Appendix

A.1. SAS CODE for Model 4.

```
proc glm data=GVIF2;class Ethnicity(REF="A");
model y = GREV_C GREQ_C TRT Male Age_C Ethnicity / solution tolerance;
means Ethnicity / welch ;run;

proc reg data=GVIF2;
model y = GREV_C GREQ_C TRT Male Age_C  B H W / tol vif;
ETHN_L: TEST   /* Long Version Showing Full L Matrix */
 0*INT + 0*GREV_C + 0*GREQ_C + 0*TRT + 0*Male + 0*Age_C + 1*B + 0*H + 0*W = 0,
 0*INT + 0*GREV_C + 0*GREQ_C + 0*TRT + 0*Male + 0*Age_C + 0*B + 1*H + 0*W = 0,
 0*INT + 0*GREV_C + 0*GREQ_C + 0*TRT + 0*Male + 0*Age_C + 0*B + 0*H + 1*W = 0;
ETHN_S: TEST B=0, H=0, W=0; /* Short Version */run;
```

A.2. STATA CODE for Model 4.

```
anova y c.GREV_C c.GREQ_C c.TRT c.Male c.Age_C EthnGRP
regress
vif

regress y GREV_C GREQ_C TRT Male Age_C B H W
test B H W
vif
```

A.3. R CODE for Model 4:

```
gvif4a <- lm(y ~ GREV_C + GREQ_C + TRT + Male + Age_C + B + H + W,
data=GVIFDAT)
summary(gvif4a)
library("car")
vif(gvif4a)  # vif will report Standard VIF when Coding Schemes are entered
Cb1 <- c(0, 0, 0, 0, 0, 0, 1, 0, 0)
Cb2 <- c(0, 0, 0, 0, 0, 0, 0, 1, 0)
Cb3 <- c(0, 0, 0, 0, 0, 0, 0, 0, 1)
Lomni <- rbind(Cb1,Cb2,Cb3)
library("gmodels")
glh.test(gvif4a, Lomni)
```

```
gvif4b <- lm(y ~ GREV_C + GREQ_C + TRT + Male + Age_C + Ethnicity,
data=GVIFDAT)
summary(gvif4b)
library("car")
vif(gvif4b)   #  vif will report GVIF when String Variable is entered
library("glmtoolbox")
gvif(gvif4b)  # gvif will report GVIF when String Variable is entered
```

A.4. SPSS CODE for Model 4:

```
REGRESSION
  /MISSING LISTWISE
  /STATISTICS COEFF OUTS CI(95) R ANOVA TOL
  /CRITERIA=PIN(.05) POUT(.10)
  /NOORIGIN
  /DEPENDENT y
  /METHOD=ENTER GREV_C GREQ_C  TRT Male Age_C B H W.
UNIANOVA  y WITH GREV_C GREQ_C  TRT Male Age_C B H W
  /METHOD=SSTYPE(3)
  /INTERCEPT=INCLUDE
  /PRINT PARAMETER
  /CRITERIA=ALPHA(.05)
  /DESIGN= GREV_150 GREQ_150 Age_25 TRT Male B H W
  /LMATRIX "omnilong Model 4"
        intercept 0 GREV_C 0 GREQ_C 0 TRT 0 Male 0 Age_C 0 B 1 H 0 W 0;
        intercept 0 GREV_C 0 GREQ_C 0 TRT 0 Male 0 Age_C 0 B 0 H 1 W 0;
        intercept 0 GREV_C 0 GREQ_C 0 TRT 0 Male 0 Age_C 0 B 0 H 0 W 1
  /LMATRIX "omnishort Model 4"
         B 1 H 0 W 0;
         B 0 H 1 W 0;
         B 0 H 0 W 1.
UNIANOVA y BY Ethnicity WITH GREV_C GREQ_C TRT Male Age_C
  /METHOD=SSTYPE(3)
  /INTERCEPT=INCLUDE
  /PRINT PARAMETER
  /CRITERIA=ALPHA(.05)
  /DESIGN= GREV_C GREQ_C TRT Male Age_C Ethnicity.
```

A.5. Modified R Output from R: `lm vif gvif`

```
gvif4a <- lm(y ~ GREV_C + GREQ_C + TRT + Male + Age_C + B + H + W, data=GVIFDAT)
summary(gvif4a)
Coefficients:
             Estimate Std. Error t value Pr(>|t|)
(Intercept) 151.31471    1.94226  77.907  < 2e-16 ***
GREV_C        0.18906    0.08655   2.184   0.0315 *
GREQ_C        0.38638    0.08789   4.396 2.98e-05 ***
TRT           3.55257    1.43647   2.473   0.0153 *
Male          1.60167    1.47849   1.083   0.2815
Age_C        -0.44118    0.26178  -1.685   0.0954 .
B            -2.02558    2.28724  -0.886   0.3782
H            -0.18590    2.28997  -0.081   0.9355
W            -2.34668    2.13088  -1.101   0.2737

Residual standard error: 6.858 on 91 degrees of freedom
Multiple R-squared:  0.4344,    Adjusted R-squared:  0.3846
F-statistic: 8.735 on 8 and 91 DF,  p-value: 8.759e-09
library("car")
vif(gvif4a)    # vif will report Standard VIF when Coding Schemes are entered
  GREV_C   GREQ_C      TRT     Male    Age_C        B        H        W
1.461678 1.657716 1.095089 1.057364 1.093911 2.242446 1.783977 2.196395
library("glmtoolbox")
gvif(gvif4a) # gvif will report Standard VIF when Coding Schemes are entered
         GVIF df GVIF^(1/(2*df))
GREV_C 1.4617  1          1.2090
GREQ_C 1.6577  1          1.2875
TRT    1.0951  1          1.0465
Male   1.0574  1          1.0283
Age_C  1.0939  1          1.0459
B      2.2424  1          1.4975
H      1.7840  1          1.3357
W      2.1964  1          1.4820
```

A.6. R Output from R: `lm vif gvif`

```
gvif4b <- lm(y ~ GREV_C + GREQ_C + TRT + Male + Age_C + Ethnicity, data=GVIFDAT)
summary(gvif4b)
Coefficients:
             Estimate Std. Error t value Pr(>|t|)
(Intercept) 151.31471    1.94226  77.907  < 2e-16 ***
GREV_C        0.18906    0.08655   2.184   0.0315 *
GREQ_C        0.38638    0.08789   4.396 2.98e-05 ***
TRT           3.55257    1.43647   2.473   0.0153 *
Male          1.60167    1.47849   1.083   0.2815
Age_C        -0.44118    0.26178  -1.685   0.0954
EthnicityB   -2.02558    2.28724  -0.886   0.3782
EthnicityH   -0.18590    2.28997  -0.081   0.9355
EthnicityW   -2.34668    2.13088  -1.101   0.2737

Residual standard error: 6.858 on 91 degrees of freedom
Multiple R-squared:  0.4344,    Adjusted R-squared:  0.3846
F-statistic: 8.735 on 8 and 91 DF,  p-value: 8.759e-09
```

```
> vif(gvif4b)
               GVIF Df GVIF^(1/(2*Df))
GREV_C     1.461678  1        1.208999
GREQ_C     1.657716  1        1.287523
TRT        1.095089  1        1.046465
Male       1.057364  1        1.028282
Age_C      1.093911  1        1.045902
Ethnicity  1.327977  3        1.048411
```

```
> gvif(gvif4b)
               GVIF df GVIF^(1/(2*df))
GREV_C     1.4617  1          1.2090
GREQ_C     1.6577  1          1.2875
TRT        1.0951  1          1.0465
Male       1.0574  1          1.0283
Age_C      1.0939  1          1.0459
Ethnicity  1.3280  3          1.0484
```

A.7. SAS/IML CODE for Computing VIF and GVIF Model (4) from Fox and Monette (1992) Approach.

```
proc iml;use GVIF2;
read all var {GREV} into GREV;
read all var {GREQ} into GREQ;
read all var {Age}  into Age;
read all var {TRT}  into TRT;
read all var {Male} into Male;
read all var {A} into A;
read all var {B} into B;
read all var {H} into H;
read all var {W} into Wx;* To not confuse with W matrix;
N=nrow(H);
ones=j(N,1,1);* N dimensional vector of ones;
* Projection Matrix based on ones;
****************** Fox & Monette (1992) Approach GVIF for GREV;
H0=ones*(inv(ones`*ones))*ones`;
X=GREV||GREQ||TRT||Male||Age||B||H||Wx; * Define X Matrix;
COVX=(X`*(I(N)-H0)*X)/(N-1);
SCOVX=(vecdiag(COVX))##0.5;
ACOVX=SCOVX*SCOVX`;
RXX=COVX/ACOVX;print RXX;
VIF=vecdiag(inv(RXX));* Calculate Standard VIF Equation (11);print VIF;
detXX=det(Rxx); * Determinant for the Rxx Correlation Matrix;
W=GREV; * Define W Equation (15);
COVW=(W`*(I(N)-H0)*W)/(N-1);print COVW;
SCOVW=(vecdiag(COVW))##0.5;print SCOVW;
ACOVW=SCOVW*SCOVW`;
```

```
RWW=COVW/ACOVW;print RWW;
detWW=det(RWW); * Determinant for the Rww Correlation Matrix;
Z= GREQ||TRT||Male||Age||B||H||Wx; * Define Z Equation (16);
COVZ=(Z`*(I(N)-H0)*Z)/(N-1);print COVZ;
SCOVZ=(vecdiag(COVZ))##0.5;print SCOVZ;
ACOVZ=SCOVZ*SCOVZ`;
RZZ=COVZ/ACOVZ;print RZZ;
detZZ=det(RZZ); * Determinant for the Rzz Correlation Matrix;
GVIF=(detWW#detZZ)/detXX;
print detWW detZZ  GVIF; * GVIF Equation (14) & (17)
print detXX;
********** Fox & Monette (1992) Approach GVIF for Ethnicity;
W=B||H||Wx; * Define W Equation (18);
COVW=(W`*(I(N)-H0)*W)/(N-1);print covW;
SCOVW=(vecdiag(COVW))##0.5;print SCOVW;
ACOVW=SCOVW*SCOVW`;
RWW=COVW/ACOVW;print RWW;
detWW=det(RWW);
Z=GREV||GREQ||TRT||Male||Age; * Define Z Equation (19);
COVZ=(Z`*(I(N)-H0)*Z)/(N-1);print covZ;
SCOVZ=(vecdiag(COVZ))##0.5;print SCOVZ;
ACOVZ=SCOVZ*SCOVZ`;
RZZ=COVZ/ACOVZ;print RZZ;
detZZ=det(RZZ);
GVIF=(detWW#detZZ)/detXX;
print detWW detZZ  GVIF; * GVIF Equation (14) & (20)
print detXX;
```

A.8 SPSS SYNTAX for Computing VIF and GVIF from Fox & Monette and Multivariate Regression. for Ethnicity in Model 4.

```
MATRIX.
GET X / VARIABLES = GREV, GREQ, TRT, Male, Age, B, H, W. /* X is the Full Matrix *.
GET Z / VARIABLES = GREV, GREQ, TRT, Male, Age. /* Z Matrix of remaining covariates.
GET W / VARIABLES = B, H, W.          /* W Matrix of Variables evaluated for GVIF .
COMPUTE N=NROW(X) .
COMPUTE ONES=MAKE(N,1,1).                    /* N-dimensional vector of ones *.
COMPUTE IN=IDENT(N,N).                       /* N-dimensional Identity Matrix *.
COMPUTE H0=ONES*(INV(T(ONES)*ONES))*T(ONES). /* Projection Matrix of ones Hat *.
COMPUTE COVX=(T(X)*(IN-H0)*X)/(N-1).         /* Covariance Matrix of X  Matrix *.
COMPUTE SCOVX=SQRT(DIAG(COVX)).
COMPUTE ACOVX=SCOVX*T(SCOVX).
COMPUTE Rxx=COVX/ACOVX.                 /* Correlation Matrix Rxx of Full X  Matrix *.
COMPUTE VIFMAT=INV(Rxx).                /* Inverse Rxx VIFs on Diagonal equation 11.
COMPUTE DETx=DET(Rxx).                  /* Determinant of Rxx .
COMPUTE COVZ=(T(Z)*(IN-H0)*Z)/(N-1). /* Covariance Matrix of Z Matrix *.
COMPUTE SCOVZ=SQRT(DIAG(COVZ)).
COMPUTE ACOVZ=SCOVZ*T(SCOVZ).
COMPUTE Rzz=COVZ/ACOVZ.                 /* Correlation Matrix Rzz of Z Matrix *.
COMPUTE DETz=DET(Rzz).                  /* Determinant of Rzz .
COMPUTE COVW=(T(W)*(IN-H0)*W)/(N-1). /* Covariance Matrix of W Matrix *.
COMPUTE SCOVW=SQRT(DIAG(COVW)).
COMPUTE ACOVW=SCOVW*T(SCOVW).
COMPUTE Rww=COVW/ACOVW.                 /* Correlation Matrix Rww of W Matrix *.
COMPUTE DETw=DET(Rww).                  /* Determinant of Rww .
COMPUTE GVIF=(DETw*DETz)/DETx.          /* GVIF Fox & Monette (1992) eq. 14 & 20 .
COMPUTE W1={ONES,W}.                    /* W Design Matrix for MANOVA approach eq. 34.
COMPUTE Hw=W1*(INV(T(W1)*W1))*T(W1). /* Hat Matrix based on W Design Matrix eq. 26.
COMPUTE Tzz=(T(Z)*(IN-H0)*Z).           /* Total SS Matrix (T) for Z equation 27.
COMPUTE Rwz=(T(Z)*(IN-Hw)*Z).           /* Residual SS Matrix (R) for Z equation 28.
```

```
COMPUTE DETT=DET(Tzz).                  /* Determinant of Total SS Matrix .
COMPUTE DETR=DET(Rwz).                  /* Determinant of Residual SS Matrix .
COMPUTE GVIFM=DETT/DETR.                /* GVIF MANOVA approach equation 31 .
PRINT COVX    / title "Covariance Matrix of Full X Matrix".
PRINT Rxx     / title "Correlation Matrix Rxx of Full X Matrix".
PRINT VIFMAT  / title "Inverse Rxx VIFs on Diagonal equation 11".
PRINT COVZ    / title "Covariance Matrix of Z Partition Matrix".
PRINT Rzz     / title "Correlation Matrix Rzz of Z partition Matrix".
PRINT COVW    / title "Covariance Matrix of W Partition Matrix".
PRINT Rww     / title "Correlation Matrix Rww of W partition  Matrix".
PRINT GVIF    / title "GVIF Fox & Monette (1992) equation 14 & 20".
PRINT Tzz     / title "Total SS Matrix (T) for Z equation 27".
PRINT Rwz     / title "Residual SS Matrix (R) for Z equation 28".
PRINT GVIFM   / title " GVIF MANOVA approach equation 31".
END MATRIX.
```

A.9. STATA MATRIX CODE to COMPUTE GVIF for Ethnicity Model 4, Fox & Monette Approach.

```
matrix accum xp = GREV GREQ TRT Male Age B H W , dev noconstant
matrix list xp
matrix s = xp/(r(N)-1)
matrix list s
matrix r = corr(s)
matrix list r
matrix vifmatrix = inv(r)
matrix list vifmat
matrix detr=det(r)
matrix list detr
matrix accum xw = B H W, dev noconstant
matrix list xw
matrix sw = xw/(r(N)-1)
matrix list sw
matrix rw = corr(sw)
matrix list rw
matrix detw=det(rw)
matrix accum zz = GREV GREQ TRT Male Age , dev noconstant
matrix list zz
matrix sz = zz/(r(N)-1)
matrix list sz
matrix rz = corr(sz)
matrix list rz
matrix detz=det(rz)
matrix list detw
matrix list detz
matrix list detr
matrix GVIF = (detw*detz)/detr[1,1]
matrix list GVIF
```

A.10. SAS CODE for Computing VIF and GVIF from MANOVA and Multivariate Regression.

```
** Model 9 GREV Tolerance Model **;
proc reg data=GVIF2;
model  GREV_C = GREQ_C Age_C TRT Male B H W  ;run;
** Model 21 GREV VIF & Tolerance Model **;
proc reg data=GVIF2;
model  GREQ_C  TRT Male Age_C B H W = GREV_C  ;
TOL_GREV: MTEST GREV_C=0 / print;run;
proc glm data=GVIF2;
model  GREQ_C Age_C TRT Male B H W = GREV_C /e;
MANOVA H= GREV_C;run;
** Model 32 Ethnicity GVIF  Model **;
proc glm data=GVIF2;class Ethnicity;
model GREV_C GREQ_C  TRT Male Age_C = Ethnicity  ;
MANOVA H= Ethnicity;run;
proc reg data=GVIF2;
model  GREV_C GREQ_C  TRT Male Age_C = B H W   ;
TOL_ETHN: MTEST B=0, H=0, W=0 /print;run;
```

A.11. STATA CODE for Computing VIF and GVIF from MANOVA.

```
** Model 21 GREV VIF & Tolerance Model **;
manova GREQ_C TRT Male Age_C B H W = c.GREV_C
** Model 32 Ethnicity GVIF  Model **;
manova GREV_C GREQ_C TRT Male Age_C = EthnGRP
```

A.12. SPSS SYNTAX for Computing VIF and GVIF from MANOVA.

```
/* Model 21 GREV VIF & Tolerance Model *.
GLM GREQ_C TRT Male Age_C B H W WITH GREV_C
  /METHOD=SSTYPE(3)
  /INTERCEPT=INCLUDE
  /CRITERIA=ALPHA(.05)
  /DESIGN=GREV_C.
/* Model 32 Ethnicity GVIF  Model *.
GLM GREV_C GREQ_C TRT Male Age_C BY Ethnicity
  /METHOD=SSTYPE(3)
  /INTERCEPT=INCLUDE
  /CRITERIA=ALPHA(.05)
  /DESIGN=Ethnicity.
```

A.13. R CODE for Computing VIF and GVIF from MANOVA.

```
# Model 21 GVIF for Ethnicity
GVIF_GREV <- lm(cbind(GREQ_C, TRT, Male, Age_C, B, H, W) ~ GREV_C, data = GVIFDAT)
anova(GVIF_GREV, test = "Wilks")


# Model 32 GVIF for Ethnicity
GVIF_ETHN <- lm(cbind(GREV_C, GREQ_C, TRT, Male, Age_C) ~ Ethnicity, data = GVIFDAT)
anova(GVIF_ETHN, test = "Wilks")
```

A.14. SAS/IML CODE for Computing VIF and GVIF for Model (4) from Multivariate Regression.

```
proc iml;use GVIF2;
read all var {GREV} into GREV;
read all var {GREQ} into GREQ;
read all var {Age}  into Age;
read all var {TRT}  into TRT;
read all var {Male} into Male;
read all var {A} into A;
read all var {B} into B;
read all var {H} into H;
read all var {W} into Wx;* To not conufuse with W matrix;
N=nrow(H);
ones=j(N,1,1);* N dimensional vector of ones;
* Projection Matrix based on ones;
H0=ones*(inv(ones`*ones))*ones`;* Equation 25;
* Computing GVIF for GREV from data using SAS/IML MANOVA **;
** Partition Z (Dependent Variables) eq. 23;
Z=GREQ||TRT||Male||Age||B||H||Wx;
W=ones||GREV;* Partition W Design matrix eq. 24;
WW=W`*W;WZ=W`*Z;
** HAT matrix based W Equation 26;
Hw=W*(inv(W`*W))*W`;
* (q+1)*M Matrix of
Regression Coefficients from eq 22;
A=(inv(W`*W))*W`*Z;
```

```
print  A;
*** Total SS Matrix for Z;
*** Equation  27;
SST=Z`*(I(N)-H0)*Z;
*** Residual SS Matrix for Z;
*** Equation  28;
SSR=Z`*(I(N)-Hw)*Z;
*** Model SS Matrix for Z ~vW;
*** Equation  29;
SSR=Z`*(Hw-H0)*Z;
print SST SSR SSM;
*** Calcualte determinants;
detT=det(SST);detR=det(SSR);
print detT detR;
* Wilks lambda eq 30;
lambda=detR/detT;
* MANOVA based GVIF  eq 31;
GVIF=detT/detR;
print detT  lambda GVIF;
print detE;
* Computing GVIF for Ethnicity from data using SAS/IML MANOVA **;
** Partition Z (Dependent Variables) eq. 33;
Z=GREV||GREQ||TRT||Male||Age;
W=ones||B||H||Wx;* Partition W Design matrix eq. 34;
WW=W`*W;WZ=W`*Z;
```

```
** HAT matrix based W Equation 26;
Hw=W*(inv(W`*W))*W`;
* (q+1)*M Matrix of
Regression Coefficients from eq 22;
A=(inv(W`*W))*W`*Z;
print  A;
*** Total SS Matrix for Z;
*** Equation  27;
SST=Z`*(I(N)-H0)*Z;
*** Residual SS Matrix for Z;
*** Equation  28;
SSR=Z`*(I(N)-Hw)*Z;
*** Model SS Matrix for Z ~vW;
*** Equation  29;
SSR=Z`*(Hw-H0)*Z;
print SST SSR SSM;
*** Calcualte determinants;
detT=det(SST);detR=det(SSR);
print detT detR;
* Wilks lambda eq 30;
lambda=detR/detT;
* MANOVA based GVIF  eq 31;
GVIF=detT/detR;
print detT  lambda GVIF;
print detE;
```

A.15. STATA MATRIX CODE to COMPUTE GVIF for Ethnicity Model 4, MANOVA Approach.

```
gen ones = 1
mkmat GREV GREQ TRT Male Age, matrix(Z)
mkmat ones B H W, matrix(W)
matrix list W
matrix A = inv(W'*W)*W'*Z
matrix list A
mkmat ones, matrix(ones)
matrix H0 = ones*(inv(ones'*ones))*ones'
matrix Hw = W*(inv(W'*W))*W'
matrix list HF
matrix IN =I(r(N))
matrix T = Z'*(IN-H0)*Z
matrix list T
matrix detT=det(T)
matrix list detT
matrix R = Z'*(IN-Hw)*Z
matrix list R
matrix M = Z'*(Hw-H0)*Z
matrix list M
matrix detR=det(R)
matrix list detR
matrix WilksL=det(R)/det(T)
matrix list WilksL
matrix GVIF=det(T)/det(R)
matrix list GVIF
```