1. **Objective:** analyzing dental data using ordinary least square (OLS) and Generalized Least Square(GLS) in STATA.

2. **Scientific question**: Determine whether there is a difference between boys and girls with respect to the distance and its change over time.

3. **Dataset:** Dental study data set (http://biosun01.biostat.jhsph.edu/~fdominic/teaching/LDA/dental.dat)

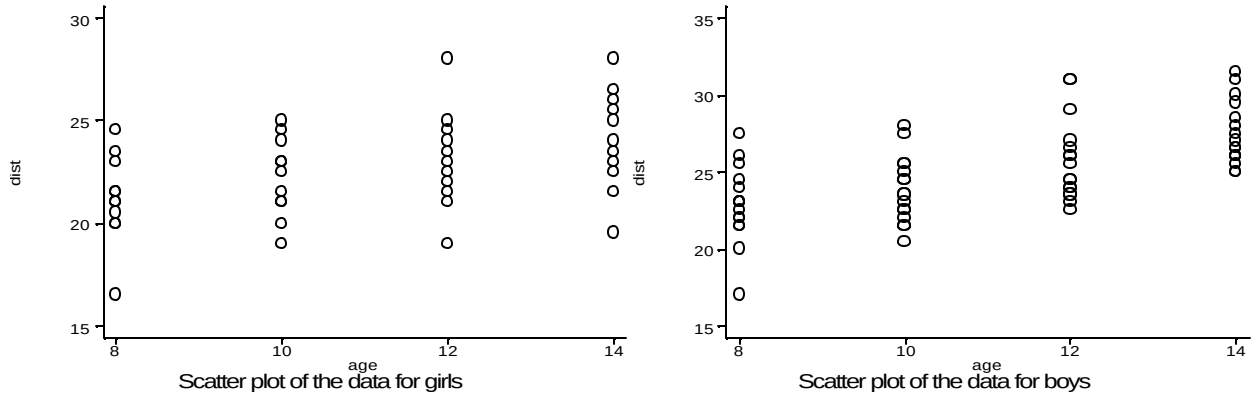
   Data description: 27 children, 16 boys and 11 girls were observed at each ages 8, 10, 12 and 14 years. The data set has the following five columns:

   Column 1: observation number
   Column 2: child id number
   Column 3: age
   Column 4: distance
   Column 3: gender indicator (0=girl, 1=boy)

   Outcome: distance, is a continuous variables.
   Covariate: age and gender.

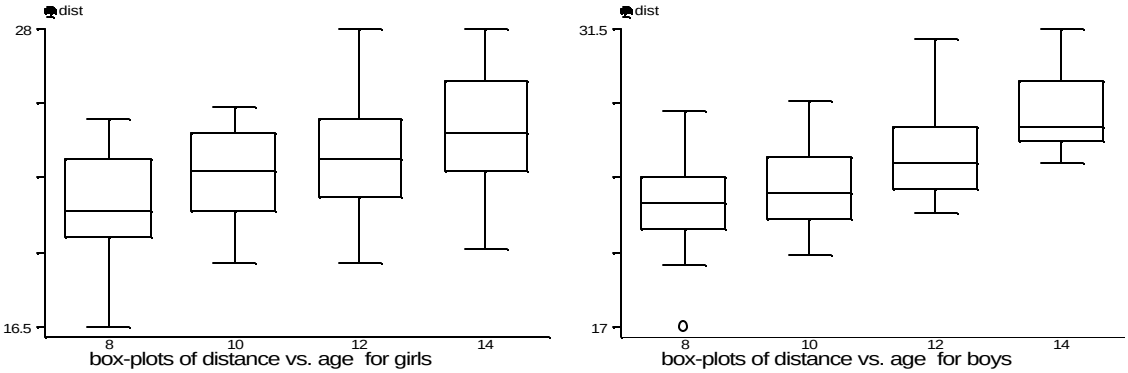
4. STATA output of the anlysis

```
. *read the dental data set
. infile obs id age dist sex using c:\data\dental.dat,clear
(108 observations read)

.
. ******************
. ******EDA*********
. ******************
.
. *scatter plots
. graph dist age if sex==0, xlab ylab ti("Scatter plot of the data for girls")
> saving(g1,replace)

. graph dist age if sex==1, xlab ylab ti("Scatter plot of the data for boys") s
> aving(g2,replace)

. graph using g1 g2
```

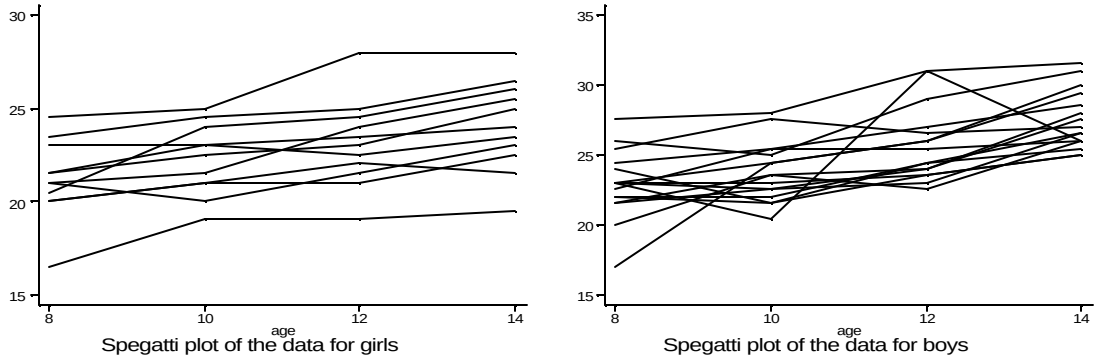



```
. *box plots
. sort age
```

```
. graph dist if sex==0, box by(age)  ti("box-plots of distance vs. age  for gir
> ls") saving(g3, replace)

. graph dist if sex==1, box by(age)  ti("box-plots of distance vs. age  for boy
> s") saving(g4, replace)

. graph using g3 g4
```



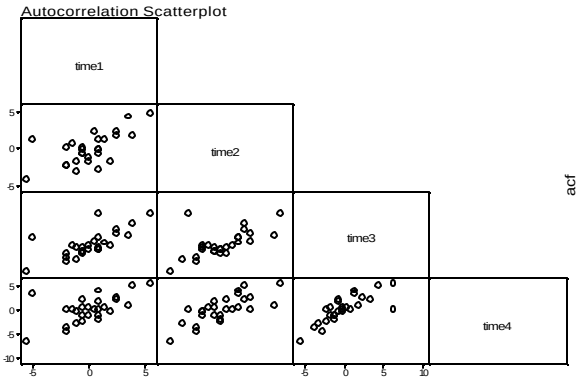

```
. *longitudinal plots
.sort id age
. graph dist age if sex==0, c(L) s(i) xlab ylab ti("Spegatti plot of the data f
> or girls") saving(g5,replace)

. graph dist age if sex==1, c(L) s(i) xlab ylab ti("Spegatti plot of the data f
> or boys") saving(g6,replace)

. graph using g5 g6
```

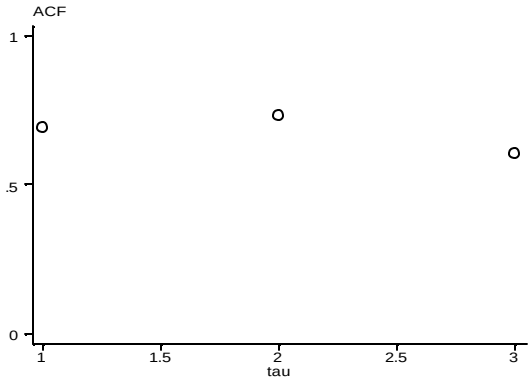



```
. *OLS(ignoring the correlation between responses for same person)
. reg dist age if sex==0

  Source |       SS       df       MS              Number of obs =      44
---------+------------------------------           F(  1,    42) =   10.80
   Model |  50.5920455     1  50.5920455           Prob > F      =  0.0021
Residual |  196.697727    42  4.68327922           R-squared     =  0.2046
---------+------------------------------           Adj R-squared =  0.1856
   Total |  247.289773    43  5.75092495           Root MSE      =  2.1641

------------------------------------------------------------------------------
    dist |      Coef.   Std. Err.       t     P>|t|       [95% Conf. Interval]
---------+--------------------------------------------------------------------
     age |   .4795455   .1459028      3.287   0.002       .1851016    .7739893
```

```
   _cons |   17.37273   1.637755     10.608   0.000        14.0676    20.67785
------------------------------------------------------------------------------

. reg dist age if sex==1

  Source |       SS       df       MS                  Number of obs =      64
---------+------------------------------               F(  1,    62) =   36.65
   Model |  196.878125     1  196.878125               Prob > F      =  0.0000
Residual |  333.059375    62   5.3719254               R-squared     =  0.3715
---------+------------------------------               Adj R-squared =  0.3614
   Total |    529.9375    63  8.41170635               Root MSE      =  2.3177

------------------------------------------------------------------------------
    dist |      Coef.   Std. Err.       t     P>|t|       [95% Conf. Interval]
---------+--------------------------------------------------------------------
     age |    .784375   .1295657      6.054   0.000       .5253769    1.043373
   _cons |   16.34063   1.454371     11.236   0.000       13.43338    19.24787
------------------------------------------------------------------------------

. reg dis age sex

  Source |       SS       df       MS                  Number of obs =     108
---------+------------------------------               F(  2,   105) =   36.41
   Model |  375.820875     2  187.910438               Prob > F      =  0.0000
Residual |  541.871254   105  5.16067861               R-squared     =  0.4095
---------+------------------------------               Adj R-squared =  0.3983
   Total |   917.69213   107  8.57656196               Root MSE      =  2.2717

------------------------------------------------------------------------------
    dist |      Coef.   Std. Err.       t     P>|t|       [95% Conf. Interval]
---------+--------------------------------------------------------------------
     age |   .6601852   .0977589      6.753   0.000       .4663473    .8540231
     sex |   2.321023   .4448862      5.217   0.000       1.438896     3.20315
   _cons |   15.38569   1.128567     13.633   0.000       13.14795    17.62343
------------------------------------------------------------------------------

. sum age

Variable |     Obs        Mean   Std. Dev.       Min        Max
---------+-----------------------------------------------------
     age |     108          11   2.246493          8         14

. egen mage=mean(age)

. disp mage
11

. gen cage=age-mage

. xi:reg dist cage sex i.sex*cage
i.sex                Isex_0-1    (naturally coded; Isex_0 omitted)
i.sex*cage           IsXcag_#    (coded as above)

  Source |       SS       df       MS                  Number of obs =     108
---------+------------------------------               F(  3,   104) =   25.39
   Model |  387.935027     3  129.311676               Prob > F      =  0.0000
Residual |  529.757102   104  5.09381829               R-squared     =  0.4227
---------+------------------------------               Adj R-squared =  0.4061
   Total |   917.69213   107  8.57656196               Root MSE      =  2.2569

------------------------------------------------------------------------------
    dist |      Coef.   Std. Err.       t     P>|t|       [95% Conf. Interval]
---------+--------------------------------------------------------------------
```

```
    cage |   .4795455   .1521635      3.152   0.002       .1777996    .7812913
     sex |   2.321023   .4419949      5.251   0.000        1.44453    3.197515
  Isex_1 |  (dropped)
    cage |  (dropped)
IsXcag_1 |   .3048295   .1976661      1.542   0.126      -.0871498    .6968089
   _cons |   22.64773   .3402478     66.562   0.000         21.973    23.32245
------------------------------------------------------------------------------

. *add quadratic term of age to the OLS
. gen age2=cage^2

. reg dis cage age2 sex

  Source |       SS       df       MS                  Number of obs =     108
---------+------------------------------               F(  3,   104) =   24.20
   Model |  377.267635     3  125.755878               Prob > F      =  0.0000
Residual |  540.424495   104  5.19638937               R-squared     =  0.4111
---------+------------------------------               Adj R-squared =  0.3941
   Total |   917.69213   107  8.57656196               Root MSE      =  2.2796

------------------------------------------------------------------------------
    dist |      Coef.   Std. Err.       t     P>|t|       [95% Conf. Interval]
---------+--------------------------------------------------------------------
    cage |   .6601852   .0980966      6.730   0.000        .465656    .8547144
    age2 |   .0289352   .0548377      0.528   0.599        -.07981    .1376803
     sex |   2.321023   .4464228      5.199   0.000        1.43575    3.206296
   _cons |   22.50305   .4396351     51.186   0.000       21.63124    23.37486
------------------------------------------------------------------------------

. *we found quadratic term of age is not significant


. *calculate the autocorrelation matrix, determine the correlation structure
. sort id age

. by id: gen num=_n

. autocor dist num id

          |    time1    time2    time3    time4
----------+------------------------------------
    time1 |   1.0000
    time2 |   0.6256   1.0000
    time3 |   0.7108   0.6349   1.0000
    time4 |   0.5998   0.7593   0.7950   1.0000

          acf
  1.   .685653
  2.  .7284871
  3.  .5998338
```






```
. *GLS(using independent, exchangeable, exponential(ar1) and unstructured corre
> lation)
. *indenpendent correlation(same as OLS)
. xtgee dist age if sex==0, i(id) corr(ind)

Iteration 1: tolerance = 6.603e-15

GEE population-averaged model                   Number of obs      =        44
Group variable:                         id      Number of groups   =        11
Link:                             identity      Obs per group: min =         4
Family:                           Gaussian                     avg =       4.0
Correlation:                   independent                     max =         4
                                                Wald chi2(1)       =     10.80
Scale parameter:                  4.683279      Prob > chi2        =    0.0010

Pearson chi2(42):                   196.70      Deviance           =    196.70
Dispersion (Pearson):             4.683279      Dispersion         =  4.683279

------------------------------------------------------------------------------
    dist |      Coef.   Std. Err.       z     P>|z|       [95% Conf. Interval]
---------+--------------------------------------------------------------------
     age |   .4795455   .1459028      3.287   0.001       .1935812    .7655097
   _cons |   17.37273   1.637755     10.608   0.000       14.16279    20.58267
------------------------------------------------------------------------------

. xtcorr

Estimated within-id correlation matrix R:

        c1      c2      c3      c4
r1  1.0000
r2  0.0000  1.0000
r3  0.0000  0.0000  1.0000
r4  0.0000  0.0000  0.0000  1.0000

. xtgee dist age if sex==1, i(id) corr(ind)

Iteration 1: tolerance = 2.663e-15

GEE population-averaged model                   Number of obs      =        64
Group variable:                         id      Number of groups   =        16
Link:                             identity      Obs per group: min =         4
Family:                           Gaussian                     avg =       4.0
Correlation:                   independent                     max =         4
                                                Wald chi2(1)       =     36.65
Scale parameter:                  5.371925      Prob > chi2        =    0.0000
```

```
Pearson chi2(62):                  333.06      Deviance           =    333.06
Dispersion (Pearson):            5.371925      Dispersion         =  5.371925

------------------------------------------------------------------------------
    dist |      Coef.   Std. Err.       z     P>|z|       [95% Conf. Interval]
---------+--------------------------------------------------------------------
     age |    .784375   .1295657      6.054   0.000       .5304309    1.038319
   _cons |   16.34063   1.454371     11.236   0.000       13.49011    19.19114
------------------------------------------------------------------------------

. xtcorr

Estimated within-id correlation matrix R:

        c1      c2      c3      c4
r1  1.0000
r2  0.0000  1.0000
r3  0.0000  0.0000  1.0000
r4  0.0000  0.0000  0.0000  1.0000

. *exchangeable correlation
. xtgee dist age if sex==0, i(id) corr(exc)

Iteration 1: tolerance = 7.735e-16

GEE population-averaged model                   Number of obs      =        44
Group variable:                         id      Number of groups   =        11
Link:                             identity      Obs per group: min =         4
Family:                           Gaussian                     avg =       4.0
Correlation:                  exchangeable                     max =         4
                                                Wald chi2(1)       =     74.22
Scale parameter:                  4.683279      Prob > chi2        =    0.0000

------------------------------------------------------------------------------
    dist |      Coef.   Std. Err.       z     P>|z|       [95% Conf. Interval]
---------+--------------------------------------------------------------------
     age |   .4795455   .0556625      8.615   0.000        .370449    .5886419
   _cons |   17.37273   .8684316     20.005   0.000       15.67063    19.07482
------------------------------------------------------------------------------

. xtcorr

Estimated within-id correlation matrix R:

        c1      c2      c3      c4
r1  1.0000
r2  0.8545  1.0000
r3  0.8545  0.8545  1.0000
r4  0.8545  0.8545  0.8545  1.0000

. xtgee dist age if sex==1, i(id) corr(exc)

Iteration 1: tolerance = 6.146e-16

GEE population-averaged model                   Number of obs      =        64
Group variable:                         id      Number of groups   =        16
Link:                             identity      Obs per group: min =         4
Family:                           Gaussian                     avg =       4.0
Correlation:                  exchangeable                     max =         4
                                                Wald chi2(1)       =     68.51
Scale parameter:                  5.371925      Prob > chi2        =    0.0000

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

```
    dist |      Coef.   Std. Err.       z     P>|z|       [95% Conf. Interval]
---------+------------------------------------------------------------------
     age |    .784375   .0947624      8.277   0.000       .5986441    .9701059
   _cons |   16.34062   1.134732     14.400   0.000       14.11659    18.56466
------------------------------------------------------------------------------

. xtcorr

Estimated within-id correlation matrix R:

       c1      c2      c3      c4
r1  1.0000
r2  0.4651  1.0000
r3  0.4651  0.4651  1.0000
r4  0.4651  0.4651  0.4651  1.0000

. *exponential correlation
. xtgee dist age if sex==0, i(id) t(age) corr(ar1)

Iteration 1: tolerance = .00359913
Iteration 2: tolerance = 1.357e-07

GEE population-averaged model                 Number of obs      =        44
Group and time vars:               id age     Number of groups   =        11
Link:                             identity    Obs per group: min =         4
Family:                           Gaussian                 avg =       4.0
Correlation:                         AR(1)                 max =         4
                                              Wald chi2(1)       =     32.30
Scale parameter:                  4.683506    Prob > chi2        =    0.0000

------------------------------------------------------------------------------
    dist |      Coef.   Std. Err.       z     P>|z|       [95% Conf. Interval]
---------+------------------------------------------------------------------
     age |   .4847376   .0852895      5.683   0.000       .3175733     .651902
   _cons |    17.3066   1.113527     15.542   0.000       15.12413    19.48907
------------------------------------------------------------------------------

. xtcorr

Estimated within-id correlation matrix R:

       c1      c2      c3      c4
r1  1.0000
r2  0.8847  1.0000
r3  0.7827  0.8847  1.0000
r4  0.6925  0.7827  0.8847  1.0000

. xtgee dist age if sex==1, i(id) t(age) corr(ar1)

Iteration 1: tolerance = .01108648
Iteration 2: tolerance = .00005707
Iteration 3: tolerance = 4.267e-07

GEE population-averaged model                 Number of obs      =        64
Group and time vars:               id age     Number of groups   =        16
Link:                             identity    Obs per group: min =         4
Family:                           Gaussian                 avg =       4.0
Correlation:                         AR(1)                 max =         4
                                              Wald chi2(1)       =     35.77
Scale parameter:                  5.376588    Prob > chi2        =    0.0000

------------------------------------------------------------------------------
    dist |      Coef.   Std. Err.       z     P>|z|       [95% Conf. Interval]
```

```
---------+----------------------------------------------------------------------
     age |    .772411   .1291524      5.981   0.000       .5192768    1.025545
   _cons |   16.53388   1.476084     11.201   0.000       13.64081    19.42695
------------------------------------------------------------------------------

. xtcorr

Estimated within-id correlation matrix R:

       c1      c2      c3      c4
r1  1.0000
r2  0.4657  1.0000
r3  0.2169  0.4657  1.0000
r4  0.1010  0.2169  0.4657  1.0000

. *unstructureed correlation
. xtgee dist age if sex==0, i(id) t(age) corr(uns)

Iteration 1: tolerance = .00563941
Iteration 2: tolerance = .00001054
Iteration 3: tolerance = 1.824e-08

GEE population-averaged model                   Number of obs      =        44
Group and time vars:               id age       Number of groups   =        11
Link:                            identity       Obs per group: min =         4
Family:                          Gaussian                     avg =       4.0
Correlation:                  unstructured                    max =         4
                                               Wald chi2(1)       =     29.50
Scale parameter:                   4.68365     Prob > chi2        =    0.0000

------------------------------------------------------------------------------
    dist |      Coef.   Std. Err.       z     P>|z|       [95% Conf. Interval]
---------+--------------------------------------------------------------------
     age |   .4711862   .0867513      5.431   0.000       .3011568    .6412155
   _cons |   17.46256   .9957054     17.538   0.000       15.51102    19.41411
------------------------------------------------------------------------------

. xtcorr

Estimated within-id correlation matrix R:

       c1      c2      c3      c4
r1  1.0000
r2  0.6505  1.0000
r3  0.8411  0.7814  1.0000
r4  0.8453  0.7918  1.0000  1.0000

. xtgee dist age if sex==1, i(id) t(age) corr(uns)

Iteration 1: tolerance = .00395941
Iteration 2: tolerance = .00004108
Iteration 3: tolerance = 5.253e-06
Iteration 4: tolerance = 5.331e-07

GEE population-averaged model                   Number of obs      =        64
Group and time vars:               id age       Number of groups   =        16
Link:                            identity       Obs per group: min =         4
Family:                          Gaussian                     avg =       4.0
Correlation:                  unstructured                    max =         4
                                               Wald chi2(1)       =     57.20
Scale parameter:                   5.372557    Prob > chi2        =    0.0000

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

```
    dist |      Coef.   Std. Err.       z     P>|z|       [95% Conf. Interval]
---------+------------------------------------------------------------------------
     age |   .7801528   .1031489      7.563   0.000       .5779846     .982321
   _cons |   16.40993   1.192964     13.756   0.000       14.07176    18.74809
------------------------------------------------------------------------------

. xtcorr

Estimated within-id correlation matrix R:

        c1      c2      c3      c4
r1  1.0000
r2  0.3833  1.0000
r3  0.6311  0.3867  1.0000
r4  0.2871  0.4803  0.5641  1.0000
```