Linear Modelling in Stata
Session 6: Further Topics in Linear Modelling

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This Week

- Categorical Variables
  - Comparing outcome between groups
  - Comparing slopes between groups (Interactions)
- Confounding
- Variable Selection
- Other considerations
  - Polynomial Regression
  - Transformation
  - Regression through the origin

Categorical Variables

- None of the linear model assumptions mention the distribution of x.
- Can use x-variables with any distribution
- This enables us to compare different groups

Dichotomous Variable

- Let $x = 0$ in group A and $x = 1$ in group B.
- Linear model equation is $\hat{Y} = \beta_0 + \beta_1 x$
- In group A, $x = 0$ so $\hat{Y} = \beta_0$
- In group B, $x = 1$ so $\hat{Y} = \beta_0 + \beta_1$
- Hence the coefficient of x gives the difference in mean between the two groups.

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Dichotomous Variable Example

- x takes values 0 or 1
- Y is normally distributed with variance 1, and mean 3 if $x = 0$ and 4 if $x = 1$.
- We wish to test if there difference in the mean value of Y between the groups with $x = 0$ and $x = 1$

Dichotomous Variable: Stata output

```
. regress Y x

      Source |       SS       df       MS              Number of obs =      40
-------------+------------------------------           F(  1,    38) =   10.97
       Model |  9.86319435     1  9.86319435           Prob > F      =  0.0020
    Residual |  34.1679607    38   .89915686           R-squared     =  0.2240
-------------+------------------------------           Adj R-squared =  0.2036
       Total |   44.031155    39  1.12900398           Root MSE      =  .94824

------------------------------------------------------------------------------
           Y |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
           x |   .9931362   .2998594     3.31   0.002     .3861025     1.60017
       _cons |     3.0325   .2120326    14.30   0.000     2.603262    3.461737
------------------------------------------------------------------------------
```

Dichotomous Variables and the T-Test

- Differences in mean between two groups usually tested for with t-test.
- Linear model results are *exactly* the same.
- Linear model assumptions are *exactly* the same.
  - Normal distribution in each group
  - Same variance in each group
- A t-test is a special case of a linear model.
- Linear model is far more versatile (can adjust for other variables).

T-Test: Stata output

```
. ttest Y, by(x)

Two-sample t test with equal variances
------------------------------------------------------------------------------
   Group |     Obs        Mean    Std. Err.   Std. Dev.   [95% Conf. Interval]
---------+--------------------------------------------------------------------
       0 |      20      3.0325    .2467866    1.103663    2.515969     3.54903
       1 |      20    4.025636    .1703292    .7617355    3.669133    4.382139
---------+--------------------------------------------------------------------
combined |      40    3.529068    .1680033    1.062546    3.189249    3.868886
---------+--------------------------------------------------------------------
    diff |           -.9931362    .2998594                -1.60017   -.3861025
------------------------------------------------------------------------------
    diff = mean(0) - mean(1)                                      t =  -3.3120
Ho: diff = 0                                     degrees of freedom =       38

    Ha: diff < 0                 Ha: diff != 0                 Ha: diff > 0
 Pr(T < t) = 0.0010         Pr(|T| > |t|) = 0.0020          Pr(T > t) = 0.9990
```

Categorical Variable with Several Categories

- What can we do if there are more than two categories ?
- Cannot use $x = 0, \ 1, \ 2, \ \ldots$.
- Instead we use "dummy" or "indicator" variables.
- If there are k categories, we need $k - 1$ indicators.

Three Groups: Example

Group	x_1	x_2	$\bar{Y}$	σ^2	
A	0	0	3	1	Baseline Group
B	1	0	5	1	
C	0	1	4	1	

- $\beta_0 = \hat{Y}$ in group A
- β_1 = difference between $\hat{Y}$ in group A and $\hat{Y}$ in group B
- β_2 = difference between $\hat{Y}$ in group A and $\hat{Y}$ in group C

Three Groups: Stata Output

```
. regress Y x1 x2

      Source |       SS       df       MS              Number of obs =      60
-------------+------------------------------           F(  2,    57) =   16.82
       Model |  37.1174969     2  18.5587485           Prob > F      =  0.0000
    Residual |  62.8970695    57  1.10345736           R-squared     =  0.3711
-------------+------------------------------           Adj R-squared =  0.3491
       Total |  100.014566    59  1.69516214           Root MSE      =  1.0505

------------------------------------------------------------------------------
           Y |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
          x1 |   1.924713   .3321833     5.79   0.000     1.259528    2.589899
          x2 |   1.035985   .3321833     3.12   0.003     .3707994    1.701171
       _cons |   3.075665   .2348891    13.09   0.000     2.605308    3.546022
------------------------------------------------------------------------------
```

Comparing Groups

- In the previous example, groups B and C both compared to group A.
- Can we compare groups B and C as well ?
- In group B, $\hat{Y} = \beta_0 + \beta_1$
- In group C, $\hat{Y} = \beta_0 + \beta_2$
- Hence difference between groups is $\beta_1 - \beta_2$
- Can use `lincom` to obtain this difference, and test its significance.

The `lincom` Command

- `lincom` is short for linear combination.
- It can be used to calculate linear combinations of the parameters of a linear model.
- Linear combination = $a_j\beta_j + a_k\beta_k + \ldots$
- Can be used to find differences between groups (Difference between Group B and Group C = $\beta_1 - \beta_2$)
- Can be used to find mean values in groups (Mean value in group B = $\beta_0 + \beta_1$).

Stata Output from `lincom`

```
. lincom x1 - x2

 ( 1)  x1 - x2 = 0

------------------------------------------------------------------------------
           Y |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
         (1) |   .8887284   .3321833     2.68   0.010     .2235428    1.553914
------------------------------------------------------------------------------

. lincom _cons + x1

 ( 1)  x1 + _cons = 0

------------------------------------------------------------------------------
           Y |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
         (1) |   5.000378   .2348891    21.29   0.000     4.530021    5.470736
------------------------------------------------------------------------------
```

Factor Variables in Stata

- Generating dummy variables can be tedious and error-prone
- Stata can do it for you
- Identify categorical variables by adding "`i.`" to the start of their name.
- For example, suppose that the variable `group` contains the values "1", "2" and "3" for the three groups in the previous example.

Stata Output with a Factor Variable

```
. regress Y i.group

      Source |       SS           df       MS      Number of obs   =        60
-------------+----------------------------------   F(2, 57)        =     16.82
       Model |  37.1174969         2  18.5587485   Prob > F        =    0.0000
    Residual |  62.8970695        57  1.10345736   R-squared       =    0.3711
-------------+----------------------------------   Adj R-squared   =    0.3491
       Total |  100.014566        59  1.69516214   Root MSE        =    1.0505

------------------------------------------------------------------------------
           Y |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
       group |
          2  |   1.924713   .3321833     5.79   0.000     1.259528    2.589899
          3  |   1.035985   .3321833     3.12   0.003     .3707994    1.701171
             |
       _cons |   3.075665   .2348891    13.09   0.000     2.605308    3.546022
------------------------------------------------------------------------------
```

Using factor variables with `lincom`

```
. lincom 2.group - 3.group

 ( 1)  2.group - 3.group = 0

------------------------------------------------------------------------------
           Y |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
         (1) |   .8887284   .3321833     2.68   0.010     .2235428    1.553914
------------------------------------------------------------------------------

. lincom _cons + 2.group

 ( 1)  2.group + _cons = 0

------------------------------------------------------------------------------
           Y |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
         (1) |   5.000378   .2348891    21.29   0.000     4.530021    5.470736
------------------------------------------------------------------------------
```

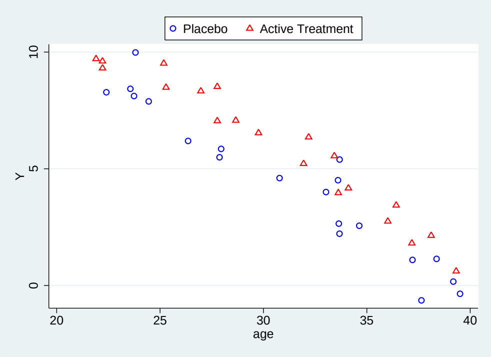
Linear Models and ANOVA

- Differences in mean between more than two groups usually tested for with ANOVA.
- Linear model results are *exactly* the same.
- Linear model assumptions are *exactly* the same.
- ANOVA is a special case of a linear model.
- Linear model is far more versatile (can adjust for other variables).

Mixing Categorical & Continuous Variables

- So far, we have only seen either continuous or categorical predictors in a linear model.
- No problem to mix both.
- E.g. Consider a clinical trial in which the outcome is strongly associated with age.
- To test the effect of treatment, need to include both age and treatment in linear model.
- Once upon a time, this was called Analysis of Covariance (ANCOVA)

Example Clinical Trial: simulated data



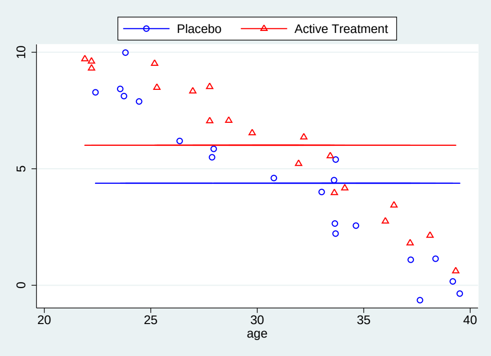
Stata Output Ignoring the Effect of Age

```
. regress Y treat

      Source |       SS       df       MS              Number of obs =      40
-------------+------------------------------           F(  1,    38) =    2.86
       Model |  26.5431819     1  26.5431819           Prob > F      =  0.0989
    Residual |  352.500943    38  9.27634061           R-squared     =  0.0700
-------------+------------------------------           Adj R-squared =  0.0456
       Total |  379.044125    39  9.71908013           Root MSE      =  3.0457

------------------------------------------------------------------------------
           Y |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
       treat |   1.629208   .9631376     1.69   0.099    -.3205623    3.578978
       _cons |   4.379165   .6810411     6.43   0.000      3.00047    5.757861
------------------------------------------------------------------------------
```

Observed and predicted values from linear model ignoring age



Stata Output Including the Effect of Age

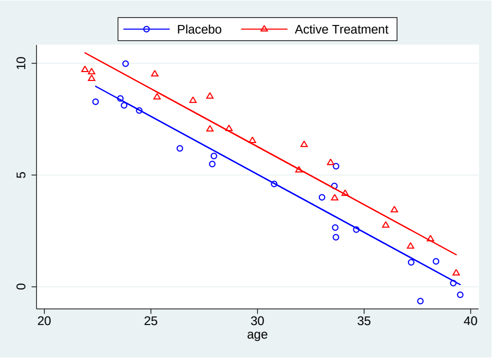
```
. regress Y treat age

      Source |       SS       df       MS              Number of obs =      40
-------------+------------------------------           F(  2,    37) =  262.58
       Model |  354.096059     2  177.04803           Prob > F      =  0.0000
    Residual |  24.9480658    37  .674272049           R-squared     =  0.9342
-------------+------------------------------           Adj R-squared =  0.9306
       Total |  379.044125    39  9.71908013           Root MSE      =  .82114

------------------------------------------------------------------------------
           Y |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
       treat |   1.238752   .2602711     4.76   0.000     .7113924    1.766111
         age |  -.5186644   .0235322   -22.04   0.000    -.5663453   -.4709836
       _cons |   20.59089   .7581107    27.16   0.000     19.05481    22.12696
------------------------------------------------------------------------------
```

- Age explains variation in Y
- This reduces RMSE (estimate of σ)
- Standard error of coefficient = $\frac{\sigma}{\sqrt{n s_x}}$

Observed and predicted values from linear model including age



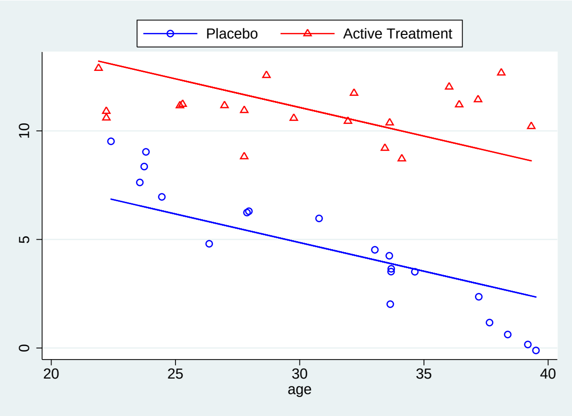
Interactions

- In previous example, assumed that the effect of age was the same in treated and untreated groups.
- I.e. regression lines were parallel.
- This may not be the case.
- If the effect of one variable varies accord to the value of another variable, this is called “interaction” between the variables.
- Don’t assume that an effect differs between two groups because it is significant in one, not in the other

Interaction Example

- Consider the clinical trial in the previous example
- Suppose treatment reverses the effect of aging, so that $\hat{Y}$ is constant in the treated group.
- Thus the difference between the treated and untreated groups will increase with increasing age.
- Need to fit different intercepts and different slopes in the two groups.

Clinical trial data with predictions assuming equal slopes



Regression Equations

- Need to fit the two equations

$$Y = \begin{cases} \beta_{00} + \beta_{10} \times \texttt{age} + \varepsilon & \text{if } \texttt{treat} = 0 \\ \beta_{01} + \beta_{11} \times \texttt{age} + \varepsilon & \text{if } \texttt{treat} = 1 \end{cases}$$

- These are equivalent to the equation

$$Y = \beta_{00} + \beta_{10} \times \text{age} + (\beta_{01} - \beta_{00}) \times \text{treat} + (\beta_{11} - \beta_{10}) \times \text{age} \times \text{treat} + \varepsilon.$$

- I.e. the output from stata can be interpreted as

_cons	The intercept *in the untreated group* (`treat == 0`)
age	The slope with age *in the untreated group*
treat	The difference in intercept between the treated and untreated groups
treat#c.age	The difference in slope between the treated and untreated groups

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Interactions: Stata Output

```
. regress Y i.treat age i.treat#c.age

      Source |       SS       df       MS              Number of obs =      40
-------------+------------------------------           F(  3,    36) =  173.38
       Model |  563.762012     3  187.920671           Prob > F      =  0.0000
    Residual |  39.0189256    36  1.08385904           R-squared     =  0.9353
-------------+------------------------------           Adj R-squared =  0.9299
       Total |  602.780938    39  15.4559215           Root MSE      =  1.0411

------------------------------------------------------------------------------
           Y |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
     1.treat |  -8.226356   1.872952    -4.39   0.000    -12.02488   -4.427833
         age |  -.4866572   .0412295   -11.80   0.000    -.5702744     -.40304
             |
 treat#c.age |
          1  |   .4682374   .0597378     7.84   0.000     .3470836    .5893912
             |
       _cons |   19.73531   1.309553    15.07   0.000     17.07942    22.39121
------------------------------------------------------------------------------
```

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Interactions: Using `lincom`

- `lincom` can be used to calculate the slope in the treated group:

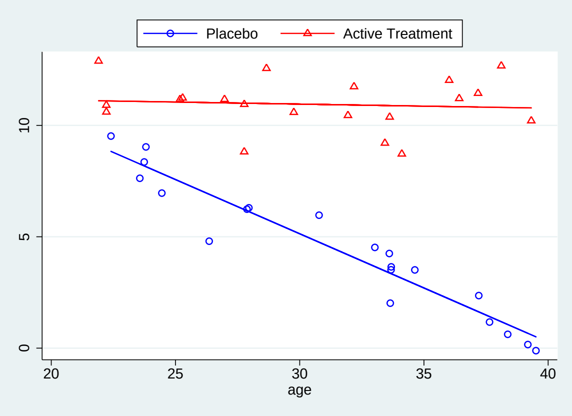
```
. lincom age + 1.treat#c.age

 ( 1)  age + 1.treat#c.age = 0

------------------------------------------------------------------------------
           Y |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
         (1) |  -.0184198   .0432288    -0.43   0.673    -.1060919    .0692523
------------------------------------------------------------------------------
```

- Can also be used to calculate intercept in treated group. However, this is not interesting since
  - We are unlikely to be be interested in subjects of age 0
  - The youngest subjects in our sample were 20, so we are extrapolating a long way from the data.

Interactions: Predictions from Linear Model



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Treatment effect at different ages

```
. lincom 1.treat + 20*1.treat#c.age

 ( 1)  1.treat + 20*1.treat#c.age = 0

------------------------------------------------------------------------------
           Y |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
         (1) |   1.138392   .7279832     1.56   0.127    -.3380261     2.61481
------------------------------------------------------------------------------

. lincom 1.treat + 40*1.treat#c.age

 ( 1)  1.treat + 40*1.treat#c.age = 0

------------------------------------------------------------------------------
           Y |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
         (1) |   10.50314   .6378479    16.47   0.000     9.209524    11.79676
------------------------------------------------------------------------------
```

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The `testparm` Command

- Used to test a number of parameters simultaneously
- Syntax: `testparm` *`varlist`*
- Test $\beta = 0$ for all variables in *varlist*
- Produces a χ^2 test on *k* degrees of freedom, where there are *k* variables in varlist.

Old and new syntax for categorical variables

- Stata used to use a different syntax for categorical variables
- Still works, but new method is preferred
- You may still see old syntax in existing do-files

	New syntax	Old Syntax
Prefix	none required	`xi:`
Variable type	Numeric	String or numeric
Interaction	#	*
Creates new variables	No	Yes
More info	`help fvvarlist`	`help xi`

Confounding

- A linear model shows association.
- It does not show *causation*.
- Apparent association may be due to a third variable which we haven't included in model
- Confounding is about causality, and knowledge of the mechanisms are required to decide if a variable is a confounder.

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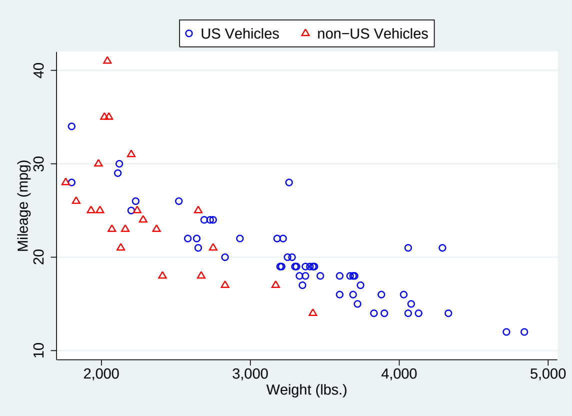
Confounding Example: Fuel Consumption

```
. regress mpg foreign

  Source |       SS       df       MS              Number of obs =      74
---------+------------------------------           F(  1,    72) =   13.18
   Model |  378.153515     1  378.153515           Prob > F      =  0.0005
Residual |  2065.30594    72  28.6848048           R-squared     =  0.1548
---------+------------------------------           Adj R-squared =  0.1430
   Total |  2443.45946    73  33.4720474           Root MSE      =  5.3558

------------------------------------------------------------------------------
     mpg |      Coef.   Std. Err.       t     P>|t|       [95% Conf. Interval]
---------+--------------------------------------------------------------------
 foreign |   4.945804   1.362162      3.631   0.001       2.230384    7.661225
   _cons |   19.82692   .7427186     26.695   0.000       18.34634    21.30751
------------------------------------------------------------------------------
```

Confounding Example: Weight and Fuel Consumption



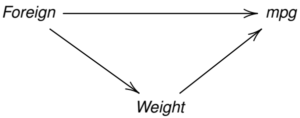
Confounding Example: Controlling for Weight

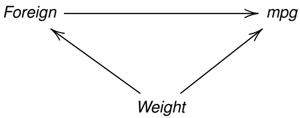
```
. regress mpg foreign weight

  Source |       SS       df       MS              Number of obs =      74
---------+------------------------------           F(  2,    71) =   69.75
   Model |   1619.2877     2  809.643849           Prob > F      =  0.0000
Residual |  824.171761    71   11.608053           R-squared     =  0.6627
---------+------------------------------           Adj R-squared =  0.6532
   Total |  2443.45946    73  33.4720474           Root MSE      =  3.4071

------------------------------------------------------------------------------
     mpg |      Coef.   Std. Err.       t     P>|t|       [95% Conf. Interval]
---------+--------------------------------------------------------------------
 foreign |  -1.650029   1.075994     -1.533   0.130       -3.7955    .4954421
  weight |  -.0065879   .0006371    -10.340   0.000      -.0078583   -.0053175
   _cons |    41.6797   2.165547     19.247   0.000       37.36172    45.99768
------------------------------------------------------------------------------
```

What is Confounding ?

- Confounding: changing a predictor does not produce expected change in outcome
- $\hat{Y} = \beta_0 + \beta_1 x$
- Two groups differing in x by Δx will differ in Y by $\beta_1 \Delta x$
- If we change x by Δx, what happens to $\hat{Y}$?
- If it changes by $\beta_1 \Delta x$, no confounding
- If it changes by anything else, there is confounding

Path Variables vs. Confounders





Weight is a path variable

Weight is a confounder

Identifying a Confounder

- Is a cause of the outcome irrespective of other predictors
- Is associated with the predictor
- Is not a consequence of the predictor
- Weight is associated with `mpg`
- This association does not depend on where the car was designed
- But is weight a path variable ?

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Identifying a Confounder

- Is a cause of the outcome irrespective of other predictors
- Is associated with the predictor
- Is not a consequence of the predictor
- Weight is associated with `mpg`
- This association does not depend on where the car was designed
- But is weight a path variable ?
  - Foreign designers produce smaller cars in order to getter better fuel consumption: path variable

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Identifying a Confounder

- Is a cause of the outcome irrespective of other predictors
- Is associated with the predictor
- Is not a consequence of the predictor

- Weight is associated with `mpg`
- This association does not depend on where the car was designed
- But is weight a path variable ?
  - Foreign designers produce smaller cars in order to getter better fuel consumption: path variable
  - Foreign designers briefed to produce smaller cars: confounder

Identifying a Confounder

- Is a cause of the outcome irrespective of other predictors
- Is associated with the predictor
- Is not a consequence of the predictor

- Weight is associated with `mpg`
- This association does not depend on where the car was designed
- But is weight a path variable ?
    - Foreign designers produce smaller cars in order to getter better fuel consumption: path variable
    - Foreign designers briefed to produce smaller cars: confounder
- I don't know enough about car design process to know if weight is a confounder

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Allowing for Confounding

- In theory, adding a confounder to a regression model is sufficient to adjust for confounding.
- Then parameters for other variables measure the effects of those variables when confounder does not change.
- This assumes
  - Confounder measured perfectly
  - Linear association between confounder and outcome
- If either of the above are not true, there will be *residual confounding*

Variable Selection

- May wish to reduce the number of predictors used in a linear model.
  - Efficiency
  - Clearer understanding
- Several suggested methods
  - Forward selection
  - Backward Elimination
  - Stepwise
  - All subsets
- Clinical intuition better than any of these
- I explain variable selection because it is widely used, not because it is a good idea

Forward Selection

- Choose a significance level p_e at which variables will enter the model.
- Fit each predictor in turn.
- Choose the most significant predictor.
- If its significance level is less than p_e, it is selected.
- Now add each remaining variable to this model in turn, and test the most significant.
- Continue until no further variables are added.

Backward Elimination

- Starts with all predictors in model.
- Removes the least significant.
- Repeat until all remaining predictors significant at chosen level p_r.
- Has the advantage that all parameters are adjusted for the effect of all other variables from the start.
- Can give unusual results if there are a large number of correlated variables.

Stepwise Selection

- Combination of preceding methods.
- Variables are added one at a time.
- Each time a variable is added, all the other variables are tested to see if they should be removed.
- Must have $p_r > p_e$, or a variable could be entered and removed on the same step.

All Subsets

- Can try every possible subset of variables.
- Can be hard work: 10 predictors = 1023 subsets.
- Need a criterion to choose best model.
- Adjusted R^2 is possible, there are others.
- Not implemented in stata.

Problems with Variable Selection

- Significance Levels
  - Hypotheses tested are not independent.
  - Variables chosen for testing not randomly selected.
  - Hence significance levels not equal to nominal levels.
  - Less of a problem in large samples.
- Differences in Models Selected
  - Models chosen by different methods may differ.
  - If variables are highly correlated, choice of variable becomes arbitrary
  - Choice of significance level will affect models.
  - Need common sense.
- Making decisions based on *p*-values alone is never a good idea

Variable Selection in Stata

- Command `sw regress` is used for forwards, backwards and stepwise selection.
- Option `pe` is used to set significance level for inclusion
- Option `pr` is used to set significance level for exclusion
- Set `pe` for forwards, `pr` for backwards and both for stepwise regression.
- The `sw` command does not work with factor variables, so the old `xi:` syntax must be used.

Variable Selection in Stata: Example 1

```
. sw regress weight  price hdroom trunk length turn displ gratio, pe(0.05)

p = 0.0000 <  0.0500  adding   length
p = 0.0000 <  0.0500  adding   displ
p = 0.0015 <  0.0500  adding   price
p = 0.0288 <  0.0500  adding   turn

  Source |       SS       df       MS              Number of obs =      74
---------+------------------------------           F(  4,    69) =  293.75
   Model |  41648450.8     4  10412112.7           Prob > F      =  0.0000
Residual |  2445727.56    69  35445.3269           R-squared     =  0.9445
---------+------------------------------           Adj R-squared =  0.9413
   Total |  44094178.4    73  604029.841           Root MSE      =  188.27

------------------------------------------------------------------------------
  weight |      Coef.   Std. Err.       t     P>|t|       [95% Conf. Interval]
---------+--------------------------------------------------------------------
  length |   19.38601   2.328203      8.327   0.000       14.74137    24.03064
   displ |   2.257083    .467792      4.825   0.000       1.323863    3.190302
   price |   .0332386   .0087921      3.781   0.000       .0156989    .0507783
    turn |   23.17863   10.38128      2.233   0.029       2.468546    43.88872
   _cons |  -2193.042   298.0756     -7.357   0.000      -2787.687   -1598.398
------------------------------------------------------------------------------
```

Variable Selection in Stata: Example 2

```
. sw regress weight  price hdroom trunk length turn displ gratio, pr(0.05)

p = 0.6348 >= 0.0500  removing hdroom
p = 0.5218 >= 0.0500  removing trunk
p = 0.1371 >= 0.0500  removing gratio

  Source |       SS       df       MS                  Number of obs =      74
---------+------------------------------               F(  4,    69) =  293.75
   Model |  41648450.8     4  10412112.7               Prob > F      =  0.0000
Residual |  2445727.56    69  35445.3269               R-squared     =  0.9445
---------+------------------------------               Adj R-squared =  0.9413
   Total |  44094178.4    73  604029.841               Root MSE      =  188.27

------------------------------------------------------------------------------
  weight |      Coef.   Std. Err.       t     P>|t|       [95% Conf. Interval]
---------+--------------------------------------------------------------------
   price |   .0332386   .0087921      3.781   0.000       .0156989    .0507783
    turn |   23.17863   10.38128      2.233   0.029       2.468546    43.88872
   displ |   2.257083    .467792      4.825   0.000       1.323863    3.190302
  length |   19.38601   2.328203      8.327   0.000       14.74137    24.03064
   _cons |  -2193.042   298.0756     -7.357   0.000      -2787.687   -1598.398
------------------------------------------------------------------------------
```

Polynomial Regression

- If association between x and Y is non-linear, can fit polynomial terms in x.
- Keep adding terms until the two highest order terms are not significant.
- Parameters are meaningless: only entire function has meaning.
- Fractional polynomials, orthogonal polynomials and splines can also be used

Transformations

- If Y is not normal or has non-constant variance, it may be possible to fit a linear model to a transformation of Y.
- Interpretation becomes more difficult after transformation.
- Log transformation has a simple interpretation.
  - $\log(Y) = \beta_0 + \beta_1 x$
  - when x increases by 1, $\log(Y)$ increases by β_1,
  - Y is multiplied by e^{β_1}
- Transforming x is not normally necessary unless the problem suggests it.

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Regression through the origin

- You may know that if $x = 0$, $y = 0$.
- Stata can force the regression line through the origin with the option `nocons`.
- However
  - R^2 is calculated differently and cannot be compared to conventional R^2.
  - If we have no data near the origin, should not force line through the origin.
  - May obtain a better fit with a non-zero intercept if there is measurement error.