Growth Curve Modeling in Stata

Hsueh-Sheng Wu
CFDR Workshop Series
February 12, 2018
Outline

• What is Growth Curve Modeling (GCM)
• Advantages of GCM
• Disadvantages of GCM
• Graphs of trajectories
• Inter-person differences in intra-person trajectories
• Key concepts of GCM
• Stata codes for determining the form of the intra-individual trajectories
• Stata codes for explaining the inter-individual differences in intra-person trajectories
• Conclusions
What is Growth Curve Modeling (GCM)

- Growth curve modeling is a technique to describe and explain an individual’s change over time.

- Main Research Questions:
  - What are the patterns of change for individuals over time?
  - What accounts for the difference in the patterns of change over time?

- Data requirement:
  - Panel data
  - The more waves of data you have, the more complex models you can estimate. For example, with three-wave panel data, you can test a linear growth curve model only, but with four-wave panel data, you can test both linear and curvilinear growth curve models.
Advantages of GCM

- Examine constructs measured at several time points simultaneously, not just the end point in time

- GCM has two main tasks:
  - Model intra-individual change: Intra-individual change refers to the change of the outcome variable for the same individual over time. Time is the only predictor of the intra-individual change. The relation between change in the outcome variable and time is often called a trajectory.
  - Explain inter-individual differences in the intra-individual trajectories: Inter-individual differences in the predictors are used to account for the variation in the intra-individual changes.

- For modeling intra-individual change, researchers examine (1) whether the trajectory is in a linear, curvilinear, cubic, other functional form and (2) whether the parameters defining the trajectory have significant variations.

- For explaining inter-individual differences, researchers use time-invariant and time-varying variables to account for variations in the parameters of the trajectory.

- Include respondents even when respondents had missing data on some of the time points
Disadvantages of GCM

• GCM can only be used if the data meet the following criteria:
  – at least 3 waves of panel data
  – Outcome variables should be measured the same way across waves
  – Data set need to have a time variable

• No theories dictate the functional form between outcome and time. Thus, researchers often need to explore and decide the best empirical functional form for the outcome variable first.

• GCM can be computationally intensive for complex models.
Graphs of Trajectories

• Researchers usually use the term, trajectory, to describe the patterns of change for individuals over time.

• Different trajectories describe different functional forms between time and the construct of interest.

• The simplest trajectory is a linear trajectory, defined by two parameters, intercept and slope. More complex trajectories are defined by intercept, slope, and additional parameters.
Sample Trajectories and Their Parameters

- A linear trajectory
  \[ Y = 4 + 0.05 \times \text{Age} + \sigma \]

- A curvilinear trajectory
  \[ Y = 4 + 0.05 \times \text{Age} + 0.03 \times \text{Age}^2 + \sigma \]

- A cubic trajectory
  \[ Y = 4 + 0.05 \times \text{Age} + 0.03 \times \text{Age}^2 + (-0.0001) \times \text{Age}^3 + \sigma \]
Table 1. Predicted Values for Sample Trajectories

<table>
<thead>
<tr>
<th>Age</th>
<th>Linear</th>
<th>Curvilinear</th>
<th>Cubic</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>10</td>
<td>4.5</td>
<td>7.5</td>
<td>7.4</td>
</tr>
<tr>
<td>20</td>
<td>5</td>
<td>17</td>
<td>16.2</td>
</tr>
<tr>
<td>30</td>
<td>5.5</td>
<td>32.5</td>
<td>29.8</td>
</tr>
<tr>
<td>40</td>
<td>6</td>
<td>54</td>
<td>47.6</td>
</tr>
<tr>
<td>50</td>
<td>6.5</td>
<td>81.5</td>
<td>69</td>
</tr>
<tr>
<td>60</td>
<td>7</td>
<td>115</td>
<td>93.4</td>
</tr>
<tr>
<td>70</td>
<td>7.5</td>
<td>154.5</td>
<td>120.2</td>
</tr>
<tr>
<td>80</td>
<td>8</td>
<td>200</td>
<td>148.8</td>
</tr>
<tr>
<td>90</td>
<td>8.5</td>
<td>251.5</td>
<td>178.6</td>
</tr>
</tbody>
</table>
Graph 1. Linear, Curvilinear, and Cubic trajectories
Example of Inter-person Differences in Linear Trajectories

<table>
<thead>
<tr>
<th></th>
<th>Woman</th>
<th></th>
<th>Man</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>intercept</td>
<td>slope</td>
<td>intercept</td>
<td>slope</td>
</tr>
<tr>
<td>Same Intercept</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Same slope</td>
<td>4</td>
<td>0.05</td>
<td>4</td>
<td>0.05</td>
</tr>
<tr>
<td>Different slope</td>
<td>4</td>
<td>0.05</td>
<td>4</td>
<td>0.1</td>
</tr>
<tr>
<td>Different Intercept</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Same slope</td>
<td>4</td>
<td>0.05</td>
<td>3</td>
<td>0.05</td>
</tr>
<tr>
<td>Different slope</td>
<td>4</td>
<td>0.05</td>
<td>3</td>
<td>0.1</td>
</tr>
<tr>
<td>Different slope</td>
<td>4</td>
<td>0.05</td>
<td>3</td>
<td>-0.1</td>
</tr>
</tbody>
</table>
### Table 2. Graphs of Inter-person Differences in Trajectories

<table>
<thead>
<tr>
<th></th>
<th>Woman</th>
<th></th>
<th>Man</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>intercept</td>
<td>slope</td>
<td>intercept</td>
</tr>
<tr>
<td><strong>Same Intercept</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(1) Same Slope</td>
<td>4</td>
<td>0.05</td>
<td>4</td>
</tr>
<tr>
<td>(2) Different Slope</td>
<td>4</td>
<td>0.05</td>
<td>4</td>
</tr>
<tr>
<td><strong>Different Intercept</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(3) Same Slope</td>
<td>4</td>
<td>0.05</td>
<td>3</td>
</tr>
<tr>
<td>(4) Different Slope</td>
<td>4</td>
<td>0.05</td>
<td>3</td>
</tr>
<tr>
<td>(5) Different Slope</td>
<td>4</td>
<td>0.05</td>
<td>3</td>
</tr>
</tbody>
</table>
Graphs of Inter-person Differences in Trajectories

(1) Same Intercept and slope
(2) Same Intercept and different slope
(3) Different Intercept and same slope
(4) Different Intercept and slope
(5) Different Intercept and slope

Women and men
Women
Men
Key Concepts of Growth Curve Modeling

• Trajectory is a function of time.

• Trajectory can take on different functional forms (e.g., linear, curvilinear, cubic, and other forms).

• Trajectory describes whether individuals change over time (Intra-individual change) and how fast they change.

• Higher-order functional forms are specified by more parameters.

• The question of why people have different trajectories is equivalent to testing whether people with different attributes have different trajectories (i.e., inter-individual differences in the intra-individual change).

• If people have different trajectories, it indicates that they differ in at least one of the parameters that define the trajectories.
Asian children in a British community who were weighed up to four times, roughly between the ages of 6 weeks and 27 months. The dataset is a random sample of data previously analyzed by Goldstein (1986) and Prosser, Rasbash, and Goldstein (1991).

use http://www.stata-press.com/data/r14/childweight.dta, clear

. des

Contains data from http://www.stata-press.com/data/r14/childweight.dta
obs: 198 Weight data on Asian children
vars: 5 23 May 2014 15:12
size: 3,168 (_dta has notes)

------------------------------------------------------------------------------------
storage display value
variable name type format label variable label
------------------------------------------------------------------------------------
id int %8.0g
age float %8.0g
weight float %8.0g
brthwt int %8.0g
girl float %9.0g
------------------------------------------------------------------------------------
Sorted by: id age
### Stata Sample Data

<table>
<thead>
<tr>
<th>id</th>
<th>age</th>
<th>weight</th>
<th>brthwt</th>
<th>girl</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>45</td>
<td>0.136893</td>
<td>5.171</td>
<td>4140</td>
</tr>
<tr>
<td>2</td>
<td>45</td>
<td>0.657084</td>
<td>10.86</td>
<td>4140</td>
</tr>
<tr>
<td>3</td>
<td>45</td>
<td>1.21834</td>
<td>13.15</td>
<td>4140</td>
</tr>
<tr>
<td>4</td>
<td>45</td>
<td>1.42916</td>
<td>13.2</td>
<td>4140</td>
</tr>
<tr>
<td>5</td>
<td>45</td>
<td>2.27242</td>
<td>15.88</td>
<td>4140</td>
</tr>
<tr>
<td>6</td>
<td>258</td>
<td>0.19165</td>
<td>5.3</td>
<td>3155</td>
</tr>
<tr>
<td>7</td>
<td>258</td>
<td>0.687201</td>
<td>9.74</td>
<td>3155</td>
</tr>
<tr>
<td>8</td>
<td>258</td>
<td>1.12799</td>
<td>9.98</td>
<td>3155</td>
</tr>
<tr>
<td>9</td>
<td>258</td>
<td>2.30527</td>
<td>11.34</td>
<td>3155</td>
</tr>
<tr>
<td>10</td>
<td>287</td>
<td>0.134155</td>
<td>4.82</td>
<td>3850</td>
</tr>
<tr>
<td>11</td>
<td>287</td>
<td>0.70089</td>
<td>9.09</td>
<td>3850</td>
</tr>
<tr>
<td>12</td>
<td>287</td>
<td>1.16906</td>
<td>11.1</td>
<td>3850</td>
</tr>
<tr>
<td>13</td>
<td>287</td>
<td>2.2423</td>
<td>16.8</td>
<td>3850</td>
</tr>
<tr>
<td>14</td>
<td>483</td>
<td>0.747433</td>
<td>5.76</td>
<td>2875</td>
</tr>
<tr>
<td>15</td>
<td>483</td>
<td>1.01848</td>
<td>6.92</td>
<td>2875</td>
</tr>
<tr>
<td>16</td>
<td>483</td>
<td>2.24504</td>
<td>9.53</td>
<td>2875</td>
</tr>
</tbody>
</table>
Stata Codes for Six GCM Models

Model 0: Traditional regression

Equation:

\[ \text{weight}_{ij} = \beta_0 + \beta_1 \text{(age)} + r_{ij} \]

Stata codes:

```
reg weight age
predict p_weight
graph twoway (line p_weight age, connect(ascending))
graph save model_0_0, replace
graph twoway (line p_weight age if girl ==0, connect(ascending))
graph save model_0_1, replace
graph twoway (line p_weight age if girl ==1, connect(ascending))
graph save model_0_2, replace
mixed weight age, nolog
est store model_0
```
Stata Codes for Six GCM Models

Model 1: Linear Growth curve model with a random intercept

Level 1 Model:
\[ \text{Weight}_{ij} = \beta_{0j} + \beta_{1j} \text{ (Age)} + r_{ij} \]

Level 2 Model:
\[ \beta_{0j} = \gamma_{00} + u_{0j} \]

Full Model:
\[ \text{Weight}_{ij} = \gamma_{00} + \gamma_{10} \text{(Age)} + u_{0j} + r_{ij} \]

Stata codes:
```
mixed weight age || id: , nolog
graph save model_1, replace
est store model_1
```
Model 2: Linear Growth curve model with random intercept and slope

Level 1 Model:
$$\text{Weight}_{ij} = \beta_{0j} + \beta_{1j} (\text{Age}) + r_{ij}$$

Level 2 Model:
$$\beta_{0j} = \gamma_{00} + u_{0j}$$
$$\beta_{1j} = \gamma_{10} + u_{1j}$$

Full Model:
$$\text{Weight}_{ij} = \gamma_{00} + \gamma_{10}(\text{Age}) + u_{0j} + u_{1j}(\text{Age}) + r_{ij}$$

Stata codes:
```
mixed weight age || id: age, covariance(unstructured) nolog
graph save model_2, replace
est store model_2
```
Stata Codes for Determining The Form of The Intra-individual Change

Model 3 : Curvilinear Growth model with random intercept

Level 1 Model:
\[ \text{Weight}_{ij} = \beta_{0j} + \beta_{1j} (\text{Age}) + \beta_{2j} (\text{Age}^2) r_{ij} \]

Level 2 Model:
\[ \begin{align*}
\beta_{0j} &= \gamma_{00} + u_{0j} \\
\beta_{1j} &= \gamma_{10} + u_{1j} \\
\beta_{2j} &= \gamma_{20} + u_{2j}
\end{align*} \]

Full Model:
\[ \text{Weight}_{ij} = \gamma_{00} + \gamma_{10}(\text{Age}) + \gamma_{20}(\text{Age}^2) + u_{0j} + u_{1j}(\text{Age}) + u_{2j}(\text{Age}^2) + r_{ij} \]

Stata codes:
```stata
mixed weight age c.age#c.age || id: age, covariance(unstructured) nolog
graph save model_3, replace
est store model_3
```

* Compare Models 1 through 3
```stata
lrtest model_0 model_1
lrtest model_1 model_2
lrtest model_2 model_3
```
Stata Codes for Explaining The Inter-individual Differences in Intra-person Trajectories

Model 4: Same linear and curvilinear time effects for boys and girls

Level 1 Model:
\[ \text{Weight}_{ij} = \beta_{0j} + \beta_{1j} (\text{Age}) + \beta_{2j} (\text{Age}^2) + r_{ij} \]

Level 2 Model:
\[ \beta_{0j} = \gamma_{00} + \gamma_{01} (\text{girl}) + u_{0j} \]
\[ \beta_{1j} = \gamma_{10} + u_{1j} \]
\[ \beta_{2j} = \gamma_{20} + u_{2j} \]

Full Model:
\[ \text{Weight}_{ij} = \gamma_{00} + \gamma_{10} (\text{Age}) + \gamma_{20} (\text{Age}^2) + \gamma_{01} (\text{girl}) + u_{0j} + u_{1j} (\text{Age}) + u_{2j} (\text{Age}^2) + r_{ij} \]

Stata codes:
```
mixed weight age c.age#c.age i.girl || id: age, covariance(unstructured) nolog
margins i.girl, at(age=(0(1)3)) vsquish
marginsplot, name(model_4, replace) x(age)
```
Stata Codes for Explaining The Inter-individual Differences in Trajectories

Model 5: Different linear and curvilinear time effects for boys and girls

Level 1 Model:
\[
\text{Weight}_{ij} = \beta_0j + \beta_1j (\text{Age}) + \beta_2j (\text{Age}^2) + r_{ij}
\]

Level 2 Model:
\[
\begin{align*}
\beta_0j &= \gamma_{00} + \gamma_{01}(\text{girl}) + u_{0j} \\
\beta_1j &= \gamma_{10} + \gamma_{11}(\text{girl}) + u_{1j} \\
\beta_2j &= \gamma_{20} + \gamma_{21}(\text{girl}) + u_{2j}
\end{align*}
\]

Full Model:
\[
\text{Weight}_{ij} = \gamma_{00} + \gamma_{01}(\text{girl}) + u_{0j} +
\gamma_{10}(\text{Age}) + \gamma_{11}(\text{Age})(\text{girl}) + u_{1j}(\text{Age}) +
\gamma_{20}(\text{Age}^2) + \gamma_{21}(\text{Age}^2)(\text{girl}) + u_{2j}(\text{Age}^2) + r_{ij}
\]

\[
= \gamma_{00} + \gamma_{10}(\text{Age}) + \gamma_{20}(\text{Age}^2) + \gamma_{01}(\text{girl}) + \gamma_{11}(\text{Age})(\text{girl}) + \gamma_{21}(\text{Age}^2)(\text{girl}) + u_{0j} +
\gamma_{1j}(\text{Age}) + u_{2j}(\text{Age}^2) + r_{ij}
\]

mixed weight i.girl##c.age##c.age|| id: age, covariance(unstructured) nolog
margins i.girl, at(age=(0(1)3)) vsquish
marginsplot, name(model_5, replace) x(age)
Conclusions

• Growth curve modeling is a statistical technique to describe and explain an individual’s change over time.

• Growth curve modeling requires at least three waves of panel data.

• This workshop focuses on using hierarchical linear modeling approach (HLM) to estimate basic growth curve models for continuous outcome variables. You can look up Stata manual if your outcome variables are not continuous or you need more complex growth curve models.

• Growth curve models can also be estimated by the use of structural equation modeling approach. If you want to include an measurement model or mediation effects in the growth curve model, structural equation model approach is better than the HLM approach.

• If you have any questions about growth curve modeling, please come see me at 5D, Williams Hall or send me an email (wuh@bgsu.edu).