Dynamic Complementarity in Skill Production: Genetic Endowments & Birth Order

D. Muslimova, H. van Kippersluis, C.A. Rietveld, S. von Hinke, S.F.W. Meddens

MOTIVATION

A complex interplay between 'nature' and 'nurture' influences EA

- **Clean G and E:**
  - birth order is random within families
  - genes are random within siblings and fixed at conception
- **This allows us to:**
  - Understand how G and E interact (nature vs/and nurture)
  - Shed light on 'dynamic complementarity' in skill formation *(Cunha and Heckman, 2007)*
    - Birth order places a natural exogenous restriction on time *(Price 2008; Pavan 2016; Berry et al., 2020)*
    - Actual investments and parenting are endogenous – respond to endowments *(Breinholt & Conley 2019)*
    - Previous measures of endowments are endogenous – already include investments (e.g. birth weight)

DYNAMIC COMPLEMENTARITY OF SKILL FORMATION

Cunha and Heckman (2007) propose a model in which skills θ_{t+1} at period *t+1* are produced according to the production function f:

$$\theta_{t+1} = f_t(h, \theta_t, I_t) \quad (1)$$

where h denotes parental characteristics and I_t reflects parental investments in period t. Iteratively substituting equation (1) implies a model in which skills are a function of initial endowments θ_0, family-invariant parental characteristics h, as well as the entire history of parental investments $I_0, \ldots, I_t$.

A signature feature of the skill production function is the concept of dynamic complementarity, where acquired skills raise the productivity of later investment $\left(\frac{\partial^2 \theta_{t+1}}{\partial \theta_t \partial I_t} > 0\right)$. In other words, children with higher (genetic) endowments for education (as part of θ_0) would benefit the most from parental investments $I_0, \ldots, I_t$.

Since we do not observe parental investments directly, and realized parental investments are endogenous to the child's endowments (e.g., Becker and Tomes, 1986; Almond and Mazumder, 2013; Breinholt and Conley 2019; Sanz-de-Galdeano and Terskaya 2019), we use the individual's birth order as an exogenous and highly predictive proxy for parental investments.

DESCRIPTIVES

Figure 1. Distributions

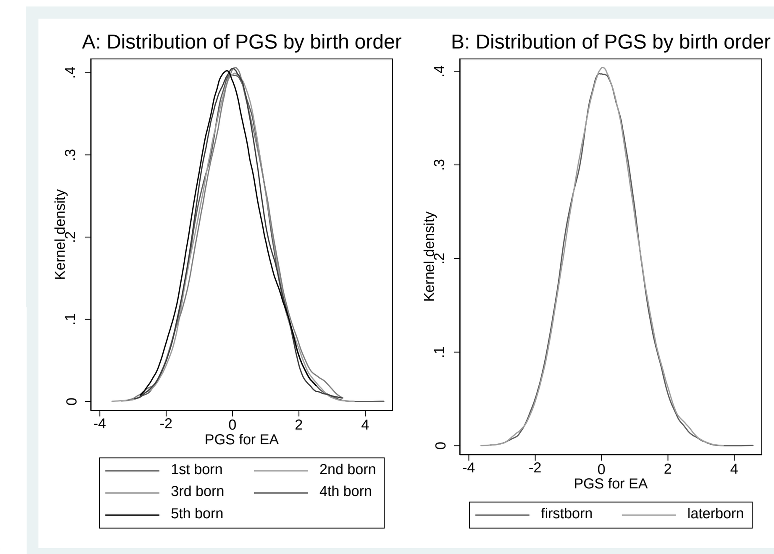
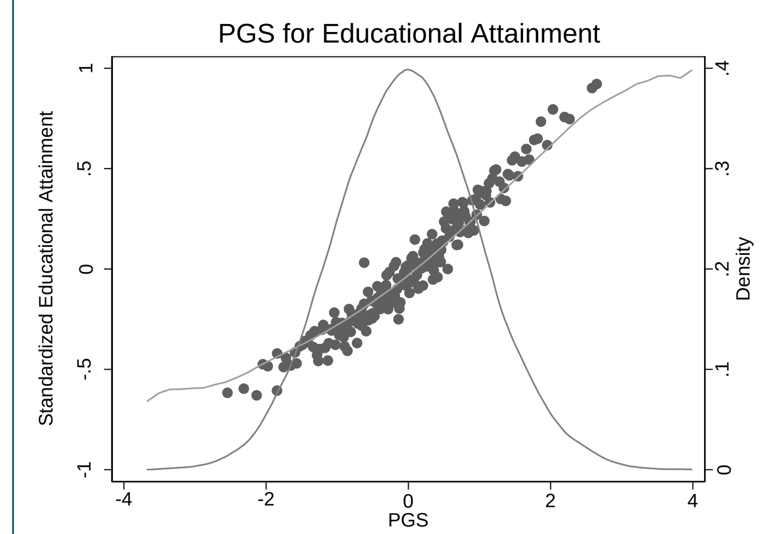


Figure 2: Does EA PGS explain EA?



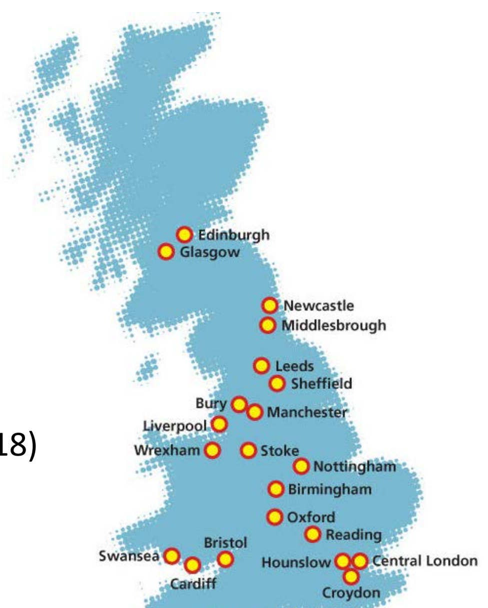
IN THIS PAPER...

We use the UK Biobank to understand dynamic complementarity and GxE between birth order and genetic endowments in the within-family sample of ~19,000 siblings:

- Run a tailor-made GWAS in the UKB data excluding siblings and their relatives
  - Relationships identified using the KING software with thresholds in Byroft et al (2018)
- Meta-analyze with the EA3 sum stats excluding UKB
- Construct EA PGS based on the above meta-analysis
- Impute birth order of siblings based on birth year and family structure
- Test predictive power of the PGS
- Test the birth order effect
- Check the correlation between the EA PGS and the birth order
- Test the interaction of the EA PGS and Birth Order when shaping one's EA

DATA – UK BIOBANK

- ~500,000 genotyped individuals aged 40-69 during 2006-2010
- ~190,000 with identifiable birth order and genotyped
- ~19,000 genotyped siblings, excluding twins and non-Europeans
- ~7,000 firstborns, 12,000 laterborns



Genetic Scores

- GWAS using fastGWA software (GCTA)
  - Excludes siblings and their relatives
  - Relationships are identified using KING software (Byroft et al, 2018)
- EA PGS using all SNPS with LD adjusted weights (LDpred)
- Interpretation: higher score -> higher the propensity to attain XX years of educatio

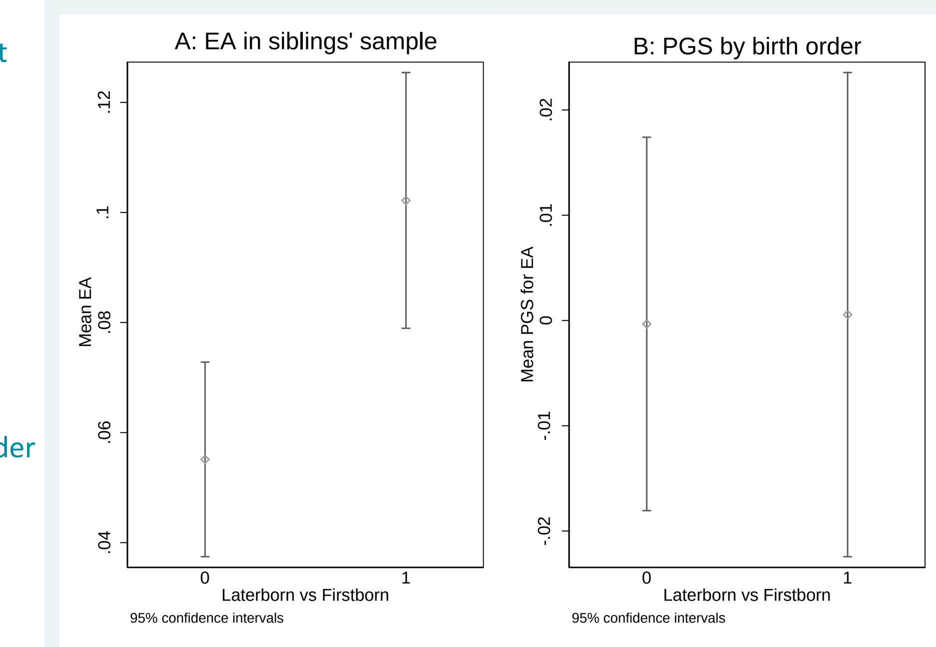
Birth Order and Educational Attainment

- Missing birth order is imputed based on available birth year and family structure (~5000)
- Years of educational attainment are based on self-reported qualifications, the variable is standardized.

BIRTH ORDER

- Our results support a birth order effect in EA, i.e. on average, firstborns achieve higher educational attainment as compared to their laterborn siblings.
- Effect size = 0.053
- When controlling for stopping rules, EA PGS is independent of the birth order

Figure 3. Birth Order Effects and Dependence of PGS on Birth Order



CONTRIBUTION TO THREE MAIN LINES OF LITERATURE

Emerging GxE studies with exogenous environments

- **E.g.** Barcellos, Carvalho and Turley (2018), Conley and Schmitz (2017)
- We push this one step further by not only considering exogenous variation in the environment, but also in the genes by using within-family framework.

Birth Order Effects

- Literature consistently finds that laterborn children have lower educational attainment (See e.g., Black, Devereux, Salvanes, 2005; 2011)
- We contribute to this literature by studying heterogeneity in the birth order effect on educational attainment with respect to genetic endowments.

Dynamic Complementarity of Skill Production

- **E.g.** Cunha and Heckman (2007), Cunha, Heckman and Schennach (2010).
- We contribute by using exogenous measures of endowments *and* investments.

PGS OF EDUCATIONAL ATTAINMENT (EA PGS)

Our EA PGS has an incremental R2 of 9% (between family) and 1.6% (within family) in the siblings' sample (~19,000)

Table 1. EA PGS and Educational Attainment

	(1) No PGSs	(2) Between Family	(3) No PGSs FE	(4) Family FE
EA PGS		0.297***		0.162***
		(0.007)		(0.014)
Constant	0.393	0.348	0.342	0.260
	(0.300)	(0.286)	(0.412)	(0.441)
N	18912	18912	18912	18912
r2	**0.035**	**0.121**	**0.029**	**0.045**

Standard errors in parentheses
Excludes non-Europeans
Controls for year and month of birth, gender and 40 first PCs
PGSs and EA are standardized
* p<0.10, ** p<0.05, *** p<0.01

GxE: BIRTH ORDER, EA PGS and EA

- Tentative evidence for a positive GxE interaction between EA PGS and birth order
  - > effect size is positive and substantial, but not precisely estimated
  - > supports the existence of dynamic complementarity in skill formation

Table 2. Birth Rank, PGSs, and Outcomes with Family Fixed Effects

	EA		
Firstborn	0.075***	0.074***	0.060**
	(0.021)	(0.021)	(0.027)
EA PGS	0.163***	0.156***	0.157***
	(0.014)	(0.015)	(0.015)
Firstborn X EA PGS		**0.019**	**0.017**
		(0.016)	**(0.016)**
Last_child			-0.031
			(0.028)
Constant	0.108	0.105	0.071
	(0.440)	(0.443)	(0.441)
N	18978	18979	18980
r2	0.047	0.047	0.047

Standard errors in parentheses
Excludes non-Europeans
Controls for year and month of birth, gender and 40 first PCs
PGSs and EA are standardized
* p<0.10, ** p<0.05, *** p<0.01