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Educational attainment and Inter-generational Mobility: a Polygenic Score Analysis

Online Appendix

(Not meant to be part of the journal publication)

Aldo Rustichini, William Iacono, James Lee, Matt McGue

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S-0.1. **Alternative Specifications of Parental Investment.** In this section we briefly outline the model in which investment of parents in human capital of children can affect human capital directly, but also the skill variable (θ).

The i^{th} household solves the optimization problem in the variables E expenditure in consumption, I^i pair of investment in the human capital and J^i of skill of the two children:

$$\max_{(E^i, J_1^i, J_2^i, I_1^i, I_2^i)} \mathbf{E}\left((1-\delta)\ln E^i + \delta \sum_{j=1,2} y_j^i\right), \tag{S-1}$$

subject to the budget constraint given by the household's income (y denotes the natural log of income):

$$E^i + \sum_{k=1,2} I_k^i + \sum_{k=1,2} J_k^i = \exp(y^i) \tag{S-2}$$

The expectation of equation (6) refers to the random shocks ϵ^h and ϵ^y.

The skill of twin ij is affected by a parental pecuniary investment J_j^i, in addition to the skill component in the genetic endowment, and is thus given by:

$$\theta_j^i = w(g_j^i) + \alpha_J \ln J_j^i + \Pi X_j^i + \epsilon_j^{\theta,i}. \tag{S-3}$$

The parameter α_J describes the effect of the parental investment on skill.

We assume the no-correlation and zero mean condition as in the main text. Human capital accumulation is described by equation 8, and income is given by equation 9, as in the main text. We assume zero mean for shocks to human capital and income as in the main text, and also assume that the shocks to human capital and income are not correlated.

At the optimal solution of the problem optimal parental investment is equal for the two siblings for both the component of the skill investment and the human capital investment, and is a constant fraction (depending on the parameters) of the total household income $exp(y^i)$, as in equation 4 of the main text. This equation can then be taken as the reduced form of the model presented in this section.

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S-0.2. **MTAG correction of PGS.** We considered a different polygenic score using a correction that increases the predicitve power of the score. To do this, after the preminary stage indicated, we applied the software tool $MTAG$ Turley et al. (2019) to increase the effective sample size of the education summary statistics by drawing upon GWAS of IQ, a trait showing a strong genetic correlation with educational attainment. In this MTAG step, we used the IQ summary statistics of both Savage et al. (2018) and Lee et al. (2018). The weights of the SNP's in the score were then calculated with the software tool PRScs Ge et al. (2019), which uses an external sample to estimate the correlations between SNP's in order to convert the univariate regressions coefficients in $GWAS$ summary statistics to partial regression coefficients. PRScs also applies Bayesian shrinkage to the partial regression coefficients, which can then be used as weights in the polygenic score. We used the 1000 Genomes European populations to estimate the correlations between SNP's and calculated the shrunken partial regression coefficients of the 450,000 SNP's that were originally genotyped in MCTFR and survived all default software filters.

The two different scores yield very similar results in our analysis, hence which one we choose turns out to be of no substantial importance. We illustrate the difference in table S-1 below, that one can compare to the table 1 in the main text. The first column is identical, hence it is omitted. Similar comparisons are possible for the other estimates in the main text, with similar results.

The small size of the difference is probably due to the fact that the sample size of the underlying GWAS (Lee et al. (2018)) is large.

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TABLE S-1. **Income at the age 29 take, family income, PGS, and Personality.** The PGS is MTAG-corrected. All variables, including College of parents and Male, are standardized to mean zero and SD 1. The signs of MPQ variables NA, Externalizing and Academic problems are reversed. Controlled for PC's and the parents-child time difference in age at income data collection.

	(1) b/se	(2) b/se
Family Income	0.127***	0.079**
	(0.027)	(0.032)
Male	0.276***	0.312***
	(0.025)	(0.029)
Male × Family Income	–0.061**	–0.050*
	(0.025)	(0.030)
PGS MTAG Corr	0.073***	0.006
	(0.025)	(0.029)
Education Years		0.257***
		(0.035)
IQ		0.011
		(0.029)
MPQ PA		0.061**
		(0.026)
MPQ NA		–0.024
		(0.027)
MPQ CN		0.034
		(0.032)
Externalizing		–0.072*
		(0.037)
Academic effort		0.057
		(0.038)
Academic problems		–0.017
		(0.034)
N	2100	1485

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S-0.3. **Fixed Effects Analysis on *DZ* twins.** In this section we report results on fixed effects analysis on *DZ* twins, for Education Years, GPA, College and Intelligence.

TABLE S-2. **Education Years, only DZ twins.** All variables are standardized to mean zero and SD 1. Fixed effects regressions.

	(1) b/se	(2) b/se	(3) b/se
PGS Education	0.115*	0.114*	0.090
	(0.060)	(0.060)	(0.058)
MPQ PA		0.041	0.036
		(0.047)	(0.047)
MPQ NA		0.005	–0.028
		(0.050)	(0.049)
MPQ CN		0.071	–0.040
		(0.051)	(0.057)
Externalizing at 17			0.107
			(0.081)
Academic effort at 17			0.176**
			(0.076)
Academic problems at 17			0.029
			(0.064)
Constant	0.244***	0.273***	0.189***
	(0.027)	(0.040)	(0.054)
N	612	612	612

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TABLE S-3. **GPA score: Fixed effects analysis in DZ twins.** All variables are standardized to mean zero and SD 1. Fixed effects regressions.

	(1) b/se	(2) b/se	(3) b/se
PGS	0.275***	0.179***	0.134***
	(0.055)	(0.053)	(0.044)
IQ		0.333***	0.186***
		(0.054)	(0.044)
MPQ PA		0.079*	0.063*
		(0.042)	(0.034)
MPQ NA		–0.001	–0.055
		(0.044)	(0.036)
MPQ CN		0.209***	0.002
		(0.045)	(0.042)
Externalizing at 17			0.106*
			(0.061)
Academic effort at 17			0.471***
			(0.057)
Academic problems at 17			0.102**
			(0.047)
Constant	–0.029	0.100***	–0.046
	(0.027)	(0.034)	(0.041)
N	682	630	590

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TABLE S-4. **College and PGS in DZ twins: logit analysis in DZ twins, odds ratios reported.** All variables standardized to mean zero and SD 1.

	(1) b/se	(2) b/se	(3) b/se
PGS	2.851***	2.191***	1.904***
	(0.397)	(0.324)	(0.318)
IQ		3.507***	3.238***
		(0.637)	(0.670)
MPQ PA		1.291**	1.426**
		(0.166)	(0.216)
MPQ NA		1.345**	1.238
		(0.176)	(0.195)
MPQ CN		1.880***	1.075
		(0.270)	(0.193)
Externalizing at 17			1.517*
			(0.332)
Academic effort at 17			2.075***
			(0.480)
Academic problems at 17			1.350
			(0.258)
Constant	0.616***	1.008	0.713
	(0.086)	(0.160)	(0.153)
σ_u^2	3.898***	3.438***	3.423***
	(1.023)	(1.119)	(1.318)
N	865	780	645

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TABLE S-5. **IQ score: Fixed effects analysis in DZ twins.** All variables are standardized to mean zero and SD 1. Fixed effects regressions.

	(1) b/se	(2) b/se	(3) b/se
PGS	0.152***	0.160***	0.125**
	(0.049)	(0.054)	(0.059)
MPQ PA		0.043	0.026
		(0.043)	(0.047)
MPQ NA		0.102**	0.108**
		(0.042)	(0.049)
MPQ CN		–0.089**	–0.161***
		(0.044)	(0.057)
Externalizing at 17			–0.151*
			(0.082)
Academic effort at 17			0.261***
			(0.075)
Academic problems at 17			0.097
			(0.064)
Constant	–0.069***	–0.058*	–0.054
	(0.024)	(0.034)	(0.056)
N	802	723	601

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S-0.4. **Additional Evidence on Gene × Environment Correlation.** We report in this section regressions estimating the existence and effect size of gene × environment correlation. In each table the dependent variable of interested is regressed on the PGS of parents, and additional controls are considered. Both DZ and MZ twins are considered.

TABLE S-6. **Education Years on PGS of Twin and PGS of parents, IQ and Soft Skills.** All variables, including Education Years, are standardized to mean zero and SD 1.

	(1) b/se	(2) b/se	(3) b/se	(4) b/se
PGS	0.082***	0.097***	0.057*	0.069**
	(0.031)	(0.030)	(0.032)	(0.031)
PGS mother	0.105***	0.054**	0.064**	0.038
	(0.027)	(0.026)	(0.027)	(0.027)
PGS father	0.102***	0.020	0.036	–0.009
	(0.028)	(0.028)	(0.028)	(0.028)
IQ			0.152***	0.122***
			(0.023)	(0.023)
Soft Skills Index			0.222***	0.212***
			(0.022)	(0.022)
Education of parents		0.186***		0.116***
		(0.025)		(0.025)
Family Income		0.110***		0.083***
		(0.027)		(0.028)
Male	–0.091***	–0.081***	–0.039	–0.032
	(0.024)	(0.022)	(0.025)	(0.024)
Constant	0.291***	0.265***	0.317***	0.296***
	(0.023)	(0.023)	(0.023)	(0.023)
N	1686	1686	1333	1333

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TABLE S-7. **GPA on PGS of Twin and PGS of parents, IQ and Soft Skills.** All variables, including GPA, are standardized to mean zero and SD 1.

	(1) b/se	(2) b/se	(3) b/se	(4) b/se
PGS	0.217***	0.226***	0.120***	0.127***
	(0.033)	(0.033)	(0.031)	(0.031)
PGS mother	0.050	0.009	0.034	0.017
	(0.033)	(0.033)	(0.029)	(0.029)
PGS father	0.062*	–0.001	0.003	–0.025
	(0.034)	(0.035)	(0.030)	(0.031)
IQ			0.242***	0.226***
			(0.022)	(0.023)
Soft Skills Index			0.384***	0.380***
			(0.021)	(0.021)
Education of parents		0.158***		0.083***
		(0.032)		(0.028)
Family Income		0.078**		0.031
		(0.036)		(0.031)
Male	–0.226***	–0.221***	–0.136***	–0.132***
	(0.029)	(0.029)	(0.026)	(0.026)
Constant	0.024	0.001	0.038	0.026
	(0.029)	(0.029)	(0.025)	(0.025)
N	1579	1579	1389	1389

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TABLE S-8. **College on PGS of Twin and PGS of parents, IQ and Soft Skills. Logit, Odds ratios displayed.** All independent variables are standardized to mean zero and SD 1. lnsig2u = panel level variance.

	(1) b/se	(2) b/se	(3) b/se	(4) b/se
PGS	1.817***	1.977***	1.616***	1.743***
	(0.276)	(0.291)	(0.285)	(0.303)
PGS mother	1.535***	1.158	1.306*	1.088
	(0.205)	(0.147)	(0.201)	(0.164)
PGS father	1.580***	1.051	1.138	0.873
	(0.221)	(0.142)	(0.181)	(0.139)
IQ			2.620***	2.193***
			(0.380)	(0.309)
Soft Skills Index			3.499***	3.326***
			(0.521)	(0.485)
Education of parents		2.607***		2.173***
		(0.333)		(0.323)
Family Income		1.612***		1.429**
		(0.216)		(0.229)
Male	0.648***	0.678***	0.838	0.867
	(0.075)	(0.073)	(0.116)	(0.116)
Constant	0.859	0.779**	0.996	0.905
	(0.098)	(0.085)	(0.130)	(0.116)
lnsig2u	6.407***	5.125***	6.314***	5.578***
	(1.076)	(0.903)	(1.322)	(1.212)
N	1805	1805	1411	1411

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TABLE S-9. **IQ on PGS of Twin and PGS of parents, IQ and Soft Skills.** All variables are standardized to mean zero and SD 1.

	(1) b/se	(2) b/se	(3) b/se	(4) b/se	(5) b/se
PGS	0.193***	0.186***	0.179***	0.209***	0.183***
	(0.033)	(0.037)	(0.037)	(0.032)	(0.036)
PGS mother	0.050	0.037	0.033	–0.008	–0.005
	(0.032)	(0.036)	(0.036)	(0.032)	(0.035)
PGS father	0.092***	0.089**	0.083**	0.003	0.011
	(0.033)	(0.037)	(0.037)	(0.034)	(0.037)
Soft Skills Index			0.087***		0.111***
			(0.025)		(0.025)
Education of parents				0.254***	0.231***
				(0.031)	(0.033)
Family Income				0.026	0.017
				(0.033)	(0.037)
zmale					0.193***
					(0.031)
Constant	–0.012	–0.006	–0.008	–0.031	–0.021
	(0.029)	(0.032)	(0.032)	(0.028)	(0.031)
N	1805	1411	1411	1805	1411

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S-0.5. **Evidence of Genetic Assortative Mating.** Table S-10 shows the size of the genetic assortative mating, and that it is robust to control for possible population stratification, as the comparison between model (1), (2) and (3) confirms.

TABLE S-10. **PGS of parents.** Dependent variable: PGS of the mother. Model (3) controls for the square of each PC (not reported).

	(1) b/se	(2) b/se	(3) b/se
PGS of father	0.156***	0.133***	0.131***
	(0.033)	(0.034)	(0.034)
pc1		8.022***	5.024*
		(2.569)	(2.963)
pc2		–6.184**	–8.653***
		(2.657)	(2.885)
pc3		–2.094	–2.113
		(2.689)	(4.485)
pc4		–5.371**	–3.787
		(2.596)	(2.693)
pc5		1.239	2.545
		(2.687)	(2.721)
pc6		–1.634	–1.672
		(2.844)	(2.859)
pc7		4.146	3.311
		(2.779)	(2.793)
pc8		–4.025	–4.418
		(2.765)	(2.773)
pc9		–0.183	–0.496
		(2.866)	(2.867)
pc10		5.819**	5.826**
		(2.790)	(2.810)
N	951	918	918

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