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?

	①		②	③	④		⑤		⑥	⑦		⑧	⑨
Response	Prog	Prog	Prog	Att	Att	Prog	Att	Prog	Att	Att	Prog	Cog	Cog
Predictors	Y	Y	Y	N	N	Y	N	Y	N	N	Y	N	N
LEA			0.2	3									
Neighbhd				2	20	4	14	1	5	4	1		0.20
Secondary	5—20		5	22		fixed	7	1	20	23	4		
Primary		5—20								3	7		
Cohort			3										0.21
Pupil	80—95	80—95	93	73	80	96	79	98	75	70	88		
MZ twins												0.86	0.78
DZ twins												0.60	0.64
Full sibs												0.47	0.51

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

⑤ Raudenbush (1993); reanalysis of Garner & Raudenbush (1991)

⑥ Leckie (2008)

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
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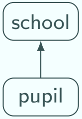

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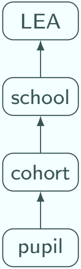

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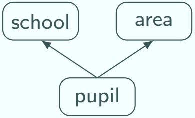

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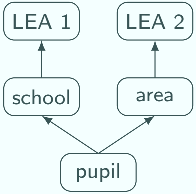

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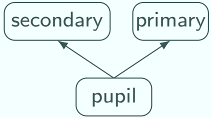

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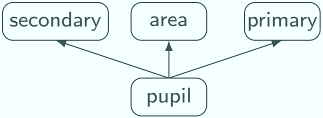

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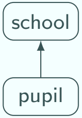

Model

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

$$u_j \sim \mathrm{N}\left(0, \sigma_u^2\right), \qquad i = 1, \ldots, n_j$$
$$e_{ij} \sim \mathrm{N}\left(0, \sigma_e^2\right), \qquad j = 1, \ldots, J$$

(B)

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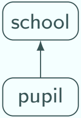

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$$\mathbf{GCSE}_{ij} = \alpha + \beta\mathbf{pretest}_{ij} + u_j + e_{ij},$$

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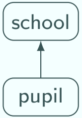

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$$\mathbf{GCSE}_{ij} = \alpha + \beta_1 \mathbf{pretest}_{ij} + \beta_2 x_{ij} + u_j + e_{ij},$$

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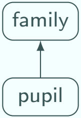

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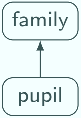

Model

$$y_{ij} = \alpha + u_j + e_{ij} + g_{ij}$$

$$u_j \sim N(0, \sigma_u^2)$$
$$e_{ij} \sim N(0, \sigma_e^2)$$
$$g_{ij} \sim N(0, \sigma_g^2)$$

$$\text{Cov}(g_{i_1 j}, g_{i_2 j}) = r_{(i_1 j, i_2 j)} \sigma_g^2$$

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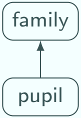

Model

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

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

$$\begin{bmatrix} e_{1ij} \\ e_{2ij} \end{bmatrix} \sim \mathrm{N}\left(\begin{bmatrix} 0 \\ 0 \end{bmatrix}, \begin{bmatrix} \sigma_{e1}^2 & \\ 0 & \sigma_{e2}^2 \end{bmatrix} \right) \qquad \text{(A)}$$

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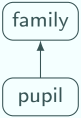

Model

$$\textbf{GCSE}_{ij} = \alpha + \textbf{twin}_j u_{1j} + \textbf{twin}_j e_{1ij} + \textbf{nontwin}_j e_{2ij}$$

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

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Our model

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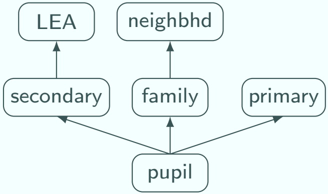

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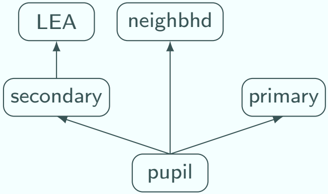

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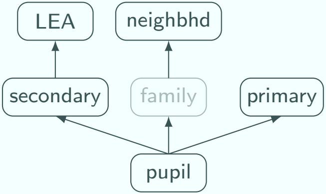

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Model

$$y_i = \alpha + \beta x_i + u^{(6)}_{\text{LEA}(i)} + u^{(5)}_{\text{sec}(i)} + u^{(4)}_{\text{nbhd}(i)} + u^{(3)}_{\text{pri}(i)} + d_{\text{fam}(i)} u^{(2)}_{\text{fam}(i)} + d_{\text{fam}(i)} e_{1i} + \left(1 - d_{\text{fam}(i)}\right) e_{2i}$$

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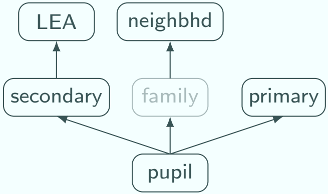

$$u^{(6)}_{\text{LEA}(i)} \sim \text{N}\left(0, \sigma^2_{u(6)}\right)$$

$$\vdots \qquad \vdots$$

$$u^{(3)}_{\text{pri}(i)} \sim \text{N}\left(0, \sigma^2_{u(3)}\right)$$

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

$$\begin{bmatrix} e_{1i} \\ e_{2i} \end{bmatrix} \sim \text{N}\left(0, \begin{bmatrix} \sigma^2_{e1} & \\ 0 & \sigma^2_{e2} \end{bmatrix}\right)$$

(C)

Our model

Model

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

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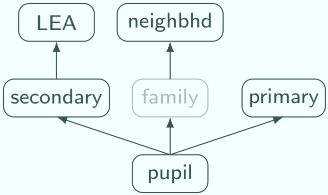

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Our data

Sample

All pupils in

- England
- state schools
- 2007 GCSE cohort

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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

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Our data

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 eligiblity

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	30507 LSOAs	3099 secondaries
5116 twin pairs	14765 primaries	149 LEAs

Results

	Model A		Model B		Model C		Model D	
cons	−0.003	(0.001)	−0.003	(0.001)	0.001	(0.008)	−0.039	(0.007)
twin	0.177	(0.008)	0.179	(0.007)	0.162	(0.007)	0.154	(0.007)
pretest	0.730	(0.001)	0.729	(0.001)	0.701	(0.001)	0.641	(0.001)
pretest.twin	−0.040	(0.007)	0.000	(0.007)	−0.027	(0.006)	−0.020	(0.006)
female							0.184	(0.002)
Asian							0.429	(0.005)
Black							0.225	(0.006)
Chinese							0.556	(0.015)
Mixed							0.045	(0.005)
Other							0.403	(0.010)
FSM							−0.248	(0.003)
age							−0.012	(0.000)
SEN							−0.231	(0.003)
IDACI							−0.103	(0.001)
LEA					0.005	(0.001)	0.005	(0.001)
Secondary			0.065	(0.002)	0.043	(0.001)	0.035	(0.001)
Primary					0.035	(0.001)	0.025	(0.000)
LSOA					0.008	(0.000)	0.002	(0.000)
Family (twin)	0.238	(0.007)			0.168	(0.005)	0.157	(0.005)
Pupil (twin)	0.160	(0.003)			0.157	(0.003)	0.150	(0.003)
Pupil (non-twin)	0.468	(0.001)	0.402	(0.002)	0.383	(0.001)	0.357	(0.001)

Using MCMC; 450,500 iterations and a burn-in of 50,000

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Variance partitioning coefficients

	A	B	C		D	
			Twins	Non-twins	Twins	Non-twins
LEA			1.2%	1.1%	1.3%	1.2%
Secondary		13.9%	10.3%	9.1%	9.4%	8.3%
Primary			8.4%	7.4%	6.7%	5.9%
LSOA			1.9%	1.7%	0.5%	0.5%
Family	59.8%		40.4%		42.0%	
Pupil	40.2%	86.1%	37.7%	80.8%	40.1%	84.2%

Research questions

Variance partitioning coefficients

	A	B	C		D	
			Twins	Non-twins	Twins	Non-twins
LEA			1.2%	1.1%	1.3%	1.2%
Secondary		13.9%	10.3%	9.1%	9.4%	8.3%
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What happens when we try to explain some of the variation using pupil, family and LSOA level covariates?

Results

	Model A		Model B		Model C		Model D	
cons	−0.003	(0.001)	−0.003	(0.001)	0.001	(0.008)	−0.039	(0.007)
twin	0.177	(0.008)	0.179	(0.007)	0.162	(0.007)	0.154	(0.007)
pretest	0.730	(0.001)	0.729	(0.001)	0.701	(0.001)	0.641	(0.001)
pretest.twin	−0.040	(0.007)	0.000	(0.007)	−0.027	(0.006)	−0.020	(0.006)
female							0.184	(0.002)
Asian							0.429	(0.005)
Black							0.225	(0.006)
Chinese							0.556	(0.015)
Mixed							0.045	(0.005)
Other							0.403	(0.010)
FSM							−0.248	(0.003)
age							−0.012	(0.000)
SEN							−0.231	(0.003)
IDACI							−0.103	(0.001)
LEA					0.005	(0.001)	0.005	(0.001)
Secondary			0.065	(0.002)	0.043	(0.001)	0.035	(0.001)
Primary					0.035	(0.001)	0.025	(0.000)
LSOA					0.008	(0.000)	0.002	(0.000)
Family (twin)	0.238	(0.007)			0.168	(0.005)	0.157	(0.005)
Pupil (twin)	0.160	(0.003)			0.157	(0.003)	0.150	(0.003)
Pupil (non-twin)	0.468	(0.001)	0.402	(0.002)	0.383	(0.001)	0.357	(0.001)

Using MCMC; 450,500 iterations and a burn-in of 50,000

Interpretation

Summary

- Around a third of the family level variation in Model A is really school or area level (mostly school)

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- To what extent can we generalise to non-nuclear families?

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

Variance functions for stress

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Stressors

- Our main stressor was IDACI, an LSOA level variable
- It aims to measure income deprivation affecting children
- Other stressors included:
  - FSM eligibility
  - House moves

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$$
\begin{aligned}
\mathbf{GCSE}_{ijk} = \alpha &+ \beta_1 \mathbf{pretest}_{ijk} + \beta_2 \mathbf{twin}_{jk} + \beta_5 \mathbf{stressor}_{jk} \\
&+ v_{0k} + u_{2jk}\mathbf{twin}_{jk} + e_{2ijk}\mathbf{twin}_{jk} + e_{3ijk}\mathbf{nontwin}_{jk} \\
&+ u_{4jk}\mathbf{twin} \cdot \mathbf{stressor}_{jk} + e_{4ijk}\mathbf{twin} \cdot \mathbf{stressor}_{jk} \\
&+ e_{6ijk}\mathbf{nontwin} \cdot \mathbf{stressor}_{jk}
\end{aligned}
$$

Variance functions for stress

Covariance structure

$$\begin{bmatrix} v_{0k} \end{bmatrix} \sim N\left(0, \begin{bmatrix} \sigma^2_{v0} \end{bmatrix}\right)$$

$$\begin{bmatrix} u_{2jk} \\ u_{4jk} \end{bmatrix} \sim N\left(0, \begin{bmatrix} \sigma^2_{u2} & \\ \sigma_{u24} & \sigma^2_{u4} \end{bmatrix}\right)$$

$$\begin{bmatrix} e_{2ijk} \\ e_{3ijk} \\ e_{4ijk} \\ e_{6ijk} \end{bmatrix} \sim N\left(0, \begin{bmatrix} \sigma^2_{e2} & & & \\ 0 & \sigma^2_{e3} & & \\ \sigma_{e24} & 0 & \sigma^2_{e4} & \\ 0 & \sigma_{e36} & 0 & \sigma^2_{e6} \end{bmatrix}\right)$$

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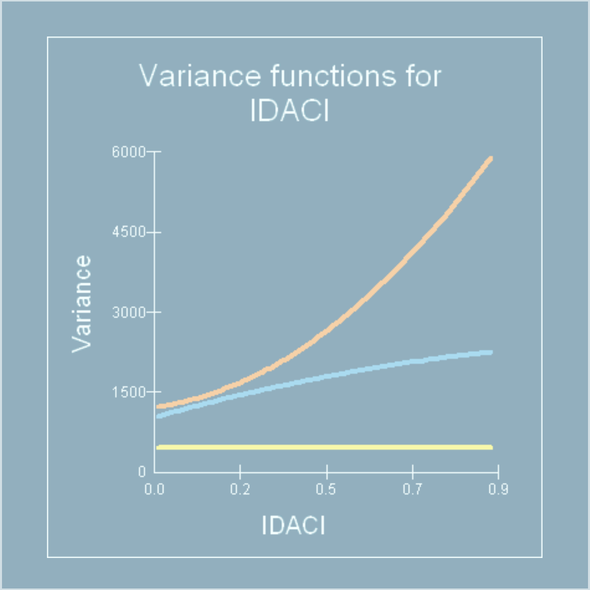
Model

$$\begin{aligned} \textbf{GCSE}_{ijk} = \alpha &+ \beta_1 \textbf{pretest}_{ijk} + \beta_2 \textbf{twin}_{jk} + \beta_5 \textbf{IDACI}_{jk} \\ &+ v_{0k} + u_{2jk}\textbf{twin}_{jk} + e_{2ijk}\textbf{twin}_{jk} + e_{3ijk}\textbf{nontwin}_{jk} \\ &+ u_{4jk}\textbf{twin} \cdot \textbf{IDACI}_{jk} + e_{4ijk}\textbf{twin} \cdot \textbf{IDACI}_{jk} \\ &+ e_{6ijk}\textbf{nontwin} \cdot \textbf{IDACI}_{jk} \end{aligned}$$

Results



Variance functions for
IDACI
Variance
6000
4500
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0.0
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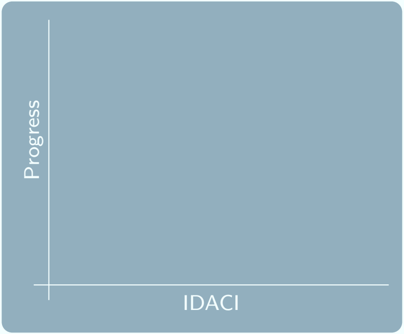
0.7
0.9
IDACI

Interpreting the results

As IDACI increases,

We have this situation:



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As IDACI increases,

- The mean progress decreases
  - $\beta_5 = -68.1$

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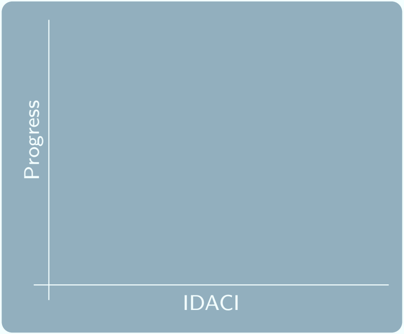

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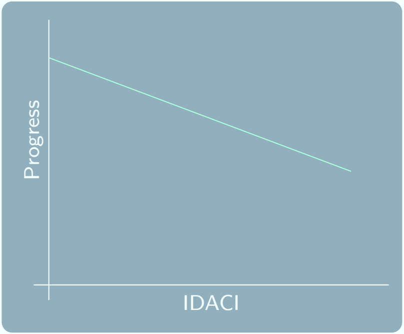

Interpreting the results

As IDACI increases,

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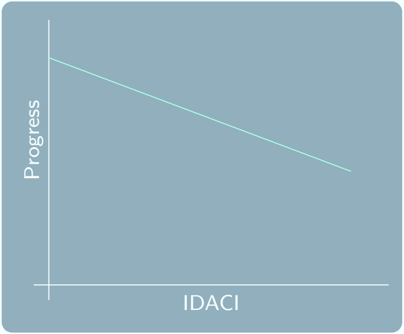

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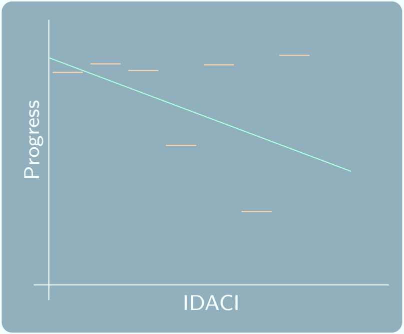

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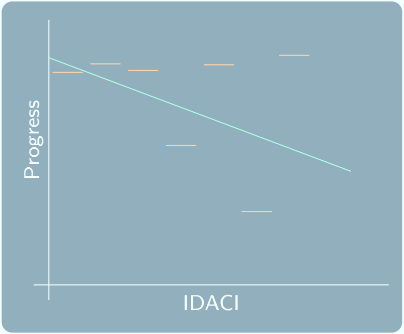

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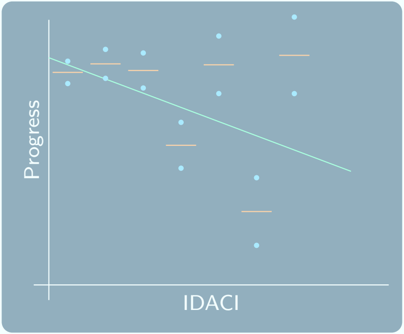

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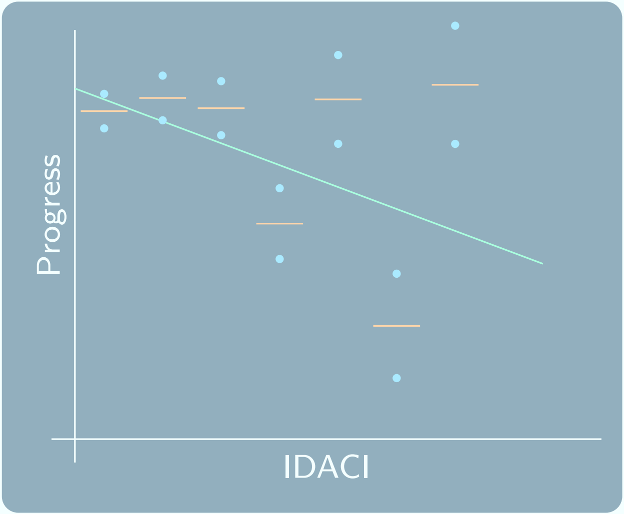

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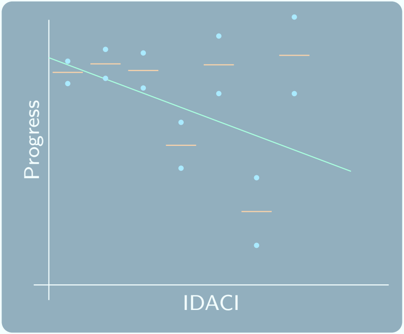

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- So at greater levels of deprivation, family becomes relatively more important in determining progress

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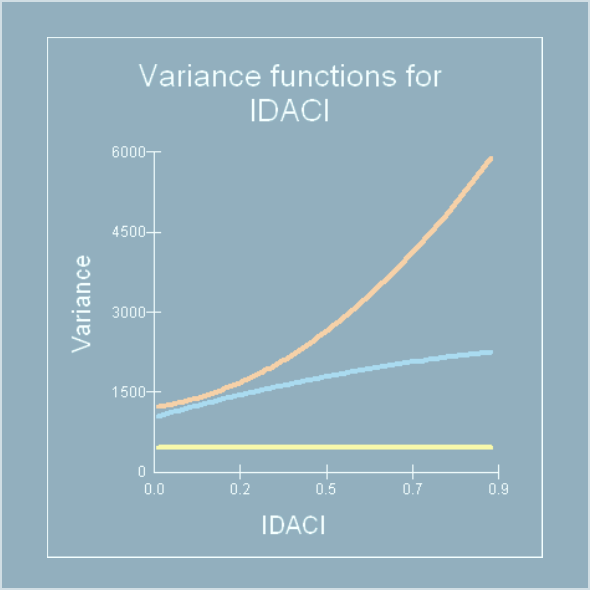

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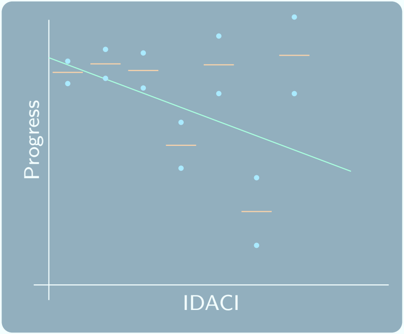

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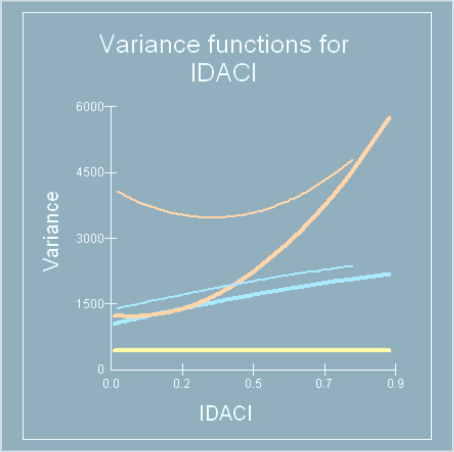
Other stressors

- 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

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- In the absence of a stressor, the genes make little difference so there is not much variability

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- In the absence of a stressor, the genes make little difference so there is not much variability
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Environmental explanation

What's going on? Possible explanations

Genetic explanation

- Within families, some children have genes which help to maintain progress in the presence of stressors, while others do not
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  - alcoholism of parent
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- In the presence of stressors, families with these factors cannot do so → variability since some families have these factors and some don't

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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 $\longrightarrow$ variability since those getting more resources can make more progress

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