STAT 224 Lecture 7

Interactions of Three or More Predictors

Yibi Huang
Department of Statistics
University of Chicago

Various Interactions of `X`, `E`, and `M`

With 3 or more predictors, there are various interaction terms we can include in the model.

- `X + E + M`
- `X + E + M + E:X`
- `X + E + M + M:X`
- `X + E + M + E:M`
- `X + E + M + E:X + M:X`
- `X + E + M + E:X + M:X + E:M`
- `X + E + M + E:X + M:X + E:M + E:M:X`

Model `X + E + M + E:X`

$$S = \beta_0 + \beta X + \delta_2 E_2 + \delta_3 E_3 + \alpha M + \gamma_2 (E_2 \cdot X) + \gamma_3 (E_3 \cdot X) + \varepsilon$$

	E(S)	
Education (E)	Other ($M = 0$)	Manager ($M = 1$)
1 (HS, $E_2 = E_3 = 0$)	$\beta_0 \quad + (\beta \quad)X$	$\beta_0 + \alpha \quad + (\beta \quad)X$
2 (BA/BS, $E_2 = 1, E_3 = 0$)	$\beta_0 + \delta_2 + (\beta + \gamma_2)X$	$\beta_0 + \alpha + \delta_2 + (\beta + \gamma_2)X$
3 (Adv, $E_2 = 0, E_3 = 1$)	$\beta_0 + \delta_3 + (\beta + \gamma_3)X$	$\beta_0 + \alpha + \delta_3 + (\beta + \gamma_3)X$

- Effect (Slope) of X depends on `E` only but not `M`
- No `E:M` or `M:X` interaction: Effect of `M` doesn't depend on `E` or `X`
  - If equally experienced and educated, managers are paid α more than others on average, and the gap α doesn't change with `X` or `E`.
- Effect of `E` depends on `X` but not on `M`
  - College graduates are paid $\delta_2 + \gamma_2 X$ more than HS graduates w/ the same experience (X years) and management status

Model `X + E + M + E:M`

$$S = \beta_0 + \beta X + \delta_2 E_2 + \delta_3 E_3 + \alpha M + \theta_2 (E_2 \cdot M) + \theta_3 (E_3 \cdot M) + \varepsilon$$

	E(S)	
Education (E)	Other ($M = 0$)	Manager ($M = 1$)
1 (HS, $E_2 = E_3 = 0$)	$\beta_0 + \beta X$	$\beta_0 + \alpha + \beta X$
2 (BA/BS, $E_2 = 1, E_3 = 0$)	$\beta_0 + \delta_2 + \beta X$	$\beta_0 + \alpha + \delta_2 + \theta_2 + \beta X$
3 (Adv, $E_2 = 0, E_3 = 1$)	$\beta_0 + \delta_3 + \beta X$	$\beta_0 + \alpha + \delta_3 + \theta_3 + \beta X$

- No `E:X` or `M:X` interactions: same slope of X for all levels of `E` & `M`
- Effect of `M` depends on `E` but not on `X`
    - If equally experienced and educated, how much are managers paid more than others?

- Effect of `E` depends on `M` but not on `X`
    - How much do college graduates earn more than HS graduates w/ the same experience and management status?

Model `X + E + M + E:M`

$$S = \beta_0 + \beta X + \delta_2 E_2 + \delta_3 E_3 + \alpha M + \theta_2 (E_2 \cdot M) + \theta_3 (E_3 \cdot M) + \varepsilon$$

	E(S)	
Education (E)	Other ($M = 0$)	Manager ($M = 1$)
1 (HS, $E_2 = E_3 = 0$)	$\beta_0 + \beta X$	$\beta_0 + \alpha + \beta X$
2 (BA/BS, $E_2 = 1, E_3 = 0$)	$\beta_0 + \delta_2 + \beta X$	$\beta_0 + \alpha + \delta_2 + \theta_2 + \beta X$
3 (Adv, $E_2 = 0, E_3 = 1$)	$\beta_0 + \delta_3 + \beta X$	$\beta_0 + \alpha + \delta_3 + \theta_3 + \beta X$

- No `E:X` or `M:X` interactions: same slope of X for all levels of `E` & `M`
- Effect of `M` depends on `E` but not on `X`
  - If equally experienced and educated, how much are managers paid more than others?
    It depends on education level but not experience,
    α if HS, $\alpha + \theta_2$ if BA/BS, $\alpha + \theta_3$ if adv.
- Effect of `E` depends on `M` but not on `X`
  - How much do college graduates earn more than HS graduates w/ the same experience and management status?

Model `X + E + M + E:M`

$$S = \beta_0 + \beta X + \delta_2 E_2 + \delta_3 E_3 + \alpha M + \theta_2 (E_2 \cdot M) + \theta_3 (E_3 \cdot M) + \varepsilon$$

	E(S)	
Education (E)	Other ($M = 0$)	Manager ($M = 1$)
1 (HS, $E_2 = E_3 = 0$)	$\beta_0 + \beta X$	$\beta_0 + \alpha + \beta X$
2 (BA/BS, $E_2 = 1, E_3 = 0$)	$\beta_0 + \delta_2 + \beta X$	$\beta_0 + \alpha + \delta_2 + \theta_2 + \beta X$
3 (Adv, $E_2 = 0, E_3 = 1$)	$\beta_0 + \delta_3 + \beta X$	$\beta_0 + \alpha + \delta_3 + \theta_3 + \beta X$

- No `E:X` or `M:X` interactions: same slope of X for all levels of `E` & `M`
- Effect of `M` depends on `E` but not on `X`
  - If equally experienced and educated, how much are managers paid more than others?
    It depends on education level but not experience,
    α if HS, $\alpha + \theta_2$ if BA/BS, $\alpha + \theta_3$ if adv.
- Effect of `E` depends on `M` but not on `X`
  - How much do college graduates earn more than HS graduates w/ the same experience and management status?
    $\delta_2 + \theta_2$ for managers and δ_2 for others

Model `X + E + M + E:M + E:X`

$$S = \beta_0 + \beta X + \delta_2 E_2 + \delta_3 E_3 + \alpha M + \theta_2 (E_2 \cdot M) + \theta_3 (E_3 \cdot M) + \gamma_2 (E_2 \cdot X) + \gamma_3 (E_3 \cdot X) + \varepsilon$$

	$\mathrm{E}(S)$	
Education (E)	Other ($M = 0$)	Manager ($M = 1$)
1 (HS, $E_2 = E_3 = 0$)	$\beta_0 + (\beta)X$	$\beta_0 + \alpha + (\beta)X$
2 (BA/BS, $E_2 = 1, E_3 = 0$)	$\beta_0 + \delta_2 + (\beta + \gamma_2)X$	$\beta_0 + \alpha + \delta_2 + \theta_2 + (\beta + \gamma_2)X$
3 (Adv, $E_2 = 0, E_3 = 1$)	$\beta_0 + \delta_3 + (\beta + \gamma_3)X$	$\beta_0 + \alpha + \delta_3 + \theta_3 + (\beta + \gamma_3)X$

- includes `E:X` but not `M:X`: slope of X changes w/ `E` but not w/ `M`
- Effect of `M` depends on `E` but not on `X`
  - If equally experienced and educated, how much are managers paid more than others?

- Effect of `E` depends on both `M` and `X`
  - How much are college graduates paid more than HS graduates w/ the same experience and management status?

Model `X + E + M + E:M + E:X`

$$S = \beta_0 + \beta X + \delta_2 E_2 + \delta_3 E_3 + \alpha M + \theta_2 (E_2 \cdot M) + \theta_3 (E_3 \cdot M) + \gamma_2 (E_2 \cdot X) + \gamma_3 (E_3 \cdot X) + \varepsilon$$

	$\mathrm{E}(S)$	
Education (E)	Other ($M = 0$)	Manager ($M = 1$)
1 (HS, $E_2 = E_3 = 0$)	$\beta_0 + (\beta)X$	$\beta_0 + \alpha + (\beta)X$
2 (BA/BS, $E_2 = 1, E_3 = 0$)	$\beta_0 + \delta_2 + (\beta + \gamma_2)X$	$\beta_0 + \alpha + \delta_2 + \theta_2 + (\beta + \gamma_2)X$
3 (Adv, $E_2 = 0, E_3 = 1$)	$\beta_0 + \delta_3 + (\beta + \gamma_3)X$	$\beta_0 + \alpha + \delta_3 + \theta_3 + (\beta + \gamma_3)X$

- includes `E:X` but not `M:X`: slope of X changes w/ `E` but not w/ `M`
- Effect of `M` depends on `E` but not on `X`
  - If equally experienced and educated, how much are managers paid more than others?
    It depends on education level but not experience,
    α if HS, $\alpha + \theta_2$ if BA/BS, $\alpha + \theta_3$ if adv.
- Effect of `E` depends on both `M` and `X`
  - How much are college graduates paid more than HS graduates w/ the same experience and management status?

Model `X + E + M + E:M + E:X`

$$S = \beta_0 + \beta X + \delta_2 E_2 + \delta_3 E_3 + \alpha M + \theta_2 (E_2 \cdot M) + \theta_3 (E_3 \cdot M) + \gamma_2 (E_2 \cdot X) + \gamma_3 (E_3 \cdot X) + \varepsilon$$

	E(S)	
Education (E)	Other ($M = 0$)	Manager ($M = 1$)
1 (HS, $E_2 = E_3 = 0$)	$\beta_0 + (\beta)X$	$\beta_0 + \alpha + (\beta)X$
2 (BA/BS, $E_2 = 1, E_3 = 0$)	$\beta_0 + \delta_2 + (\beta + \gamma_2)X$	$\beta_0 + \alpha + \delta_2 + \theta_2 + (\beta + \gamma_2)X$
3 (Adv, $E_2 = 0, E_3 = 1$)	$\beta_0 + \delta_3 + (\beta + \gamma_3)X$	$\beta_0 + \alpha + \delta_3 + \theta_3 + (\beta + \gamma_3)X$

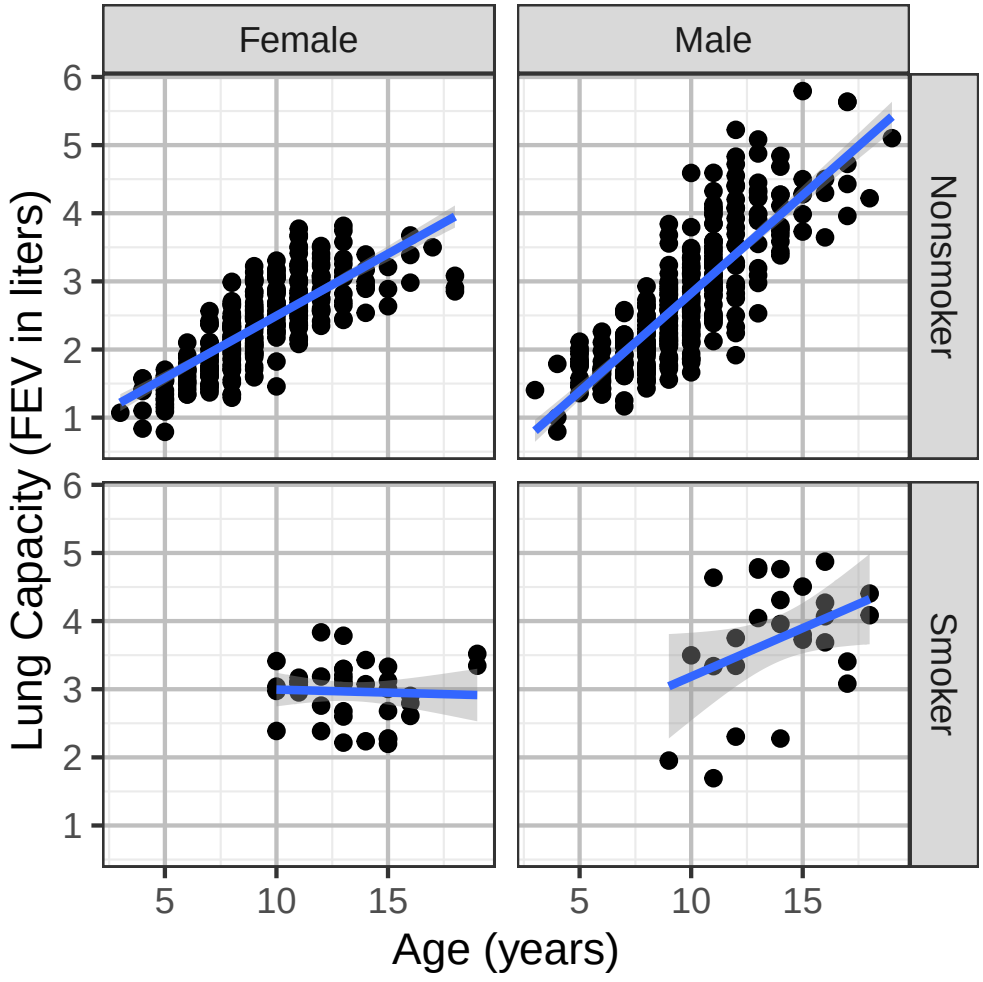
- includes `E:X` but not `M:X`: slope of X changes w/ `E` but not w/ `M`
- Effect of `M` depends on `E` but not on `X`
  - If equally experienced and educated, how much are managers paid more than others?
    It depends on education level but not experience,
    α if HS, $\alpha + \theta_2$ if BA/BS, $\alpha + \theta_3$ if adv.
- Effect of `E` depends on both `M` and `X`
  - How much are college graduates paid more than HS graduates w/ the same experience and management status?
    $\delta_2 + \theta_2 + \gamma_2 X$ for managers and $\delta_2 + \gamma_2 X$ for others

Lung Capacity Data Revisit

Sample of 654 youths, aged 3 to 19, in the area of East Boston during middle to late 1970's. The variables are

- **age**: Subject's age in years
- **fev**: Lung capacity of subject, measured by **forced expiratory volume** (abbreviated as **FEV**), the amount of air an individual can exhale in the first second of forceful breath in liters
- **ht**: Subject's height in inches
- **sex**: Gender of the subject coded as: 0 = Female, 1 = Male
- **smoke**:Smoking status coded as: 0 = Nonsmoker, 1 = Smoker

```
fevdata = read.table("fevdata.txt", header = TRUE)
fevdata$sex = factor(fevdata$sex, labels=c("Female","Male"))
fevdata$smoke = factor(fevdata$smoke, labels=c("Nonsmoker","Smoker"))
```



Does the slope change with smoking status?

Does the slope change with gender?

```r
lmfull2 = lm(fev ~ age + sex + smoke + age*sex +
               age*smoke + sex*smoke, data=fevdata)

# or simply
lmfull2 = lm(fev ~ age*sex + age*smoke + sex*smoke, data=fevdata)

summary(lmfull2)$coef
                    Estimate Std. Error  t value  Pr(>|t|)
(Intercept)          0.69028    0.10775  6.40614 2.873e-10
age                  0.18033    0.01104 16.33231 1.832e-50
sexMale             -0.76220    0.14633 -5.20868 2.559e-07
smokeSmoker          2.14912    0.37905  5.66977 2.156e-08
age:sexMale          0.10936    0.01474  7.41873 3.729e-13
age:smokeSmoker     -0.17079    0.02838 -6.01744 2.967e-09
sexMale:smokeSmoker  0.01048    0.14886  0.07037 9.439e-01
```

```
summary(lmfull2)$coef
                    Estimate Std. Error  t value  Pr(>|t|)
(Intercept)          0.69028    0.10775  6.40614 2.873e-10
age                  0.18033    0.01104 16.33231 1.832e-50
sexMale             -0.76220    0.14633 -5.20868 2.559e-07
smokeSmoker          2.14912    0.37905  5.66977 2.156e-08
age:sexMale          0.10936    0.01474  7.41873 3.729e-13
age:smokeSmoker     -0.17079    0.02838 -6.01744 2.967e-09
sexMale:smokeSmoker  0.01048    0.14886  0.07037 9.439e-01
```

What is the slope of age

- for female nonsmokers?
- for female smokers?
- for male nonsmokers?
- for male smokers?

```
summary(lmfull2)$coef
                    Estimate Std. Error  t value  Pr(>|t|)
(Intercept)          0.69028    0.10775  6.40614 2.873e-10
age                  0.18033    0.01104 16.33231 1.832e-50
sexMale             -0.76220    0.14633 -5.20868 2.559e-07
smokeSmoker          2.14912    0.37905  5.66977 2.156e-08
age:sexMale          0.10936    0.01474  7.41873 3.729e-13
age:smokeSmoker     -0.17079    0.02838 -6.01744 2.967e-09
sexMale:smokeSmoker  0.01048    0.14886  0.07037 9.439e-01
```

What is the slope of age

- for female nonsmokers? 0.18
- for female smokers?
- for male nonsmokers?
- for male smokers?

```
summary(lmfull2)$coef
                     Estimate Std. Error  t value  Pr(>|t|)
(Intercept)           0.69028    0.10775  6.40614 2.873e-10
age                   0.18033    0.01104 16.33231 1.832e-50
sexMale              -0.76220    0.14633 -5.20868 2.559e-07
smokeSmoker           2.14912    0.37905  5.66977 2.156e-08
age:sexMale           0.10936    0.01474  7.41873 3.729e-13
age:smokeSmoker      -0.17079    0.02838 -6.01744 2.967e-09
sexMale:smokeSmoker   0.01048    0.14886  0.07037 9.439e-01
```

What is the slope of age

- for female nonsmokers? 0.18
- for female smokers? $0.18 + (-0.171)$
- for male nonsmokers?
- for male smokers?

```
summary(lmfull2)$coef
                     Estimate Std. Error  t value  Pr(>|t|)
(Intercept)           0.69028    0.10775  6.40614 2.873e-10
age                   0.18033    0.01104 16.33231 1.832e-50
sexMale              -0.76220    0.14633 -5.20868 2.559e-07
smokeSmoker           2.14912    0.37905  5.66977 2.156e-08
age:sexMale           0.10936    0.01474  7.41873 3.729e-13
age:smokeSmoker      -0.17079    0.02838 -6.01744 2.967e-09
sexMale:smokeSmoker   0.01048    0.14886  0.07037 9.439e-01
```

What is the slope of age

- for female nonsmokers? 0.18
- for female smokers? $0.18 + (-0.171)$
- for male nonsmokers? $0.18 + 0.109$
- for male smokers?

```
summary(lmfull2)$coef
                     Estimate Std. Error  t value  Pr(>|t|)
(Intercept)           0.69028    0.10775  6.40614 2.873e-10
age                   0.18033    0.01104 16.33231 1.832e-50
sexMale              -0.76220    0.14633 -5.20868 2.559e-07
smokeSmoker           2.14912    0.37905  5.66977 2.156e-08
age:sexMale           0.10936    0.01474  7.41873 3.729e-13
age:smokeSmoker      -0.17079    0.02838 -6.01744 2.967e-09
sexMale:smokeSmoker   0.01048    0.14886  0.07037 9.439e-01
```

What is the slope of age

- for female nonsmokers? 0.18
- for female smokers? $0.18 + (-0.171)$
- for male nonsmokers? $0.18 + 0.109$
- for male smokers? $0.18 + 0.109 + (-0.171)$

Model w/ 3-Way Interactions

```
lmfull = lm(fev ~ age + sex + smoke + age*sex + age*smoke +
              sex*smoke + sex*smoke*age, data=fevdata)

# or simply
lmfull = lm(fev ~ age*sex*smoke, data=fevdata)
summary(lmfull)$coef
                          Estimate Std. Error t value  Pr(>|t|)
(Intercept)                0.67387    0.10978  6.1384 1.455e-09
age                        0.18209    0.01127 16.1618 1.355e-49
sexMale                   -0.73143    0.15149 -4.8281 1.722e-06
smokeSmoker                2.41025    0.50359  4.7861 2.109e-06
age:sexMale                0.10613    0.01531  6.9336 9.973e-12
age:smokeSmoker           -0.19100    0.03826 -4.9916 7.709e-07
sexMale:smokeSmoker       -0.58904    0.77534 -0.7597 4.477e-01
age:sexMale:smokeSmoker    0.04497    0.05707  0.7879 4.310e-01
```

```
summary(lmfull)$coef
```

	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	0.67387	0.10978	6.1384	1.455e-09
age	0.18209	0.01127	16.1618	1.355e-49
sexMale	-0.73143	0.15149	-4.8281	1.722e-06
smokeSmoker	2.41025	0.50359	4.7861	2.109e-06
age:sexMale	0.10613	0.01531	6.9336	9.973e-12
age:smokeSmoker	-0.19100	0.03826	-4.9916	7.709e-07
sexMale:smokeSmoker	-0.58904	0.77534	-0.7597	4.477e-01
age:sexMale:smokeSmoker	0.04497	0.05707	0.7879	4.310e-01

What is the slope of age

- for female nonsmokers?
- for female smokers?
- for male nonsmokers?
- for male smokers?

```
summary(lmfull)$coef
                          Estimate Std. Error t value  Pr(>|t|)
(Intercept)                0.67387    0.10978  6.1384 1.455e-09
age                        0.18209    0.01127 16.1618 1.355e-49
sexMale                   -0.73143    0.15149 -4.8281 1.722e-06
smokeSmoker                2.41025    0.50359  4.7861 2.109e-06
age:sexMale                0.10613    0.01531  6.9336 9.973e-12
age:smokeSmoker           -0.19100    0.03826 -4.9916 7.709e-07
sexMale:smokeSmoker       -0.58904    0.77534 -0.7597 4.477e-01
age:sexMale:smokeSmoker    0.04497    0.05707  0.7879 4.310e-01
```

What is the slope of age

- for female nonsmokers? 0.182
- for female smokers?
- for male nonsmokers?
- for male smokers?

```
summary(lmfull)$coef
```

	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	0.67387	0.10978	6.1384	1.455e-09
age	0.18209	0.01127	16.1618	1.355e-49
sexMale	-0.73143	0.15149	-4.8281	1.722e-06
smokeSmoker	2.41025	0.50359	4.7861	2.109e-06
age:sexMale	0.10613	0.01531	6.9336	9.973e-12
age:smokeSmoker	-0.19100	0.03826	-4.9916	7.709e-07
sexMale:smokeSmoker	-0.58904	0.77534	-0.7597	4.477e-01
age:sexMale:smokeSmoker	0.04497	0.05707	0.7879	4.310e-01

What is the slope of age

- for female nonsmokers? 0.182
- for female smokers? $0.182 + (-0.191)$
- for male nonsmokers?
- for male smokers?

```
summary(lmfull)$coef
```

	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	0.67387	0.10978	6.1384	1.455e-09
age	0.18209	0.01127	16.1618	1.355e-49
sexMale	-0.73143	0.15149	-4.8281	1.722e-06
smokeSmoker	2.41025	0.50359	4.7861	2.109e-06
age:sexMale	0.10613	0.01531	6.9336	9.973e-12
age:smokeSmoker	-0.19100	0.03826	-4.9916	7.709e-07
sexMale:smokeSmoker	-0.58904	0.77534	-0.7597	4.477e-01
age:sexMale:smokeSmoker	0.04497	0.05707	0.7879	4.310e-01

What is the slope of age

- for female nonsmokers? 0.182
- for female smokers? $0.182 + (-0.191)$
- for male nonsmokers? $0.182 + 0.106$
- for male smokers?

```
summary(lmfull)$coef
```

	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	0.67387	0.10978	6.1384	1.455e-09
age	0.18209	0.01127	16.1618	1.355e-49
sexMale	-0.73143	0.15149	-4.8281	1.722e-06
smokeSmoker	2.41025	0.50359	4.7861	2.109e-06
age:sexMale	0.10613	0.01531	6.9336	9.973e-12
age:smokeSmoker	-0.19100	0.03826	-4.9916	7.709e-07
sexMale:smokeSmoker	-0.58904	0.77534	-0.7597	4.477e-01
age:sexMale:smokeSmoker	0.04497	0.05707	0.7879	4.310e-01

What is the slope of age

- for female nonsmokers? 0.182
- for female smokers? $0.182 + (-0.191)$
- for male nonsmokers? $0.182 + 0.106$
- for male smokers? $0.182 + 0.106 + (-0.191) + 0.045$

```
summary(lmfull)$coef
                          Estimate Std. Error t value  Pr(>|t|)
(Intercept)                0.67387    0.10978  6.1384 1.455e-09
age                        0.18209    0.01127 16.1618 1.355e-49
sexMale                   -0.73143    0.15149 -4.8281 1.722e-06
smokeSmoker                2.41025    0.50359  4.7861 2.109e-06
age:sexMale                0.10613    0.01531  6.9336 9.973e-12
age:smokeSmoker           -0.19100    0.03826 -4.9916 7.709e-07
sexMale:smokeSmoker       -0.58904    0.77534 -0.7597 4.477e-01
age:sexMale:smokeSmoker    0.04497    0.05707  0.7879 4.310e-01
```

Do the slopes for the following groups differ significantly?

- female nonsmokers v.s. female smokers
- male nonsmokers v.s. female nonsmokers

```
summary(lmfull)$coef
                          Estimate Std. Error t value  Pr(>|t|)
(Intercept)                0.67387    0.10978  6.1384 1.455e-09
age                        0.18209    0.01127 16.1618 1.355e-49
sexMale                   -0.73143    0.15149 -4.8281 1.722e-06
smokeSmoker                2.41025    0.50359  4.7861 2.109e-06
age:sexMale                0.10613    0.01531  6.9336 9.973e-12
age:smokeSmoker           -0.19100    0.03826 -4.9916 7.709e-07
sexMale:smokeSmoker       -0.58904    0.77534 -0.7597 4.477e-01
age:sexMale:smokeSmoker    0.04497    0.05707  0.7879 4.310e-01
```

Do the slopes for the following groups differ significantly?

- female nonsmokers v.s. female smokers

  Look at `age:smokeSmoker`. Yes, P-value $= 7.71 \times 10^{-7}$
- male nonsmokers v.s. female nonsmokers

```
summary(lmfull)$coef
                          Estimate Std. Error t value  Pr(>|t|)
(Intercept)                0.67387    0.10978  6.1384 1.455e-09
age                        0.18209    0.01127 16.1618 1.355e-49
sexMale                   -0.73143    0.15149 -4.8281 1.722e-06
smokeSmoker                2.41025    0.50359  4.7861 2.109e-06
age:sexMale                0.10613    0.01531  6.9336 9.973e-12
age:smokeSmoker           -0.19100    0.03826 -4.9916 7.709e-07
sexMale:smokeSmoker       -0.58904    0.77534 -0.7597 4.477e-01
age:sexMale:smokeSmoker    0.04497    0.05707  0.7879 4.310e-01
```

Do the slopes for the following groups differ significantly?

- female nonsmokers v.s. female smokers
  Look at `age:smokeSmoker`. Yes, P-value $= 7.71 \times 10^{-7}$
- male nonsmokers v.s. female nonsmokers
  Look at `age:sexMale`. Yes, P-value $= 9.97 \times 10^{-12}$

```
summary(lmfull)$coef
                          Estimate Std. Error t value  Pr(>|t|)
(Intercept)                0.67387    0.10978  6.1384 1.455e-09
age                        0.18209    0.01127 16.1618 1.355e-49
sexMale                   -0.73143    0.15149 -4.8281 1.722e-06
smokeSmoker                2.41025    0.50359  4.7861 2.109e-06
age:sexMale                0.10613    0.01531  6.9336 9.973e-12
age:smokeSmoker           -0.19100    0.03826 -4.9916 7.709e-07
sexMale:smokeSmoker       -0.58904    0.77534 -0.7597 4.477e-01
age:sexMale:smokeSmoker    0.04497    0.05707  0.7879 4.310e-01
```

Do the slopes for the following groups differ significantly?

- male nonsmokers v.s. male smokers

- male smokers v.s. female smokers?

```
summary(lmfull)$coef
                          Estimate Std. Error t value  Pr(>|t|)
(Intercept)                0.67387    0.10978  6.1384 1.455e-09
age                        0.18209    0.01127 16.1618 1.355e-49
sexMale                   -0.73143    0.15149 -4.8281 1.722e-06
smokeSmoker                2.41025    0.50359  4.7861 2.109e-06
age:sexMale                0.10613    0.01531  6.9336 9.973e-12
age:smokeSmoker           -0.19100    0.03826 -4.9916 7.709e-07
sexMale:smokeSmoker       -0.58904    0.77534 -0.7597 4.477e-01
age:sexMale:smokeSmoker    0.04497    0.05707  0.7879 4.310e-01
```

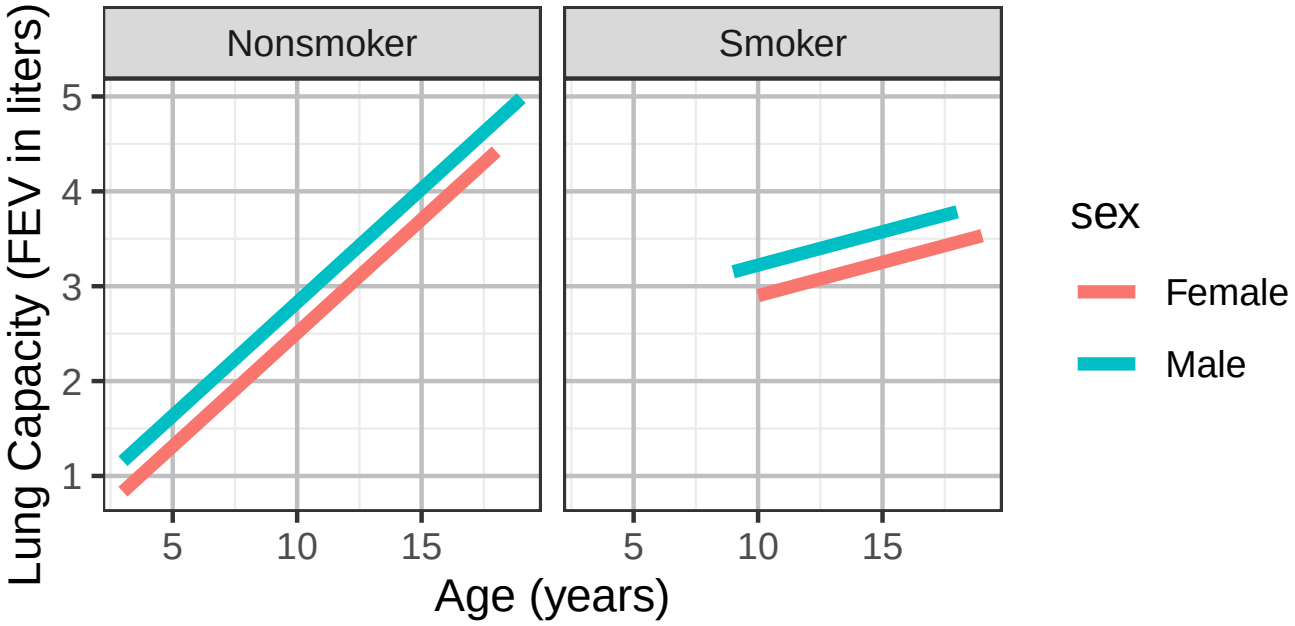
Do the slopes for the following groups differ significantly?

- male nonsmokers v.s. male smokers
  The sum of coefficients of `age:smokeSmoker` and `age:sexMale:smokeSmoker`
- male smokers v.s. female smokers?

```
summary(lmfull)$coef
                          Estimate Std. Error t value  Pr(>|t|)
(Intercept)                0.67387    0.10978  6.1384 1.455e-09
age                        0.18209    0.01127 16.1618 1.355e-49
sexMale                   -0.73143    0.15149 -4.8281 1.722e-06
smokeSmoker                2.41025    0.50359  4.7861 2.109e-06
age:sexMale                0.10613    0.01531  6.9336 9.973e-12
age:smokeSmoker           -0.19100    0.03826 -4.9916 7.709e-07
sexMale:smokeSmoker       -0.58904    0.77534 -0.7597 4.477e-01
age:sexMale:smokeSmoker    0.04497    0.05707  0.7879 4.310e-01
```

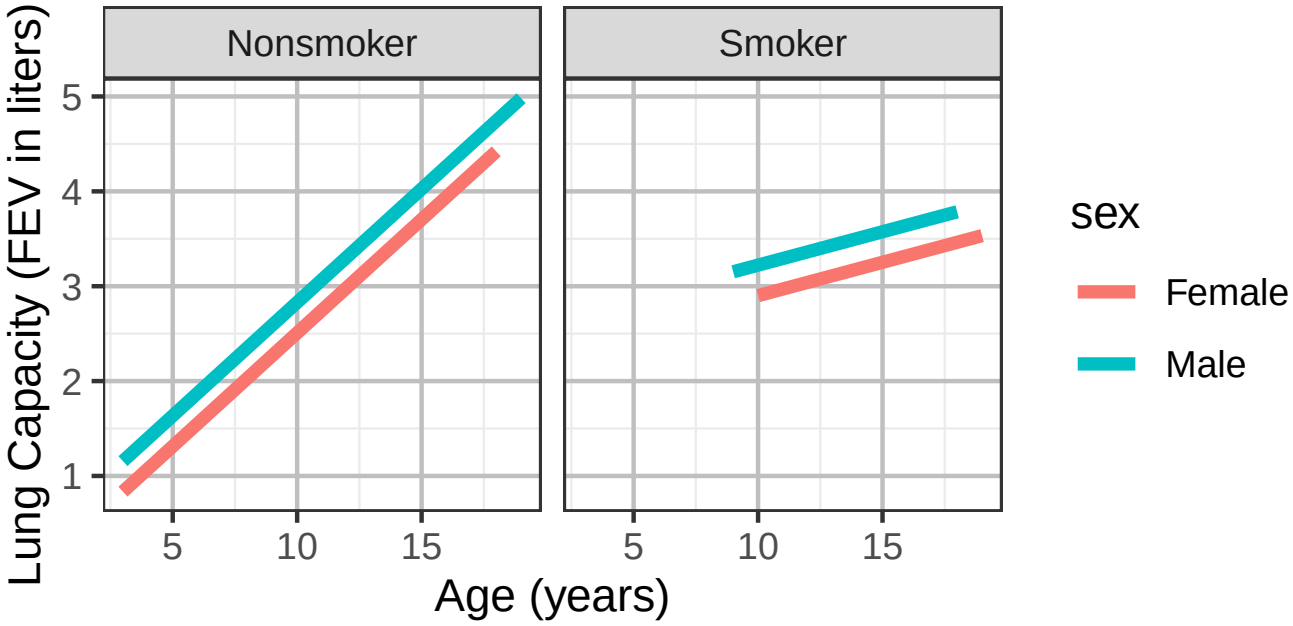
Do the slopes for the following groups differ significantly?

- male nonsmokers v.s. male smokers
  The sum of coefficients of `age:smokeSmoker` and `age:sexMale:smokeSmoker`
- male smokers v.s. female smokers?
  The sum of coefficients of `age:sexMale` and `age:sexMale:smokeSmoker`



The plots above shows the fitted regression lines for which of the following models?

- `fev ~ age + smoke + sex + age*smoke`
- `fev ~ age + smoke + sex + age*sex`
- `fev ~ age + smoke + sex + smoke*sex`
- `fev ~ age + smoke + sex + age*sex + age*smoke`



The plots above shows the fitted regression lines for which of the following models?

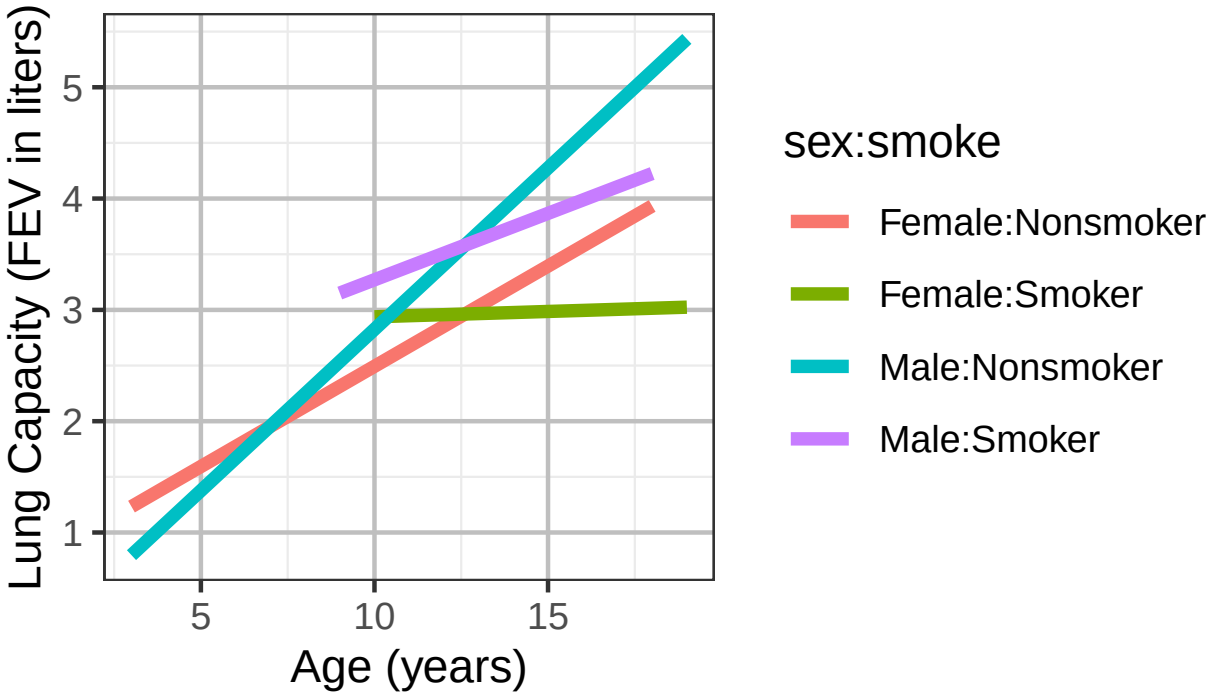
- `fev ~ age + smoke + sex + age*smoke` ← Correct Ans
- `fev ~ age + smoke + sex + age*sex`
- `fev ~ age + smoke + sex + smoke*sex`
- `fev ~ age + smoke + sex + age*sex + age*smoke`

The plots above shows the fitted regression lines for which of the following models?

- `fev ~ age + smoke + sex + age*smoke`
- `fev ~ age + smoke + sex + age*sex`
- `fev ~ age + smoke + sex + smoke*sex`
- `fev ~ age + smoke + sex + age*sex + age*smoke`

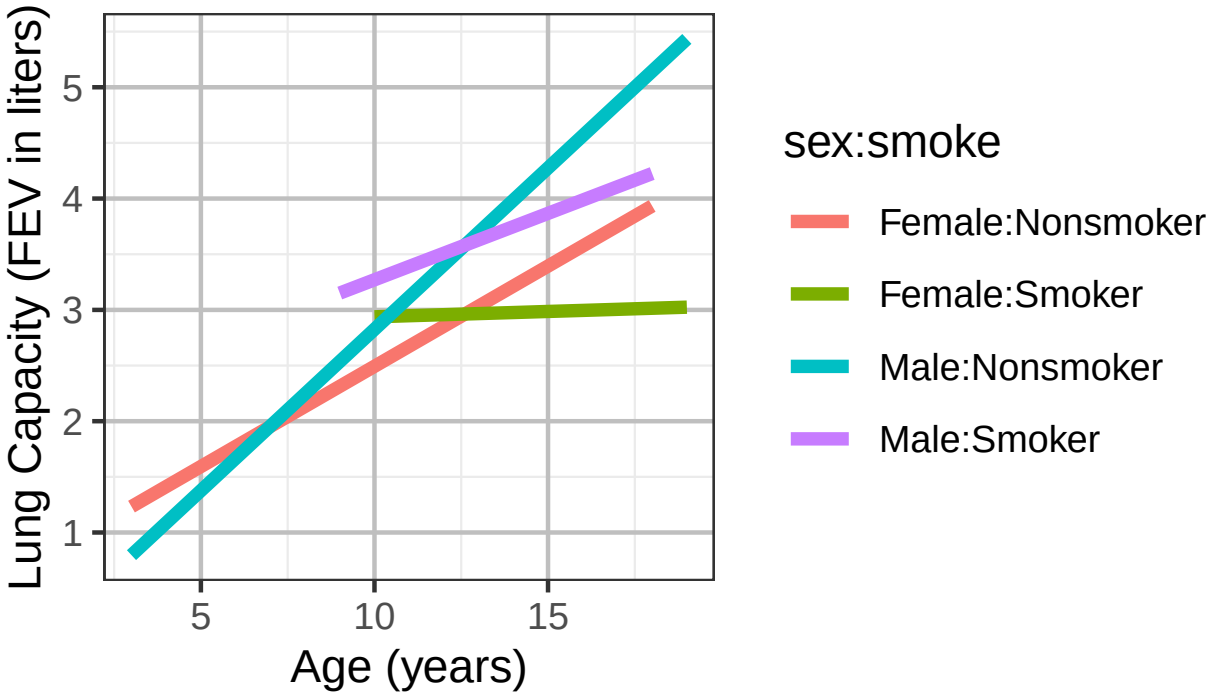
The plots above shows the fitted regression lines for which of the following models?

- `fev ~ age + smoke + sex + age*smoke`
- `fev ~ age + smoke + sex + age*sex` ← Correct Ans
- `fev ~ age + smoke + sex + smoke*sex`
- `fev ~ age + smoke + sex + age*sex + age*smoke`



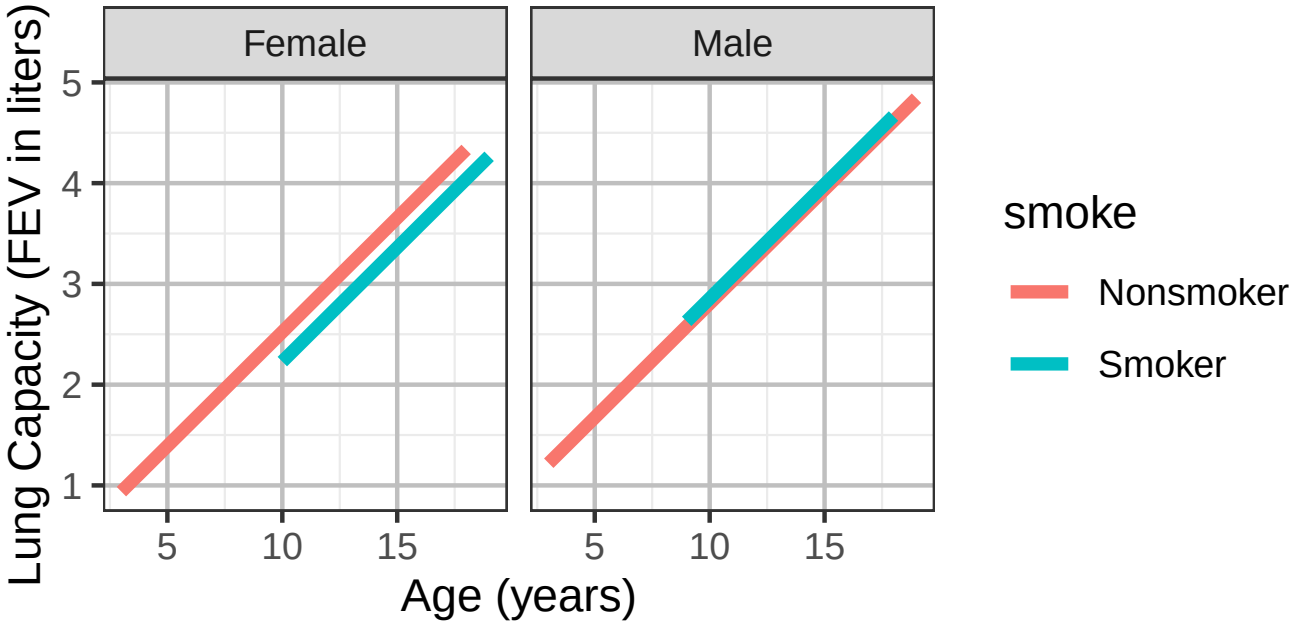
The plots above shows the fitted regression lines for which of the following models?

- `fev ~ age + smoke + sex + age*smoke`
- `fev ~ age + smoke + sex + age*sex`
- `fev ~ age + smoke + sex + smoke*sex`
- `fev ~ age + smoke + sex + age*sex + age*smoke`



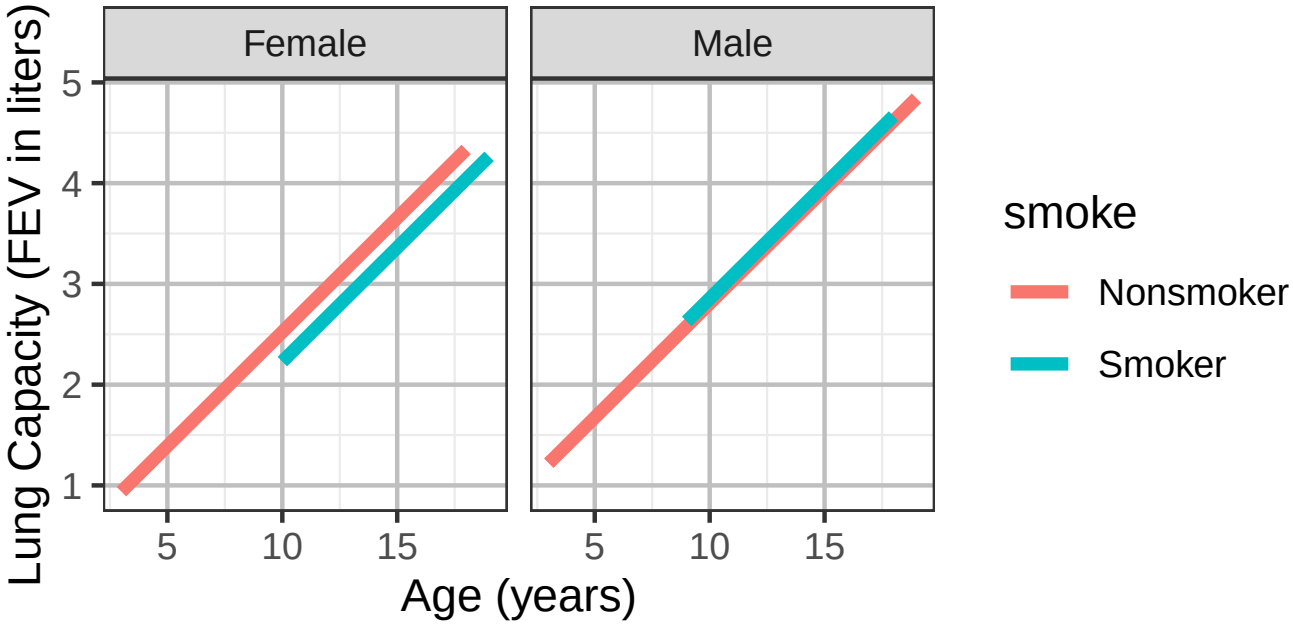
The plots above shows the fitted regression lines for which of the following models?

- `fev ~ age + smoke + sex + age*smoke`
- `fev ~ age + smoke + sex + age*sex`
- `fev ~ age + smoke + sex + smoke*sex`
- `fev ~ age + smoke + sex + age*sex + age*smoke` ← Correct Ans



The plots above shows the fitted regression lines for which of the following models?

- `fev ~ age + smoke + sex + age*smoke`
- `fev ~ age + smoke + sex + age*sex`
- `fev ~ age + smoke + sex + smoke*sex`
- `fev ~ age + smoke + sex + age*sex + age*smoke`



The plots above shows the fitted regression lines for which of the following models?

- `fev ~ age + smoke + sex + age*smoke`
- `fev ~ age + smoke + sex + age*sex`
- `fev ~ age + smoke + sex + smoke*sex` ← Correct Ans
- `fev ~ age + smoke + sex + age*sex + age*smoke`