Interactions in Logistic Regression

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Table of contents

1 Background

The purpose of this tutorial is to illustrate the idea that in *logistic regression*, the β parameter for an interaction term may not accurately characterize the underlying interactive relationships.

This idea may be easier to describe if we recall the formula for a logistic regression:

$$\ln\left(\frac{P(y)}{1-P(y)}\right) = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_1 \times x_2 \tag{1}$$

Warning

In the above formula, the sign, and statistical significance, of β_3 may not accurately characterize the underlying relationship.

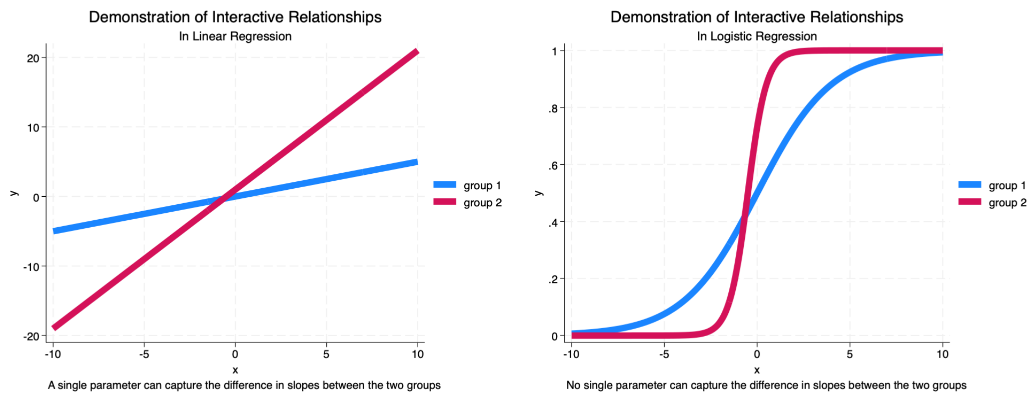

Figure 1: Demonstration of Interactive Relationships

Key Idea

In a *linear* model, a single parameter can capture the difference in slopes between the two groups. In a *non-linear* model, no single parameter can capture the difference in slopes between the two groups.

Some Calculus (Not Essential To The Discussion)

Imagine a linear model:

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_1 \times x_2 + e_i$$

Here (following (Ai and Norton 2003)):

$$\frac{\partial y}{\partial x_1 \partial x_2} = \beta_3$$

We use logit to describe:

$$\ln\left(\frac{P(y)}{1-P(y)}\right)$$

In the logistic model, the quantity:

$$\frac{\partial \text{logit}(y)}{\partial x_1 \partial x_2}$$

does not have such a straightforward solution, and–importantly for this discussion–is not simply equal to β_3.

2 Get The Data

We start by obtaining *simulated data* from StataCorp.

```
clear all

graph close _all

use http://www.stata-press.com/data/r15/margex, clear

set linesize 96 // more width for output
```

```
(Artificial data for margins)
```

3 Describe The Data

The variables are as follows:

```
describe
```

```
Running /Users/agrogan/Desktop/GitHub/newstuff/categorical/logistic-interactions-2/pr

> ofile.do ...



Contains data from http://www.stata-press.com/data/r15/margex.dta
```

```
 Observations:         3,000                  Artificial data for margins
    Variables:            11                  27 Nov 2016 14:27
---------------------------------------------------------------------------------------------
Variable      Storage   Display    Value
    name         type    format    label      Variable label
---------------------------------------------------------------------------------------------
y               float   %6.1f
outcome         byte    %2.0f
sex             byte    %6.0f      sexlbl
group           byte    %2.0f
age             float   %3.0f
distance        float   %6.2f
ycn             float   %6.1f
yc              float   %6.1f
treatment       byte    %2.0f
agegroup        byte    %8.0g      agelab
arm             byte    %8.0g
---------------------------------------------------------------------------------------------
Sorted by: group
```

4 Estimate Logistic Regression

We then run a logistic regression model in which `outcome` is the dependent variable. `sex`, `age` and `group` are the independent variables. We estimate an interaction of `sex` and `age`.

> We note that the regression coefficient for the interaction term is not statistically significant.

```
logit outcome sex##c.age i.group
```

```
Running /Users/agrogan/Desktop/GitHub/newstuff/categorical/logistic-interactions-2/pr

> ofile.do ...



Iteration 0:  Log likelihood = -1366.0718
Iteration 1:  Log likelihood =  -1118.129
Iteration 2:  Log likelihood = -1070.8227
Iteration 3:  Log likelihood = -1068.0102
```

```
Iteration 4:  Log likelihood =   -1067.99
Iteration 5:  Log likelihood =   -1067.99

Logistic regression                                     Number of obs =  3,000
                                                        LR chi2(5)    = 596.16
                                                        Prob > chi2   = 0.0000
Log likelihood = -1067.99                               Pseudo R2     = 0.2182

------------------------------------------------------------------------------
     outcome | Coefficient  Std. err.      z    P>|z|     [95% conf. interval]
-------------+----------------------------------------------------------------
         sex |
     female  |   .5565025   .6488407     0.86   0.391    -.7152019    1.828207
         age |   .0910807   .0113215     8.04   0.000     .0688909    .1132704
             |
   sex#c.age |
     female  |   -.001211   .0134012    -0.09   0.928    -.0274769     .025055
             |
       group |
          2  |  -.5854237   .1349791    -4.34   0.000    -.8499779   -.3208696
          3  |  -1.355227   .2965301    -4.57   0.000    -1.936416   -.7740391
             |
       _cons |  -5.592272   .5583131   -10.02   0.000    -6.686545   -4.497998
------------------------------------------------------------------------------
```

5 Margins

We use the `margins` command to estimate predicted probabilities at different values of `sex` and `age`.

```
margins sex, at(age = (20 30 40 50 60))
```

```
Running /Users/agrogan/Desktop/GitHub/newstuff/categorical/logistic-interactions-2/pr

> ofile.do ...



Predictive margins                                        Number of obs = 3,000
Model VCE: OIM
```

```
Expression: Pr(outcome), predict()
1._at: age = 20
2._at: age = 30
3._at: age = 40
4._at: age = 50
5._at: age = 60

------------------------------------------------------------------------------
             |            Delta-method
             |     Margin   std. err.      z    P>|z|     [95% conf. interval]
-------------+----------------------------------------------------------------
     _at#sex |
     1#male  |   .0150645   .0047348     3.18   0.001     .0057846    .0243445
   1#female  |    .025333   .0055508     4.56   0.000     .0144536    .0362124
     2#male  |   .0364848   .0075444     4.84   0.000     .0216981    .0512714
   2#female  |   .0596255   .0086074     6.93   0.000     .0427552    .0764958
     3#male  |   .0852689   .0099016     8.61   0.000     .0658622    .1046757
   3#female  |   .1329912   .0108127    12.30   0.000     .1117987    .1541838
     4#male  |   .1849367   .0163684    11.30   0.000     .1528551    .2170182
   4#female  |    .267774   .0156218    17.14   0.000     .2371558    .2983921
     5#male  |   .3518378   .0408522     8.61   0.000      .271769    .4319066
   5#female  |   .4614446   .0314754    14.66   0.000     .3997539    .5231353
------------------------------------------------------------------------------
```

6 Plotting Margins

`margins` provides a lot of results, which can be difficult to understand. Therefore, we use `marginsplot` to *plot* these `margins` results.

There certainly seems to be some kind of interaction of `sex` and `age`.

```
marginsplot

graph export mymarginsplot.png, width(1000) replace
```

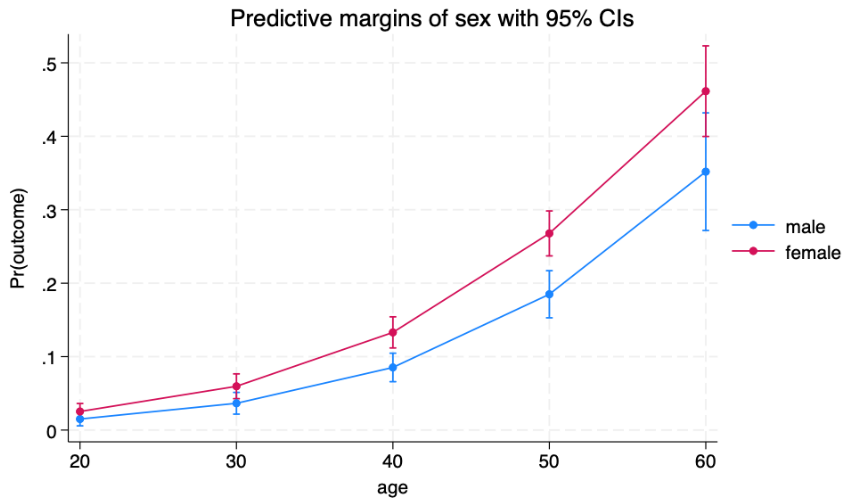

Figure 2: Margins Plot

7 Rerun `margins`, `posting` Results

We again employ the **`margins`** command, this time using the **`post`** option so that the results of the margins command are *posted* as an estimation result. This will allow us to employ the **`test`** command to statistically test different margins against each other.

```
margins sex, at(age = (20 30 40 50 60)) post
```

```
Running /Users/agrogan/Desktop/GitHub/newstuff/categorical/logistic-interactions-2/pr

> ofile.do ...



Predictive margins                                          Number of obs = 3,000
Model VCE: OIM

Expression: Pr(outcome), predict()
1._at: age = 20
2._at: age = 30
3._at: age = 40
4._at: age = 50
5._at: age = 60
```

```
--------------------------------------------------------------------------------
             |            Delta-method
             |     Margin   std. err.      z    P>|z|     [95% conf. interval]
-------------+------------------------------------------------------------------
     _at#sex |
     1#male  |   .0150645   .0047348     3.18   0.001     .0057846    .0243445
   1#female  |    .025333   .0055508     4.56   0.000     .0144536    .0362124
     2#male  |   .0364848   .0075444     4.84   0.000     .0216981    .0512714
   2#female  |   .0596255   .0086074     6.93   0.000     .0427552    .0764958
     3#male  |   .0852689   .0099016     8.61   0.000     .0658622    .1046757
   3#female  |   .1329912   .0108127    12.30   0.000     .1117987    .1541838
     4#male  |   .1849367   .0163684    11.30   0.000     .1528551    .2170182
   4#female  |    .267774   .0156218    17.14   0.000     .2371558    .2983921
     5#male  |   .3518378   .0408522     8.61   0.000      .271769    .4319066
   5#female  |   .4614446   .0314754    14.66   0.000     .3997539    .5231353
--------------------------------------------------------------------------------
```

8 `margins` with `coeflegend`

We follow up by using the `margins` command with the `coeflegend` option to see the way in which Stata has labeled the different margins.

```
margins, coeflegend
```

```
Running /Users/agrogan/Desktop/GitHub/newstuff/categorical/logistic-interactions-2/pr

> ofile.do ...



Predictive margins                                     Number of obs = 3,000
Model VCE: OIM

Expression: Pr(outcome), predict()
1._at: age = 20
2._at: age = 30
3._at: age = 40
4._at: age = 50
5._at: age = 60
```

```
------------------------------------------------------------------------------
             |     Margin   Legend
-------------+----------------------------------------------------------------
     _at#sex |
     1#male  |   .0150645   _b[1bn._at#0bn.sex]
   1#female  |    .025333   _b[1bn._at#1.sex]
     2#male  |   .0364848   _b[2._at#0bn.sex]
   2#female  |   .0596255   _b[2._at#1.sex]
     3#male  |   .0852689   _b[3._at#0bn.sex]
   3#female  |   .1329912   _b[3._at#1.sex]
     4#male  |   .1849367   _b[4._at#0bn.sex]
   4#female  |    .267774   _b[4._at#1.sex]
     5#male  |   .3518378   _b[5._at#0bn.sex]
   5#female  |   .4614446   _b[5._at#1.sex]
------------------------------------------------------------------------------
```

9 Testing Margins Against Each Other

Lastly, we test the margins at age 20 for men and women, and again at ages 50 and 60 for men and women.

> We note that the original regression parameter for the interaction term was not statistically significant. Indeed, the margins at age 20 are not statistically significantly different by sex. However, at ages 50 & 60, there is a statistically significant difference by sex.

```
test _b[1bn._at#0bn.sex] = _b[1bn._at#1.sex] // male and female at age 20

test _b[4._at#0bn.sex] = _b[4._at#1.sex] // male and female at age 50

test _b[5._at#0bn.sex] =  _b[5._at#1.sex] // male and female at age 60
```

```
Running /Users/agrogan/Desktop/GitHub/newstuff/categorical/logistic-interactions-2/pr

> ofile.do ...



 ( 1)  1bn._at#0bn.sex - 1bn._at#1.sex = 0
```

```
          chi2(  1) =    1.99
        Prob > chi2 =    0.1583


 ( 1)  4._at#0bn.sex - 4._at#1.sex = 0

          chi2(  1) =   13.03
        Prob > chi2 =    0.0003


 ( 1)  5._at#0bn.sex - 5._at#1.sex = 0

          chi2(  1) =    5.16
        Prob > chi2 =    0.0232
```

There is some suggestion that the *difference of the differences* is statistically significant. This statistical significance is only marginal [pun intended] at age 60, but truly statistically significant at age 50.

```
test _b[1bn._at#1.sex] - _b[1bn._at#0bn.sex] = _b[5._at#1.sex] - _b[5._at#0bn.sex] // test e

test _b[1bn._at#1.sex] - _b[1bn._at#0bn.sex] = _b[4._at#1.sex] - _b[4._at#0bn.sex] // test e
```

```
Running /Users/agrogan/Desktop/GitHub/newstuff/categorical/logistic-interactions-2/pr

> ofile.do ...



 ( 1)  - 1bn._at#0bn.sex + 1bn._at#1.sex + 5._at#0bn.sex - 5._at#1.sex = 0

          chi2(  1) =    3.62
        Prob > chi2 =    0.0572


 ( 1)  - 1bn._at#0bn.sex + 1bn._at#1.sex + 4._at#0bn.sex - 4._at#1.sex = 0

          chi2(  1) =    9.77
        Prob > chi2 =    0.0018
```

References

Ai, Chunrong, and Edward C. Norton. 2003. "Interaction Terms in Logit and Probit Models." *Economics Letters*. https://doi.org/10.1016/S0165-1765(03)00032-6.

Karaca-Mandic, Pinar, Edward C. Norton, and Bryan Dowd. 2012. "Interaction Terms in Nonlinear Models." *Health Services Research*. https://doi.org/10.1111/j.1475-6773.2011.01314.x.