```
1          ************************************************;
2          *** Example of Analysis of Covariance          ***;
3          ***   Steel and Torrie (1980) example (pg. 424)  ***;
4          ***     Analysis of three diet treatments on two ***;
5          ***     sexes, where X is the initial weight,   ***;
6          ***     and Y is the weight gain in pounds.     ***;
7          ************************************************;
8          OPTIONS NOCENTER PS=256 LS=132 nodate nonumber;
9          DATA HOGS; INFILE CARDS MISSOVER;
10            Title1 'Analysis of Covariance example from Steel & Torrie, 1980';
11            INPUT PEN SEX $ RATION $ X Y;
12         CARDS;
NOTE: The data set WORK.HOGS has 30 observations and 5 variables.
NOTE: DATA statement used:
      real time           0.05 seconds
      cpu time            0.05 seconds
12       !        RUN;
43         ;
44         PROC PRINT DATA=HOGS; Title2 'Raw data listing'; RUN;
NOTE: There were 30 observations read from the data set WORK.HOGS.
NOTE: The PROCEDURE PRINT printed page 1.
NOTE: PROCEDURE PRINT used:
      real time           0.04 seconds
      cpu time            0.04 seconds
```

Analysis of Covariance example from Steel & Torrie, 1980
Raw data listing

Obs	PEN	SEX	RATION	X	Y
1	1	M	a1	38	9.52
2	1	F	a1	48	9.94
3	1	M	a2	39	8.51
4	1	F	a2	48	10.00
5	1	M	a3	48	9.11
6	1	F	a3	48	9.75
7	2	M	a1	35	8.21
8	2	F	a1	32	9.48
9	2	M	a2	38	9.95
10	2	F	a2	32	9.24
11	2	M	a3	37	8.50
12	2	F	a3	28	8.66
13	3	M	a1	41	9.32
14	3	F	a1	35	9.32
15	3	M	a2	46	8.43
16	3	F	a2	41	9.34
17	3	M	a3	42	8.90
18	3	F	a3	33	7.63
19	4	M	a1	48	10.56
20	4	F	a1	46	10.90
21	4	M	a2	40	8.86
22	4	F	a2	46	9.68
23	4	M	a3	42	9.51
24	4	F	a3	50	10.37
25	5	M	a1	43	10.42
26	5	F	a1	32	8.82
27	5	M	a2	40	9.20
28	5	F	a2	37	9.67
29	5	M	a3	40	8.76
30	5	F	a3	30	8.57

```
46         PROC MIXED DATA=HOGS; CLASSES RATION SEX PEN;
47               TITLE2 'Analysis of Covariance Example';
48               TITLE3 'Design done in PROC MIXED without a covariable';
49            MODEL Y = RATION|SEX / htype=1 3 DDFM=Satterthwaite;
50               random PEN;
51               LSMEANS RATION|SEX / ADJUST=TUKEY PDIFF;
52          ods output diffs=ppp;
53          ods output lsmeans=mmm;
54          ods listing exclude diffs;
55          ods listing exclude lsmeans;
56         run;
NOTE: Convergence criteria met.
NOTE: The data set WORK.MMM has 11 observations and 8 variables.
NOTE: The data set WORK.PPP has 19 observations and 12 variables.
NOTE: The PROCEDURE MIXED printed page 2.
NOTE: PROCEDURE MIXED used:
      real time           0.22 seconds
      cpu time            0.22 seconds
57         %include 'C:\Program Files\SAS Institute\SAS\V8\stat\sample\pdmix800.sas';
673        %pdmix800(ppp,mmm,alpha=.05,sort=yes);
```

Analysis of Covariance example from Steel & Torrie, 1980
Analysis of Covariance Example
Design done in PROC MIXED without a covariable

The Mixed Procedure

Model Information

Data Set	WORK.HOGS
Dependent Variable	Y
Covariance Structure	Variance Components
Estimation Method	REML
Residual Variance Method	Profile
Fixed Effects SE Method	Model-Based
Degrees of Freedom Method	Satterthwaite

Class Level Information

Class	Levels	Values
RATION	3	a1 a2 a3
SEX	2	F M
PEN	5	1 2 3 4 5

Dimensions

Covariance Parameters	2
Columns in X	12
Columns in Z	5
Subjects	1
Max Obs Per Subject	30
Observations Used	30
Observations Not Used	0
Total Observations	30

Iteration History

Iteration	Evaluations	-2 Res Log Like	Criterion
0	1	63.35598278	
1	1	60.98295712	0.00000000

Convergence criteria met.

Covariance Parameter Estimates

Cov Parm	Estimate
PEN	0.1329
Residual	0.4157

Fit Statistics

-2 Res Log Likelihood	61.0
AIC (smaller is better)	65.0
AICC (smaller is better)	65.6
BIC (smaller is better)	64.2

Type 1 Tests of Fixed Effects

Effect	Num DF	Den DF	F Value	Pr > F
RATION	2	20	2.73	0.0896
SEX	1	20	1.04	0.3189
RATION*SEX	2	20	0.57	0.5730

Type 3 Tests of Fixed Effects

Effect	Num DF	Den DF	F Value	Pr > F
RATION	2	20	2.73	0.0896
SEX	1	20	1.04	0.3189
RATION*SEX	2	20	0.57	0.5730

Analysis of Covariance example from Steel & Torrie, 1980
Analysis of Covariance Example
Design done in PROC MIXED without a covariable

Effect=RATION Method=Tukey-Kramer(P<.05) Comparison Group=1

Obs	RATION	SEX	Estimate	Standard Error	Letter Group	MinSig Diff	MaxSig Diff	AvgSig Diff
1	a1		9.6490	0.2610	A	0.72951	0.72951	0.72951
2	a2		9.2880	0.2610	A	0.72951	0.72951	0.72951
3	a3		8.9760	0.2610	A	0.72951	0.72951	0.72951

Effect=SEX Method=Tukey-Kramer(P<.05) Comparison Group=2

Obs	RATION	SEX	Estimate	Standard Error	Letter Group	MinSig Diff	MaxSig Diff	AvgSig Diff
4		F	9.4247	0.2330	A	0.49111	0.49111	0.49111
5		M	9.1840	0.2330	A	0.49111	0.49111	0.49111

Effect=RATION*SEX Method=Tukey-Kramer(P<.05) Comparison Group=3

Obs	RATION	SEX	Estimate	Standard Error	Letter Group	MinSig Diff	MaxSig Diff	AvgSig Diff
6	a1	F	9.6920	0.3312	A	1.28177	1.28177	1.28177
7	a1	M	9.6060	0.3312	A	1.28177	1.28177	1.28177
8	a2	F	9.5860	0.3312	A	1.28177	1.28177	1.28177
9	a3	F	8.9960	0.3312	A	1.28177	1.28177	1.28177
10	a2	M	8.9900	0.3312	A	1.28177	1.28177	1.28177
11	a3	M	8.9560	0.3312	A	1.28177	1.28177	1.28177

```
677        PROC MIXED DATA=HOGS; CLASSES RATION SEX PEN;
678             TITLE3 'Design done in PROC MIXED with a covariable';
679           MODEL Y = RATION|SEX X / htype=1 3 DDFM=Satterthwaite
outp=ResidData;
680             random PEN;
681             LSMEANS RATION|SEX / ADJUST=TUKEY CL PDIFF;
682         ods output diffs=ppp;
683         ods output lsmeans=mmm;
684         ods listing exclude diffs;
685         ods listing exclude lsmeans;
686        run;
NOTE: Convergence criteria met.
NOTE: The data set WORK.MMM has 11 observations and 11 variables.
NOTE: The data set WORK.PPP has 19 observations and 17 variables.
NOTE: The data set WORK.RESIDDATA has 30 observations and 12 variables.
NOTE: The PROCEDURE MIXED printed page 4.
NOTE: PROCEDURE MIXED used:
      real time           0.27 seconds
      cpu time            0.27 seconds
687        %include 'C:\Program Files\SAS
Institute\SAS\V8\stat\sample\pdmix800.sas';
1303       %pdmix800(ppp,mmm,alpha=.05,sort=yes);
```

Analysis of Covariance example from Steel & Torrie, 1980
Design done in PROC MIXED with a covariable
The Mixed Procedure

Model Information

Data Set	WORK.HOGS
Dependent Variable	Y
Covariance Structure	Variance Components
Estimation Method	REML
Residual Variance Method	Profile
Fixed Effects SE Method	Model-Based
Degrees of Freedom Method	Satterthwaite

Class Level Information

Class	Levels	Values
RATION	3	a1 a2 a3
SEX	2	F M
PEN	5	1 2 3 4 5

Dimensions

Covariance Parameters	2
Columns in X	13
Columns in Z	5
Subjects	1
Max Obs Per Subject	30
Observations Used	30
Observations Not Used	0
Total Observations	30

Iteration History

Iteration	Evaluations	-2 Res Log Like	Criterion
0	1	55.08910489	
1	3	53.38841782	0.00015698
2	1	53.38752175	0.00000027
3	1	53.38752024	0.00000000

Convergence criteria met.

Covariance Parameter Estimates

Cov Parm	Estimate
PEN	0.06595
Residual	0.2504

Fit Statistics

-2 Res Log Likelihood	53.4
AIC (smaller is better)	57.4
AICC (smaller is better)	58.0
BIC (smaller is better)	56.6

Type 1 Tests of Fixed Effects

Effect	Num DF	Den DF	F Value	Pr > F
RATION	2	19.4	4.53	0.0243
SEX	1	19.4	1.74	0.2031
RATION*SEX	2	19.4	0.95	0.4037
X	1	18.3	17.72	0.0005

Type 3 Tests of Fixed Effects

Effect	Num DF	Den DF	F Value	Pr > F
RATION	2	19.5	4.65	0.0224
SEX	1	20	4.76	0.0413
RATION*SEX	2	19.6	0.23	0.7935
X	1	18.3	17.72	0.0005

```
Analysis of Covariance example from Steel & Torrie, 1980
Analysis of Covariance Example
Design done in PROC MIXED with a covariable

Effect=RATION   Method=Tukey-Kramer(P<.05)   Comparison Group=1

                                    Standard    Letter     MinSig     MaxSig     AvgSig
Obs    RATION    SEX    Estimate     Error     Group       Diff       Diff       Diff
  1      a1               9.6733     0.1956      A       0.56727    0.56896    0.5684
  2      a2               9.2395     0.1959      AB      0.56727    0.56896    0.5684
  3      a3               9.0003     0.1956      B       0.56727    0.56896    0.5684

Effect=SEX   Method=Tukey-Kramer(P<.05)   Comparison Group=2

                                    Standard    Letter     MinSig     MaxSig     AvgSig
Obs    RATION    SEX    Estimate     Error     Group       Diff       Diff       Diff
  4               F       9.5083     0.1740      A       0.39002    0.39002    0.39002
  5               M       9.1004     0.1740      B       0.39002    0.39002    0.39002

Effect=RATION*SEX   Method=Tukey-Kramer(P<.05)   Comparison Group=3

                                    Standard    Letter     MinSig     MaxSig     AvgSig
Obs    RATION    SEX    Estimate     Error     Group       Diff       Diff       Diff
  6      a1       F       9.8134     0.2532      A       0.99411    1.02295    1.00275
  7      a1       M       9.5332     0.2521      A       0.99411    1.02295    1.00275
  8      a2       F       9.5294     0.2519      A       0.99411    1.02295    1.00275
  9      a3       F       9.1821     0.2554      A       0.99411    1.02295    1.00275
 10      a2       M       8.9495     0.2517      A       0.99411    1.02295    1.00275
 11      a3       M       8.8185     0.2536      A       0.99411    1.02295    1.00275
```

```
1307       PROC MIXED DATA=HOGS; CLASSES RATION SEX PEN;
1308            TITLE3 'Design with Covariable and interaction';
1309          MODEL Y = RATION|SEX|X / htype=1 3 DDFM=Satterthwaite;
1310             random PEN;
1311             LSMEANS RATION|SEX / ADJUST=TUKEY PDIFF;
1312         ods output diffs=ppp;
1313         ods output lsmeans=mmm;
1314         ods listing exclude diffs;
1315         ods listing exclude lsmeans;
1316       run;
NOTE: Convergence criteria met.
NOTE: The data set WORK.MMM has 11 observations and 8 variables.
NOTE: The data set WORK.PPP has 19 observations and 12 variables.
NOTE: The PROCEDURE MIXED printed page 6.
NOTE: PROCEDURE MIXED used:
      real time           0.23 seconds
      cpu time            0.23 seconds
1317       %include 'C:\Program Files\SAS Institute\SAS\V8\stat\sample\pdmix800.sas';
1933       %pdmix800(ppp,mmm,alpha=.05,sort=yes);

Analysis of Covariance example from Steel & Torrie, 1980
Analysis of Covariance Example
Design with Covariable and interaction

The Mixed Procedure
                Model Information
Data Set                      WORK.HOGS
Dependent Variable            Y
Covariance Structure          Variance Components
Estimation Method             REML
Residual Variance Method      Profile
Fixed Effects SE Method       Model-Based
Degrees of Freedom Method     Satterthwaite
```

Class Level Information

Class	Levels	Values
RATION	3	a1 a2 a3
SEX	2	F M
PEN	5	1 2 3 4 5

Dimensions

Covariance Parameters	2
Columns in X	24
Columns in Z	5
Subjects	1
Max Obs Per Subject	30
Observations Used	30
Observations Not Used	0
Total Observations	30

Iteration History

Iteration	Evaluations	-2 Res Log Like	Criterion
0	1	64.31392830	
1	2	64.21605896	0.00000001

Convergence criteria met.

Covariance Parameter Estimates

Cov Parm	Estimate
PEN	0.01370
Residual	0.2281

Fit Statistics

-2 Res Log Likelihood	64.2
AIC (smaller is better)	68.2
AICC (smaller is better)	69.0
BIC (smaller is better)	67.4

Type 1 Tests of Fixed Effects

Effect	Num DF	Den DF	F Value	Pr > F
RATION	2	14.2	4.97	0.0231
SEX	1	14.2	1.90	0.1890
RATION*SEX	2	14.2	1.04	0.3778
X	1	8.89	23.41	0.0010
X*RATION	2	15.2	2.71	0.0987
X*SEX	1	16.6	0.00	0.9973
X*RATION*SEX	2	17.2	2.76	0.0910

Type 3 Tests of Fixed Effects

Effect	Num DF	Den DF	F Value	Pr > F
RATION	2	16.9	4.30	0.0309
SEX	1	17	0.20	0.6633
RATION*SEX	2	17.1	2.60	0.1030
X	1	14	6.88	0.0201
X*RATION	2	16.9	4.89	0.0211
X*SEX	1	17.1	0.49	0.4917
X*RATION*SEX	2	17.1	2.76	0.0912

Analysis of Covariance example from Steel & Torrie, 1980
Analysis of Covariance Example
Design with Covariable and interaction

Effect=RATION Method=Tukey-Kramer(P<.05) Comparison Group=1

Obs	RATION	SEX	Estimate	Standard Error	Letter Group	MinSig Diff	MaxSig Diff	AvgSig Diff
1	a1		9.6343	0.1631	A	0.5666	0.58313	0.57652
2	a2		9.3017	0.1616	AB	0.5666	0.58313	0.57652
3	a3		9.0224	0.1699	B	0.5666	0.58313	0.57652

Effect=SEX Method=Tukey-Kramer(P<.05) Comparison Group=2

Obs	RATION	SEX	Estimate	Standard Error	Letter Group	MinSig Diff	MaxSig Diff	AvgSig Diff
4		F	9.5240	0.1364	A	0.38597	0.38597	0.38597
5		M	9.1149	0.1398	B	0.38597	0.38597	0.38597

Effect=RATION*SEX Method=Tukey-Kramer(P<.05) Comparison Group=3

Obs	RATION	SEX	Estimate	Standard Error	Letter Group	MinSig Diff	MaxSig Diff	AvgSig Diff
6	a1	F	9.8162	0.2249	A	0.99037	1.05136	1.01377
7	a2	F	9.5582	0.2215	A	0.99037	1.05136	1.01377
8	a1	M	9.4523	0.2244	A	0.99037	1.05136	1.01377
9	a3	F	9.1977	0.2265	A	0.99037	1.05136	1.01377
10	a2	M	9.0453	0.2234	A	0.99037	1.05136	1.01377
11	a3	M	8.8471	0.2430	A	0.99037	1.05136	1.01377

```
1936       PROC UNIVARIATE DATA=ResidData PLOT NORMAL; VAR resid;
1937         TITLE4 'Residual analysis with PROC UNIVARIATE';
1938       RUN;
NOTE: The PROCEDURE UNIVARIATE printed page 8.
NOTE: PROCEDURE UNIVARIATE used:
      real time           0.03 seconds
      cpu time            0.03 seconds
1938     !      QUIT;
```

Analysis of Covariance example from Steel & Torrie, 1980
Analysis of Covariance Example
Design with Covariable and interaction
Residual analysis with PROC UNIVARIATE

The UNIVARIATE Procedure
Variable: Resid

Moments

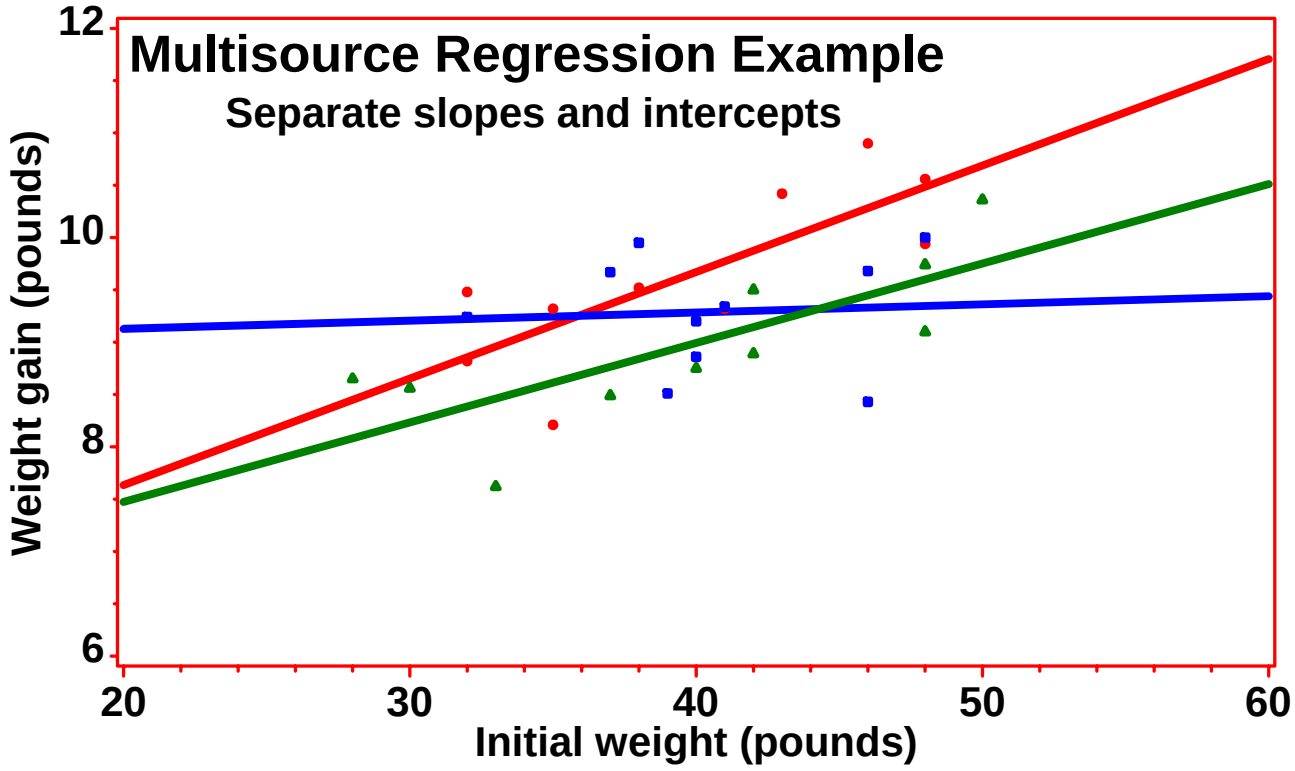
N	30	Sum Weights	30
Mean	0	Sum Observations	0
Std Deviation	0.42337753	Variance	0.17924854
Skewness	-0.3066408	Kurtosis	0.85642548
Uncorrected SS	5.19820755	Corrected SS	5.19820755
Coeff Variation	.	Std Error Mean	0.07729781

Basic Statistical Measures

Location		Variability	
Mean	0.000000	Std Deviation	0.42338
Median	0.075839	Variance	0.17925
Mode	.	Range	2.08092
		Interquartile Range	0.45165

```
          Tests for Location: Mu0=0
Test           -Statistic-    -----p Value------
Student's t    t         0    Pr > |t|    1.0000
Sign           M         2    Pr >= |M|   0.5847
Signed Rank    S      13.5    Pr >= |S|   0.7865

                  Tests for Normality
Test                  --Statistic---    -----p Value------
Shapiro-Wilk          W     0.966774    Pr < W      0.4551
Kolmogorov-Smirnov    D     0.102691    Pr > D     >0.1500
Cramer-von Mises      W-Sq  0.081279    Pr > W-Sq   0.1992
Anderson-Darling      A-Sq  0.482075    Pr > A-Sq   0.2222

Quantiles (Definition 5)
Quantile        Estimate
100% Max       1.0338795
99%            1.0338795
95%            0.5379804
90%            0.4190551
75% Q3         0.2331595
50% Median     0.0758394
25% Q1        -0.2184919
10%           -0.5928696
5%            -0.7237573
1%            -1.0470438
0% Min        -1.0470438

           Extreme Observations
------Lowest------        ------Highest-----
    Value      Obs             Value      Obs
-1.047044        7          0.320395       12
-0.723757       15          0.383313       23
-0.704528       18          0.454798       20
-0.481212       22          0.537980       25
-0.452238       26          1.033880        9

  Stem Leaf                  #  Boxplot                    Normal Probability Plot
    10 3                     1     0        1.1+                                  *   ++
     8                                        |                                 +++++
     6                                        |                              ++++
     4 54                    2     |          |                         ++++* *
     2 03338928              8  +-----+       |                    ******* *
     0 169499                6  *--+--*       |                 *****+
    -0 641                   3  |     |       |              ***+
    -2 84220                 5  +-----+       |           *****
    -4 85                    2     |          |        ++*+*
    -6 20                    2     |          |      ++*+*
    -8                                       |  +++++
   -10 5                     1     0       -1.1+++   *
      ----+----+----+----+                        +----+----+----+----+----+----+----+----+----+----+----+
   Multiply Stem.Leaf by 10**-1                      -2       -1        0       +1       +2

1941       PROC MEANS DATA=HOGS; VAR X Y;
1942            TITLE2 'Raw means';
1943       RUN;

Analysis of Covariance example from Steel & Torrie, 1980
Raw means
The MEANS Procedure
Variable     N            Mean         Std Dev         Minimum         Maximum
X           30      40.1000000       6.1831250      28.0000000      50.0000000
Y           30       9.3043333       0.7507545       7.6300000      10.9000000
```

```
1941       DATA TWO; SET HOGS; IF RATION = 'a1' THEN A = Y;
1942                          IF RATION = 'a2' THEN B = Y;
1943                          IF RATION = 'a3' THEN C = Y; RUN;
NOTE: There were 30 observations read from the data set WORK.HOGS.
NOTE: The data set WORK.TWO has 30 observations and 8 variables.
NOTE: DATA statement used:
      real time           0.02 seconds
      cpu time            0.02 seconds
1944       GOPTIONS DEVICE=cgm GSFMODE=REPLACE GSFNAME=OUT1 NOPROMPT noROTATE;
1945
1946       FILENAME OUT1 'C:\Geaghan\EXST\EXST7015New\Fall2002\SAS\25s-
AnCova&Design1.cgm';
1947       PROC GPLOT DATA=TWO;
1948          TITLE1 F=SWISS H=1 'Multisource Regression Example';
1949          TITLE2 F=SWISS H=1 'Separate slopes and intercepts';
1950        PLOT A*X B*X C*X / OVERLAY HAXIS=AXIS1 VAXIS=AXIS2;
1951        AXIS1 LABEL=(F=SWISS H=1 'Initial weight (pounds)') WIDTH=5 MINOR=(N=4)
1952              VALUE=(F=SWISS H=1) ORDER=0 TO 60 BY 10;
1953        AXIS2 LABEL=(F=SWISS H=1 'Weight gain (pounds)') WIDTH=6
1954              VALUE=(F=SWISS H=1) MINOR=(N=5) ORDER=6 TO 12 BY 2;
1955           SYMBOL1 C=red   V=J I=RL  L=1 W=2 H=1 F=SPECIAL MODE=INCLUDE;
1956           SYMBOL2 C=blue  V=K I=RL  L=1 W=2 H=1 F=SPECIAL MODE=INCLUDE;
1957           SYMBOL3 C=green V=L I=RL  L=1 W=2 H=1 F=SPECIAL MODE=INCLUDE; RUN;
WARNING: The axis frame outline was drawn with line width 6 as specified on the left
vertical axis. Any other axis line widths were ignored.
NOTE: Regression equation :  A =  5.598712 + 0.101766*X.
NOTE: 20 observation(s) contained a MISSING value for the A * X request.
NOTE: Regression equation :  B =  8.969529 + 0.007825*X.
NOTE: 20 observation(s) contained a MISSING value for the B * X request.
NOTE: Regression equation :  C =  5.953836 + 0.075934*X.
NOTE: 20 observation(s) contained a MISSING value for the C * X request.
NOTE:  26 RECORDS WRITTEN TO C:\Geaghan\EXST\EXST7015New\Fall2002\SAS\25s-
AnCova&Design1.cgm
```



Which treatment is "higher"? **Where would you compare the lines?**

```
1959       GOPTIONS GSFNAME=OUT2; FILENAME OUT2
'C:\Geaghan\EXST\EXST7015New\Fall2002\SAS\25s-AnCova&Design2.cgm';
NOTE: There were 30 observations read from the data set WORK.TWO.
NOTE: PROCEDURE GPLOT used:
      real time           0.19 seconds
      cpu time            0.12 seconds
1960       PROC GPLOT DATA=TWO;
1961          TITLE1 F=SWISS H=1 'Multisource Regression Example';
1962          TITLE2 F=SWISS H=1 'Single line with confidence intervals (99%
cli)';
1963        PLOT Y*X / OVERLAY HAXIS=AXIS1 VAXIS=AXIS2;
1964        AXIS1 LABEL=(F=SWISS H=1 'Initial weight (pounds)') WIDTH=5
MINOR=(N=4)
1965              VALUE=(F=SWISS H=1) ORDER=0 TO 60 BY 10;
1966        AXIS2 LABEL=(F=SWISS H=1 'Weight gain (pounds)') WIDTH=6
1967              VALUE=(F=SWISS H=1) MINOR=(N=5) ORDER=6 TO 12 BY 2;
1968          SYMBOL1 C=red V=J I=RLcli99 L=1 W=2 F=SPECIAL H=1 MODE=INCLUDE;
1969       RUN;
WARNING: The axis frame outline was drawn with line width 6 as specified on
the left vertical axis. Any other axis line widths were
         ignored.
NOTE: Regression equation :  Y =  6.464854 + 0.07081*X.
NOTE:  94 RECORDS WRITTEN TO C:\Geaghan\EXST\EXST7015New\Fall2002\SAS\25s-
AnCova&Design1.cgm
1970
NOTE: There were 30 observations read from the data set WORK.TWO.
NOTE: PROCEDURE GPLOT used:
      real time           0.11 seconds
      cpu time            0.05 seconds
```