

# Lectures 10–13: Summary of bivariate associations

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**Source: Healey, Joseph F. 2015. "Statistics: A Tool for Social Research." Stamford: Cengage Learning. 10th edition. Chapters 10 (pp. 247–275), 11 (pp. 276–306), 12 (pp. 308–341), 13 (pp. 342–378).**



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# Outline

- Measure of association for nominal-level variables
  - Chi Square
- Measure of association for ordinal-level variables
  - Spearman's Rho
- Measures of association for interval-ratio-level variables
  - Analysis of variance (ANOVA)
  - Scatterplots
  - Pearson's  $r$  and  $r^2$



# Measure of association for nominal-level variables

- Chi Square is a test of significance based on bivariate tables
  - Bivariate tables are also called cross tabulations, crosstabs, contingency tables
- We are looking for significant differences between
  - The actual cell frequencies observed in a table ( $f_o$ )
  - And those that would be expected by random chance or if cell frequencies were independent ( $f_e$ )



. **\*\*\*Observed frequencies (fo)**

. **tab migrant sex**

migrant	Sex		Total
	Male	Female	
Non-migrant	<b>1,462,317</b>	<b>1,535,029</b>	<b>2,997,346</b>
Internal migrant	<b>88,155</b>	<b>81,712</b>	<b>169,867</b>
International migrant	<b>8,455</b>	<b>8,431</b>	<b>16,886</b>
Total	<b>1,558,927</b>	<b>1,625,172</b>	<b>3,184,099</b>

.

. **\*\*\*Expected frequencies (fe)**

. **tab migrant sex, exp nofreq**

migrant	Sex		Total
	Male	Female	
Non-migrant	<b>1467493.2</b>	<b>1529852.8</b>	<b>2997346.0</b>
Internal migrant	<b>83,166.5</b>	<b>86,700.5</b>	<b>169,867.0</b>
International migrant	<b>8,267.3</b>	<b>8,618.7</b>	<b>16,886.0</b>
Total	<b>1558927.0</b>	<b>1625172.0</b>	<b>3184099.0</b>

$$f_e = \frac{\text{Row marginal} \times \text{Column marginal}}{n}$$

# Chi square

$$f_e = \frac{\text{Row marginal} \times \text{Column marginal}}{n}$$

$$\chi^2(\text{obtained}) = \sum \frac{(f_o - f_e)^2}{f_e}$$

$f_o$  = cell frequencies observed in the bivariate table

$f_e$  = cell frequencies that would be expected if the variables were independent

Degrees of freedom ( $df$ ) =  $(r-1)(c-1)$

$r$  = number of rows;  $c$  = number of columns



# Limitations of chi square

- Difficult to interpret
  - When variables have many categories
  - Best when variables have four or fewer categories
- With small sample size
  - We cannot assume that chi square sampling distribution will be accurate
  - Small samples are those with a high percentage of cells with expected frequencies of 5 or less
- Like all tests of hypotheses
  - Chi square is sensitive to sample size
  - As  $n$  increases, obtained chi square increases
  - Large samples: Trivial relationships may be significant
- Statistical significance (statistical test) is not the same as substantive significance (importance, magnitude)

# ACS: Migration by sex

- Is migration status different by sex?
  - The probability of not rejecting  $H_0$  is small ( $p < 0.00$ )
  - Migration status does depend on respondent's sex

```
. tab migrant sex, chi col
```

Key
<i>frequency</i>
<i>column percentage</i>

migrant	Sex		Total
	Male	Female	
Non-migrant	1,462,317 93.80	1,535,029 94.45	2,997,346 94.13
Internal migrant	88,155 5.65	81,712 5.03	169,867 5.33
International migrant	8,455 0.54	8,431 0.52	16,886 0.53
Total	1,558,927 100.00	1,625,172 100.00	3,184,099 100.00

Pearson chi2(2) = 630.3698 Pr = 0.000



# Percentages, N, missing cases

`. tab migrant sex [fweight=perwt], col // percentage & population size`

Key
<i>frequency</i>
<i>column percentage</i>

migrant	Sex		Total
	Male	Female	
Non-migrant	<b>149645178</b>	<b>155097362</b>	<b>304742540</b>
	<b>93.99</b>	<b>94.38</b>	<b>94.19</b>
Internal migrant	<b>8660884</b>	<b>8318528</b>	<b>16979412</b>
	<b>5.44</b>	<b>5.06</b>	<b>5.25</b>
International migrant	<b>900980</b>	<b>918570</b>	<b>1819550</b>
	<b>0.57</b>	<b>0.56</b>	<b>0.56</b>
Total	<b>159207042</b>	<b>164334460</b>	<b>323541502</b>
	<b>100.00</b>	<b>100.00</b>	<b>100.00</b>

`. tab migrant sex, m // missing cases`

migrant	Sex		Total
	Male	Female	
Non-migrant	<b>1,462,317</b>	<b>1,535,029</b>	<b>2,997,346</b>
Internal migrant	<b>88,155</b>	<b>81,712</b>	<b>169,867</b>
International migrant	<b>8,455</b>	<b>8,431</b>	<b>16,886</b>
.	<b>15,691</b>	<b>14,749</b>	<b>30,440</b>
Total	<b>1,574,618</b>	<b>1,639,921</b>	<b>3,214,539</b>



# Edited table

**Table 1. Distribution of U.S. population by migration status and sex, 2018**

<b>Migration status</b>	<b>Male</b>	<b>Female</b>	<b>Total</b>
Non-migrant	93.99	94.38	94.19
Internal migrant	5.44	5.06	5.25
International migrant	0.57	0.56	0.56
<b>Total</b>	<b>100.00</b>	<b>100.00</b>	<b>100.00</b>
<b>Population size (N)</b>	159,207,042	164,334,460	323,541,502
<b>Sample size (n)</b>	1,558,927	1,625,172	3,184,099
Missing cases	15,691	14,749	30,440
<b>Chi square (df=2)</b>	630.37	p-value=0.000	

Source: 2018 American Community Survey.



# ACS: Education by race/ethnicity

- Does education attainment vary by race/ethnicity?
  - The probability of not rejecting  $H_0$  is small ( $p < 0.01$ )
  - Education attainment is dependent on race/ethnicity

```
. tab educgr raceth [fweight=perwt], col nofreq
```

educgr	raceth						Total
	White	African A	Hispanic	Asian	Native Am	Ohter rac	
Less than high school	23.19	30.14	49.76	27.23	20.66	47.04	35.24
High school	26.55	29.72	26.11	16.23	34.00	17.85	26.09
Some college	20.38	22.79	14.40	12.29	25.15	16.42	17.82
College	19.92	11.04	7.12	23.26	15.36	12.51	13.78
Graduate school	9.95	6.31	2.62	20.99	4.83	6.17	7.07
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00

```
. svy: tab educgr raceth, col
(running tabulate on estimation sample)
```

Number of strata = 212  
 Number of PSUs = 114,016

Number of obs = 272,776  
 Population size = 28,995,881  
 Design df = 113,804

Pearson:

Uncorrected chi2(20) = 3.03e+04  
 Design-based F(19.11, 2.2e+06) = 676.9183

**P = 0.0000**



# Edited table

**Table 1. Percentage distribution of population by educational attainment and race/ethnicity, Texas, 2019**

<b>Educational attainment</b>	<b>Non-Hispanic White</b>	<b>Non-Hispanic Black</b>	<b>Hispanic</b>	<b>Non-Hispanic Asian</b>	<b>Non-Hispanic Native American</b>	<b>Other races</b>	<b>Total</b>
Less than high school	23.19	30.14	49.76	27.23	20.66	47.04	35.24
High school	26.55	29.72	26.11	16.23	34.00	17.85	26.09
Some college	20.38	22.79	14.40	12.29	25.15	16.42	17.82
College	19.92	11.04	7.12	23.26	15.36	12.51	13.78
Graduate school	9.95	6.31	2.62	20.99	4.83	6.17	7.07
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Population size ( <i>N</i> )	11,929,840	3,445,104	11,527,412	1,444,220	79,394	569,911	28,995,881
Chi square ( <i>df</i> = 20)	3.03e+04						
Design-based <i>F</i> (19.11, 2.2e+06)	676.92						
<i>p</i> -value	0.0000						

Source: 2019 American Community Survey.





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# Measure of association for ordinal-level variables

- Spearman's Rho ( $r_s$ ) is a measure of association for ordinal-level variables with a broad range of different scores and few ties between cases on either variable
- Computing Spearman's Rho, Spearman's  $\rho$  ( $r_s$ )
  1. It ranks cases from high to low on each variable
  2. It uses ranks, not the scores, to calculate Rho

$$r_s = 1 - \frac{6 \sum D^2}{n(n^2 - 1)}$$

where  $\sum D^2$  is the sum of the squared differences in ranks



# Interpreting Spearman's Rho

- Spearman's Rho is positive
  - As the rank of one variable increases, the rank of the other variable also increases
- Spearman's Rho is negative
  - As the rank of one variable increases, the rank of the other variable decreases



# Example of Spearman's Rho ( $r_s$ )

## Scores on Involvement in Jogging and Self-Esteem

Jogger	Involvement in Jogging (X)	Self-Esteem (Y)
Wendy	18	15
Debbie	17	18
Phyllis	15	12
Stacey	12	16
Evelyn	10	6
Tricia	9	10
Christy	8	8
Patsy	8	7
Marsha	5	5
Lynn	1	2



# Computing Spearman's Rho ( $r_s$ )

## Computing Spearman's Rho

	Involvement (X)	Rank	Self-Image (Y)	Rank	$D$	$D^2$
Wendy	18	1	15	3	-2	4
Debbie	17	2	18	1	1	1
Phyllis	15	3	12	4	-1	1
Stacey	12	4	16	2	2	4
Evelyn	10	5	6	8	-3	9
Tricia	9	6	10	5	1	1
Christy	8	7.5	8	6	1.5	2.25
Patsy	8	7.5	7	7	0.5	0.25
Marsha	5	9	5	9	0	0
Lynn	1	10	2	10	0	0
					$\Sigma D = 0$	$\Sigma D^2 = 22.5$





# Result of Spearman's Rho ( $r_s$ )

- In the column headed  $D^2$ , each difference is squared to eliminate negative signs
- The sum of this column is  $\sum D^2$ , and this quantity is entered directly into the formula

$$r_s = 1 - \frac{6 \sum D^2}{n(n^2 - 1)} = 1 - \frac{6(22.5)}{10(100 - 1)} = 0.86$$

# Interpreting Spearman's Rho ( $r_s$ )

- Rho is positive, therefore jogging and self-image share a positive association
  - As jogging rank increases, self-image rank also increases
- On its own, Rho does not have a good strength interpretation
  - But  $Rho^2$  is a PRE measure...

# PRE measures

- The logic of Proportional Reduction in Error (PRE) measures is based on two predictions
  - First prediction,  $E_1$ : How many errors in predicting the value of the dependent variable (Y) do we make if we **ignore** information about the independent variable (X)
  - Second prediction,  $E_2$ : How many errors in predicting the value of the dependent variable (Y) do we make if we take the independent variable (X) into account
- If the variables are associated, we should make fewer errors of the second kind ( $E_2$ ) than we make of the first kind ( $E_1$ )



# Spearman's $Rho^2$

- $Rho^2$  is a PRE measure
- For this example,  $Rho^2 = (0.86)^2 = 0.74$
- We would make 74% fewer errors if we used the rank of jogging (X) to predict the rank on self-image (Y) compared to if we ignored the rank on jogging

# ACS: Education by age

- Is educational attainment different by age group?

. tab educgr agegr, col

Key
<i>frequency</i>
<i>column percentage</i>

educgr	agegr								Total
	0	16	20	25	35	45	55	65	
Less than high school	571,701 99.97	89,702 52.61	10,262 5.51	25,198 6.49	30,960 8.25	35,040 8.52	39,879 8.44	74,522 11.67	877,264 27.29
High school	157 0.03	59,928 35.15	71,447 38.39	119,445 30.78	111,837 29.79	141,857 34.50	184,217 38.97	259,161 40.58	948,049 29.49
Some college	0 0.00	20,766 12.18	72,420 38.92	93,352 24.05	85,507 22.78	91,946 22.36	107,832 22.81	123,053 19.27	594,876 18.51
College	0 0.00	105 0.06	29,469 15.84	102,919 26.52	85,850 22.87	85,309 20.75	84,454 17.86	98,425 15.41	486,531 15.14
Graduate school	0 0.00	0 0.00	2,495 1.34	47,199 12.16	61,261 16.32	57,053 13.87	56,382 11.93	83,429 13.06	307,819 9.58
Total	571,858 100.00	170,501 100.00	186,093 100.00	388,113 100.00	375,415 100.00	411,205 100.00	472,764 100.00	638,590 100.00	3,214,539 100.00

# Spearman's Rho in Stata

```
. spearman educgr agegr
```

```
Number of obs = 3214539  
Spearman's rho = 0.4405
```

```
Test of Ho: educgr and agegr are independent  
Prob > |t| = 0.0000
```

$$\text{Rho}^2 = (0.4405)^2 = 0.1940$$

# ACS: Percentages with weight

- Use column percentages from this table

```
. tab educgr agegr [fweight=perwt], col
```

Key
<i>frequency</i>
<i>column percentage</i>

educgr	agegr								Total
	0	16	20	25	35	45	55	65	
Less than high school	64932988 99.97	9592001 55.79	1233939 5.67	3146621 6.95	3999381 9.59	4047164 9.73	4092972 9.68	6713748 12.81	97758814 29.88
High school	17628 0.03	5676286 33.02	8516860 39.11	14302836 31.59	12637092 30.31	14222739 34.20	16105938 38.09	20704168 39.51	92183547 28.18
Some college	0 0.00	1915448 11.14	8462363 38.86	11380862 25.14	9705561 23.28	9436932 22.69	9710019 22.96	10211276 19.48	60822461 18.59
College	0 0.00	8720 0.05	3288424 15.10	11420420 25.22	9104449 21.84	8441402 20.30	7508620 17.76	8093763 15.44	47865798 14.63
Graduate school	0 0.00	0 0.00	276404 1.27	5026278 11.10	6240807 14.97	5444101 13.09	4864635 11.51	6684594 12.76	28536819 8.72
Total	64950616 100.00	17192455 100.00	21777990 100.00	45277017 100.00	41687290 100.00	41592338 100.00	42282184 100.00	52407549 100.00	327167439 100.00

# Edited table

**Table 1. Distribution of U.S. population by educational attainment and age group, 2018**

Educational attainment	Age group							
	0–15	16–19	20–24	25–34	35–44	45–54	55–64	65+
Less than high school	99.97	55.79	5.67	6.95	9.59	9.73	9.68	12.81
High school	0.03	33.02	39.11	31.59	30.31	34.20	38.09	39.51
Some college	0.00	11.14	38.86	25.14	23.28	22.69	22.96	19.48
College	0.00	0.05	15.10	25.22	21.84	20.30	17.76	15.44
Graduate school	0.00	0.00	1.27	11.10	14.97	13.09	11.51	12.76
<b>Total</b>	<b>100.00</b>	<b>100.00</b>	<b>100.00</b>	<b>100.00</b>	<b>100.00</b>	<b>100.00</b>	<b>100.00</b>	<b>100.00</b>
<b>Population size (N)</b>	64,950,616	17,192,455	21,777,990	45,277,017	41,687,290	41,592,338	42,282,184	52,407,549
<b>Sample size (n)</b>	571,858	170,501	186,093	388,113	375,415	411,205	472,764	638,590
<b>Spearman's Rho</b>	0.4405	p-value: 0.000						

Source: 2018 American Community Survey.







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# Measures of association for interval-ratio-level variables

- Analysis of variance (ANOVA)
- Scatterplots
- Pearson's  $r$



# Analysis of variance (ANOVA)

- ANOVA can be used in situations where the researcher is interested in the differences in sample means across three or more categories
  - How do Protestants, Catholics, and Jews vary in terms of number of children?
  - How do Republicans, Democrats, and Independents vary in terms of income?
  - How do older, middle-aged, and younger people vary in terms of frequency of church attendance?



# Extension of $t$ -test

- We can think of ANOVA as an extension of  $t$ -test for more than two groups
  - Are the differences between the samples large enough to reject the null hypothesis and justify the conclusion that the populations represented by the samples are different?
- Null hypothesis,  $H_0$ 
  - $H_0: \mu_1 = \mu_2 = \mu_3 = \dots = \mu_k$
  - All population means are similar to each other
- Alternative hypothesis,  $H_1$ 
  - At least one of the populations means is different



# Between and within differences

- If the  $H_0$  is true, the sample means should be about the same value
  - If the  $H_0$  is true, there will be little difference between sample means
- If the  $H_0$  is false
  - There should be substantial differences between sample means (between categories)
  - There should be relatively little difference within categories
    - The sample standard deviations should be small within groups



# Likelihood of rejecting $H_0$

- The greater the difference between categories (as measured by the means)
  - Relative to the differences within categories (as measured by the standard deviations)
  - The more likely the  $H_0$  can be rejected
- When we reject  $H_0$ 
  - We are saying there are differences between the populations represented by the sample



# Computation of ANOVA

1. Find total sum of squares (SST)

$$SST = \sum X_i^2 - n\bar{X}^2$$

2. Find sum of squares between (SSB)

$$SSB = \sum n_k (\bar{X}_k - \bar{X})^2$$

- SSB = sum of squares between categories
- $n_k$  = number of cases in a category
- $\bar{X}_k$  = mean of a category

3. Find sum of squares within (SSW)

$$SSW = SST - SSB$$



# 4. Degrees of freedom

$$\text{dfb} = k - 1$$

- $\text{dfb}$  = degrees of freedom between
- $k$  = number of categories

$$\text{dfw} = n - k$$

- $\text{dfw}$  = degrees of freedom within
- $n$  = total number of cases
- $k$  = number of categories





# Final estimations

5. Find mean square estimates

$$\text{Mean square between} = \frac{SSB}{dfb}$$

$$\text{Mean square within} = \frac{SSW}{dfw}$$

6. Find the  $F$  ratio

$$F(\text{obtained}) = \frac{\text{Mean square between}}{\text{Mean square within}}$$



# Limitations of ANOVA

- Requires interval-ratio level measurement of the dependent variable
- Requires roughly equal numbers of cases in the categories of the independent variable
- Statistically significant differences are not necessarily important (small magnitude)
- The alternative (research) hypothesis is not specific
  - It only asserts that at least one of the population means differs from the others



# ACS: Income by race/ethnicity

- We know the average income by race/ethnicity

```
. tabstat income if income!=0 & income!=. [fweight=perwt], by(raceth) stat(mean sd n)
```

Summary for variables: income  
Group variable: raceth

raceth	Mean	SD	N
White	63199.24	74601.04	6081513
African American	40079.03	40410.99	1766063
Hispanic	36595.08	38076.88	5250789
Asian	66528.88	73827.69	776722
Native American	44246.01	57666.53	44743
Other races	46151.98	58649.93	235029
Total	50285.44	60567.56	1.42e+07

- Does at least one category of race/ethnicity have average income different than the others?
  - This is not a perfect example for ANOVA, because race/ethnicity does not have equal numbers of cases across its categories

```
. svy, subpop(if income!=0 & income!=.): mean income, over(raceth)
(running mean on estimation sample)
```

```
. estat sd
(correct standard deviation)
```

Over	Mean	Std. dev.
c.income@ raceth		
White	63199.24	81952.97
African A..	40079.03	33729.03
Hispanic	36595.08	34417.96
Asian	66528.88	71633.26
Native Am..	44246.01	57876.89
Other races	46151.98	56501.55

```
. svy, subpop(if income!=0 & income!=.): mean income
(running mean on estimation sample)
```

```
. estat sd
```

	Mean	Std. dev.
income	50285.44	59920.72

# ANOVA in Stata

- The probability of not rejecting  $H_0$  is small ( $p < 0.01$ )
  - At least one category of the race/ethnicity variable has average income different than the others with a 99% confidence level
  - However, ANOVA does not inform which category has an average income significantly different than the others

```
. oneway income raceth if income!=0 & income!=. [aweight=perwt]
```

Analysis of variance					
Source	SS	df	MS	F	Prob > F
Between groups	2.2032e+13	5	4.4065e+12	1259.17	<b>0.0000</b>
Within groups	4.5608e+14	130325	3.4995e+09		(statistical significance)
Total	4.7811e+14	130330	3.6685e+09		

```
Bartlett's equal-variances test: chi2(5) = 1.2e+04 Prob>chi2 = 0.000
```

Source: 2019 American Community Survey, Texas.



# ACS: n, N

. \*\*\*Sample size of each category of race/ethnicity and missing cases  
 . tab raceth if income!=0 & income!=., m

raceth	Freq.	Percent	Cum.
White	69,043	52.98	52.98
African American	11,574	8.88	61.86
Hispanic	40,359	30.97	92.82
Asian	6,879	5.28	98.10
Native American	424	0.33	98.43
Other races	2,052	1.57	100.00
Total	130,331	100.00	

. \*\*\*Population size of each category of race/ethnicity  
 . tab raceth if income!=0 & income!=. [fweight=perwt]

raceth	Freq.	Percent	Cum.
White	6,081,513	42.96	42.96
African American	1,766,063	12.48	55.44
Hispanic	5,250,789	37.10	92.54
Asian	776,722	5.49	98.02
Native American	44,743	0.32	98.34
Other races	235,029	1.66	100.00
Total	14,154,859	100.00	

(correct percentage distribution)



# Edited table

**Table 1. One-way analysis of variance for wage and salary income by race/ethnicity, Texas, 2019**

Race/ethnicity	Income		Population percentage
	Mean	Standard deviation	
White	63,199.24	81,952.97	42.96
African American	40,079.03	33,729.03	12.48
Hispanic	36,595.08	34,417.96	37.10
Asian	66,528.88	71,633.26	5.49
Native American	44,246.01	57,876.89	0.32
Other races	46,151.98	56,501.55	1.66
Total	50,285.44	59,920.72	100.00
Population size	—	—	14,154,859
Sample size	—	—	130,331

ANOVA	Sum of squares	Degrees of freedom	Mean of squares	F-test	Prob > F
Between groups	2.20e+13	5	4.41e+12	1,259.17	0.0000
Within groups	4.56e+14	130,325	3.50e+09		
Total	4.78e+14	130,330	3.67e+09		





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# Scatterplots

- Scatterplots can be used to answer these questions
  1. Is there an association?
  2. How strong is the association?
  3. What is the pattern of the association?

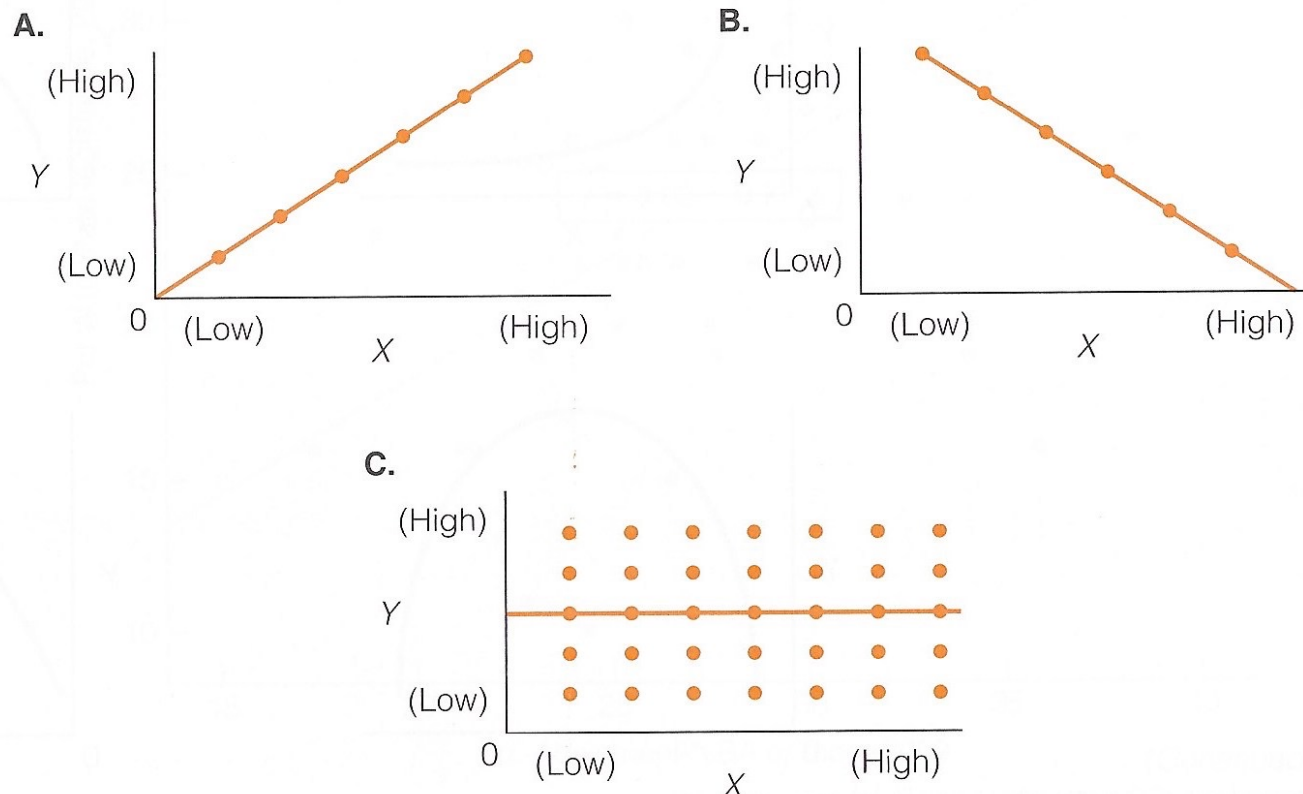




# Pattern of the association

- The pattern or direction of association is determined by the angle of the regression line

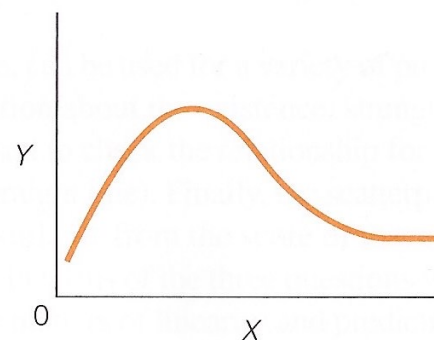
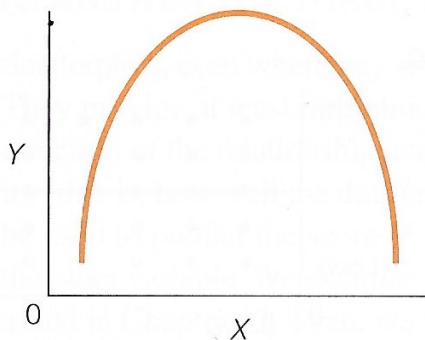
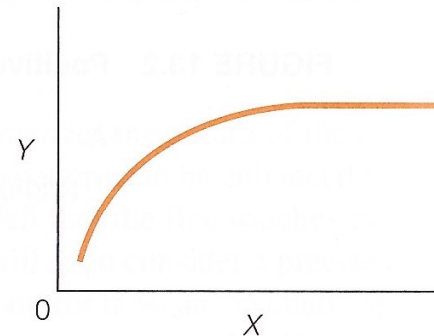
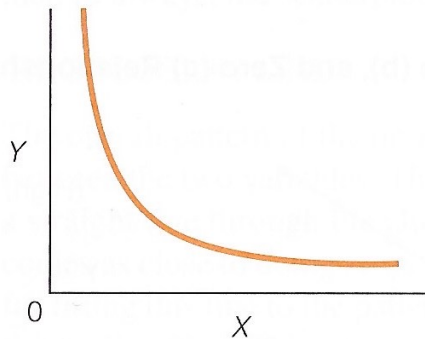
Positive (a), Negative (b), and Zero (c) Relationships



# Nonlinear associations

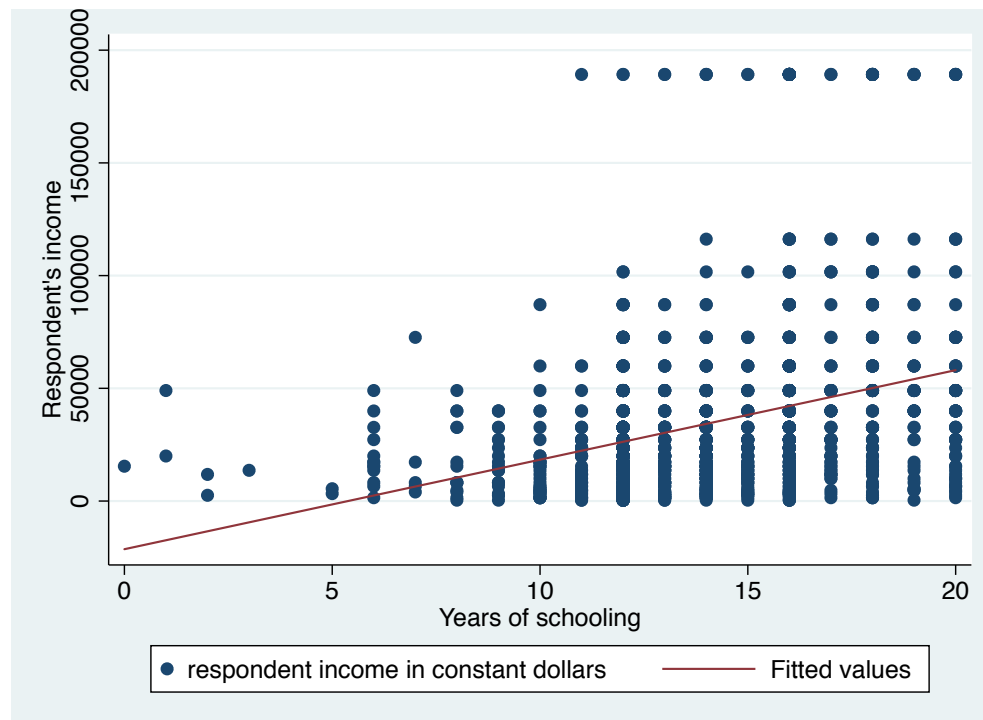
- In a nonlinear association, the dots do not form a straight line pattern

Some Nonlinear Relationships



# GSS: Income by education

**Figure 1. Respondent's income by years of schooling, U.S. adult population, 2016**



$$\text{Income} = -26,219.18 + 4,326.10(\text{Years of schooling})$$

Note: The scatterplot was generated without the complex survey design of the General Social Survey. The regression was generated taking into account the complex survey design of the General Social Survey.

Source: 2016 General Social Survey.

# GSS: Income = F(Education)

```

***Dependent variable: Respondent's income (conrinc)
***Independent variable: Years of schooling (educ)

***Scatterplot with regression line
tway scatter conrinc educ || lfit conrinc educ, ytitle(Respondent's income) xtitle(Years of schooling)

***Regression coefficients
***Least-squares regression model
***They can be reported in the footnote of the scatterplot
svy: reg conrinc educ

```

```

. svy: reg conrinc educ
(running regress on estimation sample)

```

Survey: Linear regression

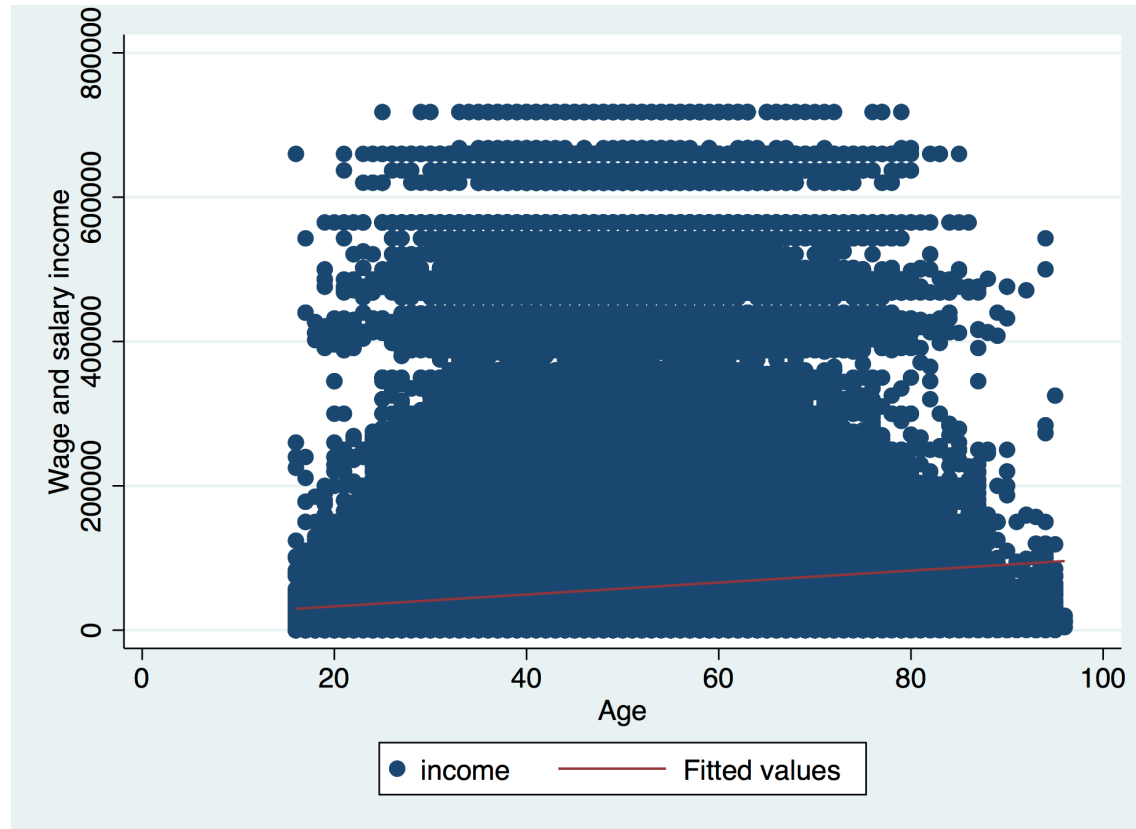
Number of strata	=	<b>65</b>	Number of obs	=	<b>1,631</b>
Number of PSUs	=	<b>130</b>	Population size	=	<b>1,694.7478</b>
			Design df	=	<b>65</b>
			F( 1, 65)	=	<b>88.15</b>
			Prob > F	=	<b>0.0000</b>
			R-squared	=	<b>0.1147</b>

conrinc	Linearized				
	Coef.	Std. Err.	t	P> t	[95% Conf. Interval]
educ	<b>4326.103</b>	<b>460.7631</b>	<b>9.39</b>	<b>0.000</b>	<b>3405.896 5246.311</b>
_cons	<b>-26219.18</b>	<b>5819.513</b>	<b>-4.51</b>	<b>0.000</b>	<b>-37841.55 -14596.81</b>



# ACS: Income by age

Figure 1. Wage and salary income by age, U.S. 2018



$$\text{Income} = 13,447.38 + 888.23(\text{Age})$$

Note: The scatterplot was generated without the ACS complex survey design. The regression was generated taking into account the ACS complex survey design. Only people with some wage and salary income are included.

Source: 2018 American Community Survey (ACS).

# ACS: Income = F(Age)

\*\*\*Dependent variable: Wage and salary income (income)

\*\*\*Independent variable: Age (age)

\*\*\*Scatterplot with regression line

twoway (scatter income age) (lfit income age) if income!=0, ytitle(Wage and salary income) xtitle(Age)

```
. svy, subpop(if income!=. & income!=0): reg income age
(running regress on estimation sample)
```

Survey: Linear regression

Number of strata = 2,351  
Number of PSUs = 1,410,976

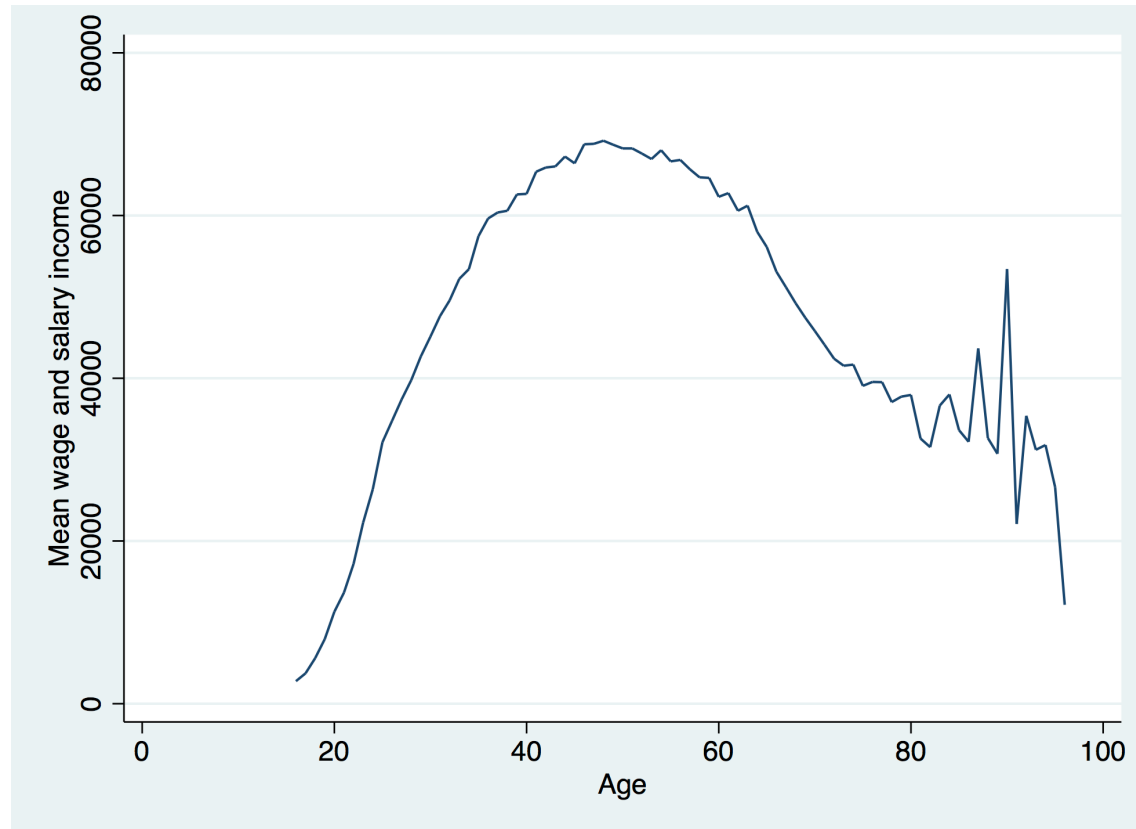
Number of obs = 3,214,539  
Population size = 327,167,439  
Subpop. no. obs = 1,574,313  
Subpop. size = 163,349,075  
Design df = 1,408,625  
F( 1,1408625) = 57648.04  
Prob > F = 0.0000  
R-squared = 0.0449

income	Linearized					
	Coef.	Std. Err.	t	P> t	[95% Conf. Interval]	
age	888.2282	3.699409	240.10	0.000	880.9775	895.479
_cons	13447.38	138.3572	97.19	0.000	13176.21	13718.56



# ACS: Mean income by age

Figure 1. Mean wage and salary income by age, U.S. 2018



$$\text{Income} = -73,956.52 + 5,492.81(\text{Age}) - 53.36(\text{Age squared})$$

Note: The line graph was generated taking into account the ACS sample weight. The regression was generated taking into account the ACS complex survey design. Only people with some wage and salary income are included.

Source: 2018 American Community Survey (ACS).

# ACS: Income = F(Age, Age<sup>2</sup>)

```

***Dependent variable: Wage and salary income (income)
***Independent variables: Age (age), age squared (agesq)

***Generate variable with mean income by age
bysort age: egen mincage=mean(income) if income!=0

***Line graph of income by age
tway line mincage age [fweight=perwt], ytitle("Mean wage and salary income") ylabel(0(20000)80000)

***Generate age squared
gen agesq=age * age

. svy, subpop(if income!=. & income!=0): reg income age agesq
(running regress on estimation sample)

```

Survey: Linear regression

Number of strata	=	2,351	Number of obs	=	3,214,539
Number of PSUs	=	1,410,976	Population size	=	327,167,439
			Subpop. no. obs	=	1,574,313
			Subpop. size	=	163,349,075
			Design df	=	1,408,625
			F( 2,1408624)	=	85652.78
			Prob > F	=	0.0000
			R-squared	=	0.0839

income	Linearized					
	Coef.	Std. Err.	t	P> t	[95% Conf. Interval]	
age	5492.806	20.13499	272.80	0.000	5453.342	5532.27
agesq	-53.36376	.2435244	-219.13	0.000	-53.84106	-52.88646
_cons	-73956.52	352.3116	-209.92	0.000	-74647.03	-73266





# ACS: Income by age group

```
. ***Use aweight to get sample size by age group  
. table agegr [aweight=perwt] if income!=0, c(mean income sd income n income)
```

agegr	mean(income)	sd(income)	N(income)
0			0
16	6255.097	10792.61	82,884
20	18744.6	19610.05	146,813
25	42093.8	39527.84	315,787
35	60282.16	65996.67	296,932
45	66337.25	74647.34	315,072
55	63089.86	73052.64	296,653
65	47947.36	72828.89	120,172



# ACS: Income = F(Age groups)

```
. ***Reference category: 45-54
. char agegr[omit] 45

.
. ***Income <- Age groups
. xi: svy, subpop(if income!=. & income!=0): reg income i.agegr
i.agegr      _Iagegr_0-65      (naturally coded; _Iagegr_45 omitted)
(running regress on estimation sample)
```

Survey: Linear regression

Number of strata	=	2,351	Number of obs	=	3,214,539
Number of PSUs	=	1,410,976	Population size	=	327,167,439
			Subpop. no. obs	=	1,574,313
			Subpop. size	=	163,349,075
			Design df	=	1,408,625
			F( 6,1408620)	=	62649.13
			Prob > F	=	0.0000
			R-squared	=	0.0808

income	Linearized		t	P> t	[95% Conf. Interval]	
	Coef.	Std. Err.				
_Iagegr_0	0 (omitted)					
_Iagegr_16	-60082.15	166.6691	-360.49	0.000	-60408.82	-59755.48
_Iagegr_20	-47592.64	172.1686	-276.43	0.000	-47930.09	-47255.2
_Iagegr_25	-24243.44	181.4771	-133.59	0.000	-24599.13	-23887.76
_Iagegr_35	-6055.089	215.5623	-28.09	0.000	-6477.584	-5632.594
_Iagegr_55	-3247.394	225.8159	-14.38	0.000	-3689.985	-2804.802
_Iagegr_65	-18389.89	299.2292	-61.46	0.000	-18976.37	-17803.41
_cons	66337.25	158.7966	417.75	0.000	66026.01	66648.48





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# Pearson's $r$

- Pearson's  $r$  is a measure of association for interval-ratio level variables

$$r = \frac{\sum(X - \bar{X})(Y - \bar{Y})}{\sqrt{[\sum(X - \bar{X})^2][\sum(Y - \bar{Y})^2]}}$$

- Pearson's  $r$  indicate the direction of association
  - $-1.00$  indicates perfect negative association
  - $0.00$  indicates no association
  - $+1.00$  indicates perfect positive association
- It doesn't have a direct interpretation of strength

# Coefficient of determination ( $r^2$ )

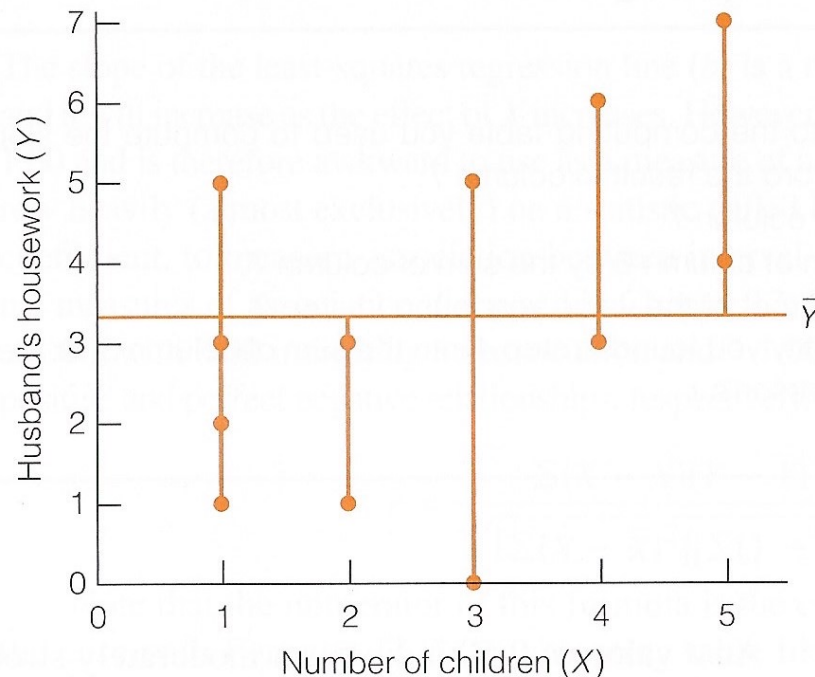
- For a more direct interpretation of the strength of the linear association between two variables
  - Calculate the coefficient of determination ( $r^2$ )
- The coefficient of determination informs the percentage of the variation in Y explained by X
- It uses a logic similar to the proportional reduction in error (PRE) measure
  - Y is predicted while ignoring the information on X
    - Mean of the Y scores:  $\bar{Y}$
  - Y is predicted taking into account information on X



# Predicting Y without X

- The scores of any variable vary less around the mean than around any other point
  - The vertical lines from the actual scores to the predicted scores represent the amount of error of predicting Y while ignoring X

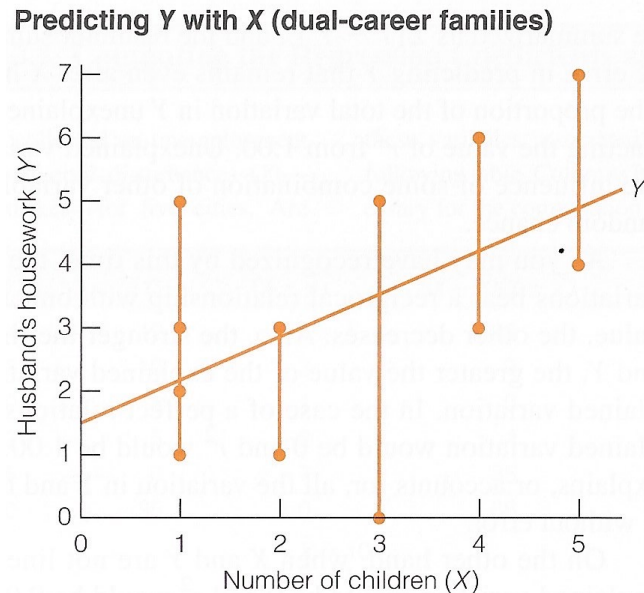
Predicting Y Without X (dual-career families)



# Predicting Y with X

- If the Y and X have a linear association
  - Predicting scores on Y from the least-squares regression equation will incorporate knowledge of X
  - The vertical lines from each data point to the regression line represent the amount of error in predicting Y that remains even after X has been taken into account

$$Y' = a + bX$$



# Estimating $r^2$

- **Total variation**:  $\sum(Y - \bar{Y})^2$ 
  - Gives the error we incur by predicting ***Y without knowledge of X***
- **Explained variation**:  $\sum(Y' - \bar{Y})^2 = \sum(\hat{Y} - \bar{Y})^2$ 
  - Improvement in our ability to predict ***Y when taking X into account***
- $r^2$  indicates how much X helps us predict Y

$$r^2 = \frac{\sum(\hat{Y} - \bar{Y})^2}{\sum(Y - \bar{Y})^2} = \frac{\text{Explained variation}}{\text{Total variation}}$$





# Unexplained variation

- **Unexplained variation**:  $\sum(Y - Y')^2 = \sum(Y - \hat{Y})^2$ 
  - Difference between our best prediction of Y with X ( $Y'$ ) and the actual scores (Y)
  - It is the aggregation of vertical lines from the actual scores to the regression line
  - This is the amount of error in predicting Y that remains after X has been taken into account
  - It is caused by omitted variables, measurement error, and/or random chance
  - This is the residual of the regression



# Example: Pearson's $r$

- Number of children ( $X$ ) and hours per week husband spends on housework ( $Y$ )

Computation of Pearson's  $r$

1	2	3	4	5	6	7
$X$	$X - \bar{X}$	$Y$	$Y - \bar{Y}$	$(X - \bar{X})(Y - \bar{Y})$	$(X - \bar{X})^2$	$(Y - \bar{Y})^2$
1	-1.67	1	-2.33	3.89	2.79	5.43
1	-1.67	2	-1.33	2.22	2.79	1.77
1	-1.67	3	-0.33	0.55	2.79	0.11
1	-1.67	5	1.67	-2.79	2.79	2.79
2	-0.67	3	-0.33	0.22	0.45	0.11
2	-0.67	1	-2.33	1.56	0.45	5.43
3	0.33	5	1.67	0.55	0.11	2.79
3	0.33	0	-3.33	-1.10	0.11	11.09
4	1.33	6	2.67	3.55	1.77	7.13
4	1.33	3	-0.33	-0.44	1.77	0.11
5	2.33	7	3.67	8.55	5.43	13.47
<u>5</u>	<u>2.33</u>	<u>4</u>	<u>0.67</u>	<u>1.56</u>	<u>5.43</u>	<u>0.45</u>
32	-0.04	40	0.04	18.32	26.68	50.68



Example: calculate  $r$

$$r = \frac{\sum(X - \bar{X})(Y - \bar{Y})}{\sqrt{[\sum(X - \bar{X})^2][\sum(Y - \bar{Y})^2]}}$$

$$r = \frac{18.32}{\sqrt{(26.68)(50.68)}}$$

$$r = 0.50$$



# Example: interpretation

- $r = 0.50$ 
  - The association between X and Y is positive
  - As the number of children increases, husbands' hours of housework per week also increases
- $r^2 = (0.50)^2 = 0.25$ 
  - The number of children explains 25% of the total variation in husbands' hours of housework per week
  - We make 25% fewer errors by basing the prediction of husbands' housework hours on number of children
    - We make 25% fewer errors by using the regression line
    - As opposed to ignoring the X variable and predicting the mean of Y for every case



# Test Pearson's $r$ for significance

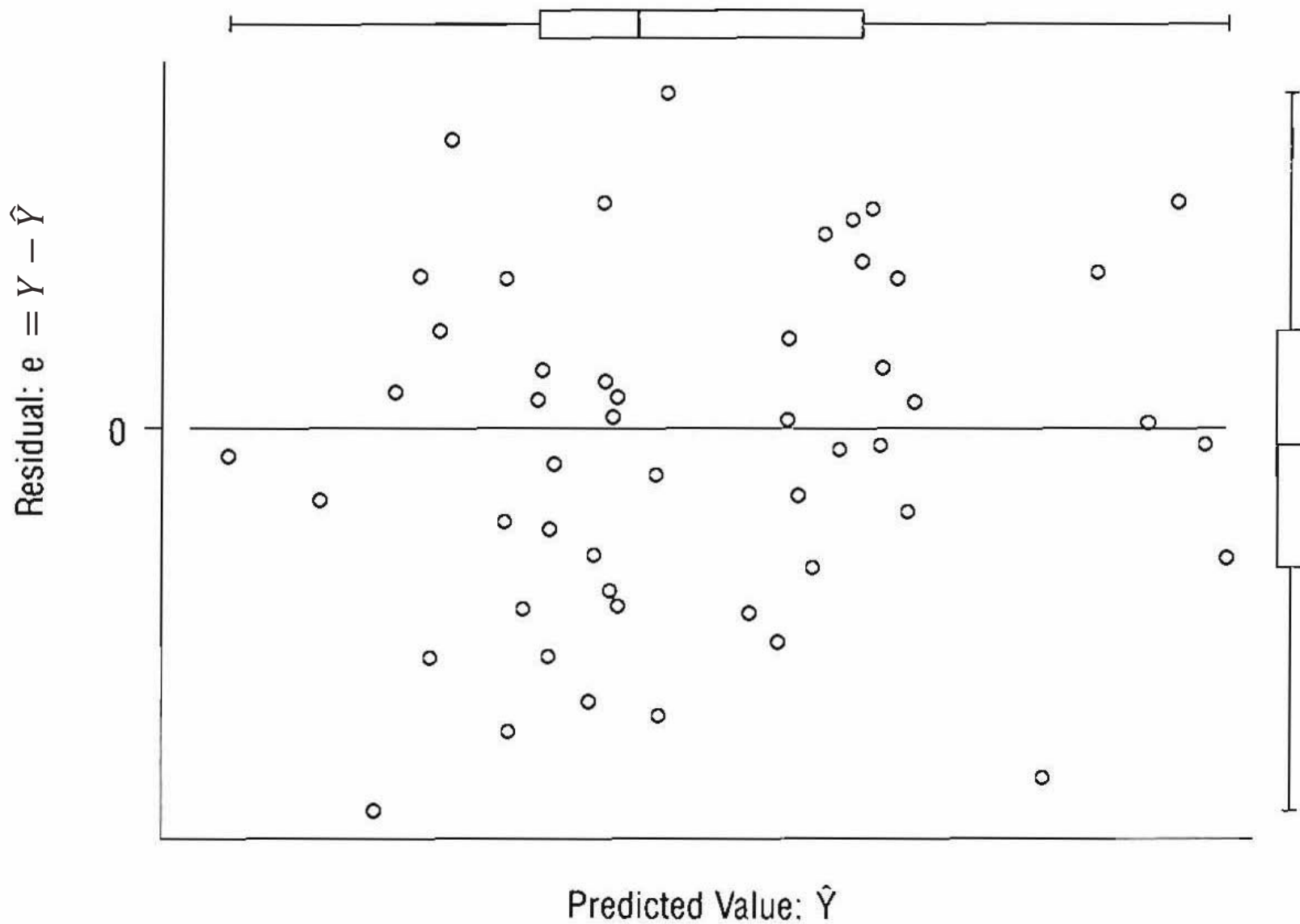
- Use the five-step model
  1. Make assumptions and meet test requirements
  2. Define the null hypothesis ( $H_0$ )
  3. Select the sampling distribution and establish the critical region
  4. Compute the test statistic
  5. Make a decision and interpret the test results



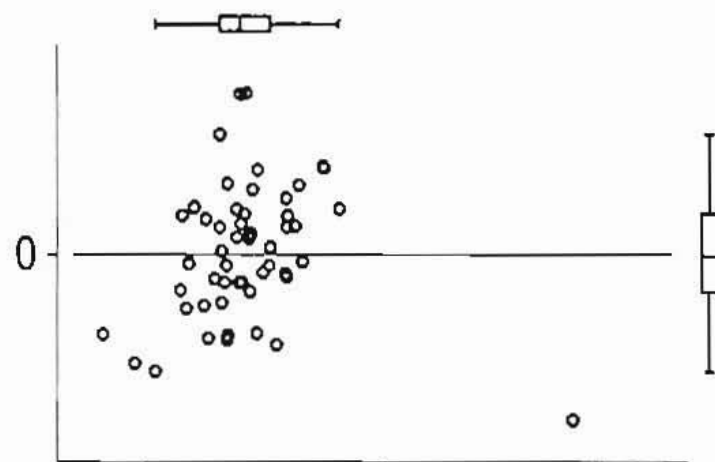
# Step 1: Assumptions, requirements

- Random sampling
- Interval-ratio level measurement
- Bivariate normal distributions
- Linear association
- Homoscedasticity
  - The variance of Y scores is uniform for all values of X
  - If the Y scores are evenly spread above and below the regression line for the entire length of the line, the association is homoscedastic
- Normal sampling distribution

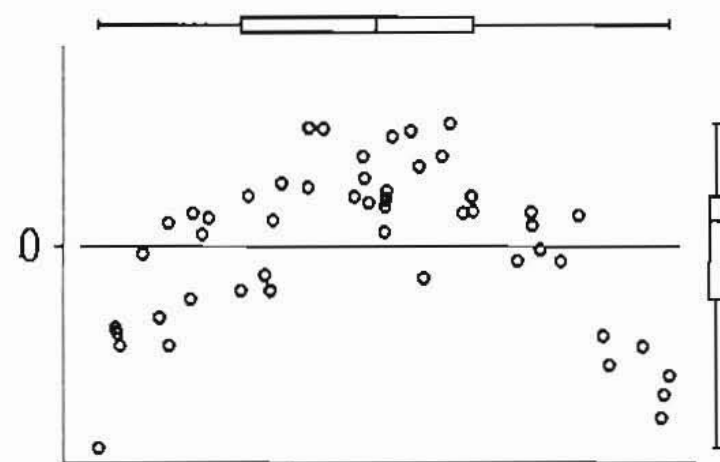




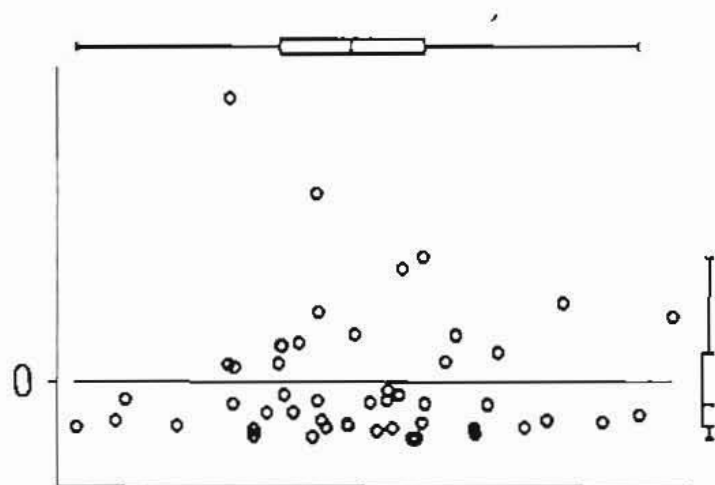
**Figure 2.10** "All clear"  $e$ -versus- $\hat{Y}$  plot (artificial data).



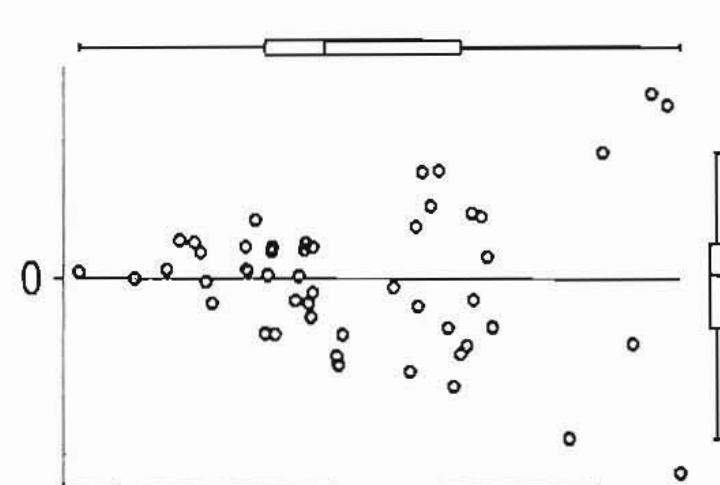
Influential Case



Curvilinear Relation



Nonnormal Residual Distribution



Heteroscedasticity

**Figure 2.11** Examples of trouble seen in  $e$ -versus- $\hat{Y}$  plots (artificial data).



# Step 2: Null hypothesis

- Null hypothesis,  $H_0: \rho = 0$ 
  - $H_0$  states that there is no correlation between the number of children ( $X$ ) and hours per week husband spends on housework ( $Y$ )
  
- Alternative hypothesis,  $H_1: \rho \neq 0$ 
  - $H_1$  states that there is a correlation between the number of children ( $X$ ) and hours per week husband spends on housework ( $Y$ )

# Step 3: Distribution, critical region

- Sampling distribution: Student's  $t$
- Alpha = 0.05 (two-tailed)
- Degrees of freedom =  $n - 2 = 12 - 2 = 10$
- $t(\text{critical}) = \pm 2.228$



## Step 4: Test statistic

$$t(\textit{obtained}) = r \sqrt{\frac{n - 2}{1 - r^2}}$$

$$t(\textit{obtained}) = (0.50) \sqrt{\frac{12 - 2}{1 - (0.50)^2}}$$

$$t(\textit{obtained}) = 1.83$$



# Step 5: Decision, interpret

- $t(\text{obtained}) = 1.83$ 
  - This is not beyond the  $t(\text{critical}) = \pm 2.228$
  - The  $t(\text{obtained})$  does not fall in the critical region, so we ***do not reject*** the  $H_0$
- The two variables are not correlated in the population
  - The correlation between number of children (X) and hours per week husband spends on housework (Y) is not statistically significant



# Correlation matrix

- Table that shows the associations between all possible pairs of variables
  - Which are the strongest and weakest associations among birth rate, education, poverty, and teen births?

A Correlation Matrix Showing the Relationships Among Four Variables

	1	2	3	4
	Birth Rate	Education	Poverty	Teen Births
1. Birth Rate	1.00	-0.24	0.16	0.26
2. Education	-0.24	1.00	-0.71	-0.78
3. Poverty	0.16	-0.71	1.00	0.88
4. Teen Births	0.26	-0.78	0.88	1.00

KEY: "Birth Rate" is number of births per 1000 population.

"Education" is percentage of the population with a college degree or more.

"Poverty" is percentage of families below the poverty line.

"Teen Births" is the percentage of all births to teenagers.

# GSS: Income, Age, Education

```
. ***Respondent's income income, age, education
. pcorr conrinc age educ [aweight=wtssall], sig
```

	conrinc	age	educ
conrinc	1.0000		
age	0.1852 0.0000	1.0000	
educ	0.3387 0.0000	-0.0131 0.4857	1.0000

```
.
. ***Coefficient of determination (r-squared)
. ***Respondent's income and age
. di .1852^2
.03429904
```

```
.
. ***Coefficient of determination (r-squared)
. ***Respondent's income and education
. di .3387^2
.11471769
```



# Edited table

**Table 1. Pearson's  $r$  and coefficient of determination ( $r^2$ ) for the association of respondent's income with age and years of schooling, U.S. adult population, 2016**

<b>Independent variable</b>	<b>Pearson's <math>r</math></b>	<b>Coefficient of determination (<math>r^2</math>)</b>
Age	0.1852***	0.0343
Years of schooling	0.3387***	0.1147

Note: Pearson's  $r$  and coefficient of determination ( $r^2$ ) were generated taking into account the survey weight of the General Social Survey. \*Significant at  $p < 0.10$ ; \*\*Significant at  $p < 0.05$ ; \*\*\*Significant at  $p < 0.01$ .

Source: 2016 General Social Survey.

# ACS: Income, Age, Education

```
. ***Wage and salary income, age, education  
. pcorr income age educ if income!=0 [aweight=perwt], sig
```

	income	age	educ
income	1.0000		
age	0.2118 0.0000	1.0000	
educ	0.3360 0.0000	0.6768 0.0000	1.0000

```
.  
. ***Coefficient of determination (r-squared)  
. ***Income and age  
. di .2118^2  
.04485924
```

```
.  
. ***Coefficient of determination (r-squared)  
. ***Income and education  
. di .3360^2  
.112896
```





# Edited table

**Table 1. Pearson's  $r$  and coefficient of determination ( $r^2$ ) for the association of wage and salary income with age and educational attainment, United States, 2018**

<b>Independent variable</b>	<b>Pearson's <math>r</math></b>	<b>Coefficient of determination (<math>r^2</math>)</b>
Age	0.2118***	0.0449
Educational attainment	0.3360***	0.1129

Note: Pearson's  $r$  and coefficient of determination ( $r^2$ ) were generated taking into account the survey weight of the American Community Survey. \*Significant at  $p < 0.10$ ; \*\*Significant at  $p < 0.05$ ; \*\*\*Significant at  $p < 0.01$ .

Source: 2018 American Community Survey.





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