Example 5a: Multivariate General Linear Models for Family (Triadic) Data
Part 1 using Univariate Software: SAS MIXED, STATA MIXED, and R GLS (from NLME)
Part 2 using Path Analysis Software: Mplus, STATA SEM, and R LAVAAN
(complete syntax and output available for SAS, STATA, and R electronically)

These data were collected as part of a study of family dynamics conducted at Penn State University. The sample for this example includes 140 families with data from three family members: a mother, a father, and an adult child. The example outcome is a scale mean (range from 1–4) of attitudes about gender roles in marriage, in which higher scores indicate more conservative attitudes. The example predictors are the gender of the adult child (0=girl, 1=boy) and the years of education of each family member (centered such that 0=12 years). In all models, we will use an unstructured **R** matrix (in which the residual variances and covariances are estimated separately for each type of family member).

We will predict all three family members' outcomes simultaneously two ways. In Part 1 we will estimate multivariate general linear models within univariate software (i.e., with an identity link and conditional multivariate normal distributions) using residual maximum likelihood (REML), and we will (try to) test fixed effects using Satterthwaite denominator degrees of freedom. Note that STATA and R both provide incorrect AIC and BIC values using REML (they count all parameters instead of variance parameters only), so those values are not referred to below. In Part 2, we will estimate the same models using path analysis, whose software restrictions mean we must switch to maximum likelihood and text fixed effects without denominator degrees of freedom.

The marginal outcome distributions of the showed some positive skew (with an observed floor effect for the adult children), but a conditional normal distribution appears to be a reasonable choice among the readily-available options for multivariate models. This is evidenced in the final model by predicted outcomes that stayed within the outcome bounds without the use a link function to do so, and plausible homogeneity of variance across predicted outcomes. In Part 2, we will also invoke robust standard errors that protect against deviations from residual multivariate normality.

Part 1 will require "reshaping" (i.e., stacking) our original data stored in <u>wide</u> (multivariate) format, in which one row holds all variables per family, with per-person versions in separate columns…

	FamilyID: Family ID Number	KidBoy: Kid's Gender (0=girl, 1=boy)	KidEd12: Kid's Years of Education (0=12)	MomEd12: Mother's Years of Edcation (0=12)	DadEd12: Father's Years of Edcation (0=12)	KidMarital: Kid's Marital Gender Attitudes Mean (1-4)	MomMarital: Mom's Marital Gender Attitudes Mean (1-4)	DadMarital: Dad's Marital Gender Attitudes Mean (1-4)
1	3996	1	2	2	2	1	1.8333333333	1
2	4425	1	3	0	0	1	1.3333333333	2.5

…into this new format called <u>stacked</u> (long, univariate), with one row per person per family:

	FamilyID: Family ID Number	KidBoy: Kid's Gender (0=girl, 1=boy)	KidEd12: Kid's Years of Education (0=12)	MomEd12: Mother's Years of Edcation	DadEd12: Father's Years of Edcation (0=12)	DV: 1K,2M,3D	kid: Is Adult Child (0=no, 1=yes)	mom: Is Mother (0=no, 1=yes)	dad: Is Father (0=no, 1=yes)	marital: Marital Gender Attitudes Mean (1-4)
1	3996	1	2	2	2	1.Kid	1	0	0	1
2	3996	1	2	2	2	2.Mom	0	1	0	1.83333333
3	3996	1	2	2	2	3.Dad	0	0	1	1
4	4425	1	3	0	0	1.Kid	1	0	0	1
5	4425	1	3	0	0	2.Mom	0	1	0	1.33333333
6	4425	1	3	0	0	3.Dad	0	0	1	2.5

Part 2 will use the original wide format for path analysis instead.

SAS Syntax for Importing and Stacking Wide Data into Long (to get one row per person per family):

```
* Location for original files for these models - change this path;
* \\Client\ precedes path in Virtual Desktop outside H drive;
%LET filesave=C:\Dropbox\22_PSQF6270\PSQF6270_Example5a;
LIBNAME filesave "&filesave.";

* Import Example 5a multivariate data into work library and stack it;
DATA work.Example5a; SET filesave.PSQF6270_Example5aWide; * Adding dummy codes while stacking;
     DV="1.Kid"; kid=1; mom=0; dad=0; marital=KidMarital; OUTPUT;
     DV="2.Mom"; kid=0; mom=1; dad=0; marital=MomMarital; OUTPUT;
     DV="3.Dad"; kid=0; mom=0; dad=1; marital=DadMarital; OUTPUT;
     LABEL DV=      "DV: 1K,2M,3D"
           kid=     "kid: Is Adult Child (0=no, 1=yes)"
           mom=     "mom: Is Mother (0=no, 1=yes)"
           dad=     "dad: Is Father (0=no, 1=yes)"
           marital= "marital: Marital Gender Attitudes Mean (1-4)";
     DROP KidMarital MomMarital DadMarital; * Remove original outcomes;
RUN; * Remove missing predictors or row-specific (will happen anyway);
DATA work.Example5a; SET work.Example5a;
     IF NMISS(KidBoy,KidEd12,MomEd12,DadEd12,marital)>0 THEN DELETE;
RUN;
```

STATA Syntax for Importing and Stacking Wide Data into Long (to get one row per person per family):

```
// Defining global variable for file location to be replaced in code below
// \\Client\ precedes path in Virtual Desktop outside H drive;
global filesave "C:\Dropbox\22_PSQF6270\PSQF6270_Example5a"
// Import Example 5a wide Stata data
use "$filesave\PSQF6270_Example5aWide.dta", clear
// Rename variables with numeric suffix to use with reshape (old)(new)
rename (kidmarital mommarital dadmarital) (marital1 marital2 marital3)
// Stack data: list multivariate variables first, i(higher index) j(repeated)
reshape long marital, i(familyid) j(DV)
// Create value labels and apply to dv
label define dvlabel 1 "1.Kid" 2 "2.Mom" 3 "3.Dad"
label values DV dvlabel
// Create per-outcome dummy codes
gen kid=0
gen mom=0
gen dad=0
recode kid (0=1) if DV==1
recode mom (0=1) if DV==2
recode dad (0=1) if DV==3
// Label new variables
label variable DV      "DV: 1K,2M,3D"
label variable kid     "kid: Is Adult Child (0=no, 1=yes)"
label variable mom     "mom: Is Mother (0=no, 1=yes)"
label variable dad     "dad: Is Father (0=no, 1=yes)"
label variable marital "marital: Marital Gender Attitudes Mean (1-4)"
// Remove missing predictors or row-specific outcome (will happen anyway)
egen nummiss = rowmiss(kidboy kided12 momed12 daded12 marital)
drop if nummiss>0
```

R Syntax for Importing and Stacking Wide Data into Long (to get one row per person per family):

```
# Define variables for working directory and data name
filesave = "C:\\Dropbox/22_PSQF6270/PSQF6270_Example5a/"
filename = "PSQF6270_Example5aWide.sas7bdat"
setwd(dir=filesave)

# Import Example 5a SAS data
Example5a_wide = read_sas(data_file=paste0(filesave,filename))
# Convert to data frame without labels to use for analysis
Example5a_wide = as.data.frame(Example5a_wide)
```

```
# Stack into long format (one row per outcome per family)
Example5a = reshape(Example5a_wide,  direction="long", idvar="FamilyID",
                    varying=c("KidMarital","MomMarital","DadMarital"),
                    v.names="marital", timevar="DVnum", times=c(1,2,3))
# Work-around to add value labels for categorical variables DV
# Make a concatenated list of labels in order of values to be labeled
DVLabels = c("1.Kid", "2.Mom", "3.Dad")
# Create new text-format string variable with the labels instead of values
Example5a$DV = DVLabels[Example5a$DVnum]
# Create per-person dummy codes
Example5a$kid=0
Example5a$mom=0
Example5a$dad=0
Example5a$kid[which(Example5a$DVnum==1)]=1
Example5a$mom[which(Example5a$DVnum==2)]=1
Example5a$dad[which(Example5a$DVnum==3)]=1
# Make new variable for DV with reference=Dad to match other programs
Example5a$DV3=relevel(factor(Example5a$DV), ref=3)

# Remove missing predictors or row-specific outcome (will happen anyway)
Example5a = Example5a[complete.cases(Example5a[ ,
                      c("KidBoy","KidEd12","MomEd12","DadEd12","marital")]),]
```

Part 1: Multivariate General Linear Models via Univariate Software

Model 0: Empty Means, Unstructured Variance Model for Marital Conservative Gender Attitudes
Two Ways for General Intercept Version: $\widehat{Marital}_{fi} = \beta_{00} + \beta_{01}\left(Kid_{fi}\right) + \beta_{02}\left(Mom_{fi}\right)$

```
TITLE1 "SAS Empty Means, Unstructured Variance Models for Marital Attitudes";
TITLE2 "SAS Model 0a: General Intercept (Dad=Ref DV) using 2 Dummy Codes";
PROC MIXED DATA=work.Example5a NOCLPRINT COVTEST NAMELEN=100 METHOD=REML;
* CLASS is for ID variables and program-categorical predictors;
  CLASS FamilyID DV;  * Fixed intercept will be for dad (as omitted);
  MODEL marital = kid mom / SOLUTION DDFM=Satterthwaite;
  REPEATED DV / R RCORR TYPE=UN SUBJECT=FamilyID;
  CONTRAST "DF=2 Intercept Diff"          kid 1, mom 1;
  ESTIMATE "Kid Intercept (Dad+diff)"     intercept 1 kid 1 mom 0;
  ESTIMATE "Mom Intercept (Dad+diff)"     intercept 1 kid 0 mom 1;
  ESTIMATE "Kid vs. Mom: Intercept Diff"  kid -1 mom 1;
RUN; TITLE2;

TITLE2 "SAS Model 0b: General Intercept (Dad=Ref DV) using Program-Categorical DV";
PROC MIXED DATA=work.Example5a NOCLPRINT COVTEST NAMELEN=100 METHOD=REML;
* CLASS is for ID variables and program-categorical predictors;
  CLASS FamilyID DV;  * Fixed intercept is for last DV (dad here);
  MODEL marital = DV / SOLUTION DDFM=Satterthwaite;
  REPEATED DV / R RCORR TYPE=UN SUBJECT=FamilyID;
* F-test given by default when program-categorical DV is used;
  CONTRAST "DF=2 Intercept Diff"          DV -1 0 1, DV -1 1 0;
* LSMEANS gives all means and mean diffs (given by ESTIMATEs below);
  LSMEANS DV / DIFF=ALL;
  ESTIMATE "Kid Intercept (Dad+diff)"     intercept 1 DV 1 0 0;
  ESTIMATE "Mom Intercept (Dad+diff)"     intercept 1 DV 0 1 0;
  ESTIMATE "Kid vs. Mom: Intercept Diff"  DV -1 1 0;
RUN; TITLE2;

display "STATA Empty Means, Unstructured Variance Models for Marital Attitudes"
display "STATA Model 0a: General Intercept (Dad=Ref DV) using 2 Dummy Codes"
mixed marital c.kid c.mom,         /// Fixed intercept will be for dad (as omitted)
      || familyid: , noconstant    /// This NOCONSTANT removes family random intercept
      variance reml residuals(unstructured,t(DV)) /// Unstructured R matrix by DV
      dfmethod(satterthwaite) dftable(pvalue)      // Use Satterthwaite denominator DF
display "-2LL=" e(ll)*-2           // Print -2LL for model
estat wcorrelation, covariance     // R matrix
estat wcorrelation                 // RCORR matrix
test (c.kid=0)(c.mom=0), small     // DF=2 Intercept Diff (small = use denominator DF)
```

```
lincom _cons*1  + c.kid*1, small  // Kid Intercept (Dad + diff)
lincom _cons*1  + c.mom*1, small  // Mom Intercept (Dad + diff)
lincom c.kid*-1 + c.mom*1, small  // Kid vs. Mom: Intercept Diff

display "STATA Model 0b: General Intercept (Dad=Ref DV) using Program-Categorical DV"
mixed marital ib(last).DV,        /// Fixed intercept is for last DV (dad here)
      || familyid: , noconstant   /// This NOCONSTANT removes family random intercept
      variance reml residuals(unstructured,t(DV)) /// Unstructured R matrix by DV
      dfmethod(satterthwaite) dftable(pvalue)      // Use Satterthwaite denominator DF
display "-2LL=" e(ll)*-2            // Print -2LL for model
estat wcorrelation, covariance      // R matrix
estat wcorrelation                  // RCORR matrix
margins DV                          // Means per person (as given by LINCOM below)
margins DV, pwcompare(pveffects) df(139)  // Pairwise differences (using denominator DF)
test (1.DV=2.DV)(1.DV=3.DV), small  // DF=2 Intercept Diff (small = use denominator DF)
// These LINCOMs would be given by margins, but here's how to get them this way
lincom _cons*1 + 1.DV*1, small      // Kid Intercept (Dad + diff)
lincom _cons*1 + 2.DV*1, small      // Mom Intercept (Dad + diff)
lincom 1.DV*-1 + 2.DV*1, small      // Kid vs. Mom: Intercept Diff
```

```
print("R Empty Means, Unstructured Variance Models for Marital Attitudes")
print("R Model 0a: General Intercept (Dad=Ref DV) using 2 Dummy Codes")
Model0a = gls(data=Example5a, method="REML",
              model=marital~1+kid+mom,    # Fixed intercept will be for dad (as omitted)
              correlation=corSymm(form=~DVnum|FamilyID),  # Unstructured correlations
              weights=varIdent(form=~1|DV))               # Separate variance by DV
print("Print -2LL and Results")  # Btw, AIC and BIC are incorrect (match STATA)
-2*logLik(Model0a); summary(Model0a)
print("Show R and RCORR matrices for first family in the data")
getVarCov(Model0a, individual="3996");
corMatrix(Model0a$modelStruct$corStruct)[[3]] # 3=Dimensions of R here

print("DF=2 Intercept Diff -- Get error that it used Chi-Square instead of F")
F0a = glht(model=Model0a, linfct=rbind(c(0,1,0),c(0,0,1)), df=139)
SaveF0a = summary(F0a, test=Ftest()); SaveF0a # Joint F-test
print("Get and show hidden results for F, dfnum, dfden, and p-value")
SaveF0a$test$fstat; SaveF0a$test$df; SaveF0a$df
pf(SaveF0a$test$fstat,df1=SaveF0a$test$df,df2=SaveF0a$df,lower.tail=FALSE)

print("Missing Intercepts and Difference -- Had to give it correct Denominator DF")
summary(glht(model=Model0a, df=139, linfct=rbind(
  "Kid Intercept (Dad+Diff)"     = c(1,1,0),  # in order of fixed effects
  "Mom Intercept (Dad+Diff)"     = c(1,0,1),
  "Kid vs. Mom: Intercept Diff" = c(0,-1,1))), test=adjusted("none"))

print("R Model 0b: General Intercept (Dad=Ref DV) using Program-Categorical DV")
Model0b = gls(data=Example5a, method="REML",
              model=marital~1+factor(DV3),  # Fixed intercept will be for DV=3
              correlation=corSymm(form=~DVnum|FamilyID),
              weights=varIdent(form=~1|DV))
print("Print -2LL and Results")  # Btw, AIC and BIC are incorrect (match STATA)
-2*logLik(Model0b); summary(Model0b)
print("Show R and RCORR matrices for first family in the data")
getVarCov(Model0b, individual="3996");
corMatrix(Model0b$modelStruct$corStruct)[[3]] # 3=Dimensions of R here
print("DV means, pairwise mean differences, and omnibus F-test")
print("Error message says appx-satterthwaite used instead -- close but not quite")
emmeans(ref_grid(Model0b), pairwise~DV3, adjust="none"); joint_tests(Model0b)
```

SAS Output—Variance parameters, fit statistics, and contrasts are the same from all Model 0 variants:

```
                    Iteration History
Iteration     Evaluations     -2 Res Log Like       Criterion
        0               1        729.02493914
        1               2        706.95470511      0.00000000
```

For your homework using SAS, get your −2LL value from this table to get two digits after the decimal.

```
   Estimated R Matrix for FAMILYID 3996        Estimated R Correlation Matrix for FAMILYID 3996
  Row        Col1         Col2         Col3          Row        Col1         Col2         Col3
    1       0.3312      0.04133      0.08240           1       1.0000       0.1264       0.2533
    2      0.04133       0.3230      0.09371           2       0.1264       1.0000       0.2917
    3      0.08240      0.09371       0.3196           3       0.2533       0.2917       1.0000

                Covariance Parameter Estimates
                                 Standard        Z
Cov Parm    Subject    Estimate       Error     Value        Pr Z
UN(1,1)     FamilyID     0.3312     0.03973      8.34      <.0001  Variance across Kids
UN(2,1)     FamilyID    0.04133     0.02796      1.48      0.1394  Kid-Mom Covariance
UN(2,2)     FamilyID     0.3230     0.03875      8.34      <.0001  Variance across Moms
UN(3,1)     FamilyID    0.08240     0.02847      2.89      0.0038  Kid-Dad Covariance
UN(3,2)     FamilyID    0.09371     0.02839      3.30      0.0010  Mom-Dad Covariance
UN(3,3)     FamilyID     0.3196     0.03834      8.34      <.0001  Variance across Dads

                         Information Criteria
Neg2LogLike    Parms        AIC        AICC        HQIC         BIC        CAIC
      707.0        6      719.0       719.2       726.1       736.6       742.6

                             Contrasts
Label                     Num DF    Den DF    F Value    Pr > F
DF=2 Diff in Intercept?        2       139      16.19    <.0001
```

Partial STATA Output for variance parameters, fit statistics, and contrasts for all Model 0 variants:

```
Mixed-effects REML regression                   Number of obs     =        420
Group variable: familyid                        Number of groups  =        140
                                                Obs per group:
                                                              min =          3
                                                              avg =        3.0
                                                              max =          3
DF method: Satterthwaite                        DF:           min =     139.00
                                                              avg =     139.00
                                                              max =     139.00

                                                F(2,   139.00)    =      16.19 → Multiv Wald test given
Log restricted-likelihood = -353.47735          Prob > F          =     0.0000

------------------------------------------------------------------------------
  Random-effects Parameters  |   Estimate   Std. Err.     [95% Conf. Interval]
-----------------------------+------------------------------------------------
familyid:             (empty) | (No random effect variances in this model)
-----------------------------+------------------------------------------------
Residual: Unstructured       |
                   var(e1) |   .3311924   .0397272      .2618044    .4189707  Variance across Kids
                   var(e2) |   .3230136   .0387461      .2553391    .4086242  Variance across Moms
                   var(e3) |   .3195886   .0383353      .2526318    .4042916  Variance across Dads
                cov(e1,e2) |    .041334    .027963     -.0134724    .0961405  Kid-Mom Covariance
                cov(e1,e3) |   .0824049   .0284663       .026612    .1381978  Kid-Dad Covariance
                cov(e2,e3) |   .0937145   .0283876      .0380758    .1493531  Mom-Dad Covariance
------------------------------------------------------------------------------

    Covariances for familyid = 3996:     Correlations:
           DV |       1        2        3            DV |       1        2        3
  -------------+------------------------   -------------+------------------------
            1 |   0.331                               1 |   1.000
            2 |   0.041    0.323                      2 |   0.126    1.000
            3 |   0.082    0.094    0.320             3 |   0.253    0.292    1.000
```

R and RCORR from estat wcorrelation

SDs for R also printed (not shown here)

Partial R Output for variance parameters, fit statistics, and contrasts for all Model 0 variants:

```
[1] "Print -2LL and Results"
> -2 * logLik(Model0a)
'log Lik.' 706.95471 (df=9)
```

−2LL requested separately

```
Generalized least squares fit by REML
  Model: marital ~ 1 + kid + mom
  Data: Example5a
        AIC       BIC     logLik
  724.95471 761.25248 -353.47735
```

LL instead, and incorrect version of AIC and BIC (counting all parameters instead of just variance model parameters, as in STATA too)

```
Correlation Structure: General
  1     2
2 0.126
3 0.253 0.292
```

Inside of RCORR (given in full below)

```
Variance function:
 Structure: Different standard deviations per stratum
 Formula: ~1 | DV
 Parameter estimates:
     1.Kid      2.Mom      3.Dad
1.00000000 0.98757870 0.98232045
```

Weird multiplication factors to compute SD relative to first DV → ignore this

```
Standardized residuals:
         Min           Q1           Med           Q3          Max
-1.690995001 -0.806539334  0.077916333  0.643753422  3.402105330

Residual standard error: 0.57549394
Degrees of freedom: 420 total; 417 residual
```

Naïve denominator DF given

```
[1] "Show R and RCORR matrices for first family in the data"
> getVarCov(Model0a, individual = "3996")
Marginal variance covariance matrix
         [,1]     [,2]     [,3]
[1,] 0.331190 0.041336 0.082407
[2,] 0.041336 0.323020 0.093715
[3,] 0.082407 0.093715 0.319590

  Standard Deviations: 0.57549 0.56835 0.56532
```

Actual **R** matrix!

```
> corMatrix(Model0a$modelStruct$corStruct)[[3]]
           [,1]       [,2]       [,3]
[1,] 1.00000000 0.12637845 0.25329512
[2,] 0.12637845 1.00000000 0.29167759
[3,] 0.25329512 0.29167759 1.00000000
```

Actual **RCORR** matrix!

```
[1] "DF=2 Intercept Diff -- Get error that it used Chi-Square instead of F"
> F0a = glht(model = Model0a, linfct = rbind(c(0, 1, 0), c(0, 0, 1)), df = 139)
> SaveF0a = summary(F0a, test = Ftest()); SaveF0a

        General Linear Hypotheses
Linear Hypotheses:
       Estimate
1 == 0 -0.32643
2 == 0 -0.05619
Global Test:
   Chisq DF    Pr(>Chisq)
1 32.376  2 0.00000009324
```

R told me it wouldn't compute the F test… except it secretly did! So I just asked for it

```
[1] "Get and show hidden results for F, dfnum, dfden, and p-value"
> SaveF0a$test$fstat
         [,1]
[1,] 16.18809
> SaveF0a$test$df
[1] 2
> SaveF0a$df
[1] 139
> pf(SaveF0a$test$fstat, df1 = SaveF0a$test$df, df2 = SaveF0a$df,
+ lower.tail = FALSE)
                 [,1]
[1,] 0.00000047859907
```

Model-Estimated Fixed Effects from <u>General Intercept Version</u> using Dummy Codes:

Solution for Fixed Effects $\widehat{Marital_{fi}} = \beta_{00} + \beta_{01}(Kid_{fi}) + \beta_{02}(Mom_{fi})$

Effect	Estimate	Standard Error	DF	t Value	Pr > |t|	
Intercept	1.9560	0.04778	139	40.94	<.0001	Dad intercept B00
kid	-0.3264	0.05892	139	-5.54	<.0001	Kid intercept diff B01
mom	-0.05619	0.05702	139	-0.99	0.3261	Mom intercept diff B02

Model-Estimated Fixed Effects from General Intercept Version using Categorical DV:

Solution for Fixed Effects $\widehat{Marital_{fi}} = \beta_{00} + \beta_{01}(Kid_{fi}) + \beta_{02}(Mom_{fi})$

Effect	DV: 1K,2M,3D	Estimate	Standard Error	DF	t Value	Pr > |t|	
Intercept		1.9560	0.04778	139	40.94	<.0001	Dad intercept B00
DV	1.Kid	-0.3264	0.05892	139	-5.54	<.0001	Kid intercept diff B01
DV	2.Mom	-0.05619	0.05702	139	-0.99	0.3261	Mom intercept diff B02
DV	3.Dad	0	.	.	.	.	

Requested Linear Combination Estimates from General Intercept Version either way:

Estimates $\widehat{Marital_{fi}} = \beta_{00} + \beta_{01}(Kid_{fi}) + \beta_{02}(Mom_{fi})$

Label	Estimate	Standard Error	DF	t Value	Pr > |t|	
Kid Intercept (Dad+diff)	1.6295	0.04864	139	33.50	<.0001	B00 + B01
Mom Intercept (Dad+diff)	1.8998	0.04803	139	39.55	<.0001	B00 + B02
Kid vs. Mom: Intercept Diff	0.2702	0.06389	139	4.23	<.0001	B02 - B01

Output from Program-Categorical SAS LSMEANS (Model 0b)—EMMEANS in R, MARGINS in STATA

Least Squares Means

Effect	DV: 1K,2M,3D	Estimate	Standard Error	DF	t Value	Pr > |t|	
DV	1.Kid	1.6295	0.04864	139	33.50	<.0001	Kid intercept B00 + B01
DV	2.Mom	1.8998	0.04803	139	39.55	<.0001	Mom intercept B00 + B02
DV	3.Dad	1.9560	0.04778	139	40.94	<.0001	Dad intercept B00

Differences of Least Squares Means

Effect	DV: 1K,2M,3D	DV: 1K,2M,3D	Estimate	Standard Error	DF	t Value	Pr > |t|	
DV	1.Kid	2.Mom	-0.2702	0.06389	139	-4.23	<.0001	B01 - B02
DV	1.Kid	3.Dad	-0.3264	0.05892	139	-5.54	<.0001	B01
DV	2.Mom	3.Dad	-0.05619	0.05702	139	-0.99	0.3261	B02

Model 0, continued: Empty Means, Unstructured Variance Model for Marital Conservative Gender Attitudes Two Ways for DV-Specific Intercept Version: $\widehat{Marital_{fi}} = \beta_{00}(Dad_{fi}) + \beta_{01}(Kid_{fi}) + \beta_{02}(Mom_{fi})$

```
TITLE2 "SAS Model 0c: DV-Specific Intercepts using All 3 Dummy Codes";
PROC MIXED DATA=work.Example5a NOCLPRINT COVTEST NAMELEN=100 IC METHOD=REML;
* CLASS is for ID variables and program-categorical predictors;
  CLASS FamilyID DV; * NOINT removes general fixed intercept;
  MODEL marital = kid mom dad / NOINT SOLUTION DDFM=Satterthwaite;
  REPEATED DV / R RCORR TYPE=UN SUBJECT=FamilyID; * UN = unstructured R;
  CONTRAST "DF=2 Intercept Diff"          kid -1 mom 1, kid -1 dad 1;
  ESTIMATE "Kid vs. Mom: Intercept Diff"  kid -1 mom 1;
  ESTIMATE "Kid vs. Dad: Intercept Diff"  kid -1 dad 1;
  ESTIMATE "Mom vs. Dad: Intercept Diff"  mom -1 dad 1;
RUN; TITLE2;

TITLE2 "SAS Model 0d: DV-Specific Intercepts using Program-Categorical DV";
PROC MIXED DATA=work.Example5a NOCLPRINT COVTEST NAMELEN=100 IC METHOD=REML;
* CLASS is for ID variables and program-categorical predictors;
  CLASS FamilyID DV; * NOINT removes general fixed intercept;
  MODEL marital = DV / NOINT SOLUTION DDFM=Satterthwaite;
  REPEATED DV / R RCORR TYPE=UN SUBJECT=FamilyID;
* F-test given by default is INCORRECT without a general intercept;
  CONTRAST "DF=2 Intercept Diff"          DV -1 0 1, DV -1 1 0;
* LSMEANS gives all means and mean diffs (given by ESTIMATEs below);
  LSMEANS DV / DIFF=ALL;
  ESTIMATE "Kid vs. Mom: Intercept Diff"  DV -1  1  0;
  ESTIMATE "Kid vs. Dad: Intercept Diff"  DV -1  0  1;
  ESTIMATE "Mom vs. Dad: Intercept Diff"  DV  0 -1  1;
RUN; TITLE2; TITLE1;
```

```
display "STATA Model 0c: DV-Specific Intercepts using All 3 Dummy Codes"
mixed marital c.kid c.mom c.dad, noconstant /// This NOCONSTANT removes general fixed intercept
       || familyid: , noconstant            /// This NOCONSTANT removes family random intercept
      variance reml residuals(unstructured,t(DV)) /// Unstructured R matrix by DV
      dfmethod(satterthwaite) dftable(pvalue)      // Use Satterthwaite denominator DF
display "-2LL=" e(ll)*-2                    // Print -2LL for model
estat wcorrelation, covariance              // R matrix
estat wcorrelation                          // RCORR matrix
test (c.kid=c.mom)(c.kid=c.dad), small      // DF=2 Intercept Diff (small = use denominator DF)
lincom c.kid*-1 + c.mom*1, small            // Kid vs. Mom: Intercept Diff
lincom c.kid*-1 + c.dad*1, small            // Kid vs. Dad: Intercept Diff
lincom c.mom*-1 + c.dad*1, small            // Mom vs. Dad: Intercept Diff

display "STATA Model 0d: DV-Specific Intercepts using Program-Categorical DV"
display "ibn. = use all factor levels (no base as reference)"
mixed marital ibn.DV, noconstant    /// This NOCONSTANT removes general fixed intercept
      || familyid: , noconstant     /// This NOCONSTANT removes family random intercept
      variance reml residuals(unstructured,t(DV)) /// Unstructured R matrix by DV
      dfmethod(satterthwaite) dftable(pvalue)      // Use Satterthwaite denominator DF
display "-2LL=" e(ll)*-2            // Print -2LL for model
estat wcorrelation, covariance      // R matrix
estat wcorrelation                  // RCORR matrix
test (1.DV=2.DV)(1.DV=3.DV), small  // DF=2 Intercept Diff (small = use denominator DF)
lincom 1.DV*-1 + 2.DV*1, small      // Kid vs. Mom: Intercept Diff
lincom 1.DV*-1 + 3.DV*1, small      // Kid vs. Dad: Intercept Diff
lincom 2.DV*-1 + 3.DV*1, small      // Mom vs. Dad: Intercept Diff


print("R Model 0c: DV-Specific Intercepts using All 3 Dummy Codes")
Model0c = gls(data=Example5a, method="REML",
              model=marital~0+kid+mom+dad,                # 0 removes fixed intercept
              correlation=corSymm(form=~DVnum|FamilyID),  # Unstructured correlations
              weights=varIdent(form=~1|DV))               # Separate variance by DV
print("Print -2LL and Results")  # Btw, AIC and BIC are incorrect (match STATA)
-2*logLik(Model0c); summary(Model0c)
print("Show R and RCORR matrices for first family in the data")
getVarCov(Model0c, individual="3996");
corMatrix(Model0c$modelStruct$corStruct)[[3]] # 3=Dimensions of R here

print("DF=2 Intercept Diff -- Get error that it used Chi-Square instead of F")
F0c = glht(model=Model0c, linfct=rbind(c(-1,1,0),c(0,-1,1)), df=139)
SaveF0c = summary(F0c, test=Ftest()); SaveF0a # Joint F-test
print("Get and show hidden results for F, dfnum, dfden, and p-value")
SaveF0c$test$fstat; SaveF0c$test$df; SaveF0c$df
pf(SaveF0c$test$fstat,df1=SaveF0c$test$df,df2=SaveF0c$df,lower.tail=FALSE)

print("Pairwise Intercept Diffs -- Had to give it correct Denominator DF")
summary(glht(model=Model0c, df=139, linfct=rbind(
  "Kid vs. Mom: Intercept Diff" = c(-1,1,0),  # in order of fixed effects
  "Kid vs. Dad: Intercept Diff" = c(-1,0,1),
  "Mom vs. Dad: Intercept Diff" = c(0,-1,1))), test=adjusted("none"))


print("R Model 0d: DV-Specific Intercepts using Program-Categorical DV")
Model0d = gls(data=Example5a, method="REML",
              model=marital~0+factor(DV),  # 0 removes fixed intercept
              correlation=corSymm(form=~DVnum|FamilyID),
              weights=varIdent(form=~1|DV))
print("Print -2LL and Results")  # Btw, AIC and BIC are incorrect (match STATA)
-2*logLik(Model0d); summary(Model0d)
print("Show R and RCORR matrices for first family in the data")
getVarCov(Model0d, individual="3996");
corMatrix(Model0d$modelStruct$corStruct)[[3]] # 3=Dimensions of R here
print("DV means, pairwise mean differences, and omnibus F-test")
print("Error message says appx-satterthwaite used instead -- close but not quite")
emmeans(ref_grid(Model0d), pairwise~DV, adjust="none"); joint_tests(Model0d)
```

Model-Estimated Fixed Effects from DV-Specific Intercept Version using Dummy Codes:

Solution for Fixed Effects $\widehat{Marital}_{fi} = \beta_{00}(Dad_{fi}) + \beta_{01}(Kid_{fi}) + \beta_{02}(Mom_{fi})$

Effect	Estimate	Standard Error	DF	t Value	Pr > |t|	
kid	1.6295	0.04864	139	33.50	<.0001	Kid intercept B01
mom	1.8998	0.04803	139	39.55	<.0001	Mom intercept B02
dad	1.9560	0.04778	139	40.94	<.0001	Dad intercept B00

Model-Estimated Fixed Effects from DV-Specific Intercept Version using Categorical DV:

Solution for Fixed Effects $\widehat{Marital}_{fi} = \beta_{00}(Dad_{fi}) + \beta_{01}(Kid_{fi}) + \beta_{02}(Mom_{fi})$

Effect	DV: 1K,2M,3D	Estimate	Standard Error	DF	t Value	Pr > |t|	
DV	1.Kid	1.6295	0.04864	139	33.50	<.0001	Kid intercept B01
DV	2.Mom	1.8998	0.04803	139	39.55	<.0001	Mom intercept B02
DV	3.Dad	1.9560	0.04778	139	40.94	<.0001	Dad intercept B00

Requested Linear Combination Estimates from DV-Specific Intercept Version either way:

Estimates $\widehat{Marital}_{fi} = \beta_{00}(Dad_{fi}) + \beta_{01}(Kid_{fi}) + \beta_{02}(Mom_{fi})$

Label	Estimate	Standard Error	DF	t Value	Pr > |t|	
Kid vs. Mom: Intercept Diff	0.2702	0.06389	139	4.23	<.0001	B02 - B01
Kid vs. Dad: Intercept Diff	0.3264	0.05892	139	5.54	<.0001	B00 - B01
Mom vs. Dad: Intercept Diff	0.05619	0.05702	139	0.99	0.3261	B00 - B02

Output from Program-Categorical SAS LSMEANS (Model 0d)—EMMEANS in R, MARGINS in STATA

Least Squares Means

Effect	DV: 1K,2M,3D	Estimate	Standard Error	DF	t Value	Pr > |t|	
DV	1.Kid	1.6295	0.04864	139	33.50	<.0001	Kid intercept B01
DV	2.Mom	1.8998	0.04803	139	39.55	<.0001	Mom intercept B02
DV	3.Dad	1.9560	0.04778	139	40.94	<.0001	Dad intercept B00

Differences of Least Squares Means

Effect	DV: 1K,2M,3D	DV: 1K,2M,3D	Estimate	Standard Error	DF	t Value	Pr > |t|	
DV	1.Kid	2.Mom	-0.2702	0.06389	139	-4.23	<.0001	B01 - B02
DV	1.Kid	3.Dad	-0.3264	0.05892	139	-5.54	<.0001	B01 - B00
DV	2.Mom	3.Dad	-0.05619	0.05702	139	-0.99	0.3261	B02 - B00

To avoid confusion, we will proceed using Model 0c: DV-specific intercepts implemented via three dummy codes. This approach also aligns most directly with path model variants of these models (Part 2).

Model 1: DV-Specific Intercepts adding Kid's Gender as Predictor for Each Attitude

$$\widehat{Marital}_{fi} = \beta_{00}(Dad_{fi}) + \beta_{01}(Kid_{fi}) + \beta_{02}(Mom_{fi})$$
$$+\beta_{10}(Dad_{fi})(KidBoy_f) + \beta_{11}(Kid_{fi})(KidBoy_f) + \beta_{12}(Mom_{fi})(KidBoy_f)$$

```
TITLE "SAS Model 1: DV-Specific Intercepts -- Add Kid Gender";
PROC MIXED DATA=work.Example5a NOCLPRINT COVTEST NAMELEN=100 IC METHOD=REML;
  CLASS FamilyID DV;  * CLASS is for ID variables;
  MODEL marital = kid mom dad kid*KidBoy mom*KidBoy dad*KidBoy
                  / NOINT SOLUTION DDFM=Satterthwaite;
  REPEATED DV / R RCORR TYPE=UN SUBJECT=FamilyID;
  CONTRAST "DF=2 Diff in KidBoy Slope?" kid*KidBoy -1 Mom*KidBoy 1, kid*KidBoy -1 Dad*KidBoy 1;
  ESTIMATE "Kid vs. Mom: KidBoy Slope Diff"  kid*KidBoy -1 Mom*KidBoy 1;
  ESTIMATE "Kid vs. Dad: KidBoy Slope Diff"  kid*KidBoy -1 Dad*KidBoy 1;
  ESTIMATE "Mom vs. Dad: KidBoy Slope Diff"  Mom*KidBoy -1 Dad*KidBoy 1;
  ESTIMATE "Parent KidBoy Slope" Mom*KidBoy 1 Dad*KidBoy 1 / DIVISOR=2;
  ESTIMATE "Kid vs. Parents: KidBoy Diff"  Kid*KidBoy -2  Mom*KidBoy 1 Dad*KidBoy 1 / DIVISOR=2;
RUN; TITLE;
```

```
display "STATA Model 1: DV-Specific Intercepts -- Add Kid Gender"
mixed marital c.kid c.mom c.dad c.kid#c.kidboy c.mom#c.kidboy c.dad#c.kidboy, noconstant ///
      || familyid: , noconstant     /// This NOCONSTANT removes family random intercept
      variance reml residuals(unstructured,t(DV)) /// Unstructured R matrix by DV
      dfmethod(satterthwaite) dftable(pvalue)      // Use Satterthwaite denominator DF
display "-2LL=" e(ll)*-2             // Print -2LL for model
estat wcorrelation, covariance       // R matrix
estat wcorrelation                   // RCORR matrix
// DF=2 Diff in Kidboy Slope
test (c.kid#c.kidboy=c.mom#c.kidboy)(c.kid#c.kidboy=c.dad#c.kidboy), small
lincom c.kid#c.kidboy*-1 + c.mom#c.kidboy*1, small // Kid vs. Mom: Kidboy Slope Diff
lincom c.kid#c.kidboy*-1 + c.dad#c.kidboy*1, small // Kid vs. Dad: Kidboy Slope Diff
lincom c.mom#c.kidboy*-1 + c.dad#c.kidboy*1, small // Mom vs. Dad: Kidboy Slope Diff
lincom 0.5*(c.mom#c.kidboy*1 + c.dad#c.kidboy*1), small // Parent: Kidboy Slope
// Mom vs. Dad: Kidboy Slope Diff
lincom 0.5*(c.kid#c.kidboy*-2 + c.mom#c.kidboy*1 + c.dad#c.kidboy*1), small
```

```
print("R Model 1: DV-Specific Intercepts -- Add Kid Gender")
Model1 = gls(data=Example5a, method="REML",
             model=marital~0+kid+mom+dad+kid:KidBoy+mom:KidBoy+dad:KidBoy,
             correlation=corSymm(form=~DVnum|FamilyID),  # Unstructured correlations
             weights=varIdent(form=~1|DV))               # Separate variance by DV
print("Print -2LL and Results")
-2*logLik(Model1); summary(Model1)
print("Show R and RCORR matrices for first family in the data")
getVarCov(Model1, individual="3996");
corMatrix(Model1$modelStruct$corStruct)[[3]] # 3=Dimensions of R here

print("DF=2 Diff in KidBoy Effect -- Get error that it used Chi-Square instead of F")
F1 = glht(model=Model1, linfct=rbind(c(0,0,0,-1,1,0),c(0,0,0,-1,0,1)), df=138)
SaveF1 = summary(F1, test=Ftest()); SaveF0a # Joint F-test
print("Get and show hidden results for F, dfnum, dfden, and p-value")
SaveF1$test$fstat; SaveF1$test$df; SaveF1$df
pf(SaveF1$test$fstat,df1=SaveF1$test$df,df2=SaveF1$df,lower.tail=FALSE)

print("KidBoy Slope Diffs -- Had to give it correct Denominator DF")
summary(glht(model=Model1, df=138, linfct=rbind(
  "Kid vs. Mom: KidBoy Slope Diff"     = c(0,0,0,-1,1,0),  # in order of fixed effects
  "Kid vs. Dad: KidBoy Slope Diff"     = c(0,0,0,-1,0,1),
  "Mom vs. Dad: KidBoy Slope Diff"     = c(0,0,0,0,-1,1),
  "Parent KidBoy Effect"               = c(0,0,0,0,1/2,1/2),
  "Kids vs. Parent KidBoy Effect Diff" = c(0,0,0,-1,1/2,1/2))), test=adjusted("none"))
```

Partial SAS Output for Model 1: DV-Specific Intercepts adding Kid's Gender as Predictor for Each Attitude

$$\widehat{Marital}_{fi} = \beta_{00}(Dad_{fi}) + \beta_{01}(Kid_{fi}) + \beta_{02}(Mom_{fi})$$
$$+\beta_{10}(Dad_{fi})(KidBoy_f) + \beta_{11}(Kid_{fi})(KidBoy_f) + \beta_{12}(Mom_{fi})(KidBoy_f)$$

Estimated R Matrix for FAMILYID 3996

Row	Col1	Col2	Col3
1	0.3136	0.03725	0.07733
2	0.03725	0.3244	0.09315
3	0.07733	0.09315	0.3203

Estimated R Correlation Matrix for FAMILYID 3996

Row	Col1	Col2	Col3
1	1.0000	0.1168	0.2440
2	0.1168	1.0000	0.2890
3	0.2440	0.2890	1.0000

Information Criteria

Neg2LogLike	Parms	AIC	AICC	HQIC	BIC	CAIC
707.0	6	719.0	719.2	726.2	736.7	742.7

Contrasts

Label	Num DF	Den DF	F Value	Pr > F
DF=2 Diff in KidBoy Effect?	2	138	1.90	0.1529

```
                      Solution for Fixed Effects
                                 Standard
Effect          Estimate         Error       DF     t Value     Pr > |t|
kid               1.4950       0.06554      138       22.81       <.0001   Kid intercept B01
mom               1.8703       0.06666      138       28.06       <.0001   Mom intercept B02
dad               1.9178       0.06624      138       28.95       <.0001   Dad intercept B00
kid*KidBoy        0.2811       0.09474      138        2.97       0.0035   girl vs boy for Kid B11
mom*KidBoy       0.06152       0.09636      138        0.64       0.5242   girl vs boy for Mom B12
dad*KidBoy       0.07970       0.09575      138        0.83       0.4066   girl vs boy for Dad B10

                                              Estimates
                                                       Standard
Label                                   Estimate         Error       DF     t Value     Pr > |t|
Kid vs. Mom: KidBoy Slope Diff           -0.2196        0.1270      138       -1.73       0.0860   B12 - B11
Kid vs. Dad: KidBoy Slope Diff           -0.2014        0.1171      138       -1.72       0.0877   B10 - B11
Mom vs. Dad: KidBoy Slope Diff           0.01818        0.1145      138        0.16       0.8741   B10 - B12
Parent KidBoy Slope                      0.07061       0.07711      138        0.92       0.3614   0.5*(B10+B12)
Kid vs. Parents: KidBoy Slope Diff       -0.2105        0.1079      138       -1.95       0.0531   0.5*(B10+B12)-B11
```

It looks like we need to control for the effect of kid gender only for the kid (which makes sense, since we don't know about the gender of their siblings). Next, we'll test the effects of each person's education on their own attitude, followed by the incremental effect of dad's education on kid and mom attitudes after controlling for own education.

Model 2: DV-Specific Intercepts adding Own Education as Predictor of Own Attitude

$$\widehat{Marital}_{fi} = \beta_{00}(Dad_{fi}) + \beta_{01}(Kid_{fi}) + \beta_{02}(Mom_{fi}) + \beta_{11}(Kid_{fi})(KidBoy_f) \\ +\beta_{20}(Dad_{fi})(DadEd_f - 12) + \beta_{31}(Kid_{fi})(KidEd_f - 12) + \beta_{42}(Mom_{fi})(MomEd_f - 12)$$

```
TITLE "SAS Model 2: DV-Specific Intercepts -- KidBoy on Kid Only, Add Own Educ";
PROC MIXED DATA=work.Example5a NOCLPRINT COVTEST NAMELEN=100 IC METHOD=REML;
  CLASS FamilyID DV;  * CLASS is for ID variables;
  MODEL marital = kid mom dad kid*KidBoy kid*KidEd12 mom*MomEd12 dad*DadEd12
                  / NOINT SOLUTION DDFM=Satterthwaite;
  REPEATED DV / R RCORR TYPE=UN SUBJECT=FamilyID;
RUN; TITLE;

display "STATA Model 2: DV-Specific Intercepts -- KidBoy on Kid Only, Add Own Education"
mixed marital c.kid c.mom c.dad c.kid#c.kidboy                            ///
      c.kid#c.kided12 c.mom#c.momed12 c.dad#c.daded12, noconstant      ///
      || familyid: , noconstant    /// This NOCONSTANT removes family random intercept
      variance reml residuals(unstructured,t(DV)) /// Unstructured R matrix by DV
      dfmethod(satterthwaite) dftable(pvalue)       // Use Satterthwaite denominator DF
display "-2LL=" e(ll)*-2                 // Print -2LL for model
estat wcorrelation, covariance           // R matrix
estat wcorrelation                       // RCORR matrix

print("R Model 2: DV-Specific Intercepts -- KidBoy on Kid Only, Add Own Educ")
Model2 = gls(data=Example5a, method="REML",
             model=marital~0+kid+mom+dad +kid:KidBoy +kid:KidEd12+mom:MomEd12+dad:DadEd12,
             correlation=corSymm(form=~DVnum|FamilyID),  # Unstructured correlations
             weights=varIdent(form=~1|DV))               # Separate variance by DV
print("Print -2LL and Results")
-2*logLik(Model2); summary(Model2)
print("Show R and RCORR matrices for first family in the data")
getVarCov(Model2, individual="3996");
corMatrix(Model2$modelStruct$corStruct)[[3]] # 3=Dimensions of R here
```

Partial SAS Output for Model 2:

$$\widehat{Marital}_{fi} = \beta_{00}(Dad_{fi}) + \beta_{01}(Kid_{fi}) + \beta_{02}(Mom_{fi}) + \beta_{11}(Kid_{fi})(KidBoy_f)$$
$$+\beta_{20}(Dad_{fi})(DadEd_f - 12) + \beta_{31}(Kid_{fi})(KidEd_f - 12) + \beta_{42}(Mom_{fi})(MomEd_f - 12)$$

```
   Estimated R Matrix for FAMILYID 3996           Estimated R Correlation Matrix for FAMILYID 3996
  Row        Col1         Col2         Col3           Row        Col1         Col2         Col3
    1      0.3156      0.03837      0.07669              1      1.0000       0.1207       0.2501
    2     0.03837       0.3205      0.08441              2      0.1207       1.0000       0.2732
    3     0.07669      0.08441       0.2979              3      0.2501       0.2732       1.0000

                                     Information Criteria
Neg2LogLike     Parms         AIC        AICC        HQIC         BIC        CAIC
      708.6         6       720.6       720.8       727.8       738.3       744.3

                                  Solution for Fixed Effects
                                    Standard
Effect            Estimate         Error      DF     t Value     Pr > |t|
kid                 1.5117       0.09814     141       15.40       <.0001    Kid intercept B01
mom                 1.9359       0.05976     142       32.39       <.0001    Mom intercept B02
dad                 2.0700       0.05663     145       36.55       <.0001    Dad intercept B00
kid*KidBoy          0.2641       0.09204     137        2.87       0.0048    girl vs boy for Kid B11
kid*KidEd12       -0.00280       0.02344     138       -0.12       0.9052    Kid Ed for kid B31
mom*MomEd12       -0.01725       0.01711     142       -1.01       0.3150    Mom Ed for mom B42
dad*DadEd12       -0.05447       0.01570     143       -3.47       0.0007    Dad Ed for dad B20
```

Model 3: DV-Specific Intercepts adding Dad Education as Predictor of Kid and Mom Attitudes

$$\widehat{Marital}_{fi} = \beta_{00}(Dad_{fi}) + \beta_{01}(Kid_{fi}) + \beta_{02}(Mom_{fi}) + \beta_{11}(Kid_{fi})(KidBoy_f)$$
$$+\beta_{20}(Dad_{fi})(DadEd_f - 12) + \beta_{31}(Kid_{fi})(KidEd_f - 12) + \beta_{42}(Mom_{fi})(MomEd_f - 12)$$
$$+\beta_{21}(Kid_{fi})(DadEd_f - 12) + \beta_{22}(Mom_{fi})(DadEd_f - 12)$$

```
TITLE "SAS Model 3: DV-Specific Intercepts -- Add Dad Educ (Control for Own Educ)";
PROC MIXED DATA=work.Example5a NOCLPRINT COVTEST NAMELEN=100 METHOD=REML;
  CLASS FamilyID DV;  * CLASS is for ID variables;
  MODEL marital = kid mom dad kid*KidBoy Kid*KidEd12 Mom*MomEd12 Dad*DadEd12
                  Kid*DadEd12 Mom*DadEd12 / NOINT SOLUTION DDFM=Satterthwaite RESIDUAL;
  REPEATED DV / R RCORR TYPE=UN SUBJECT=FamilyID; * RESIDUAL requests plots of residuals;
  ESTIMATE "Kid vs. Mom: DadEd12 Slope Diff"  kid*DadEd12 -1 mom*DadEd12 1;
  ESTIMATE "Kid vs. Dad: DadEd12 Slope Diff"  kid*DadEd12 -1 dad*DadEd12 1;
  ESTIMATE "Mom vs. Dad: DadEd12 Slope Diff"  mom*DadEd12 -1 dad*DadEd12 1;
RUN; TITLE;

display "STATA Model 3: DV-Specific Intercepts -- Add Dad Educ (Control for Own Educ)"
mixed marital c.kid c.mom c.dad c.kid#c.kidboy c.kid#c.kided12 c.mom#c.momed12  ///
      c.dad#c.daded12 c.kid#c.daded12 c.mom#c.daded12, noconstant              ///
      || familyid: , noconstant   /// This NOCONSTANT removes family random intercept
      variance reml residuals(unstructured,t(DV)) /// Unstructured R matrix by DV
      dfmethod(satterthwaite) dftable(pvalue)     // Use Satterthwaite denominator DF
display "-2LL=" e(ll)*-2            // Print -2LL for model
estat wcorrelation, covariance      // R matrix
estat wcorrelation                  // RCORR matrix
lincom c.kid#c.daded12*-1 + c.mom#c.daded12*1, small // Kid vs. Mom: DadEd12 Slope Diff
lincom c.kid#c.daded12*-1 + c.dad#c.daded12*1, small // Kid vs. Dad: DadEd12 Slope Diff
lincom c.mom#c.daded12*-1 + c.dad#c.daded12*1, small // Mom vs. Dad: DadEd12 Slope Diff
predict Model3pred, xb         // Save yhat from fixed effects
predict Model3res, rstandard   // Save "standardized" residuals from fixed effects
hist Model3res                 // Histogram of residuals (for normality)
graph export "$filesave\STATA Model 3 Residual Histogram.png", replace
twoway (scatter Model3res Model3pred)  // Scatterplot by predicted (for constant variance)
graph export "$filesave\STATA Model 3 Residual Scatterplot.png", replace
```

```
print("R Model 3: DV-Specific Intercepts -- Add Dad Educ (Control for Own Educ)")
Model3 = gls(data=Example5a, method="REML",
             model=marital~0+kid+mom+dad+ kid:KidBoy +kid:KidEd12+mom:MomEd12+dad:DadEd12
                          +kid:DadEd12+mom:DadEd12,
             correlation=corSymm(form=~DVnum|FamilyID),  # Unstructured correlations
             weights=varIdent(form=~1|DV))               # Separate variance by DV
print("Print -2LL and Results")  # Btw, AIC and BIC are incorrect (match STATA)
-2*logLik(Model3); summary(Model3)
print("Show R and RCORR matrices for first family in the data")
getVarCov(Model3, individual="3996");
corMatrix(Model3$modelStruct$corStruct)[[3]] # 3=Dimensions of R here

print("DadEd Slope Diffs -- Had to give it correct Denominator DF")
summary(glht(model=Model3, df=136, linfct=rbind(
  "Kid vs. Mom: DadEd12 Slope Diff" = c(0,0,0,0,0,0,0,-1,1),  # in order of fixed effects
  "Kid vs. Dad: DadEd12 Slope Diff" = c(0,0,0,0,0,0,1,-1,0),
  "Mom vs. Dad: DadEd12 Slope Diff" = c(0,0,0,0,0,0,1,0,-1))), test=adjusted("none"))

print("Save yhat from fixed effects and Pearson residuals")
Example5a$Model3pred = predict(Model3, type="response")
Example5a$Model3res = residuals(Model3, type="pearson")
print ("Histogram of Residuals for normality")
hist(x=Example5a$Model3res, freq=FALSE, ylab="Density",xlab="Model 3 Residuals")
print ("Scatterplot of residuals by prediced for constant variance")
plot(x=Example5a$Model3res, y=Example5a$Model3pred,
     ylab="Residual",xlab="Model 3 Predicted Outcome")
```

Partial SAS Output for Model 3:

$$\widehat{Marital}_{fi} = \beta_{00}(Dad_{fi}) + \beta_{01}(Kid_{fi}) + \beta_{02}(Mom_{fi}) + \beta_{11}(Kid_{fi})(KidBoy_f)$$
$$+\beta_{20}(Dad_{fi})(DadEd_f - 12) + \beta_{31}(Kid_{fi})(KidEd_f - 12) + \beta_{42}(Mom_{fi})(MomEd_f - 12)$$
$$+\beta_{21}(Kid_{fi})(DadEd_f - 12) + \beta_{22}(Mom_{fi})(DadEd_f - 12)$$

Estimated R Matrix for FAMILYID 3996

Row	Col1	Col2	Col3
1	0.3179	0.03856	0.07720
2	0.03856	0.3229	0.08514
3	0.07720	0.08514	0.2982

Estimated R Correlation Matrix for FAMILYID 3996

Row	Col1	Col2	Col3
1	1.0000	0.1204	0.2508
2	0.1204	1.0000	0.2744
3	0.2508	0.2744	1.0000

Information Criteria

Neg2LogLike	Parms	AIC	AICC	HQIC	BIC	CAIC
720.8	6	732.8	733.0	739.9	750.4	756.4

Solution for Fixed Effects

Effect	Estimate	Standard Error	DF	t Value	Pr > |t|	
kid	1.5123	0.1003	140	15.08	<.0001	Kid intercept B01
mom	1.9373	0.06305	138	30.73	<.0001	Mom intercept B02
dad	2.0707	0.05769	138	35.89	<.0001	Dad intercept B00
kid*KidBoy	0.2639	0.09258	136	2.85	0.0050	girl vs boy for Kid B11
kid*KidEd12	-0.00264	0.02458	136	-0.11	0.9147	Kid Ed for kid B31
mom*MomEd12	-0.01624	0.02068	137	-0.79	0.4338	Mom Ed for mom B42
dad*DadEd12	-0.05484	0.01654	138	-3.32	0.0012	Dad Ed for dad B20
kid*DadEd12	-0.00048	0.01791	138	-0.03	0.9787	Dad Ed for kid B21
mom*DadEd12	-0.00169	0.02069	141	-0.08	0.9349	Dad Ed for mom B22

Estimates

Label	Estimate	Standard Error	DF	t Value	Pr > |t|	
Kid vs. Mom: DadEd12 Slope Diff	-0.00121	0.02601	162	-0.05	0.9629	B22 - B21
Kid vs. Dad: DadEd12 Slope Diff	-0.05436	0.02127	143	-2.56	0.0117	B20 - B21
Mom vs. Dad: DadEd12 Slope Diff	-0.05314	0.02335	154	-2.28	0.0242	B20 - B22

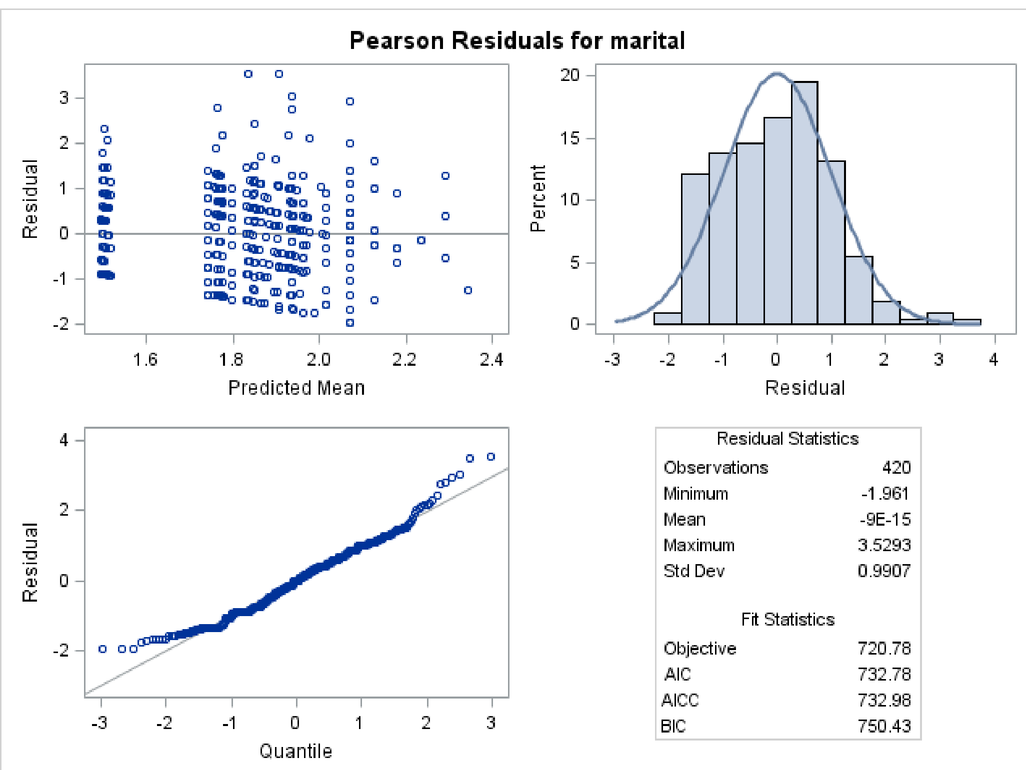
Moral of the story? Multivariate models can be estimated in univariate software to capture the relationships between person-specific predictors and person-specific outcomes (such as in "actor–partner" models for dyadic data as well).

Example results section for Part 1 Models 0–3:

The extent to which gender and education predicted marital attitudes was examined in 140 families, in which responses were collected from adult children, their mothers, and their fathers. Higher outcomes indicated more conservative marital attitudes (i.e., gender-traditional attitudes measured as the mean across items on a scale of 1 to 4). Given that the outcomes were correlated within families, multivariate general linear models (i.e., with conditionally multivariate normal residuals) were used to predict all three outcomes for each family simultaneously. All models were estimated using residual maximum likelihood and Satterthwaite denominator degrees of freedom. All models allowed separate means and residual variances across the three outcomes for the three types of family members, as well as covariances among the residuals from the same family. ESTIMATE statements were used to estimate simple slopes and simple slope differences as linear combinations of the model fixed effects. Prior to adding predictors, an empty means model (i.e., an unconditional model with no predictors) revealed significant differences in marital attitudes across type of family member, $F(2, 139) = 16.19$, $p < .001$. Although mean attitudes were similar across mothers and fathers (1.90 and 1.96, respectively, $p = .27$), the mean attitudes of children (1.63) were significantly less conservative on average than those of their parents ($p < .001$ for both comparisons).

To begin, we examined the extent to which the gender of the adult child (coded 0=woman, 1=man) who was surveyed was related to the martial attitudes of each type of family member. Although the attitudes of adult male children were significantly more conservative than those of adult female children (diff = 0.28, $p = .004$), there were no significant effects of the gender of the adult child for the marital attitudes of their mothers or fathers. Thus, we retained a predictor for the gender of the adult child only for the adult child's outcome. We then examined the extent to which the education (centered at 12 years) of each type of family member predicted their own attitudes, which was significant only for the father: for every additional year of father's education, his own attitudes were expected to be less conservative by 0.05 ($p < .001$). Next, we examined whether father's education incrementally predicted the marital attitudes of the mother or adult child after controlling for their own education, but neither effect was significant (and the effect of father's education on his own attitudes was significantly larger).

But how do we know if Model 3 is sufficient?? One aspect concerns the fit of the conditional distribution—in absence of Pearson χ^2/DF, we can examine residual plots, such as shown for SAS below:



These plots suggest some deviation from normality of the residuals, although the assumption of constant variance looks not terribly unreasonable.

Unfortunately, multivariate options for generalized linear models do not include beta-binomial alternatives that might have been useful here (given that the outcomes are bounded by 1 and 4). Also, given that all predicted outcomes stayed in bounds, it appears we don't need a link function.

Instead, we can see how the results differ using "robust" standard errors…so stay tuned for Part 2!

The other issue whether all relationships among the predictors and outcomes have been captured adequately by the model… for a more efficient way to answer that question, **stay tuned for Part 2 using path analysis**!

Part 2: Multivariate General Linear Models via Path Analysis Software

In Part 2, we begin by estimating Model 3 using path analysis in Mplus, STATA SEM, and R LAVAAN, which each require us to switch to maximum likelihood and test fixed effects without denominator degrees of freedom. For Model 4, we will also invoke “robust” standard errors (that correct for deviations from multivariate non-normality).

SAS Syntax to prepare wide-format data file in .csv format for Mplus:

```
* Export original wide format to Mplus;
DATA work.ForMplus; SET filesave.PSQF6270_Example5aWide;
     * Fixing any missing values;
     ARRAY vars(8) FamilyID KidBoy KidEd12 MomEd12 DadEd12 KidMarital MomMarital DadMarital;
          DO i=1 TO 8; IF vars(i)=. THEN vars(i)=-999; END; DROP i; RUN;
PROC EXPORT DATA=work.ForMplus OUTFILE= "&filesave.\PSQF6270_Example5aWide.csv"
     DBMS=CSV REPLACE; PUTNAMES=NO; RUN;
```

STATA Syntax to prepare wide-format data file in .csv format for Mplus:

```
// Import Example 5a wide STATA data
use "$filesave\PSQF6270_Example5aWide.dta", clear

// Example of how to export a .csv file for use in Mplus
// Replace all missing values with -999 for Mplus
mvencode _all, mv(-999)
// export delimited below: using lists the path and name of the new .csv file
// replace means it will be replaced if a file already exists with that name
// delimiter indicates a comma-delimited file
// nolabel will save actual data (numbers) instead of any value labels included
// novarnames tells it not to write the names to the top of the .csv file
export delimited using "$filesave\PSQF6270_Example5aWide_STATA.csv", ///
                 delimiter(",") replace nolabel novarnames
```

R Syntax to prepare wide-format data file in .csv format for Mplus:

```
# Example of how to export a .csv file for use in Mplus
# Copy data, replace all missing values with -999 for Mplus
Example5a_Mplus = Example5a_wide
Example5a_Mplus[is.na(Example5a_Mplus)] <- -999
# Write to .csv file without column names
write.table(x=Example5a_Mplus, col.names=FALSE, row.names=FALSE, sep=",",
            file=paste0(filesave,"PSQF6270_Example5aWide_R.csv"))
```

Model 3: DV-Specific Intercept Version adding Dad Education as Predictor of Kid and Mom Attitudes

$$
\begin{aligned}
\widehat{Marital}_{fi} = {} & \beta_{00}(Dad_{fi}) + \beta_{01}(Kid_{fi}) + \beta_{02}(Mom_{fi}) + \beta_{11}(Kid_{fi})(KidBoy_f) \\
& + \beta_{20}(Dad_{fi})(DadEd_f - 12) + \beta_{31}(Kid_{fi})(KidEd_f - 12) + \beta_{42}(Mom_{fi})(MomEd_f - 12) \\
& + \beta_{21}(Kid_{fi})(DadEd_f - 12) + \beta_{22}(Mom_{fi})(DadEd_f - 12)
\end{aligned}
$$

STATA Syntax and Output for Previous Model 3 as a Path Model (estimated with ML; regular SEs):

See STATA code updated online for how to get H1 saturated model LL and # of estimated parameters:

```
display "LL for H1 Model= " e(critvalue_s)
display "# of parameters= " e(df_m)
```

```
// Import Example 5a wide STATA data
use "$filesave\PSQF6270_Example5aWide.dta", clear

* /// means continue the command + comment
*  // means comment only

display "STATA Model 3: Own Education + Dad Education a Predictor of Each Attitude"
display "Using SEM to create path analysis model estimated with ML on wide-format data"
sem                                          ///
   (kidmarit mommarit dadmarit <- _cons)     /// All intercepts estimated (by default)
   (kidmarit <- kidboy kided12)              /// Regressions: y outcomes ON x predictors
   (mommarit <- momed12)                     ///
   (kidmarit mommarit dadmarit <- daded12),  ///
    var(e.kidmarit e.mommarit e.dadmarit)    /// All residual variances estimated (by default)
```

```
    covariance(e.kidmarit*e.mommarit         /// All pairwise residual covariances (not default)
               e.mommarit*e.dadmarit         ///
               e.kidmarit*e.dadmarit)        ///
    method(mlmv)                              // Full-information ML
    lincom _b[mommarital:daded12] - _b[kidmarital:daded12] // Kid v. Mom: Dad Educ Effect Diff
    lincom _b[dadmarital:daded12] - _b[kidmarital:daded12] // Kid v. Dad: Dad Educ Effect Diff
    lincom _b[dadmarital:daded12] - _b[mommarital:daded12] // Mom v. Dad: Dad Educ Effect Diff
    sem, coeflegend                         // Print parameter labels, too (to use in lincom)
    sem, standardized                       // Print fully standardized solution, too
    estat gof, stats(all)                   // Print fit statistics
    estat eqgof                             // Print R2 per variable
    estat residuals                         // Print how far off each predicted covariance is
    estat mindices, minchi2(3.84) showpclass(all) // Print voodoo to improve model fit at p<.05
```

```
Structural equation model                        Number of obs     =        140
Estimation method  = mlmv
Log likelihood     = -1374.4822 → Does NOT match Mplus because all predictors are in the likelihood,
                                  not just the outcomes, but rest of the fit tests do match
------------------------------------------------------------------------------------------
UNSTANDARDIZED SOLUTION      |                 OIM
                             |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]   IN MIXED
-----------------------------+------------------------------------------------------------
Structural                   |
  kidmarital <-              |   These unstandardized <- paths are the fixed slopes in MIXED.
                      kidboy |   .2638938   .0914365     2.89   0.004     .0846816    .4431059    B11
                     kided12 |   -.002641   .0242338    -0.11   0.913    -.0501385    .0448565    B31
                     daded12 |  -.0004795   .0176566    -0.03   0.978    -.0350857    .0341268    B21
                       _cons |   1.512271   .0989087    15.29   0.000     1.318414    1.706129    B01
  ---------------------------+------------------------------------------------------------
  mommarital <-              |
                     momed12 |  -.0162593   .0211854    -0.77   0.443    -.0577819    .0252634    B42
                     daded12 |  -.0016793   .0206962    -0.08   0.935    -.0422431    .0388845    B22
                       _cons |   1.937305    .062596    30.95   0.000     1.814619    2.059991    B02
  ---------------------------+------------------------------------------------------------
  dadmarital <-              |
                     daded12 |  -.0548368    .016422    -3.34   0.001    -.0870233   -.0226502    B20
                       _cons |   2.070718   .0572756    36.15   0.000      1.95846    2.182976    B00
-----------------------------+------------------------------------------------------------
        Below are the residual variances and covariances from the R matrix in MIXED.
            var(e.kidmarital)|   .3091381   .0369567                      .2445646    .3907613    UN(1,1)
            var(e.mommarital)|   .3161529   .0379111                      .2499347    .3999152    UN(2,2)
            var(e.dadmarital)|   .2938981   .0351275                      .2325192    .3714795    UN(3,3)
-----------------------------+------------------------------------------------------------
cov(e.kidmarital,e.mommarital)|  .0380059   .0266924     1.42   0.154    -.0143102     .090322    UN(2,1)
cov(e.kidmarital,e.dadmarital)|  .0761007   .0263037     2.89   0.004     .0245463    .1276551    UN(3,1)
cov(e.mommarital,e.dadmarital)|  .0839167   .0273732     3.07   0.002     .0302662    .1375671    UN(3,2)
------------------------------------------------------------------------------------------
LR test of model vs. saturated: chi2(6)   =     10.93, Prob > chi2 = 0.0906
```

```
.    lincom _b[mommarital:daded12] - _b[kidmarital:daded12] // Kid v. Mom: Dad Educ Effect Diff
 ( 1)  - [kidmarital]daded12 + [mommarital]daded12 = 0
------------------------------------------------------------------------------
             |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
         (1) |  -.0011998   .0258607    -0.05   0.963    -.0518858    .0494862  B22 - B21
------------------------------------------------------------------------------

.     lincom _b[dadmarital:daded12] - _b[kidmarital:daded12] // Kid v. Dad: Dad Educ Effect Diff
 ( 1)  - [kidmarital]daded12 + [dadmarital]daded12 = 0
------------------------------------------------------------------------------
             |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
         (1) |  -.0543573   .0210185    -2.59   0.010    -.0955527   -.0131618  B20 - B21
------------------------------------------------------------------------------

.     lincom _b[dadmarital:daded12] - _b[mommarital:daded12] // Mom v. Dad: Dad Educ Effect Diff
 ( 1)  - [mommarital]daded12 + [dadmarital]daded12 = 0
------------------------------------------------------------------------------
             |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
         (1) |  -.0531575    .023324    -2.28   0.023    -.0988717   -.0074432  B20 - B22
------------------------------------------------------------------------------
```

```
.    sem, coeflegend                       // Print parameter labels, too (to use in lincom)
----------------------------------------------------------------------------------------------
                              |      Coef.  Legend
------------------------------+---------------------------------------------------------------
Structural                    |
  kidmarital <-               |
                       kidboy |   .2638938  _b[kidmarital:kidboy]
                      kided12 |   -.002641  _b[kidmarital:kided12]
                      daded12 |  -.0004795  _b[kidmarital:daded12]
                        _cons |   1.512271  _b[kidmarital:_cons]
  ----------------------------+---------------------------------------------------------------
  mommarital <-               |
                      momed12 |  -.0162593  _b[mommarital:momed12]
                      daded12 |  -.0016793  _b[mommarital:daded12]
                        _cons |   1.937305  _b[mommarital:_cons]
  ----------------------------+---------------------------------------------------------------
  dadmarital <-               |
                      daded12 |  -.0548368  _b[dadmarital:daded12]
                        _cons |   2.070718  _b[dadmarital:_cons]
------------------------------+---------------------------------------------------------------
             var(e.kidmarital)|   .3091381  _b[var(e.kidmarital):_cons]
             var(e.mommarital)|   .3161529  _b[var(e.mommarital):_cons]
             var(e.dadmarital)|   .2938981  _b[var(e.dadmarital):_cons]
------------------------------+---------------------------------------------------------------
cov(e.kidmarital,e.mommarital)|   .0380059  _b[cov(e.kidmarital,e.mommarital):_cons]
cov(e.kidmarital,e.dadmarital)|   .0761007  _b[cov(e.kidmarital,e.dadmarital):_cons]
cov(e.mommarital,e.dadmarital)|   .0839167  _b[cov(e.mommarital,e.dadmarital):_cons]
----------------------------------------------------------------------------------------------
LR test of model vs. saturated: chi2(6)   =     10.93, Prob > chi2 = 0.0906
```

This table from `sem, coeflegend` provides the parameter names for the LINCOM statements above.

```
.    sem, standardized                     // Print fully standardized solution, too
----------------------------------------------------------------------------------------------
 Standardized Solution:       |                 OIM
 All variables M=0, SD=1      |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
------------------------------+---------------------------------------------------------------
Structural                    |
  kidmarital <-               |
                       kidboy |   .2306503   .0770785     2.99   0.003     .0795792    .3817214
                      kided12 |  -.0090898   .0834042    -0.11   0.913    -.1725591    .1543794
                      daded12 |  -.0023406   .0861915    -0.03   0.978    -.1712728    .1665916
                        _cons |   2.645964   .2466043    10.73   0.000     2.162628    3.129299
  ----------------------------+---------------------------------------------------------------
  mommarital <-               |
                      momed12 |  -.0782303   .1019932    -0.77   0.443    -.2781333    .1216728
                      daded12 |  -.0083038   .1023122    -0.08   0.935     -.208832    .1922244
                        _cons |   3.433518   .2280257    15.06   0.000     2.986595     3.88044
  ----------------------------+---------------------------------------------------------------
  dadmarital <-               |
                      daded12 |  -.2716069   .0768234    -3.54   0.000     -.422178   -.1210357
                        _cons |   3.676054   .2200636    16.70   0.000     3.244738    4.107371
------------------------------+---------------------------------------------------------------
             var(e.kidmarital)|   .9463698   .0355442                      .8792068    1.018663
             var(e.mommarital)|   .9930701   .0139521                      .9660976    1.020796
             var(e.dadmarital)|   .9262297   .0417315                      .8479448    1.011742
------------------------------+---------------------------------------------------------------
cov(e.kidmarital,e.mommarital)|     .12157   .0835428     1.46   0.146    -.0421709    .2853109
cov(e.kidmarital,e.dadmarital)|   .2524724   .0792209     3.19   0.001     .0972022    .4077426
cov(e.mommarital,e.dadmarital)|   .2752969   .0801933     3.43   0.001     .1181209     .432473
----------------------------------------------------------------------------------------------
```

These standardized <- paths are standardized regression coefficients.

These standardized covariances are residual correlations (in RCORR).

```
.    estat gof, stats(all)                     // Print fit statistics
----------------------------------------------------------------------------
Fit statistic        |      Value   Description (from STATA!)                 Notes from Lesa:
---------------------+------------------------------------------------------
Likelihood ratio     |
          chi2_ms(6) |     10.929   model vs. saturated                       This is -2ΔLL for our H0-H1
            p > chi2 |      0.091                                             Test of exact fit: NS is good!
         chi2_bs(15) |     52.998   baseline vs. saturated                    This is -2ΔLL for H0-H1 if
            p > chi2 |      0.000                                             H0 had no paths at all
---------------------+------------------------------------------------------
Population error     |
               RMSEA |      0.077   Root mean squared error of approximation  Should be < .08 or so
 90% CI, lower bound |      0.000
         upper bound |      0.148
              pclose |      0.229   Probability RMSEA <= 0.05                 Test of exact fit: NS is good!
---------------------+------------------------------------------------------
```

```
Information criteria |
                 AIC |   2778.964   Akaike's information criterion           Does not match Mplus
                 BIC |   2823.089   Bayesian information criterion           Does not match Mplus
---------------------+------------------------------------------------------
Baseline comparison  |
                 CFI |      0.870   Comparative fit index                    Should be > .9 or so
                 TLI |      0.676   Tucker-Lewis index                       Should be > .9 or so
---------------------+------------------------------------------------------
Size of residuals    |
                SRMR |      0.039   Standardized root mean squared residual  Should be < .05 or so
                  CD |      0.132   Coefficient of determination             Like an overall R2 across DVs
----------------------------------------------------------------------------
.    estat eqgof                           // Print R2 per variable
Equation-level goodness of fit
------------------------------------------------------------------------------
             |              Variance              |
     depvars |    fitted  predicted   residual | R-squared        mc      mc2
-------------+--------------------------------+-----------------------------
observed     |                                  |
  kidmarital |  .3266568   .0175187   .3091381 |  .0536302   .231582  .0536302
  mommarital |  .3183591   .0022062   .3161529 |  .0069299  .0832462  .0069299
  dadmarital |  .3173058   .0234077   .2938981 |  .0737703  .2716069  .0737703
-------------+--------------------------------+-----------------------------
     overall |                                  |  .1323532
------------------------------------------------------------------------------
mc  = correlation between depvar and its prediction
mc2 = mc^2 is the Bentler-Raykov squared multiple correlation coefficient

.    estat residuals                       // Print how far off each predicted covariance is
Residuals of observed variables
  Mean residuals
                 | kidmari~l  mommari~l  dadmari~l     kidboy    kided12    momed12    daded12
    -------------+-----------------------------------------------------------------------------
             raw |     0.000      0.000      0.000      0.000      0.000      0.000      0.000
    -------------------------------------------------------------------------------------------
```

Above: the means are recovered perfectly because each outcome has its own intercept (and predictor means are not part of the model). Below: the bolded covariances indicate the biggest sources of misfit—it looks like momed12 needs to predict each outcome!

```
  Covariance residuals
                 | kidmari~l  mommari~l  dadmari~l     kidboy    kided12    momed12    daded12
    -------------+-----------------------------------------------------------------------------
      kidmarital |     0.002
      mommarital |     0.003      0.002
      dadmarital |     0.004      0.005      0.000
          kidboy |     0.004      0.015      0.014      0.000
         kided12 |    -0.001      0.016     -0.008      0.000      0.000
         momed12 |     0.068     -0.072     -0.280      0.000      0.000      0.000
         daded12 |    -0.000     -0.000     -0.000      0.000      0.000      0.000      0.000
    -------------------------------------------------------------------------------------------

.   estat mindices, minchi2(3.84) showpclass(all)  // Print voodoo to improve model fit at p<.05
Modification indices
---------------------------------------------------------------
                |                                      Standard
                |        MI     df   P>MI        EPC        EPC
----------------+----------------------------------------------
Structural      |
  dadmarital <- |
     mommarital |     9.061      1   0.00    3.68633   3.692443  This is already in the model as a cov
        momed12 |     9.061      1   0.00  -.0599371  -.2888608  This is MomEd → DadMarit
---------------------------------------------------------------
EPC = expected parameter change
```

R Syntax for Previous Model 3 as a Path Model (estimated with ML; regular SEs):

```
print("R Model 3: Own Education + Dad Education a Predictor of Each Attitude")
# Create model syntax as separate text object
Syntax3 = "
# Residual variances estimated separately (by default)
  KidMarital ~~ KidMarital; MomMarital ~~ MomMarital; DadMarital ~~ DadMarital
# All possible pairwise residual covariances (not estimated by default)
  KidMarital ~~ MomMarital + DadMarital; MomMarital ~~ DadMarital
# All intercepts estimated separately (by default)
```

```
  KidMarital ~ 1; MomMarital ~ 1; DadMarital ~ 1
# Regressions: y outcomes ON x predictors (label to do math on later)
  KidMarital ~ KidBoy + KidEd12
  MomMarital ~ MomEd12
  KidMarital ~ (DadEd2K)*DadEd12
  MomMarital ~ (DadEd2M)*DadEd12
  DadMarital ~ (DadEd2D)*DadEd12
# Getting differences in effect of DadEd for each person
  KvMDadEd := DadEd2M - DadEd2K;  # Kid v. Mom: Dad Educ Effect Diff
  KvDDadEd := DadEd2D - DadEd2K;  # Kid v. Dad: Dad Educ Effect Diff
  MvDDadEd := DadEd2D - DadEd2M;  # Mom v. Dad: Dad Educ Effect Diff
"
print("lavaan path analysis model estimated with ML on wide-format data")
PathModel3 = lavaan(data=Example5a_wide, model=Syntax3, estimator="ML", mimic="mplus")
summary(PathModel3, fit.measures=TRUE, rsquare=TRUE, standardized=TRUE, ci=TRUE)
print("Request sorted modification indices for p<.05 to troubleshoot local misfit")
modindices(object=PathModel3, sort=TRUE, minimum.value=3.84)
print("Request residual covariance matrix =leftover from observed minus predicted")
resid(object=PathModel3, type="raw") # also type="cor" for correlation matrix
```

Mplus Syntax and Output for Previous Model 3 as a Path Model (estimated with ML; regular SEs):

```
!!!!!!!!!!!!!!!!!!!!!!!!! Mplus Lines Cannot Exceed 90 Characters !!!!!!!!!!!!!!!!!!!!
TITLE: Example 5a Model 3: Own Education + Dad Education a Predictor of Each Attitude;

DATA:    FILE = PSQF6270_Example5aWide.csv;  ! Can just list file name if in same folder;
         FORMAT = free;              ! FREE (default) or FIXED format;
         TYPE = individual;          ! Individual (default) or matrix data as input;
VARIABLE:
! List of ALL variables in original wide data file, in order;
! Mplus names must use 8 characters or fewer (so rename as needed);
  NAMES = FamilyID KidBoy KidEd12 MomEd12 DadEd12 KidMarit MomMarit DadMarit;
! List of ALL variables used in model;
  USEVARIABLES = KidBoy KidEd12 MomEd12 DadEd12 KidMarit MomMarit DadMarit;
! Missing data codes (here, -999);
  MISSING = ALL (-999);

ANALYSIS:   TYPE = GENERAL;       ! Used for path models;
            ESTIMATOR = ML;       ! Full-information maximum likelihood;

OUTPUT:     CINTERVAL;            ! Print confidence intervals;
            STDYX;                ! Print fully standardized solution, too;
            RESIDUAL;             ! Print how far off each predicted covariance is;
            MODINDICES (3.84);    ! Print voodoo to improve our model fit at p<.05;

MODEL: ! * --> Estimated parameter (all listed below for clarity);

! All residual variances estimated separately (by default);
  KidMarit* MomMarit* DadMarit*;

! All possible pairwise residual covariances (not estimated by default);
  KidMarit MomMarit DadMarit WITH KidMarit* MomMarit* DadMarit*;

! All intercepts estimated separately (by default);
  [KidMarit* MomMarit* DadMarit*];

! Regressions: y outcomes ON x predictors (label to do math on later);
  KidMarit ON KidBoy* KidEd12*;
  MomMarit ON MomEd12*;
  KidMarit MomMarit DadMarit ON DadEd12* (DadEd2K DadEd2M DadEd2D);

! Getting differences in effect of DadEd for each person;
  MODEL CONSTRAINT:
  NEW (KvMDadEd KvDDadEd MvDDadEd); ! List names of linear combinations here;
  KvMDadEd = DadEd2M - DadEd2K;     ! Kid v. Mom: Dad Educ Effect Diff;
  KvDDadEd = DadEd2D - DadEd2K;     ! Kid v. Dad: Dad Educ Effect Diff;
  MvDDadEd = DadEd2D - DadEd2M;     ! Mom v. Dad: Dad Educ Effect Diff;
```

```
THE MODEL ESTIMATION TERMINATED NORMALLY
```

```
MODEL FIT INFORMATION
Number of Free Parameters                        15   Notes from Lesa:
Loglikelihood
          H0 Value                         -337.106   For OUR model: Larger is better
          H1 Value                         -331.641   For model with all possible paths estimated
Information Criteria
          Akaike (AIC)                      704.211   For our model: Smaller is better
          Bayesian (BIC)                    748.336
          Sample-Size Adjusted BIC          700.878
            (n* = (n + 2) / 24)
Chi-Square Test of Model Fit
          Value                              10.929   This is -2ΔLL for our H0-H1
          Degrees of Freedom                      6   This is counting the covariances between X’s and Y’s too
          P-Value                            0.0906   Test of exact fit: Nonsignificant is good!
RMSEA (Root Mean Square Error Of Approximation)
          Estimate                            0.077   Should be < .08 or so
          90 Percent C.I.              0.000  0.148
          Probability RMSEA <= .05            0.229   Test of close fit: Nonsignificant is good!
CFI/TLI
          CFI                                 0.870   Should be > .9 or so
          TLI                                 0.676   Should be > .9 or so
Chi-Square Test of Model Fit for the Baseline Model
          Value                              52.998   This is -2ΔLL for H0-H1 if H0 had no paths at all
          Degrees of Freedom                     15
          P-Value                            0.0000
SRMR (Standardized Root Mean Square Residual)
          Value                               0.046   Should be < .05 or so
```

```
MODEL RESULTS (UNSTANDARDIEZD SOLUTION; Mplus reorders them to list paths first)
                                                  Two-Tailed
                    Estimate       S.E.  Est./S.E.    P-Value  IN MIXED
 KIDMARIT ON
    KIDBOY             0.264      0.091      2.886      0.004  B11
    KIDED12           -0.003      0.024     -0.109      0.913  B31
    DADED12            0.000      0.018     -0.027      0.978  B21
 MOMMARIT ON
    MOMED12           -0.016      0.021     -0.767      0.443  B42
    DADED12           -0.002      0.021     -0.081      0.935  B22
 DADMARIT ON
    DADED12           -0.055      0.016     -3.339      0.001  B20
KIDMARIT WITH
    MOMMARIT           0.038      0.027      1.424      0.154  UN(2,1)
    DADMARIT           0.076      0.026      2.893      0.004  UN(3,1)
 MOMMARIT WITH
    DADMARIT           0.084      0.027      3.066      0.002  UN(3,2)
 Intercepts
    KIDMARIT           1.512      0.099     15.290      0.000  B01
    MOMMARIT           1.937      0.063     30.949      0.000  B02
    DADMARIT           2.071      0.057     36.154      0.000  B00
 Residual Variances
    KIDMARIT           0.309      0.037      8.365      0.000  UN(1,1)
    MOMMARIT           0.316      0.038      8.339      0.000  UN(2,2)
    DADMARIT           0.294      0.035      8.367      0.000  UN(3,3)
New/Additional Parameters (FROM MODEL CONSTRAINT, like ESTIMATE or LINCOM)
    KVMDADED          -0.001      0.026     -0.046      0.963  B22 - B21
    KVDDADED          -0.054      0.021     -2.586      0.010  B20 - B21
    MVDDADED          -0.053      0.023     -2.279      0.023  B20 - B22
```

These unstandardized ON paths are the fixed slopes from MIXED.

These unstandardized WITH covariances are residual covariances (in R).

Note that because we are using ML, the residual variances are smaller than in MIXED (that used REML instead to avoid this downward bias).

```
STANDARDIZED MODEL RESULTS – ALL VARIABLES HAVE MEAN=0, SD=1
STDYX Standardization
                                                  Two-Tailed
                    Estimate       S.E.  Est./S.E.    P-Value
 KIDMARIT ON
    KIDBOY             0.231      0.078      2.950      0.003
    KIDED12           -0.009      0.083     -0.109      0.913
    DADED12           -0.002      0.086     -0.027      0.978
 MOMMARIT ON
    MOMED12           -0.078      0.102     -0.766      0.444
    DADED12           -0.008      0.102     -0.081      0.935
 DADMARIT ON
    DADED12           -0.272      0.078     -3.470      0.001
 KIDMARIT WITH
    MOMMARIT           0.122      0.084      1.455      0.146
    DADMARIT           0.252      0.079      3.187      0.001
 MOMMARIT WITH
    DADMARIT           0.275      0.080      3.433      0.001
```

These standardized ON paths are standardized regression coefficients.

These standardized WITH covariances are residual correlations (in RCORR).

```
 Intercepts
    KIDMARIT           2.646      0.247     10.723      0.000
    MOMMARIT           3.434      0.228     15.057      0.000
    DADMARIT           3.676      0.221     16.659      0.000
 Residual Variances
    KIDMARIT           0.946      0.036     26.246      0.000
    MOMMARIT           0.993      0.014     71.055      0.000
    DADMARIT           0.926      0.043     21.782      0.000
R-SQUARE
    Observed                                         Two-Tailed
    Variable        Estimate       S.E.  Est./S.E.    P-Value
    KIDMARIT           0.054      0.036      1.487      0.137
    MOMMARIT           0.007      0.014      0.496      0.620
    DADMARIT           0.074      0.043      1.735      0.083

ESTIMATED MODEL AND RESIDUALS (OBSERVED - ESTIMATED)
```

The means are recovered perfectly because each outcome has its own intercept (and predictor means are not part of the model).

```
Residuals for Means
  KIDMARIT      MOMMARIT      DADMARIT      KIDBOY        KIDED12      MOMED12       DADED12
  ________      ________      ________      ________      ________     ________      ______
    0.000         0.000         0.000         0.000         0.000        0.000        0.000

 Residuals for Covariances
              KIDMARIT     MOMMARIT     DADMARIT     KIDBOY       KIDED12      MOMED12      DADED12
              ________     ________     ________     ________     ________     ________     ________
 KIDMARIT       0.002
 MOMMARIT       0.003        0.002
 DADMARIT       0.004        0.005        0.000
 KIDBOY         0.004        0.015        0.014        0.000
 KIDED12       -0.001        0.016       -0.008        0.000        0.000
 MOMED12        0.068       -0.072       -0.280        0.000        0.000        0.000
 DADED12        0.000        0.000        0.000        0.000        0.000        0.000        0.000
```

After shutting off the MODEL CONSTRAINT code and running it again, we get these "helpful" suggestions for how to improve model fit:

The bolded covariances indicate the biggest sources of misfit—it looks like momed12 needs to predict each outcome!

```
Minimum M.I. value for printing the modification index     3.840
                                   M.I.     E.P.C.  Std E.P.C.  StdYX E.P.C.

ON Statements
DADMARIT ON MOMMARIT              9.062      3.687      3.687        3.693  This is already in the model as a cov
DADMARIT ON MOMED12               9.061     -0.060     -0.060       -0.289  This is MomEd → DadMarit

WITH Statements
MOMED12  WITH DADMARIT            9.336     -0.294     -0.294       -0.200  This is MomEd ←→ DadMarit
DADED12  WITH DADMARIT            8.134      0.491      0.491        0.324  This is already in the model as a path
```

Model 4 in Univariate Software: DV-Specific Intercepts adding Mom Education as Predictor of Each Attitude
uses long-format data, ML estimation, and robust standard errors to adjust for multivariate non-normality

$$\begin{aligned}\widehat{Marital}_{fi} = {} & \beta_{00}(Dad_{fi}) + \beta_{01}(Kid_{fi}) + \beta_{02}(Mom_{fi}) + \beta_{10}(Dad_{fi})(KidBoy_f) \\ & +\beta_{20}(Dad_{fi})(DadEd_f - 12) + \beta_{31}(Kid_{fi})(KidEd_f - 12) + \beta_{42}(Mom_{fi})(MomEd_f - 12) \\ & +\beta_{21}(Kid_{fi})(DadEd_f - 12) + \beta_{22}(Mom_{fi})(DadEd_f - 12) \\ & +\beta_{41}(Kid_{fi})(MomEd_f - 12) + \beta_{40}(Dad_{fi})(MomEd_f - 12)\end{aligned}$$

```
TITLE1 "SAS Model 4: DV-Specific Intercepts -- Add Mom Educ (Controlling for Own+Dad Educ)";
TITLE2 "To match path model, switch to ML estimation, robust SEs via EMPIRICAL";
TITLE3 "Satterthwaite DF not allowed with EMPIRICAL, so switch to residual (N-k)";
PROC MIXED DATA=work.Example5a NOCLPRINT COVTEST NAMELEN=100 IC METHOD=ML EMPIRICAL;
  CLASS FamilyID DV;  * CLASS is for ID variables;
  MODEL marital = kid mom dad kid*KidBoy  kid*KidEd12 mom*MomEd12 dad*DadEd12
                  kid*DadEd12 mom*DadEd12 kid*MomEd12 dad*MomEd12
                   / NOINT SOLUTION DDFM= RESIDUAL /* OUTPM saves y-hat from fixed effects */
                     OUTPM=work.PredFinal RESIDUAL; * RESIDUAL requests plots of residuals;
  REPEATED DV / R RCORR TYPE=UN SUBJECT=FamilyID;
  ESTIMATE "Kid vs. Mom: DadEd12 Slope Diff"  kid*DadEd12 -1 mom*DadEd12 1;
  ESTIMATE "Kid vs. Dad: DadEd12 Slope Diff"  kid*DadEd12 -1 dad*DadEd12 1;
  ESTIMATE "Mom vs. Dad: DadEd12 Slope Diff"  mom*DadEd12 -1 dad*DadEd12 1;
```

```
  ESTIMATE "Kid vs. Mom: MomEd12 Slope Diff"  kid*MomEd12 -1 mom*MomEd12 1;
  ESTIMATE "Kid vs. Dad: MomEd12 Slope Diff"  kid*MomEd12 -1 dad*MomEd12 1;
  ESTIMATE "Mom vs. Dad: MomEd12 Slope Diff"  mom*MomEd12 -1 dad*MomEd12 1;
RUN; TITLE1; TITLE2;
* Save corr of pred and actual marital attitudes to square as R2;
TITLE "Correlation of Predicted and Actual Marital Attitudes by DV";
PROC SORT DATA=work.PredFinal; BY DV FamilyID; RUN;
PROC CORR NOSIMPLE DATA=work.PredFinal OUT=work.Rpred;
     BY DV; VAR marital; WITH pred; RUN;
* Compute R2 in saved output;
DATA work.Rpred; SET work.Rpred;
     WHERE _TYPE_="CORR"; R2=marital*marital; RUN;
TITLE "R2 of Predicted and Actual Marital Attitudes by DV";
PROC PRINT NOOBS DATA=work.Rpred; ID DV; VAR R2; RUN; TITLE;
```

```
display "STATA Model 4: DV-Specific Intercepts -- Add Mom Educ (Controlling for Own+Dad Educ)"
display "To match path model in Part 2, switch to ML estimation, robust SEs"
display "Satterthwaite DF not allowed with EMPIRICAL, so switch to residual (N-k)"
mixed marital c.kid c.mom c.dad c.kid#c.kidboy c.kid#c.kided12 c.mom#c.momed12  ///
      c.dad#c.daded12 c.kid#c.daded12 c.mom#c.daded12                           ///
      c.kid#c.momed12 c.dad#c.momed12, noconstant                               ///
      || familyid: , noconstant   /// This NOCONSTANT removes family random intercept
      variance mle residuals(unstructured,t(DV))  /// Unstructured R matrix by DV
      vce(robust)   // Use robust SEs, so no denominator DF allowed
display "-2LL=" e(ll)*-2            // Print -2LL for model
estat wcorrelation, covariance      // R matrix
estat wcorrelation                  // RCORR matrix
predict pred, xb  // Add column pred of predicted outcomes to data
lincom c.kid#c.daded12*-1 + c.mom#c.daded12*1, small // Kid vs. Mom: DadEd12 Slope Diff
lincom c.kid#c.daded12*-1 + c.dad#c.daded12*1, small // Kid vs. Dad: DadEd12 Slope Diff
lincom c.mom#c.daded12*-1 + c.dad#c.daded12*1, small // Mom vs. Dad: DadEd12 Slope Diff
lincom c.kid#c.momed12*-1 + c.mom#c.momed12*1, small // Kid vs. Mom: MomEd12 Slope Diff
lincom c.kid#c.momed12*-1 + c.dad#c.momed12*1, small // Kid vs. Dad: MomEd12 Slope Diff
lincom c.mom#c.momed12*-1 + c.dad#c.momed12*1, small // Mom vs. Dad: MomEd12 Slope Diff
// Get correlation of actual and predicted outcomes to form R2
pwcorr marital pred if DV==1, sig
display "DV=1 Kid R2= " r(rho)^2  // Print R2 relative to empty model
pwcorr marital pred if DV==2, sig
display "DV=2 Mom R2= " r(rho)^2  // Print R2 relative to empty model
pwcorr marital pred if DV==3, sig
display "DV=3 Dad R2= " r(rho)^2  // Print R2 relative to empty model
```

```
print("R Model 4: DV-Specific Intercepts -- Add Mom Educ (Controlling for Own+Dad Educ)")
print("To match path model, switch to ML estimation, but robust SEs not directly available")
Model4 = gls(data=Example5a, method="ML",
             model=marital~0+kid+mom+dad+ kid:KidBoy +kid:KidEd12+mom:MomEd12+dad:DadEd12
             +kid:DadEd12+mom:DadEd12 +kid:MomEd12+dad:MomEd12,
             correlation=corSymm(form=~DVnum|FamilyID),  # Unstructured correlations
             weights=varIdent(form=~1|DV))               # Separate variance by DV
print("Print -2LL and Results")  # Btw, AIC and BIC are incorrect (match STATA)
-2*logLik(Model4); summary(Model4)
print("Show R and RCORR matrices for first family in the data")
getVarCov(Model4, individual="3996");
corMatrix(Model4$modelStruct$corStruct)[[3]] # 3=Dimensions of R here

print("DadEd Slope Diffs -- Had to give it correct Denominator DF")
summary(glht(model=Model4, df=135, linfct=rbind(
  "Kid vs. Mom: DadEd12 Slope Diff" = c(0,0,0,0,0,0,0,-1,1,0,0),  # in order of fixed effects
  "Kid vs. Dad: DadEd12 Slope Diff" = c(0,0,0,0,0,0,1,-1,0,0,0),
  "Mom vs. Dad: DadEd12 Slope Diff" = c(0,0,0,0,0,0,1,0,-1,0,0),
  "Kid vs. Mom: MomEd12 Slope Diff" = c(0,0,0,0,0,1,0,0,0,-1,0),
  "Kid vs. Dad: MomEd12 Slope Diff" = c(0,0,0,0,0,0,0,0,0,-1,1),
  "Mom vs. Dad: MomEd12 Slope Diff" = c(0,0,0,0,0,-1,0,0,0,0,1))), test=adjusted("none"))

print("Save predicted marital attitudes and correlate with actual marital attitudes")
Example5a$Pred = predict(Model4, type="response")
```

```
rPred1 = cor.test(x=Example5a$Pred[which(Example5a$DVnum==1)],
                  y=Example5a$marital[which(Example5a$DVnum==1)], method="pearson")
print("R and R2 for DV=1 Kid"); rPred1$estimate; rPred1$estimate^2

rPred2 = cor.test(x=Example5a$Pred[which(Example5a$DVnum==2)],
                  y=Example5a$marital[which(Example5a$DVnum==2)], method="pearson")
print("R and R2 for DV=2 Mom"); rPred2$estimate; rPred2$estimate^2

rPred3 = cor.test(x=Example5a$Pred[which(Example5a$DVnum==3)],
                  y=Example5a$marital[which(Example5a$DVnum==3)], method="pearson")
print("R and R2 for DV=3 Dad"); rPred3$estimate; rPred3$estimate^2
```

Model 4 in Path Model Software: DV-Specific Intercepts adding Mom Education as Predictor of Each Attitude
uses wide-format data, ML estimation, and "robust" standard errors to adjust for multivariate non-normality

$$\begin{aligned}\widehat{Marital}_{fi} = {} & \beta_{00}(Dad_{fi}) + \beta_{01}(Kid_{fi}) + \beta_{02}(Mom_{fi}) + \beta_{11}(Kid_{fi})(KidBoy_f) \\ & +\beta_{20}(Dad_{fi})(DadEd_f - 12) + \beta_{31}(Kid_{fi})(KidEd_f - 12) + \beta_{42}(Mom_{fi})(MomEd_f - 12) \\ & +\beta_{21}(Kid_{fi})(DadEd_f - 12) + \beta_{22}(Mom_{fi})(DadEd_f - 12) \\ & +\beta_{40}(Dad_{fi})(MomEd_f - 12) + \beta_{41}(Kid_{fi})(MomEd_f - 12)\end{aligned}$$

```
display "STATA Model 4: Own + Dad & Mom Education a Predictor of Each Attitude"
display "Using SEM to create path analysis model estimated with ML on wide-format data"
sem                                                 ///
    (kidmarit mommarit dadmarit <- _cons)           /// All intercepts estimated (by default)
    (kidmarit <- kidboy kided12)                    /// Regressions: y outcomes ON x predictors
    (kidmarit mommarit dadmarit <- daded12)         ///
    (kidmarit mommarit dadmarit <- momed12),        /// New effects go here
     var(e.kidmarit e.mommarit e.dadmarit)          /// All residual variances estimated (by default)
     covariance(e.kidmarit*e.mommarit               /// All pairwise residual covariances (not default)
                e.mommarit*e.dadmarit               ///
                e.kidmarit*e.dadmarit)              ///
     method(mlmv)                                    // Full-information ML
     lincom _b[mommarital:daded12] - _b[kidmarital:daded12] // Kid v. Mom: Dad Educ Effect Diff
     lincom _b[dadmarital:daded12] - _b[kidmarital:daded12] // Kid v. Dad: Dad Educ Effect Diff
     lincom _b[dadmarital:daded12] - _b[mommarital:daded12] // Mom v. Dad: Dad Educ Effect Diff
     lincom _b[mommarital:momed12] - _b[kidmarital:momed12] // Kid v. Mom: Mom Educ Effect Diff
     lincom _b[dadmarital:momed12] - _b[kidmarital:momed12] // Kid v. Dad: Mom Educ Effect Diff
     lincom _b[dadmarital:momed12] - _b[mommarital:momed12] // Mom v. Dad: Mom Educ Effect Diff
     sem, coeflegend                            // Print parameter labels, too (to use in lincom)
     sem, standardized                          // Print fully standardized solution, too
     estat gof, stats(all)                      // Print fit statistics
     estat eqgof                                // Print R2 per variable
     estat residuals                            // Print how far off each predicted covariance is
     estat mindices, minchi2(3.84) showpclass(all) // Print voodoo to improve model fit at p<.05
```

```
!!!!!!!!!!!!!!!!!!!!!!!!!!! Mplus Lines Cannot Exceed 90 Characters !!!!!!!!!!!!!!!!!!!!
TITLE: Example 5a Model 4: Own Ed + Dad & Mom Ed a Predictor of Each Attitude;
```

DATA, VARIABLE, and OUTPUT are the same as Model 3 except for **ANALYSIS: ESTIMATOR = MLR;**

```
MODEL: ! * --> Estimated parameter (all listed below for clarity);

! All residual variances estimated separately (by default);
  KidMarit* MomMarit* DadMarit*;

! All possible pairwise residual covariances (not estimated by default);
  KidMarit MomMarit DadMarit WITH KidMarit* MomMarit* DadMarit*;

! All intercepts estimated separately (by default);
  [KidMarit* MomMarit* DadMarit*];

! Regressions: y outcomes ON x predictors (label to do math on later);
  KidMarit ON KidBoy* KidEd12*;
  KidMarit MomMarit DadMarit ON DadEd12* (DadEd2K DadEd2M DadEd2D);
```

```
  KidMarit MomMarit DadMarit ON MomEd12* (MomEd2K MomEd2M MomEd2D); ! New effects here;

! Getting differences in effect of DadEd for each person;
  MODEL CONSTRAINT: ! List names of linear combinations here;
  NEW (KvMDadEd KvDDadEd MvDDadEd KvMMomEd KvDMomEd MvDMomEd);
  KvMDadEd = DadEd2M - DadEd2K;     ! Kid v. Mom: Dad Educ Effect Diff;
  KvDDadEd = DadEd2D - DadEd2K;     ! Kid v. Dad: Dad Educ Effect Diff;
  MvDDadEd = DadEd2D - DadEd2M;     ! Mom v. Dad: Dad Educ Effect Diff;
  KvMMomEd = MomEd2M - MomEd2K;     ! Kid v. Mom: Mom Educ Effect Diff;
  KvDMomEd = MomEd2D - MomEd2K;     ! Kid v. Dad: Mom Educ Effect Diff;
  MvDMomEd = MomEd2D - MomEd2M;     ! Mom v. Dad: Mom Educ Effect Diff;
```

```
print("R Model 4: Own + Dad + Mom Education a Predictor of Each Attitude")
# Create model syntax as separate text object
Syntax4 = "
# Residual variances estimated separately (by default)
  KidMarital ~~ KidMarital; MomMarital ~~ MomMarital; DadMarital ~~ DadMarital
# All possible pairwise residual covariances (not estimated by default)
  KidMarital ~~ MomMarital + DadMarital; MomMarital ~~ DadMarital
# All intercepts estimated separately (by default)
  KidMarital ~ 1; MomMarital ~ 1; DadMarital ~ 1
# Regressions: y outcomes ON x predictors (label to do math on later)
  KidMarital ~ KidBoy + KidEd12
  KidMarital ~ (DadEd2K)*DadEd12
  MomMarital ~ (DadEd2M)*DadEd12
  DadMarital ~ (DadEd2D)*DadEd12
# New effects here
  KidMarital ~ (MomEd2K)*MomEd12
  MomMarital ~ (MomEd2M)*MomEd12
  DadMarital ~ (MomEd2D)*MomEd12

# Getting differences in effect of DadEd for each person
  KvMDadEd := DadEd2M - DadEd2K;  # Kid v. Mom: Dad Educ Effect Diff
  KvDDadEd := DadEd2D - DadEd2K;  # Kid v. Dad: Dad Educ Effect Diff
  MvDDadEd := DadEd2D - DadEd2M;  # Mom v. Dad: Dad Educ Effect Diff
  KvMMomEd := MomEd2M - MomEd2K;  # Kid v. Mom: Mom Educ Effect Diff
  KvDMomEd := MomEd2D - MomEd2K;  # Kid v. Dad: Mom Educ Effect Diff
  MvDMomEd := MomEd2D - MomEd2M;  # Mom v. Dad: Mom Educ Effect Diff
"
print("lavaan path analysis model estimated with ML on wide-format data")
PathModel4 = lavaan(data=Example5a_wide, model=Syntax4, estimator="ML", mimic="mplus")
summary(PathModel4, fit.measures=TRUE, rsquare=TRUE, standardized=TRUE, ci=TRUE)
print("Request sorted modification indices for p<.05 to troubleshoot local misfit")
modindices(object=PathModel4, sort=TRUE, minimum.value=3.84)
print("Request residual correlation matrix =leftover from observed minus predicted")
resid(object=PathModel4, type="raw") # also type="cor" for correlation matrix
```

R LAVAAN Output—shows both regular ML and "robust" ML fit statistics:

```
Estimator                                         ML
  Optimization method                         NLMINB
  Number of model parameters                      17
  Number of observations                         140
  Number of missing patterns                       1

Model Test User Model:
                                              Standard      Robust
  Test Statistic                                 1.034       1.026  This is -2ΔLL for our H0-H1
  Degrees of freedom                                 4           4
  P-value (Chi-square)                           0.905       0.906
  Scaling correction factor                                  1.007
       Yuan-Bentler correction (Mplus variant)


Model Test Baseline Model:
  Test statistic                                52.998      52.902
  Degrees of freedom                                15          15
  P-value                                        0.000       0.000
  Scaling correction factor                                  1.002
```

```
User Model versus Baseline Model:
  Comparative Fit Index (CFI)                    1.000       1.000  Want close to 1
  Tucker-Lewis Index (TLI)                       1.293       1.294
  Robust Comparative Fit Index (CFI)                         1.000
  Robust Tucker-Lewis Index (TLI)                            1.296

Loglikelihood and Information Criteria:
  Loglikelihood user model (H0)               -332.158    -332.158  For our model: Larger is better
  Scaling correction factor                                  1.007  1=multivariate normality (so not bad!)
      for the MLR correction
  Loglikelihood unrestricted model (H1)       -331.641    -331.641  For model with all paths estimated
  Scaling correction factor                                  1.007
      for the MLR correction

  Akaike (AIC)                                 698.316     698.316  For our model: Smaller is better
  Bayesian (BIC)                               748.324     748.324  For our model: Smaller is better
  Sample-size adjusted Bayesian (BIC)          694.538     694.538  For our model: Smaller is better

Root Mean Square Error of Approximation:
  RMSEA                                          0.000       0.000  Want close to 0
  90 Percent confidence interval - lower         0.000       0.000
  90 Percent confidence interval - upper         0.052       0.051
  P-value RMSEA <= 0.05                          0.947       0.948  Test of RMSEA <=.05

  Robust RMSEA                                               0.000
  90 Percent confidence interval - lower                     0.000
  90 Percent confidence interval - upper                     0.052

Standardized Root Mean Square Residual:
  SRMR                                           0.016       0.016  Want close to 0
```

Parameter estimates, their SEs, and standardized estimates would be Table 1

```
Regressions:  -- THESE ARE THE FIXED SLOPES FROM MIXED
                   Estimate  Std.Err  z-value  P(>|z|) ci.lower ci.upper   Std.lv  Std.all=STDYX IN MPLUS
  KidMarital ~
    KidBoy            0.258    0.093    2.786    0.005    0.076    0.439    0.258    0.225  B11
    KidEd12          -0.011    0.024   -0.441    0.659   -0.058    0.037   -0.011   -0.037  B31
    DadEd12 (DE2K)   -0.007    0.020   -0.367    0.714   -0.046    0.032   -0.007   -0.035  B21
  MomMarital ~
    DadEd12 (DE2M)    0.006    0.020    0.316    0.752   -0.033    0.046    0.006    0.031  B22
  DadMarital ~
    DadEd12 (DE2D)   -0.024    0.017   -1.388    0.165   -0.057    0.010   -0.024   -0.117  B20
  KidMarital ~
    MomEd12 (ME2K)    0.015    0.022    0.681    0.496   -0.028    0.059    0.015    0.072  B41
  MomMarital ~
    MomEd12 (ME2M)   -0.031    0.022   -1.412    0.158   -0.073    0.012   -0.031   -0.148  B42
  DadMarital ~
    MomEd12 (ME2D)   -0.056    0.019   -2.974    0.003   -0.094   -0.019   -0.056   -0.272  B40

Covariances: -- THESE ARE RESIDUAL COVARIANCES FROM R MATRIX OFF-DIAGONALS
                   Estimate  Std.Err  z-value  P(>|z|) ci.lower ci.upper   Std.lv  Std.all
 .KidMarital ~~
   .MomMarital        0.039    0.028    1.400    0.162   -0.016    0.094    0.039    0.126  UN(1,2)
   .DadMarital        0.080    0.024    3.296    0.001    0.033    0.128    0.080    0.274  UN(1,3)
 .MomMarital ~~
   .DadMarital        0.080    0.020    4.011    0.000    0.041    0.119    0.080    0.270  UN(2,3)

Intercepts: -- THESE ARE THE FIXED INTERCEPTS FROM MIXED
                   Estimate  Std.Err  z-value  P(>|z|) ci.lower ci.upper   Std.lv  Std.all
   .KidMarital        1.522    0.101   15.125    0.000    1.325    1.719    1.522    2.664  B01
   .MomMarital        1.951    0.063   30.825    0.000    1.827    2.075    1.951    3.445  B02
   .DadMarital        2.123    0.060   35.574    0.000    2.006    2.240    2.123    3.769  B00

Variances: -- THESE ARE THE RESIDUAL VARIANCES FROM R MATRIX DIAGONAL
                   Estimate  Std.Err  z-value  P(>|z|) ci.lower ci.upper   Std.lv  Std.all
   .KidMarital        0.308    0.031   10.096    0.000    0.248    0.368    0.308    0.944  UN(1,1)
   .MomMarital        0.315    0.045    7.081    0.000    0.228    0.402    0.315    0.983  UN(2,2)
   .DadMarital        0.278    0.034    8.092    0.000    0.211    0.345    0.278    0.876  UN(3,3)

R-Square: -- THESE ARE CLOSE TO BUT NOT THE SAME AS WAS FOUND IN THE UNIVARIATE MODELS
                   Estimate
    KidMarital        0.056
    MomMarital        0.017
    DadMarital        0.124
```

```
Defined Parameters: -- THESE ARE ESTIMATE/LINCOM/GLHT/MODEL CONSTRAINT LINEAR COMBINATIONS
                   Estimate  Std.Err  z-value  P(>|z|) ci.lower ci.upper   Std.lv  Std.all
    KvMDadEd          0.014    0.026    0.522    0.602   -0.038    0.065    0.014    0.067  B22 - B21
    KvDDadEd         -0.016    0.022   -0.741    0.459   -0.059    0.027   -0.016   -0.081  B20 - B21
    MvDDadEd         -0.030    0.025   -1.212    0.225   -0.078    0.018   -0.030   -0.148  B20 - B22
    KvMMomEd         -0.046    0.029   -1.569    0.117   -0.103    0.011   -0.046   -0.219  B42 - B41
    KvDMomEd         -0.072    0.027   -2.657    0.008   -0.124   -0.019   -0.072   -0.344  B40 - B41
    MvDMomEd         -0.026    0.025   -1.041    0.298   -0.074    0.023   -0.026   -0.124  B40 - B42


$cov - THESE ARE THE DISCREPANCIES FOR OBSERVED MINUS PREDICTED COVARIANCES
           KdMrtl MmMrtl DdMrtl KidBoy KdEd12 DdEd12 MmEd12
KidMarital 0.002
MomMarital 0.004  0.000
DadMarital 0.003  0.000  0.000
KidBoy     0.005  0.015  0.015  0.000
KidEd12    0.013  0.029  0.043  0.000  0.000
DadEd12    0.000  0.000  0.000  0.000  0.000  0.000
MomEd12    0.000  0.000  0.000  0.000  0.000  0.000  0.000
```

Only the kid predictors on the mom and dad outcomes have leftover covariance, and no single added paths would help the model.

```
$mean
KidMarital MomMarital DadMarital     KidBoy    KidEd12    DadEd12    MomEd12
         0          0          0          0          0          0          0
```

Example results section for Part 2 Models 3–4 (picking up from Part 1; using R LAVAAN output):

Next, we examined whether father’s education incrementally predicted the marital attitudes of the mother or adult child after controlling for their own education, but neither effect was significant (and the effect of father’s education on his own attitudes was significantly larger). The effect of father’s education on his own attitudes remained significant, while the effect of education on their own attitudes for the adult child and mother remained nonsignificant).

Finally, we examined the incremental effects of mother’s education on marital attitudes, and results from this final model are shown in Table 1. For every additional year of mother’s education, father’s attitudes were expected to be significantly less conservative by 0.056 (p = .003). The effect of mother’s education on the adult child attitudes was nonsignificant and significantly smaller than its effect on father’s attitudes.

We re-estimated the final model as a path analysis in the R package lavaan (using robust maximum likelihood) in order to obtain indices of absolute model fit. The model had excellent fit, $\chi^2(4) = 1.026$, p = .906, RMSEA = .00 [CI = .00–.051], CFI = 1.00, indicating that no further paths were needed. This final model is depicted in Figure 1 below.

Figure 1 (line types used to help visually distinguish the paths; standardized coefficients may also be added)