix} E(Y_1) \\ E(Y_2) \\ \vdots \\ E(Y_n) \end{bmatrix} = \begin{bmatrix} \mu_1 \\ \mu_2 \\ \vdots \\ \mu_n \end{bmatrix} \\ \mathbf{Var}(\mathbf{Y}) &= \mathbf{E}((\mathbf{Y} - \boldsymbol{\mu}_{\mathbf{Y}})(\mathbf{Y} - \boldsymbol{\mu}_{\mathbf{Y}})^T) \\ &= \mathbf{E}\left(\begin{bmatrix} (Y_1 - \mu_1)^2 & (Y_1 - \mu_1)(Y_2 - \mu_2) & \dots \\ (Y_2 - \mu_2)(Y_1 - \mu_1) & (Y_2 - \mu_2)^2 & \dots \\ \dots & \dots & \dots \end{bmatrix}\right) \\ &= \mathbf{E}([(Y_i - \mu_i)(Y_j - \mu_j), i = 1, 2, \dots, n, j = 1, 2, \dots, n]) \\ &= (\sigma_{ij})_{i=1,2,\dots,n; j=1,2,\dots,n}\end{aligned}$$

where $\sigma_{ij} = Cov(Y_i, Y_j)$

Linear functions

Let $\mathbf{X} \in \mathbb{R}^{k \times 1}$, $\mathbf{Y} \in \mathbb{R}^{n \times 1}$ and $\mathbf{A} \in \mathbb{R}^{k \times 1}$, $\mathbf{B} \in \mathbb{R}^{k \times n}$ be non-random, then

$$\begin{aligned}\mathbf{X} &= \mathbf{A} + \mathbf{B} \mathbf{Y} \\ \mathbf{E}(\mathbf{X}) &= \mathbf{A} + \mathbf{B} \mathbf{E}(\mathbf{Y}) \\ \mathbf{Var}(\mathbf{X}) &= \mathbf{B} \mathbf{Var}(\mathbf{Y}) \mathbf{B}^T\end{aligned}$$

Sums of random vectors

$$\begin{aligned}\mathbf{X} &= \mathbf{Y} + \mathbf{Z} \\ \mathbf{E}(\mathbf{X}) &= \mathbf{E}(\mathbf{Y}) + \mathbf{E}(\mathbf{Z}) = \mathbf{E}(\mathbf{Y} + \mathbf{Z})\end{aligned}$$

Note that there is no independence assumed above.

$$\mathbf{Var}(\mathbf{X}) = \mathbf{Var}(\mathbf{Y} + \mathbf{Z}) = \mathbf{Var}(\mathbf{Y}) + \mathbf{Var}(\mathbf{Z}) + Cov(\mathbf{Y}, \mathbf{Z}) + Cov(\mathbf{Z}, \mathbf{Y})$$

If \mathbf{Y}, \mathbf{Z} are uncorrelated, then $\mathbf{Var}(\mathbf{X}) = \mathbf{Var}(\mathbf{Y}) + \mathbf{Var}(\mathbf{Z})$

Dummy-variable regression

For categorical data (factor), we use dummy variable regression:

$$Y_i = \beta_0 + \beta_1 X_i + \beta_2 D_i + \epsilon_i$$

where D , called a dummy variable regressor or an indicator variable, is coded 1 for one level and 0 for all others,

$$D_i = \begin{cases} 1 & \text{for men} \\ 0 & \text{for women} \end{cases}.$$

Therefore, for women, the model becomes

$$Y_i = \beta_0 + \beta_1 X_i + \epsilon_i$$

and for men

$$Y_i = \beta_0 + \beta_1 X_i + \beta_2 + \epsilon_i = (\beta_0 + \beta_2) + \beta_1 X_i + \epsilon_i$$

For example, Figure 15.1 (a) and (b) represents two small (idealized) populations. In both cases, the within-gender regressions of income on education are parallel. Parallel regressions imply additive effects of education and gender on income: Holding education constant, the “effect” of gender is the vertical distance between the two regression lines, which, for parallel lines, is everywhere the same.

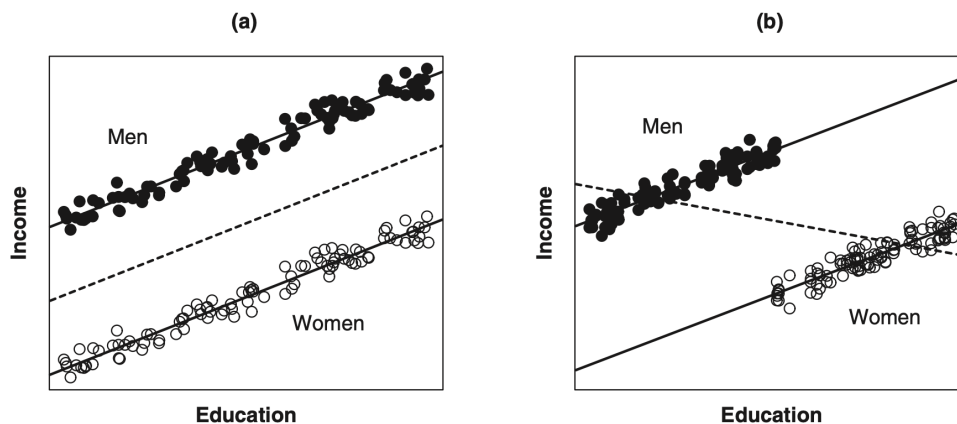


Figure 15.1: Idealized data representing the relationship between income and education for populations of men (filled circles) and women (open circles). In (a), there is no relationship between education and gender; in (b), women have a higher average level of education than men. In both (a) and (b), the within-gender (i.e., partial) regressions (solid lines) are parallel. In each graph, the overall (i.e. marginal) regression of income on education (ignoring gender) is given by the broken line. JF Figure 7.1.

Multi-level factor

We can model the effects of classification factors with m categories (levels) by using $m - 1$ indicator variables.

For example, the three-category occupational-type factor can be represented in the regression equation by introducing two dummy regressors:

Category	D_1	D_2
Professional and managerial	1	0
White collar	0	1
Blue collar	0	0

A model for the regression of prestige on income, education, and type of occupation is then

$$Y_i = \beta_0 + \beta_1 X_{i1} + \beta_2 X_{i2} + \gamma_1 D_{i1} + \gamma_2 D_{i2} + \epsilon_i$$

where X_1 is income and X_2 is education. This model describes three parallel regression planes, which can differ in their intercepts:

$$\begin{aligned} \text{Professional:} \quad Y_i &= (\beta_0 + \gamma_1) + \beta_1 X_{i1} + \beta_2 X_{i2} + \epsilon_i \\ \text{White collar:} \quad Y_i &= (\beta_0 + \gamma_2) + \beta_1 X_{i1} + \beta_2 X_{i2} + \epsilon_i \\ \text{Blue collar:} \quad Y_i &= \beta_0 + \beta_1 X_{i1} + \beta_2 X_{i2} + \epsilon_i \end{aligned}$$

Therefore, the coefficient β_0 gives the intercept for blue-collar occupations; γ_1 represents the constant vertical difference between the parallel regression planes for professional and blue-collar occupations (fixing the values of education and income); and γ_2 represents the constant vertical distance between the regression planes for white-collar and blue-collar occupations (again, fixing education and income).

In the above prestige example, we chose “blue collar” as the baseline category. Sometimes, it is natural to pick a particular category as the baseline category, for example, the “control group” in an experiment. However, in most applications, the choice of a baseline category is entirely arbitrary.

Matrix representation

For the above prestige model

$$Y_i = \beta_0 + \beta_1 X_{i1} + \beta_2 X_{i2} + \gamma_1 D_{i1} + \gamma_2 D_{i2} + \epsilon_i$$

we have the design matrix \mathbf{X} as

$$\mathbf{X} = \begin{bmatrix} 1 & X_{11} & X_{12} & D_{11} & D_{12} \\ 1 & X_{21} & X_{22} & D_{21} & D_{22} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ 1 & X_{n1} & X_{n2} & D_{n1} & D_{n2} \end{bmatrix}$$

and the vector of coefficients β is

$$\beta = \begin{bmatrix} \beta_0 \\ \beta_1 \\ \beta_2 \\ \gamma_1 \\ \gamma_2 \end{bmatrix}$$

such that we have (again) the linear model in matrix form:

$$\mathbf{Y} = \mathbf{X}\beta + \epsilon$$

where $\epsilon_i \stackrel{iid}{\sim} N(0, \sigma^2)$, in other words, $\epsilon \sim N(\mathbf{0}, \sigma^2 \mathbf{I}_n)$.

Interactions

Two explanatory variables are said to interact in determining a response variable when the partial effect of one depends on the value of the other. Consider the hypothetical data shown in Figure 15.2.

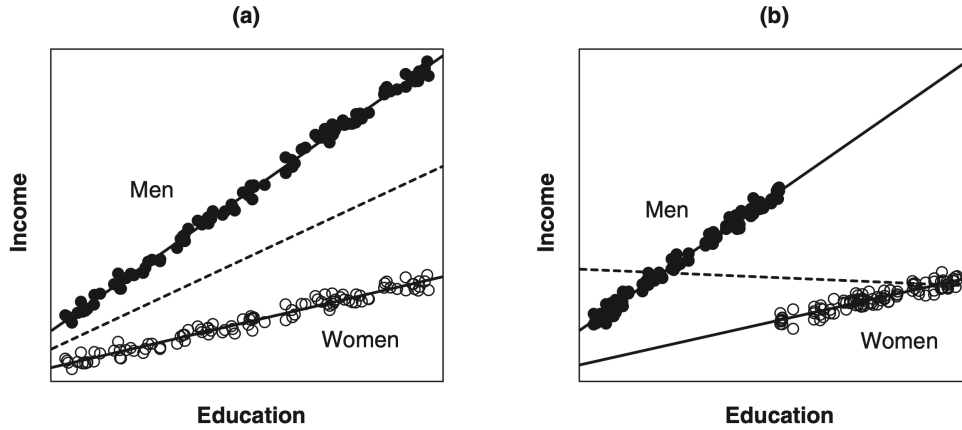


Figure 15.2: Idealized data representing the relationship between income and education for populations of men (filled circles) and women (open circles). In (a), there is no relationship between education and gender; in (b), women have a higher average level of education than men. In both (a) and (b), the within-gender (i.e., partial) regressions (solid lines) are not parallel. The slope for men is greater than the slope for women, and consequently education and gender interact in affecting income. In each graph, the overall regression of income on education (ignoring gender) is given by the broken line. JF Figure 7.7.

It is apparent in both Figure 15.2 (a) and (b) the within-gender regressions of income on education are not parallel: In both cases, the slope for men is larger than the slope for women.

Modeling interactions

We accommodate the interaction of education and gender by:

$$Y_i = \beta_0 + \beta_1 X_i + \beta_2 D_i + \beta_3 (X_i D_i) + \epsilon_i$$

where we introduce the interaction regressor XD into the regression equation. For women, the model becomes

$$\begin{aligned} Y_i &= \beta_0 + \beta_1 X_i + \beta_2 \cdot 0 + \beta_3 (X_i \cdot 0) + \epsilon_i \\ &= \beta_0 + \beta_1 X_i + \epsilon_i \end{aligned}$$

and for men

$$\begin{aligned} Y_i &= \beta_0 + \beta_1 X_i + \beta_2 \cdot 1 + \beta_3 (X_i \cdot 1) + \epsilon_i \\ &= (\beta_0 + \beta_2) + (\beta_1 + \beta_3) X_i + \epsilon_i \end{aligned}$$

The parameters β_0 and β_1 are, respectively, the intercept and slope for the regression of income on education among women (the baseline category for gender); β_2 gives the difference in intercepts between the male and female groups; and β_3 gives the difference in slopes between the two groups.

Usual guidance: Models that include an interaction between two predictors should also include the individual predictors by themselves regardless of the statistical significance of the associated β 's.

Test for the interaction

We can simply test the hypothesis $H_0 : \beta_3 = 0$ and construct the test statistic $t = \frac{\hat{\beta}_3 - 0}{\widehat{SE}(\hat{\beta}_3)} \sim t_{n-4} \ (p = 3)$.

Interactions with multi-level factor

We can easily extend the method for modeling interactions by forming product regressors to multi-level factors, to several factors, and to several quantitative explanatory variables. Using the occupational prestige example, the occupational type could possibly interact both with income (X_1) and with education (X_2):

$$\begin{aligned} Y_i &= \beta_0 + \beta_1 X_{i1} + \beta_2 X_{i2} + \gamma_1 D_{i1} + \gamma_2 D_{i2} \\ &\quad + \delta_{11} X_{i1} D_{i1} + \delta_{12} X_{i1} D_{i2} + \delta_{21} X_{i2} D_{i1} + \delta_{22} X_{i2} D_{i2} + \epsilon_i \end{aligned}$$

The model therefore permits different intercepts and slopes for the three types of occupations:

Professional:	$Y_i =$	$(\beta_0 + \gamma_1) +$	$(\beta_1 + \delta_{11})X_{i1} +$	$(\beta_2 + \delta_{21})X_{i2} +$	ϵ_i
White collar:	$Y_i =$	$(\beta_0 + \gamma_2) +$	$(\beta_1 + \delta_{12})X_{i1} +$	$(\beta_2 + \delta_{22})X_{i2} +$	ϵ_i
Blue collar:	$Y_i =$	$\beta_0 +$	$\beta_1 X_{i1} +$	$\beta_2 X_{i2} +$	ϵ_i