# Bivariate Probit Models

## Model for Financial Restructuring Strategies

The study focused on answering how Thai distressed firms chose restructuring strategy in recovering their firm performance.

**Bivariate Probit Models**

The model can be shown as

$$y_1^* = \beta_1' x + \varepsilon_1, \qquad y_1 = 1 \;\; if \;\; y_1^* > 0, \;\; 0 \;\; otherwise$$

$$y_2^* = \beta_2' x + \varepsilon_2, \qquad y_2 = 1 \;\; if \;\; y_2^* > 0, \;\; 0 \;\; otherwise$$

where:

$$E\left[\varepsilon_1 \middle| x_1, x_2, x_3, x_4\right] = E\left[\varepsilon_2 \middle| x_1, x_2, x_3, x_4\right] = 0$$

$$Var\left[\varepsilon_1 \middle| x_1, x_2, x_3, x_4\right] = Var\left[\varepsilon_2 \middle| x_1, x_2, x_3, x_4\right] = 1$$

$$Cov\left[\varepsilon_1, \varepsilon_2 \middle| x_1, x_2, x_3, x_4\right] = \rho$$

**Data**

$y_{1it}$ = 1 if firm i choose debt restructuring, 0 otherwise
$y_{2it}$ = 1 if firm i choose asset expansion action, 0 otherwise
$x_{1it}$ = Firm's leverage
$x_{2it}$ = Firm's size
$x_{3it}$ = Proportion of outside directors to total directors
$x_{4it}$ = Country's GDP growth rate

Two Separate Probit Models

```
. probit y1 x1 x2 x3 x4

Iteration 0:   log likelihood = -1053.0627
Iteration 1:   log likelihood = -979.26803
Iteration 2:   log likelihood = -978.63736
Iteration 3:   log likelihood = -978.63691
Iteration 4:   log likelihood = -978.63691

Probit regression                                 Number of obs     =      1,543
                                                  LR chi2(4)        =     148.85
                                                  Prob > chi2       =     0.0000
Log likelihood = -978.63691                       Pseudo R2         =     0.0707

------------------------------------------------------------------------------
          y1 |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
          x1 |   .0010014   .0001838     5.45   0.000     .0006412    .0013615
          x2 |  -.0955169   .0187219    -5.10   0.000    -.1322112   -.0588226
          x3 |   -.008575   .0026366    -3.25   0.001    -.0137426   -.0034074
          x4 |   .0673559   .0079195     8.51   0.000      .051834    .0828778
       _cons |   .3568971   .1445463     2.47   0.014     .0735916    .6402026
------------------------------------------------------------------------------

. probit y2 x1 x2 x3 x4

Iteration 0:   log likelihood = -913.94299
Iteration 1:   log likelihood = -832.82564
Iteration 2:   log likelihood = -830.65401
Iteration 3:   log likelihood = -830.56871
Iteration 4:   log likelihood = -830.56869

Probit regression                                 Number of obs     =      1,543
                                                  LR chi2(4)        =     166.75
                                                  Prob > chi2       =     0.0000
Log likelihood = -830.56869                       Pseudo R2         =     0.0912
```

```
------------------------------------------------------------------------------
          y2 |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
          x1 |  -.0010529   .0003819    -2.76   0.006    -.0018014   -.0003045
          x2 |   .1657084   .0206766     8.01   0.000     .125183    .2062338
          x3 |   .0125813   .0027806     4.52   0.000     .0071314    .0180311
          x4 |   .0170502   .0087229     1.95   0.051    -.0000464    .0341468
       _cons |  -1.992698   .1734121   -11.49   0.000    -2.332579   -1.652816
------------------------------------------------------------------------------
```

## Bivariate Probit Models

```
. biprobit y1 y2 x1 x2 x3 x4

Fitting comparison equation 1:

Iteration 0:   log likelihood = -1053.0627
Iteration 1:   log likelihood = -979.26803
Iteration 2:   log likelihood = -978.63736
Iteration 3:   log likelihood = -978.63691
Iteration 4:   log likelihood = -978.63691

Fitting comparison equation 2:

Iteration 0:   log likelihood = -913.94299
Iteration 1:   log likelihood = -832.82564
Iteration 2:   log likelihood = -830.65401
Iteration 3:   log likelihood = -830.56871
Iteration 4:   log likelihood = -830.56869

Comparison:    log likelihood = -1809.2056

Fitting full model:

Iteration 0:   log likelihood = -1809.2056
Iteration 1:   log likelihood = -1802.6093
Iteration 2:   log likelihood = -1802.6028
Iteration 3:   log likelihood = -1802.6028

Bivariate probit regression                     Number of obs     =      1,543
                                                Wald chi2(8)      =     269.26
Log likelihood = -1802.6028                     Prob > chi2       =     0.0000

------------------------------------------------------------------------------
             |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
y1           |
          x1 |   .0009977   .0001835     5.44   0.000      .000638    .0013574
          x2 |  -.0955578   .0187098    -5.11   0.000    -.1322282   -.0588873
          x3 |  -.0084887   .0026315    -3.23   0.001    -.0136464    -.003331
          x4 |   .0668233   .0078856     8.47   0.000     .0513678    .0822787
       _cons |   .3563222    .144177     2.47   0.013     .0737404     .638904
-------------+----------------------------------------------------------------
y2           |
          x1 |   -.000827   .0003474    -2.38   0.017    -.0015079   -.0001461
          x2 |   .1695905   .0206041     8.23   0.000     .1292071    .2099739
          x3 |   .0124783   .0027839     4.48   0.000     .0070219    .0179347
          x4 |    .016554   .0087379     1.89   0.058    -.0005721      .03368
       _cons |  -2.032975   .1706191   -11.92   0.000    -2.367383   -1.698568
-------------+----------------------------------------------------------------
     /athrho |  -.1712861   .0471648    -3.63   0.000    -.2637273   -.0788449
-------------+----------------------------------------------------------------
         rho |  -.1696304   .0458076                     -.2577785   -.0786819
------------------------------------------------------------------------------
LR test of rho=0: chi2(1) = 13.2057                    Prob > chi2 = 0.0003

. margins, dydx(*) predict(p11)

Average marginal effects                        Number of obs     =      1,543
Model VCE    : OIM

Expression   : Pr(y1=1,y2=1), predict(p11)
dy/dx w.r.t. : x1 x2 x3 x4

------------------------------------------------------------------------------
```

```
             |            Delta-method
             |      dy/dx   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
          x1 |   3.39e-06   .0000431     0.08   0.937    -.0000811    .0000879
          x2 |   .0101383   .0027857     3.64   0.000     .0046784    .0155982
          x3 |   .0006011   .0003916     1.53   0.125    -.0001665    .0013687
          x4 |   .0085562    .001317     6.50   0.000     .0059749    .0111375
------------------------------------------------------------------------------

. margins, dydx(*) predict(p10)

Average marginal effects                        Number of obs     =      1,543
Model VCE    : OIM

Expression   : Pr(y1=1,y2=0), predict(p10)
dy/dx w.r.t. : x1 x2 x3 x4

------------------------------------------------------------------------------
             |            Delta-method
             |      dy/dx   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
          x1 |   .0003621   .0000641     5.65   0.000     .0002366    .0004877
          x2 |  -.0451454   .0054884    -8.23   0.000    -.0559025   -.0343883
          x3 |  -.0037109   .0007891    -4.70   0.000    -.0052576   -.0021642
          x4 |   .0159242   .0022885     6.96   0.000     .0114387    .0204096
------------------------------------------------------------------------------

. margins, dydx(*) predict(p01)

Average marginal effects                        Number of obs     =      1,543
Model VCE    : OIM

Expression   : Pr(y1=0,y2=1), predict(p01)
dy/dx w.r.t. : x1 x2 x3 x4

------------------------------------------------------------------------------
             |            Delta-method
             |      dy/dx   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
          x1 |  -.0002563   .0000697    -3.68   0.000    -.0003928   -.0001197
          x2 |   .0417133   .0044214     9.43   0.000     .0330476     .050379
          x3 |   .0032141   .0006101     5.27   0.000     .0020183    .0044098
          x4 |  -.0034949    .001856    -1.88   0.060    -.0071327    .0001429
------------------------------------------------------------------------------

. margins, dydx(*) predict(p00)

Average marginal effects                        Number of obs     =      1,543
Model VCE    : OIM

Expression   : Pr(y1=0,y2=0), predict(p00)
dy/dx w.r.t. : x1 x2 x3 x4

------------------------------------------------------------------------------
             |            Delta-method
             |      dy/dx   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
          x1 |  -.0001093   .0000802    -1.36   0.173    -.0002665    .0000479
          x2 |  -.0067062   .0058912    -1.14   0.255    -.0182528    .0048404
          x3 |  -.0001043   .0008318    -0.13   0.900    -.0017345    .0015259
          x4 |  -.0209855   .0024158    -8.69   0.000    -.0257204   -.0162506
------------------------------------------------------------------------------
```

# Multivariate Probit Models

## Model for Financial Restructuring Strategies

### Multivariate Probit Models

The model can be shown as

$$y_1^* = \beta_1' x + \varepsilon_1, \qquad y_1 = 1 \;\; if \;\; y_1^* > 0, \;\; 0 \;\; otherwise$$
$$y_2^* = \beta_2' x + \varepsilon_2, \qquad y_2 = 1 \;\; if \;\; y_2^* > 0, \;\; 0 \;\; otherwise$$
$$y_3^* = \beta_3' x + \varepsilon_3, \qquad y_3 = 1 \;\; if \;\; y_3^* > 0, \;\; 0 \;\; otherwise$$
$$\begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \varepsilon_3 \end{bmatrix} \sim N\left( \begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix}, \begin{bmatrix} 1 & & \\ \rho_{21} & 1 & \\ \rho_{31} & \rho_{32} & 1 \end{bmatrix} \right)$$

### Data

$y_{1it}$ = 1 if firm i choose debt restructuring, 0 otherwise
$y_{2it}$ = 1 if firm i choose asset expansion action, 0 otherwise
$y_{3it}$ = 1 if firm i choose equity issues, 0 otherwise
$x_{1it}$ = Firm's leverage
$x_{2it}$ = Firm's size
$x_{3it}$ = Proportion of outside directors to total directors
$x_{4it}$ = Country's GDP growth rate

Three Separate Probit

```
. probit y1 x1 x2 x3 x4

Iteration 0:   log likelihood = -1053.0627
Iteration 1:   log likelihood = -979.26803
Iteration 2:   log likelihood = -978.63736
Iteration 3:   log likelihood = -978.63691
Iteration 4:   log likelihood = -978.63691

Probit regression                                 Number of obs     =      1,543
                                                  LR chi2(4)        =     148.85
                                                  Prob > chi2       =     0.0000
Log likelihood = -978.63691                       Pseudo R2         =     0.0707

------------------------------------------------------------------------------
          y1 |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
          x1 |   .0010014   .0001838     5.45   0.000     .0006412    .0013615
          x2 |  -.0955169   .0187219    -5.10   0.000    -.1322112   -.0588226
          x3 |   -.008575   .0026366    -3.25   0.001    -.0137426   -.0034074
          x4 |   .0673559   .0079195     8.51   0.000      .051834    .0828778
       _cons |   .3568971   .1445463     2.47   0.014     .0735916    .6402026
------------------------------------------------------------------------------

. probit y2 x1 x2 x3 x4

Iteration 0:   log likelihood = -913.94299
Iteration 1:   log likelihood = -832.82564
Iteration 2:   log likelihood = -830.65401
Iteration 3:   log likelihood = -830.56871
Iteration 4:   log likelihood = -830.56869

Probit regression                                 Number of obs     =      1,543
                                                  LR chi2(4)        =     166.75
                                                  Prob > chi2       =     0.0000
Log likelihood = -830.56869                       Pseudo R2         =     0.0912

------------------------------------------------------------------------------
```

```
          y2 |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
          x1 |  -.0010529   .0003819    -2.76   0.006    -.0018014   -.0003045
          x2 |   .1657084   .0206766     8.01   0.000     .125183    .2062338
          x3 |   .0125813   .0027806     4.52   0.000     .0071314    .0180311
          x4 |   .0170502   .0087229     1.95   0.051    -.0000464    .0341468
       _cons |  -1.992698   .1734121   -11.49   0.000    -2.332579   -1.652816
------------------------------------------------------------------------------

. probit y3 x1 x2 x3 x4

Iteration 0:   log likelihood = -755.76479
Iteration 1:   log likelihood =  -745.3106
Iteration 2:   log likelihood = -745.28817
Iteration 3:   log likelihood = -745.28817

Probit regression                                 Number of obs     =      1,543
                                                  LR chi2(4)        =      20.95
                                                  Prob > chi2       =     0.0003
Log likelihood = -745.28817                       Pseudo R2         =     0.0139

------------------------------------------------------------------------------
          y3 |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
          x1 |   .0001631    .000149     1.09   0.274    -.0001289    .0004551
          x2 |   .0479281   .0201193     2.38   0.017     .0084949    .0873612
          x3 |   -.009301   .0029449    -3.16   0.002    -.0150729   -.0035291
          x4 |   .0223691   .0086452     2.59   0.010     .0054248    .0393134
       _cons |  -.9731337   .1567073    -6.21   0.000    -1.280274    -.665993
------------------------------------------------------------------------------
```

MVProbit

```
. mvprobit (y1 x1 x2 x3 x4) (y2 x1 x2 x3 x4) (y3 x1 x2 x3 x4)

Iteration 0:   log likelihood = -2554.4938
Iteration 1:   log likelihood = -2515.6056
Iteration 2:   log likelihood = -2514.4332
Iteration 3:   log likelihood = -2514.4327
Iteration 4:   log likelihood = -2514.4327

Multivariate probit (MSL, # draws = 5)            Number of obs   =       1543
                                                  Wald chi2(12)   =     289.22
Log likelihood = -2514.4327                       Prob > chi2     =     0.0000

------------------------------------------------------------------------------
             |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
y1           |
          x1 |   .0009642   .0001791     5.38   0.000     .0006131    .0013153
          x2 |  -.0965383   .0187268    -5.16   0.000    -.1332422   -.0598344
          x3 |  -.0087426    .002646    -3.30   0.001    -.0139286   -.0035565
          x4 |   .0662534    .007812     8.48   0.000     .0509422    .0815645
       _cons |   .3768172   .1448893     2.60   0.009     .0928394    .6607949
-------------+----------------------------------------------------------------
y2           |
          x1 |  -.0008594   .0003569    -2.41   0.016    -.0015588   -.0001599
          x2 |   .1682279   .0206195     8.16   0.000     .1278145    .2086413
          x3 |   .0124525   .0027845     4.47   0.000      .006995      .01791
          x4 |    .016316   .0087388     1.87   0.062    -.0008117    .0334437
       _cons |  -2.019538   .1712945   -11.79   0.000    -2.355269   -1.683807
-------------+----------------------------------------------------------------
y3           |
          x1 |   .0001839   .0001505     1.22   0.222    -.0001111    .0004789
          x2 |   .0486581   .0199159     2.44   0.015     .0096237    .0876926
          x3 |  -.0087212   .0029242    -2.98   0.003    -.0144525     -.00299
          x4 |   .0216971   .0084655     2.56   0.010      .005105    .0382892
       _cons |  -.9974393   .1565215    -6.37   0.000    -1.304216   -.6906628
-------------+----------------------------------------------------------------
    /atrho21 |  -.1384162    .044514    -3.11   0.002    -.2256621   -.0511704
-------------+----------------------------------------------------------------
    /atrho31 |   .3831571   .0471425     8.13   0.000     .2907596    .4755547
-------------+----------------------------------------------------------------
    /atrho32 |  -.0450691   .0456688    -0.99   0.324    -.1345784    .0444401
-------------+----------------------------------------------------------------
```

```
       rho21 |   -.137539   .0436719    -3.15   0.002     -.221908   -.0511257
-------------+------------------------------------------------------------------
       rho31 |   .3654461   .0408466     8.95   0.000     .2828338    .4426765
-------------+------------------------------------------------------------------
       rho32 |  -.0450386   .0455762    -0.99   0.323    -.1337717    .0444109
------------------------------------------------------------------------------
Likelihood ratio test of  rho21 = rho31 = rho32 = 0:
             chi2(3) =  80.1221   Prob > chi2 = 0.0000

. mvppred pmarg, pmarg
(pmarg will be stored in variables pmargi, i = 1,...,#eqs)

. sum pmarg1 pmarg2 pmarg3

    Variable |        Obs        Mean    Std. Dev.       Min        Max
-------------+---------------------------------------------------------
      pmarg1 |      1,543    .4270183    .1378704   .0809701   .9999002
      pmarg2 |      1,543    .2795515     .140703   7.42e-06   .7976359
      pmarg3 |      1,543    .1919922    .0444743   .0365036   .3873732

. mvppred pall, pall
(Pr(all zeros), Pr(all ones) will be stored in variables pall0s, pall1s)

. sum pall0s pall1s

    Variable |        Obs        Mean    Std. Dev.       Min        Max
-------------+---------------------------------------------------------
      pall0s |      1,543    .3426681    .1123748   .0000965   .6709439
      pall1s |      1,543    .0284488    .0169754   2.48e-06   .0963519
```