



Analysis of air traffic control data

Contents

1. Introduction	1
2. Variance decomposition model for Air Force data	3
3. Non-linear model for air traffic data	7
4. Including additional variables in the air traffic data analysis	9

1. Introduction

The data used in this example are described by Kanfer & Ackerman (1989).¹ The data consists of information for 141 U.S. Air Force enlisted personnel. The personnel carried out a computerized air traffic controller task developed by Kanfer and Ackerman.

The subjects were instructed to accept planes into their hold pattern and land them safely and efficiently on one of four runways, varying in length and compass directions, according to rules governing plane movements and landing requirements. For each subject, the success of a series of between three and six 10-minute trials was recorded. The measurement employed was the number of correct landings per trial.

The Armed Services Vocational Battery (ASVB) was also administered to each subject. A global measure of cognitive ability, obtained from the sum of scores on the 10 subscales, is included in the data.

The data for this example can be found in the **KANFER.PSF** file. The variable labels and first few records of this data file are shown below.

¹ Permission for SSI to use the copyrighted raw data was provided by R. Kanfer and P.L. Ackerman. The data are from experiments reported in: Kanfer, R., & Ackerman, P.L. (1989).

The data remain the copyrighted property of Ruth Kanfer and Phillip L. Ackerman. Further publication or further dissemination of these data is not permitted without the expressed consent of the copyright owners.

	control	time	measure	ability	constant	timesq
1	1.00	1.00	24.00	142.16	1.00	1.00
2	1.00	2.00	27.00	142.16	1.00	4.00
3	1.00	3.00	30.00	142.16	1.00	9.00
4	1.00	4.00	32.00	142.16	1.00	16.00
5	1.00	5.00	38.00	142.16	1.00	25.00
6	1.00	6.00	41.00	142.16	1.00	36.00
7	2.00	1.00	2.00	-7.63	1.00	1.00
8	2.00	2.00	3.00	-7.63	1.00	4.00
9	2.00	3.00	9.00	-7.63	1.00	9.00
10	2.00	4.00	13.00	-7.63	1.00	16.00
11	2.00	5.00	13.00	-7.63	1.00	25.00
12	2.00	6.00	14.00	-7.63	1.00	36.00
13	3.00	1.00	12.00	-67.43	1.00	1.00
14	3.00	2.00	18.00	-67.43	1.00	4.00
15	3.00	3.00	24.00	-67.43	1.00	9.00
16	3.00	4.00	24.00	-67.43	1.00	16.00
17	3.00	5.00	27.00	-67.43	1.00	25.00
18	3.00	6.00	28.00	-67.43	1.00	36.00
19	4.00	1.00	7.00	11.50	1.00	1.00
20	4.00	2.00	19.00	11.50	1.00	4.00

The variables in the data set are:

CONTROL	The identifying number of the air traffic controller
TIME	The number of the trial (between 1 and 6)
MEASURE	The number of successful trials for the trial
ABILITY	The cognitive ability score (combined ASVB score)
CONSTANT	The intercept term, with value 1 throughout
TIMESQ	TIME*TIME, a quadratic term

Using this data, three models will be fitted:

- The first model, a variance decomposition model, will investigate the variation in the number of correct trials over subjects and also over measurements for each subject.
- In the next model, a non-linear growth model will be considered.
- Finally, the cognitive ability measure, a controller-related variable, will be introduced into the non-linear growth model.

2. Variance decomposition model for Air Force data

To start the input file, we select the defaults for output options, maximum number of iterations, and convergence criterion, then provide an optional title for the analysis.

Title and Options [X]

Title (Maximum 70 characters):
Kanfer and Ackerman data: variance decomposition

Maximum Number of Iterations: 10

Convergence Criterion: 0.001

Missing Data Value: -999999 Nfree: 0

Missing Dep Value: -999999 Deviance:

Use OLS for starting values Calculate effect sizes

Additional Output

Asymptotic Covariances Residuals

Empirical Bayes Estimates No Data Summary

Between and Within Covariance Matrices

Next >> Cancel OK

To build Syntax, proceed to the Random Variables screen and click the Finish Button

The variable CONTROL, identifying the air traffic controller, is used as level-2 identification, as up to six measurements are available for each controller. The variable TIME, indicating the number of the trial, is used as level-1, or measurement, identification.

The number of successful landings per trial is represented by the variable MEASURE, which we select as the response variable for this particular model. We include the intercept term. By doing so, the intercept will automatically be assumed to be a random variable at both levels of the model.

Select Response and Fixed Variables X

The resulting input file (**KANFER1.PRL**) is as follows:

```
OPTIONS Maxiter=30 Conv=0.0001 ACM=Yes;  
TITLE=Kanfer and Ackerman data: Variance decomposition;  
SY=KANFER.LSF;  
ID2=control;  
RESPONSE=measure;  
FIXED=intcept;  
RANDOM1=intcept;  
RANDOM2=intcept;
```

Partial output is given and discussed below.

N2 : 137 138 139 140 141
 N1 : 6 5 5 5 3

=====

 CONVERGENCE REACHED IN 4 ITERATIONS

Kanfer and Ackerman data: Variance decomposition

ITERATION NUMBER 4

+-----+
 | FIXED PART OF MODEL |
 +-----+

COEFFICIENTS	BETA-HAT	STD.ERR.	Z-VALUE	PR > Z
intcept	26.15108	0.66707	39.20293	0.00000

+-----+
 | -2 LOG-LIKELIHOOD |
 +-----+

DEVIANCE= -2*LOG(LIKELIHOOD) = 6380.91436790376
 NUMBER OF FREE PARAMETERS = 3

+-----+
 | RANDOM PART OF MODEL |
 +-----+

LEVEL 2	TAU-HAT	STD.ERR.	Z-VALUE	PR > Z
intcept /intcept	47.22948	7.51714	6.28290	0.00000

LEVEL 1	TAU-HAT	STD.ERR.	Z-VALUE	PR > Z
intcept /intcept	92.17651	4.93041	18.69552	0.00000

LEVEL 2 COVARIANCE MATRIX

intcept
 intcept 47.22948

LEVEL 2 CORRELATION MATRIX

```
          intcept
intcept   1.0000
```

LEVEL 1 COVARIANCE MATRIX

```
          intcept
intcept   92.17651
```

LEVEL 1 CORRELATION MATRIX

```
          intcept
intcept   1.0000
```

- From the Data Summary, we see that we have complete data for all but the last four air traffic controllers.
- The mean number of successful trials, as obtained from the output for the fixed part of the model, is 26.15108. From exploratory analysis of this data done prior to analysis, it is known that the number of successful trials ranged between 0 and 57.
- From the output for the random part of the model, we see that the variation over measurements is approximately half of the variation over the controllers (47.2298 versus 92.1765), indicating significant differences in the intercepts between controllers.
- A value of 6380.914 was obtained for $-2 \ln L$.

In the next model, we will consider a non-linear growth model and compare results with the results obtained here.

3. Non-linear model for air traffic data

In data of this nature, it can be expected that the number of successful landings per trial may be influenced by previous experience. In order to take this into account, we now introduce the order of the measurements into the model. The variable TIME indicates the number of the trial, and TIMESQ the quadratic term equal to TIME*TIME.

To fit such a model, the FIXED and RANDOM2 commands used previously have to be changed to:

```
FIXED = constant time timesq;
RANDOM2 = constant time timesq;
```

These changes can be made by directly editing the **KANFER1.PRL** file used in the previous analysis, and saving it as **KANFER2.PRL**:

```
OPTIONS Maxiter=30 Conv=0.0001 ACM=Yes;
TITLE=Kanfer and Ackerman data: non-linear model;
SY=KANFER.LSF;
ID2=control;
RESPONSE=measure;
FIXED=intcept time timesq;
```

RANDOM1=intcept;
 RANDOM2=intcept time timesq;

Partial output for this model follows.

ITERATION NUMBER 4

```

+-----+
| FIXED PART OF MODEL |
+-----+
  
```

COEFFICIENTS	BETA-HAT	STD.ERR.	Z-VALUE	PR > Z
intcept	1.67806	0.87343	1.92123	0.05470
time	11.48966	0.50397	22.79838	0.00000
timesq	-1.03583	0.06141	-16.86761	0.00000

```

+-----+
| -2 LOG-LIKELIHOOD |
+-----+
  
```

DEVIANCE= -2*LOG(LIKELIHOOD) = 5095.46585430941
 NUMBER OF FREE PARAMETERS = 10

```

+-----+
| RANDOM PART OF MODEL |
+-----+
  
```

LEVEL 2	TAU-HAT	STD.ERR.	Z-VALUE	PR > Z
intcept /intcept	77.02126	12.98193	5.93296	0.00000
time /intcept	-24.73085	6.50474	-3.80197	0.00014
time /time	22.66462	4.35831	5.20033	0.00000
timesq /intcept	2.26771	0.76607	2.96017	0.00307
timesq /time	-2.38073	0.52370	-4.54595	0.00001
timesq /timesq	0.27282	0.06566	4.15473	0.00003

LEVEL 1	TAU-HAT	STD.ERR.	Z-VALUE	PR > Z
intcept /intcept	9.49299	0.65567	14.47823	0.00000

LEVEL 2 COVARIANCE MATRIX

	intcept	time	timesq
intcept	77.02126		
time	-24.73085	22.66462	
timesq	2.26771	-2.38073	0.27282

LEVEL 2 CORRELATION MATRIX

	intcept	time	timesq
intcept	1.0000		
time	-0.5919	1.0000	
timesq	0.4947	-0.9574	1.0000

LEVEL 1 COVARIANCE MATRIX

	intcept
intcept	9.49299

LEVEL 1 CORRELATION MATRIX

	intcept
intcept	1.0000

From the output above, we see that:

- Both the TIME and TIMESQ variables, introduced as fixed effects in this model, have coefficients which are highly significant. From the large coefficient for TIME (11.48966) we see that there is a positive increase of 11 successful landings expected between successive trials.
- From the random part of the output, it follows that all the estimates of the random coefficients on level 2 of the model are significant. This is also true for all the interaction terms on this level of the model.
- The estimate of the coefficient of the level-1 variance is now 9.49299, compared to the coefficient for the similar term in the previous model of 92.17651, where TIME and TIMESQ were not allowed to vary randomly at the controller level. Variation over measurements has been drastically reduced in the extended model.
- For this model, a $-2 \ln L$ value of 5095.466 was obtained, compared to the previous model where $-2 \ln L$ was 6380.914. In the previous model, 3 parameters were estimated, while for the extended model 10 parameters were estimated. The inclusion of TIME and TIMESQ significantly improved the fit of the model.

In the two models considered thus far, the measure of cognitive ability available for each controller has not been considered. In the third and final analysis of this data, we will include this measure in the model considered in this section.

4. Including additional variables in the air traffic data analysis

In the previous example a non-linear model was considered. Recall that the data set also includes a measure of cognitive ability (composite ASVB score) for each of the 141 air traffic controllers, denoted by ABILITY in the file **KANFER.PSF**. We now include this variable as a fixed effect in the model.

To add ABILITY to the model, the input file used in the previous example may be edited. After it has been added to the fixed variables field, the input file for this analysis is as follows (**KANFER3.PRL**).

```
OPTIONS ;  
TITLE=Kanfer and Ackerman data: Non-linear model with covariate;  
SY=KANFER.PSF;
```

```

ID2=control;
RESPONSE=measure;
FIXED=intcept time timesq ability;
RANDOM1=intcept;
RANDOM2=intcept time timesq;

```

Partial output for this analysis is shown below.

ITERATION NUMBER 5

```

+-----+
| FIXED PART OF MODEL |
+-----+

```

COEFFICIENTS	BETA-HAT	STD.ERR.	Z-VALUE	PR > Z
intcept	1.67596	0.78914	2.12380	0.03369
time	11.49203	0.50393	22.80468	0.00000
timesq	-1.03639	0.06140	-16.87926	0.00000
ability	0.03703	0.00519	7.12991	0.00000

```

+-----+
| -2 LOG-LIKELIHOOD |
+-----+

```

DEVIANCE= -2*LOG(LIKELIHOOD) = 5052.79195876026
NUMBER OF FREE PARAMETERS = 11

```

+-----+
| RANDOM PART OF MODEL |
+-----+

```

LEVEL 2	TAU-HAT	STD.ERR.	Z-VALUE	PR > Z
intcept /intcept	57.26990	10.66626	5.36926	0.00000
time /intcept	-22.58401	5.99975	-3.76416	0.00017
time /time	22.66331	4.35767	5.20078	0.00000
timesq /intcept	2.09446	0.70777	2.95925	0.00308
timesq /time	-2.38017	0.52358	-4.54597	0.00001
timesq /timesq	0.27273	0.06565	4.15461	0.00003

LEVEL 1	TAU-HAT	STD.ERR.	Z-VALUE	PR > Z
intcept /intcept	9.49057	0.65551	14.47819	0.00000

LEVEL 2 COVARIANCE MATRIX

	intcept	time	timesq
intcept	57.26990		
time	-22.58401	22.66331	
timesq	2.09446	-2.38017	0.27273

LEVEL 2 CORRELATION MATRIX

	intcept	time	timesq
intcept	1.0000		
time	-0.6269	1.0000	
timesq	0.5300	-0.9574	1.0000

LEVEL 1 COVARIANCE MATRIX

	intcept
intcept	9.49057

LEVEL 1 CORRELATION MATRIX

	intcept
intcept	1.0000

From the output above, we see that:

- The effect of ability on the number of successful landings is small in size and positive, indicating a small, and highly significant increase in the expected number of successful landings per trial. The largest effect is that of the order of trials, indicating that a higher number of successful landings are expected in a following trial.
- From the large coefficient for TIME (11.4920), we see that there is a positive increase of 11 successful landings expected between successive trials.
- From the random part of the output, it follows that all the estimates of the random coefficients on level 2 of the model are significant. This is also true for all the interaction terms at this level of the model. Note that the coefficient for the intercept at this level has been reduced to 57.26989, compared to 77.02126 in the previous model, where the cognitive ability measure was not included. The introduction of this measure into the model leads to a reduction in the variation of mean outcome scores over controllers.
- The estimate of the coefficient of the level-1 variance is now 9.4057, which is very similar to the estimate obtained for the model without ABILITY. Inclusion of this variable did not contribute to the reduction in the variation over measurements nested within each controller.
- For this model, a $-2\ln L$ value of 5052.792 was obtained, compared to the previous model where $-2\ln L$ was 5095.466. As only one extra parameter was estimated in this model, we conclude that the inclusion of ABILITY in the non-linear model significantly improved the fit of the model.