

STAT 224 Lecture 9

Interactions of Three or More Predictors

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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 $X + E + M + E:X$

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

Education (E)	$E(S)$	
	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, $E_2 = 1, E_3 = 0$)	$\beta_0 + \delta_2 + (\beta + \gamma_2)X$	$\beta_0 + \alpha + \delta_2 + (\beta + \gamma_2)X$
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 $X + E + M + E:M$

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

Education (E)	$E(S)$	
	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 $X + E + M + E:M$

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

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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 $X + E + M + E:M$

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

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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 $X + E + M + E:M + E:X$

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

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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 $X + E + M + E:M + E:X$

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

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- ▶ 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 $X + E + M + E:M + E:X$

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

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3 (Adv, $E_2 = 0, E_3 = 1$)	$\beta_0 + \delta_3 + (\beta + \gamma_3)X$	$\beta_0 + \alpha + \delta_3 + \theta_3 + (\beta + \gamma_3)X$

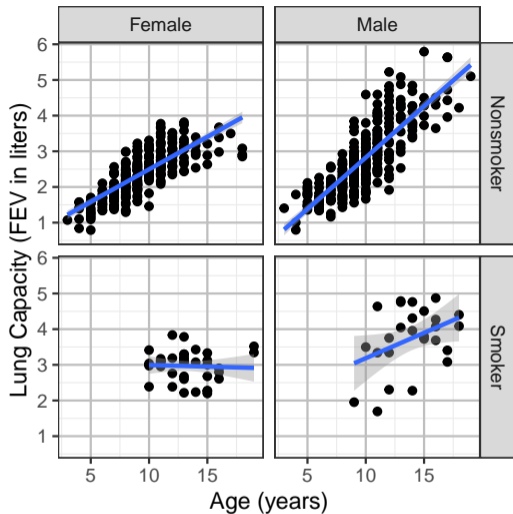
- ▶ includes $E:X$ but not $M:X$: slope of X changes w/ E but not w/ M
- ▶ Effect of M depends on E but not on X
 - ▶ If equally experienced and educated, how much are managers paid more than others?
It depends on education level but not experience,
 α if HS, $\alpha + \theta_2$ if BA/BS, $\alpha + \theta_3$ 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?

```

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
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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
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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)
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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
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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
```

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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
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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
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	Estimate	Std. Error	t value	Pr(> t)
(Intercept)	0.67387	0.10978	6.1384	1.455e-09
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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
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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
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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
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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)
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Do the slopes for the following groups differ significantly?

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

```
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```

	Estimate	Std. Error	t value	Pr(> t)
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age:sexMale:smokeSmoker	0.04497	0.05707	0.7879	4.310e-01

Do the slopes for the following groups differ significantly?

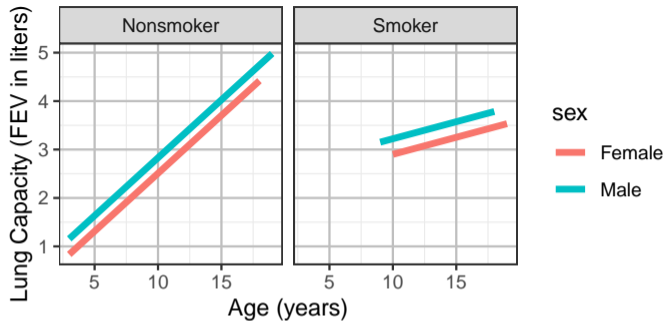
- ▶ female nonsmokers v.s. female smokers
 Look at `age:smokeSmoker`. Yes, $P\text{-value} = 7.71 \times 10^{-7}$
- ▶ male nonsmokers v.s. female nonsmokers

```
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

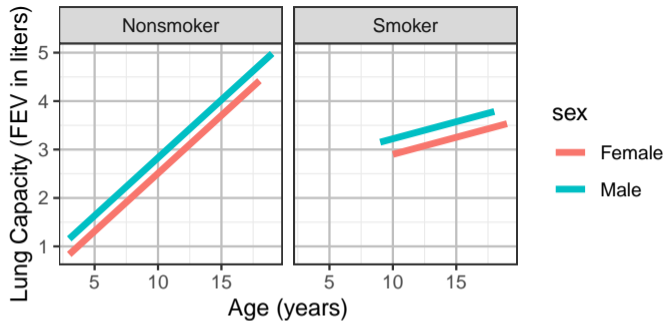
Do the slopes for the following groups differ significantly?

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



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`



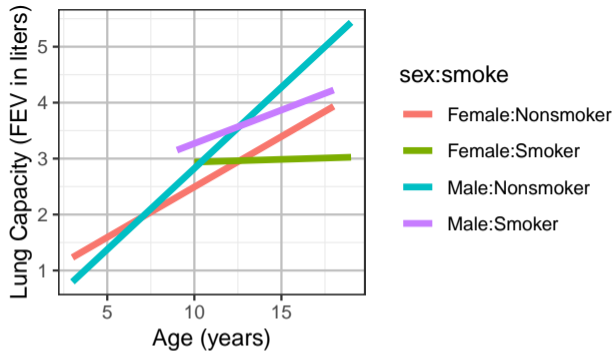
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- ▶ `fev ~ age + smoke + sex + age*sex`
- ▶ `fev ~ age + smoke + sex + smoke*sex`
- ▶ `fev ~ age + smoke + sex + age*sex + age*smoke`



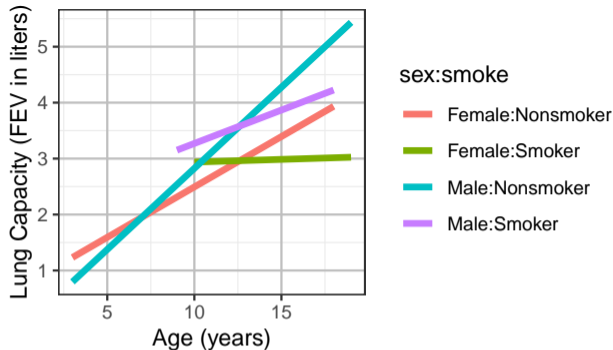
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- ▶ `fev ~ age + smoke + sex + age*sex` ← Correct Ans
- ▶ `fev ~ age + smoke + sex + smoke*sex`
- ▶ `fev ~ age + smoke + sex + age*sex + age*smoke`



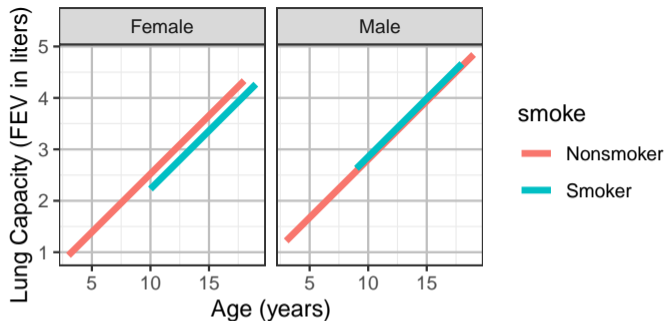
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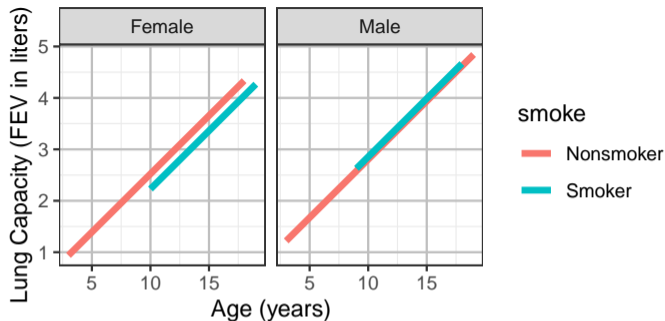
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The plots above shows the fitted regression lines for which of the following models?

- ▶ $fev \sim age + smoke + sex + age*smoke$
- ▶ $fev \sim age + smoke + sex + age*sex$
- ▶ $fev \sim age + smoke + sex + smoke*sex$ ← Correct Ans
- ▶ $fev \sim age + smoke + sex + age*sex + age*smoke$