Including family effects in multilevel models for pupil progress

Rebecca Pillinger, Jon Rasbash, George Leckie and Jenny Jenkins
1. Partitioning variation in progress
## What do we already know?

<table>
<thead>
<tr>
<th>Response Predictors</th>
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<td>Cohort</td>
<td>80—95</td>
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<td>93</td>
<td>73</td>
<td>80</td>
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<td>MZ twins</td>
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<td>Full sibs</td>
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1. Typical school effectiveness studies, e.g. Goldstein et al. (2007) (primary schools) and Leckie (2008) (secondary schools)
2. Yang & Woodhouse (2001), progress from GCSE to A-level
3. Fielding et al. (2006)
4. Garner & Raudenbush (1991); predictors include family background, neighbourhood social deprivation and school fixed effects
7. Leckie (2008)
8. Bouchard & McGue (1981); metaanalysis of 110 studies
9. Duncan et al. (2001); US data; response is Peabody Picture Vocabulary Test
Previous studies

**School effectiveness**
- Models usually have pupils within schools (2 levels)
- There have been studies that also included area or primary school
- But no studies have included family
- The largest component of variation in these models is the pupil level
- How much of that is really family level?

**Developmental Psychology**
- Models usually have children within families
- Researchers recognise that really these models partition into shared environment and non-shared environment
- What is the shared environment?
- In other words, How much of the shared environment is family, school and area?
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Classification diagram:
- School
- Pupil
Previous studies

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Classification diagram

LEA

school

pupil
Previous studies

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Classification diagram

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### Previous studies

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**Classification diagram**

```
LEA 1  LEA 2
  |     |
school  area
  |     |
pupil
```

\[
\begin{align*}
\text{u}_j & \sim \mathcal{N}(0, \sigma^2_u), i = 1, \ldots, n_j \\
\text{e}_{ij} & \sim \mathcal{N}(0, \sigma^2_e), j = 1, \ldots, J(B)
\end{align*}
\]
**Previous studies**

### School effectiveness
- Models usually have pupils within schools (2 levels)
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### Classification diagram

- pupil
  - secondary
  - primary
School effectiveness

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Classification diagram:

- Secondary
- Area
- Primary
- Pupil

$u_j \sim N(0, \sigma^2_u)$, $i = 1, \ldots, n$

$e_{ij} \sim N(0, \sigma^2_e)$, $j = 1, \ldots, J$
Previous studies

School effectiveness

- Models usually have pupils within schools (2 levels)
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Classification diagram

Model

\[ y_{ij} = \alpha + \beta x_{ij} + u_j + e_{ij}, \]

\[ u_j \sim N(0, \sigma_u^2), \quad i = 1, \ldots, n_j \]

\[ e_{ij} \sim N(0, \sigma_e^2), \quad j = 1, \ldots, J \]

(B)
**Previous studies**

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- Models usually have pupils within schools (2 levels)
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**Classification diagram**

**Model**

\[
\text{GCSE}_{ij} = \alpha + \beta \text{pretest}_{ij} + u_j + e_{ij},
\]

\[
u_j \sim N(0, \sigma_u^2), \quad i = 1, \ldots, n_j
\]

\[
e_{ij} \sim N(0, \sigma_e^2), \quad j = 1, \ldots, J
\]
Previous studies

School effectiveness
- Models usually have pupils within schools (2 levels)
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Classification diagram
- school
- pupil

Model
\[
\text{GCSE}_{ij} = \alpha + \beta_1 \text{pretest}_{ij} + \beta_2 x_{ij} + u_j + e_{ij},
\]
\[
u_j \sim N(0, \sigma_u^2) , \quad i = 1, \ldots, n_j
\]
\[
e_{ij} \sim N(0, \sigma_e^2) , \quad j = 1, \ldots, J
\]
Models usually have children within families

Researchers recognise that really these models partition into shared environment and non-shared environment

What is the shared environment?

In other words, How much of the shared environment is family, school and area?
Previous studies

Classification diagram

Model

\[ y_{ij} = \alpha + u_j + e_{ij} + g_{ij} \]

\[ u_j \sim \mathcal{N}(0, \sigma_u^2) \]

\[ e_{ij} \sim \mathcal{N}(0, \sigma_e^2) \]

\[ g_{ij} \sim \mathcal{N}(0, \sigma_g^2) \]

\[ \text{Cov}(g_{i1j}, g_{i2j}) = r_{(i1j, i2j)} \sigma_g^2 \]

Developmental Psychology

- Models usually have children within families.
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- What is the shared environment?
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Previous studies

Classification diagram

![Diagram](image)

Model

\[ y_{ij} = \alpha + d_j u_{1j} + d_j e_{1ij} + (1 - d_j) e_{2ij} \]

\[ u_{1j} \sim N(0, \sigma^2_u), \quad [e_{1ij}] \sim N\left(\begin{bmatrix} 0 \\ 0 \end{bmatrix}, \begin{bmatrix} \sigma^2_{e1} & 0 \\ 0 & \sigma^2_{e2} \end{bmatrix}\right) \]

Developmental Psychology

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Previous studies

Classification diagram

Model

\[
\text{GCSE}_{ij} = \alpha + \text{twin}_j u_{1j} + \text{twin}_j e_{1ij} + \text{nontwin}_j e_{2ij}
\]

\[
u_{1j} \sim N \left(0, \sigma_u^2\right),
\]

\[
\begin{bmatrix} e_{1ij} \\ e_{2ij} \end{bmatrix} \sim N \left(\begin{bmatrix} 0 \\ 0 \end{bmatrix}, \begin{bmatrix} \sigma_{e1}^2 & \sigma_{e2}^2 \\ \sigma_{e2}^2 & \sigma_{e2}^2 \end{bmatrix}\right)
\]

(A)

Developmental Psychology

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Our model

Classification diagram

- LEA
- neighbhd
  - secondary
  - family
  - primary
  - pupil

\[ y_i = \alpha + \beta x_i + u_i \]
Our model

Classification diagram

LEA \rightarrow \text{secondary} \rightarrow \text{pupil} \sim N(0, \sigma^2_{u(6)})

neighbhd \rightarrow \text{primary} \rightarrow \text{pupil} \sim N(0, \sigma^2_{u(6)})

\text{fam}(i) \sim N(0, \sigma^2_{u(2)})

dfam(i) \sim N(0, \sigma^2_{u(2)})

\left[ e_1(i) \quad e_2(i) \right] \sim N(0, \left[ \sigma^2_{e1} \quad \sigma^2_{e2} \right])
Our model

\[ y_i = \alpha + \beta x_i + u_6(i) \]

\[ \text{LEA}(i) \]

\[ \text{sec}(i) \]

\[ \text{nbhd}(i) \]

\[ \text{pri}(i) \]

\[ \text{dfam}(i) \]

\[ u_2(fam) \]

\[ e_1(i) \]

\[ e_2(i) \]

\[ \sim N(0, \sigma^2_{u6}) \]

\[ \sim N(0, \sigma^2_{u3}) \]

\[ \sim N(0, \sigma^2_{u2}) \]

\[ \sim N(0, \sigma^2_{e1} \sigma^2_{e2}) \]

Classification diagram

- LEA
- Neighbourhood
- Secondary
- Family
- Primary
- Pupil
Our model

Model

\[ y_i = \alpha + \beta x_i + u^{(6)}_{\text{LEA}(i)} + u^{(5)}_{\text{sec}(i)} + u^{(4)}_{\text{nbhd}(i)} + u^{(3)}_{\text{pri}(i)} \]
\[ + d_{fam}(i) u^{(2)}_{\text{fam}(i)} + d_{fam}(i) e_1i + (1 - d_{fam}(i)) e_2i \]

Classification diagram

\[
\begin{align*}
    u^{(6)}_{\text{LEA}(i)} &\sim N \left( 0, \sigma^2 u^{(6)} \right) \\
    \vdots &\vdots \\
    u^{(3)}_{\text{pri}(i)} &\sim N \left( 0, \sigma^2 u^{(3)} \right) \\
    u^{(2)}_{\text{fam}(i)} &\sim N \left( 0, \sigma^2 u^{(2)} \right) \\
    \begin{bmatrix} e_1i \\ e_2i \end{bmatrix} &\sim N \left( 0, \begin{bmatrix} \sigma^2 e_1 \\ 0 \\ \sigma^2 e_2 \end{bmatrix} \right) 
\end{align*}
\]
\((C)\)
Our model

\[ \text{Model} \]
\[
\text{GCSE}_i = \alpha + \beta_1 \text{pretest}_i + \beta_2 \text{twin}_i + \beta_3 \text{pretest} \cdot \text{twin}_i \\
+ u_{\text{LEA}(i)}^{(6)} + u_{\text{sec}(i)}^{(5)} + u_{\text{nbhd}(i)}^{(4)} + u_{\text{pri}(i)}^{(3)} \\
+ \text{twin}_{\text{fam}(i)} u_{\text{fam}(i)}^{(2)} + \text{twin}_{\text{fam}(i)} e_{1i} + \text{nontwin}_{\text{fam}(i)} e_{2i}
\]

\[
u^{(6)}_{\text{LEA}(i)} \sim \mathcal{N} \left(0, \sigma^2 u^{(6)}\right) \\
\vdots \quad \vdots \\

\[
u^{(3)}_{\text{pri}(i)} \sim \mathcal{N} \left(0, \sigma^2 u^{(3)}\right) \\
\nu^{(2)}_{\text{fam}(i)} \sim \mathcal{N} \left(0, \sigma^2 u^{(2)}\right) \\
\begin{bmatrix} e_{1i} \\ e_{2i} \end{bmatrix} \sim \mathcal{N} \left(0, \begin{bmatrix} \sigma^2 e_{1} & 0 \\ 0 & \sigma^2 e_{2} \end{bmatrix}\right) (C)
\]
Our data

Sample

All pupils in

- England
- state schools
- 2007 GCSE cohort
Our data

Sample
All pupils in
- England
- state schools
- 2007 GCSE cohort

Variables
- Test scores from the NPD
  - GCSE (our response) and key stage 2 (KS2)
- Background characteristics from PLASC
  - age
  - gender
  - ethnicity
  - FSM eligibility
  - SEN
  - EAL
- ONS data on LSOAs
  - IDACI

All continuous variables have been standardized
Our data

Sample
All pupils in
- England
- state schools
- 2007 GCSE cohort

Levels
- The data records which
  - LEA
  - secondary school
  - primary school
  - area (LSOA)
  each pupil belongs to
- But not which family

Variables
- Test scores from the NPD
  - GCSE (our response) and
  - key stage 2 (KS2)
- Background characteristics from PLASC
  - age
  - gender
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  - FSM eligibility
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All continuous variables have been standardized
Identifying twins

- We get the family level by identifying twin pairs
- by matching on time invariant characteristics
  - date of birth
  - ethnicity
  - EAL
- and pattern of time-varying characteristics
  - postcode sector
  - FSM eligibility

How successful is this?

- 11.54 twin births per 1000 maternities in 1990 & 1991
- 9.37 twin pairs per 1000 families in our matching
- We may also have labelled some unrelated pupils as a ‘twin pair’
- Calculation suggests around 10% of ‘twin pairs’ will be coincidental matches

Size of dataset

- 551,220 pupils
- 5116 twin pairs
- 30507 LSOAs
- 3099 secondaries
- 14765 primaries
- 149 LEAs
### Results

<table>
<thead>
<tr>
<th></th>
<th>Model A</th>
<th>Model B</th>
<th>Model C</th>
<th>Model D</th>
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</thead>
<tbody>
<tr>
<td>cons</td>
<td>-0.003 (0.001)</td>
<td>-0.003 (0.001)</td>
<td>0.001 (0.008)</td>
<td>-0.039 (0.007)</td>
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<tr>
<td>twin</td>
<td>0.177 (0.008)</td>
<td>0.179 (0.007)</td>
<td>0.162 (0.007)</td>
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<tr>
<td>pretest</td>
<td>0.730 (0.001)</td>
<td>0.729 (0.001)</td>
<td>0.701 (0.001)</td>
<td>0.641 (0.001)</td>
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<tr>
<td>pretest.twin</td>
<td>-0.040 (0.007)</td>
<td>0.000 (0.007)</td>
<td>-0.027 (0.006)</td>
<td>-0.020 (0.006)</td>
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<tr>
<td>female</td>
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<td></td>
<td></td>
<td>0.184 (0.002)</td>
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<tr>
<td>Asian</td>
<td></td>
<td></td>
<td></td>
<td>0.429 (0.005)</td>
</tr>
<tr>
<td>Black</td>
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<td>0.225 (0.006)</td>
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<td>Chinese</td>
<td></td>
<td></td>
<td></td>
<td>0.556 (0.015)</td>
</tr>
<tr>
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<td></td>
<td></td>
<td></td>
<td>0.045 (0.005)</td>
</tr>
<tr>
<td>Other</td>
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<td>0.403 (0.010)</td>
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<td>-0.248 (0.003)</td>
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*Using MCMC; 450,500 iterations and a burn-in of 50,000*
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### LEA

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*Using MCMC; 450,500 iterations and a burn-in of 50,000*
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<tbody>
<tr>
<td>cons</td>
<td>−0.003 (0.001)</td>
<td>−0.003 (0.001)</td>
<td>0.001 (0.008)</td>
<td>−0.039 (0.007)</td>
</tr>
<tr>
<td>twin</td>
<td>0.177 (0.008)</td>
<td>0.179 (0.007)</td>
<td>0.162 (0.007)</td>
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</tr>
<tr>
<td>pretest</td>
<td>0.730 (0.001)</td>
<td>0.729 (0.001)</td>
<td>0.701 (0.001)</td>
<td>0.641 (0.001)</td>
</tr>
<tr>
<td>pretest.twin</td>
<td>−0.040 (0.007)</td>
<td>0.000 (0.007)</td>
<td>−0.027 (0.006)</td>
<td>−0.020 (0.006)</td>
</tr>
<tr>
<td>female</td>
<td></td>
<td></td>
<td></td>
<td>0.184 (0.002)</td>
</tr>
<tr>
<td>Asian</td>
<td></td>
<td></td>
<td></td>
<td>0.429 (0.005)</td>
</tr>
<tr>
<td>Black</td>
<td></td>
<td></td>
<td></td>
<td>0.225 (0.006)</td>
</tr>
<tr>
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<tr>
<td>Mixed</td>
<td></td>
<td></td>
<td></td>
<td>0.045 (0.005)</td>
</tr>
<tr>
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<td></td>
<td></td>
<td></td>
<td>0.403 (0.010)</td>
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<tr>
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<td></td>
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*Using MCMC; 450,500 iterations and a burn-in of 50,000*
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<tr>
<td>LEA</td>
<td></td>
<td></td>
<td>1.2%</td>
<td>1.1%</td>
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</tr>
<tr>
<td>Secondary</td>
<td>13.9%</td>
<td></td>
<td>10.3%</td>
<td>9.1%</td>
<td>9.4%</td>
<td>8.3%</td>
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<tr>
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<td></td>
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<td>84.2%</td>
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### Research questions

1. How much of the shared environmental variation is due to family, school and area?
2. How much of the ‘pupil’ level variation in school effectiveness studies is really family level?
3. What happens when we try to explain some of the variation using pupil, family and LSOA level covariates?
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Caveats

- Our family effects are purely derived from twin pairs
- The twins are a mix of MZ and DZ so we are not estimating $\sigma^2_u + \sigma^2_g$
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- Shared environment in womb they may elicit more similar environments
- Have same age sibling
- To what extent can we generalise to non-nuclear families?
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2. What happens under stress?
Variance functions for stress

Data
- Data is from previous cohort, who took GCSEs in 2006
- Postcodes with more than 2 students excluded
- Continuous variables not standardized

Model

\[ \text{GCSE}_{ijk} = \alpha + \beta_1 \text{pretest}_{ijk} + \beta_2 \text{twin}_{jk} + \beta_5 \text{stressor}_{jk} + \nu_0_k + u_2_{jk} \text{twin}_{jk} + e_2_{ijk} \text{twin}_{jk} + e_3_{ijk} \text{nontwin}_{jk} + u_4_{jk} \text{twin} \cdot \text{stressor}_{jk} + e_4_{ijk} \text{twin} \cdot \text{stressor}_{jk} + e_6_{ijk} \text{nontwin} \cdot \text{stressor}_{jk} \]
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- Our main stressor was IDACI, an LSOA level variable
- It aims to measure income deprivation affecting children
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Model
\[
\text{GCSE}_{ijk} = \alpha + \beta_1 \text{pretest}_{ijk} + \beta_2 \text{twin}_{jk} + \beta_5 \text{stressor}_{jk} \\
+ \nu_{0k} + u_{2jk} \text{twin}_{jk} + e_{2ijk} \text{twin}_{jk} + e_{3ijk} \text{nontwin}_{jk} \\
+ u_{4jk} \text{twin} \cdot \text{stressor}_{jk} + e_{4ijk} \text{twin} \cdot \text{stressor}_{jk} \\
+ e_{6ijk} \text{nontwin} \cdot \text{stressor}_{jk}
\]
Variance functions for stress

Covariance structure

\[
\begin{bmatrix}
  \nu_{0k} \\
  u_{2jk} \\
  u_{4jk} \\
  e_{2ijk} \\
  e_{3ijk} \\
  e_{4ijk} \\
  e_{6ijk}
\end{bmatrix}
\sim N \left( 0, \begin{bmatrix}
  \sigma^2_{\nu0} \\
  \sigma^2_{u2} & \sigma^2_{u4} \\
  \sigma^2_{e2} & 0 & \sigma^2_{e3} \\
  0 & \sigma^2_{e24} & 0 & \sigma^2_{e4} \\
  0 & 0 & \sigma^2_{e36} & 0 & \sigma^2_{e6}
\end{bmatrix} \right)
\]

Model

\[
\text{GCSE}_{ijk} = \alpha + \beta_1 \text{pretest}_{ijk} + \beta_2 \text{twin}_{jk} + \beta_5 \text{stressor}_{jk}
\]

\[
+ \nu_{0k} + u_{2jk} \text{twin}_{jk} + e_{2ijk} \text{twin}_{jk} + e_{3ijk} \text{nontwin}_{jk}
\]

\[
+ u_{4jk} \text{twin} \cdot \text{stressor}_{jk} + e_{4ijk} \text{twin} \cdot \text{stressor}_{jk}
\]

\[
+ e_{6ijk} \text{nontwin} \cdot \text{stressor}_{jk}
\]
Variance functions for stress

Covariance structure

\[
\begin{bmatrix}
  v_{0k}
  \\
  u_{2jk}
  \\
  u_{4jk}
\end{bmatrix}
\sim N(0, \begin{bmatrix}
  \sigma^2_{v0} \\
  \sigma^2_{u2} & \sigma^2_{u4}
\end{bmatrix})
\]

\[
\begin{bmatrix}
  e_{2ijk} \\
  e_{3ijk} \\
  e_{4ijk} \\
  e_{6ijk}
\end{bmatrix}
\sim N(0, \begin{bmatrix}
  \sigma^2_{e2} & 0 & 0 & 0 \\
  0 & \sigma^2_{e3} & 0 & 0 \\
  0 & 0 & \sigma^2_{e4} & 0 \\
  0 & 0 & 0 & \sigma^2_{e6}
\end{bmatrix})
\]

Model

\[\text{GCSE}_{ijk} = \alpha + \beta_1\text{pretest}_{ijk} + \beta_2\text{twin}_{jk} + \beta_5\text{IDACI}_{jk} + v_{0k} + u_{2jk}\text{twin}_{jk} + e_{2ijk}\text{twin}_{jk} + e_{3ijk}\text{nontwin}_{jk} + u_{4jk}\text{twin} \cdot \text{IDACI}_{jk} + e_{4ijk}\text{twin} \cdot \text{IDACI}_{jk} + e_{6ijk}\text{nontwin} \cdot \text{IDACI}_{jk}\]
Variance functions for IDACI
Interpreting the results

As IDACI increases,

We have this situation:

\[ \beta_5 = -68.1 \]

Between family variation increases
Within family variation increases
The mean progress decreases

So at greater levels of deprivation, family becomes relatively more important in determining progress.
As IDACI increases,

- The mean progress decreases
  \[ \beta_5 = -68.1 \]

We have this situation:

![Diagram showing progression vs. IDACI]

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Within family variation increases
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As IDACI increases,

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\[ \beta = -6.1 \]

We have this situation:

Progress

IDACI

So at greater levels of deprivation, family becomes relatively more important in determining progress.
As IDACI increases,
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We have this situation:

- Between family variation increases more dramatically than within family variation
- So at greater levels of deprivation, family becomes relatively more important in determining progress
Results

Variance functions for IDACI
As IDACI increases,
- Between family variation increases
- Within family variation increases
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  \[ \beta_5 = -68.1 \]

We have this situation:

Between family variation increases more dramatically than within family variation
So at greater levels of deprivation, family becomes relatively more important in determining progress
We fitted the same model with different stressors:
- IMD
- FSM eligibility
- Ever moved house
- Number of house moves
- Time since house move

In almost all cases we see the same pattern.

We also fitted models with more than one stressor:
- e.g. IDACI and FSM eligibility

In these models, both stressors show the same pattern.
What’s going on? Possible explanations

Genetic explanation

- Some families have genes which help to maintain progress in the presence of stressors, while others do not

Environmental explanation
### What's going on? Possible explanations

#### Genetic explanation
- **Some families** have genes which help to maintain progress in the presence of stressors, while others do not.
- In the absence of a stressor, the genes make little difference so there is not much variability.

#### Environmental explanation
- Some families, across all levels of the stressors, have factors that make it harder to be good parents.
- Alcoholism of parent, violent spouse.
- In the absence of stressors, even families with these factors can provide a good environment for progress.
- In the presence of stressors, families with these factors cannot do so → variability since some families have these factors and some don't.
What’s going on? Possible explanations

Genetic explanation

- Some families have genes which help to maintain progress in the presence of stressors, while others do not
- In the absence of a stressor, the genes make little difference so there is not much variability
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<table>
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<tr>
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Environmental explanation
- Children in families compete for resources.
- In the absence of stressors, there are enough resources for the needs of all children.
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Environmental explanation
- Children in families compete for resources.
- In the absence of stressors, there are enough resources for the needs of all children.
- In the presence of stressors, there are fewer resources and some children will have their needs met while others will not → variability since those getting more resources can make more progress.
References


