Two Sides of the Same Coin? How Cognitive and Noncognitive Skills Shape Academic Achievement

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Questions

This research examines the **joint effects of cognitive and noncognitive skills** on **academic achievement**.
→ What are the relative contributions of cognitive and noncognitive skills to academic performance, as measured by standardized test scores?
→ To what extent can noncognitive skills substitute for cognitive skills in producing academic outcomes, and how does this vary across subjects and genders?
→ Which type of skill improvement (cognitive or noncognitive) has a greater impact on grades, and does this differ between subjects like Maths and English?

Introduction

- **Context**: Irish secondary students, using Growing Up in Ireland longitudinal study data.
- **Methodology**: linear and translog production functions.
- **Main contribution**: Application of a flexible translog production function to quantify cognitive–noncognitive interactions in academic achievement across genders and subjects.
- **Key insights:**
  - Non-linear relationships and varying substitution elasticities across subjects and genders
  - Nuanced view of skill complementarity and substitutability
  - Optimization of human capital formation and resource allocation
  - Gender gap implications in educational strategies
- **Impact**: Informs targeted interventions and policies, emphasizing personalized approaches to human capital development.

Timeline

Timeline:

Event	Date	Age (in years)	Variables of interest
Study-child is born	Nov/97 - Oct/98	0	
Wave 2 data collection	Aug/11 - Mar/12	13	Independent variables: Cognition composite, SDQ and TIPI scales, controls
Study-child sits the Junior Cert	Jun/13 - Jun/14	15-16	
Wave 3 data collection	Apr/15 - Aug/16	17-18	Dependent variables: Junior Cert scores in Maths and English

Table: Timeline of Events - Growing Up in Ireland '98 Cohort

Main Variables | Control Variables | Notes I | Notes II

Data and Model Specification

Data: Growing Up in Ireland longitudinal study (Waves 2 & 3, '98 Cohort)

Main Equation:

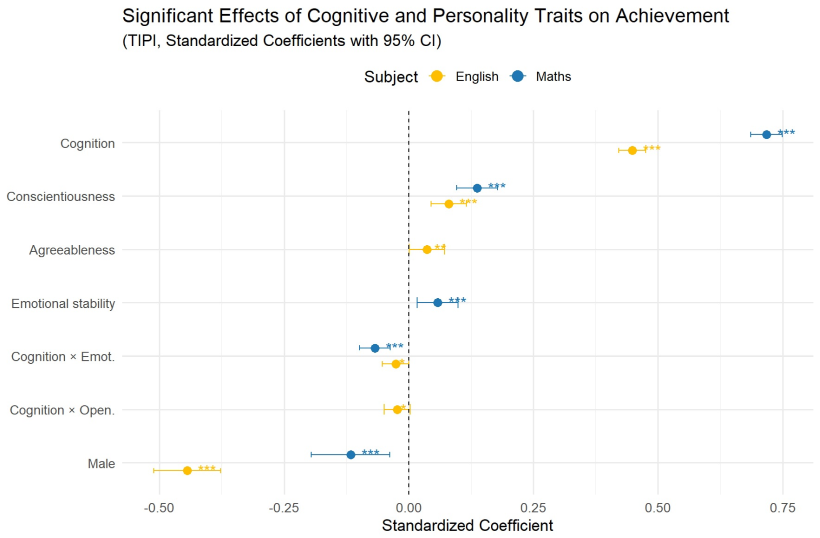
$$\text{Points\_JC}_{i,l} = \beta_0 + \beta_C \cdot \text{Cognition}_i + \sum_{j=1}^{J} \beta_{Nj} \cdot \text{NonCognition}_{i,k,j}$$

$$+ \sum_{j=1}^{J} \gamma_j \cdot (\text{Cognition}_i \cdot \text{NonCognition}_{i,k,j}) + \boldsymbol{\delta}' \cdot \textbf{Controls}_i + \varepsilon_{i,l,k,j}$$

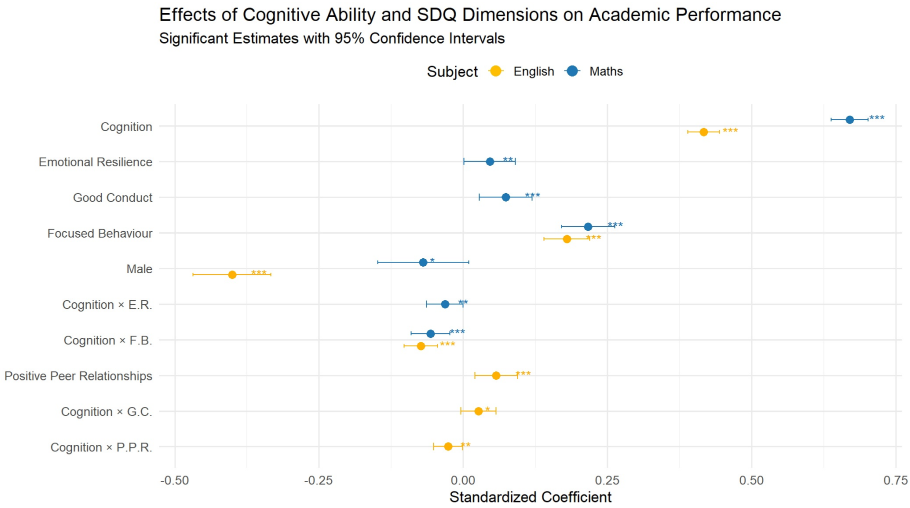
Key Components (independent vars are z-distributed):

- **DV**: Junior Cert scores (Maths, English)
- **Cognitive Ability**: Principal Component (Naming, Maths, Vocabulary)
- **Noncognitive Measures**: Inverted SDQ (behavioural and emotional skills: Emotional Resilience, Good Conduct, Focused Behaviour Positive Peer Relationships), TIPI (personality traits: Agreeableness, Conscientiousness, Emotional Stability, Extroversion, Openness)
- **Controls**: SES, parental education, income, school characteristics
- Indices: i: individual, l: Subject, k: Caregiver, j: Noncognitive measures

Results - Linear Estimation - TIPI



Results - Linear Estimation - SDQ



Discussion - Linear Estimation

- **Cognitive Skills:** Strongest predictor of academic performance; one SD increase yields +0.67 (SDQ) to +0.72 (TIPI) points in Maths and +0.42 (SDQ) to +0.45 (TIPI) points in English.
- **Noncognitive Skills:** Focused Behaviour significantly boosts scores (+0.22 in Maths, +0.18 in English); Conscientiousness contributes modestly (+0.14 in Maths, +0.08 in English).
- **Interaction Effects:** Highly significant negative interactions between cognitive ability and noncognitive skill, which suggests importance for students with lower cognitive abilities.
- **Gender Differences:** Boys perform worse than girls, especially in English (-0.44 points); smaller gap in Maths (-0.12 points).
- **Subject Differences:** Cognitive skills have a stronger impact on Maths; noncognitive skills are more influential in English.

Nonlinear Estimation: Translog P.F.

Equation:

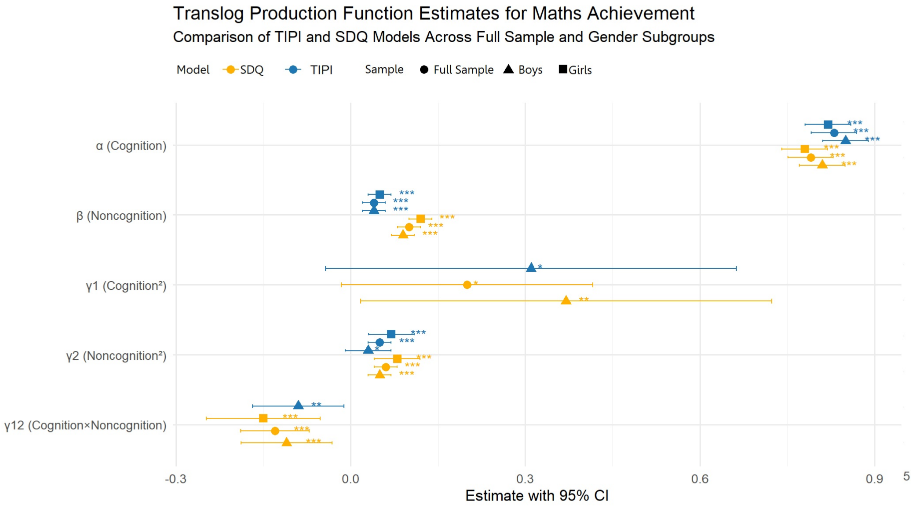
$$Y = AC^{\alpha} N^{\beta} \exp\left\{\frac{1}{2}\gamma_1 \left[\ln(C)\right]^2 + \frac{1}{2}\gamma_2 \left[\ln(N)\right]^2 + \gamma_{12} \ln(C)\ln(N)\right\}$$

Where:

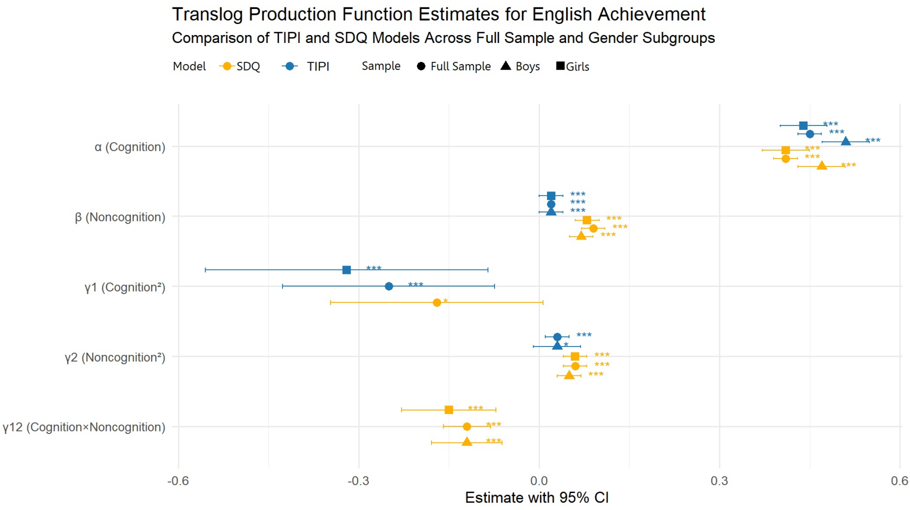
- Y: Output (JC scores in Maths/English); C: Cognitive input (PC, $\mu = 100$, $\sigma = 15$); N: Noncognitive input (Focused Behaviour or Conscientiousness, original scales)
- α, β: Output elasticities with respect to C and N
- γ_1, γ_2, γ_{12}: Capture curvature and input interactions. A negative γ_{12} implies diminishing marginal returns when both C and N are high.

The translog production function allows for variable elasticities of substitution and nonlinear input interactions. As a flexible second-order approximation, it extends beyond traditional models (e.g., Cobb-Douglas) and accommodates richer input-output relationships.

Results - Nonlinear Estimation - Maths



Results - Nonlinear Estimation - English



Discussion - Nonlinear Estimation

- **Cognitive Skills (α):** Strong influence on performance; $\alpha = 0.79$ (SDQ, Maths) and 0.83 (TIPI, Maths) vs. $\alpha = 0.41$ (SDQ, English) and 0.45 (TIPI, English).
- **Noncognitive Skills (β):** Smaller but significant contributions; $\beta = 0.11$ (Maths, SDQ) vs. $\beta = 0.09$ (English, SDQ); TIPI values lower at 0.04 (Maths) and 0.02 (English).
- **Interaction Effects (γ_{12}):** Negative and significant for SDQ ($\gamma_{12} = -0.13$ for Maths, -0.12 for English), suggesting that the marginal effect of one input decreases as the level of the other increases — consistent with diminishing returns when both skills are high.

Discussion - Nonlinear Estimation

- **Gender Differences:** Cognitive skills impact varies; girls: $\alpha = 0.778$ (Maths, SDQ), boys: $\alpha = 0.806$ (Maths, SDQ). Noncognitive skills are higher for girls in both subjects.
- **Measurement Tool Impact:** SDQ measures show stronger relationships with outcomes than TIPI, suggesting better relevance for academic performance.

Results - Nonlinear Estimation

	Maths			English		
Estimate	**Full**	**Boys**	**Girls**	**Full**	**Boys**	**Girls**
TIPI Model						
MP (Cognition)	0.078	0.080	0.078	0.046	0.049	0.047
MP (Conscientiousness)	0.084	0.073	0.091	0.051	0.041	0.035
OE (α Cognition)	0.828	0.859	0.820	0.454	0.506	0.447
OE (β Conscientiousness)	0.043	0.036	0.048	0.024	0.019	0.017
EoS	0.533	0.288	1.096	0.478	0.344	0.675
MRTS	0.927	1.102	0.858	0.894	1.217	1.342
SDQ Model						
MP (Cognition)	0.074	0.076	0.074	0.042	0.045	0.043
MP (Focused Behaviour)	0.123	0.103	0.140	0.110	0.088	0.095
OE (α Cognition)	0.785	0.813	0.778	0.414	0.466	0.416
OE (β Focused Behaviour)	0.105	0.084	0.125	0.088	0.069	0.078
EoS	0.471	0.451	0.488	0.452	0.396	0.370
MRTS	0.605	0.733	0.530	0.379	0.513	0.455

Note: MP = Marginal Product, OE = Output Elasticity, EoS = Elasticity of Substitution, MRTS = Marginal Rate of Technical Substitution.

Definitions

Discussion - Nonlinear Estimation

- **Higher Marginal Products (MPs):** Both cognitive and noncognitive skills yield greater returns in Maths than in English (particularly in the SDQ model)
- **Output Elasticities (OEs):** Cognitive skills remain the dominant drivers of achievement across subjects and genders, but noncognitive traits contribute meaningfully, particularly for girls in Maths.
- **Elasticity of Substitution (ES):** Estimates consistently below 1 indicate limited substitutability between skill types, except for girls in Maths (TIPI model: ES = 1.096), suggesting greater substitutability in this subgroup.
- **Marginal Rate of Technical Substitution (MRTS):** MRTS values below 1 in most models suggest that increasing noncognitive skills alone cannot fully offset deficits in cognitive skills.
- **Decreasing Returns to Scale:** The sum of $\alpha + \beta$ remains below 1 across all models, indicating diminishing returns to combined skill investments (a hallmark of constrained educational production).

Conclusion

- **Focus of Study:** Examined interactions of cognitive and noncognitive skills on academic achievement in Maths and English, highlighting gender differences.
- **Cognitive Skills:** Consistently the strongest predictor of performance, particularly influential in Maths across all models.
- **Noncognitive Skills:** Show meaningful but smaller effects; Focused Behaviour has a stronger impact in Maths, especially for girls (SDQ model).
- **Gender Differences:** Boys exhibit higher cognitive output elasticities; girls show greater substitutability between skills and stronger returns to noncognitive traits in some subjects.
- **Model Insights:** The translog specification reveals nonlinearities, interaction effects, and varying elasticity of substitution, offering richer insight than linear models.
- **Policy Implications:** Effective interventions should integrate both skill types and be tailored by subject and gender, given the observed differences in how students convert skills into achievement.

Takeaways

→ Cognitive skills matter most for academic success—especially in Maths.
→ But noncognitive traits, like focused behaviour, consistently boost outcomes, particularly for girls.
→ Cognition and behaviour work best together: they are complements in most cases (ES < 1), not substitutes → these skills do not easily replace each other. Students need support in both areas.
→ To boost achievement, strategies should match students' needs by subject, by skill, and by gender.

Conclusion

Thank you so much.
Any questions or suggestions?
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Descriptive Statistics - Main Variables

Table: Descriptive Statistics - Main Variables

Variable	Mean	Std. Dev.	Min	Max	N
Dependent variables					
Maths points (Junior Cert)	9.60	1.74	2.00	12.00	5631
English points (Junior Cert)	10.15	1.34	5.00	12.00	5631
Independent variables: Cognition					
Drumcondra Verbal Reasoning (% of correct answers)	64.89	21.92	0.00	100.00	5631
Drumcondra Numerical Ability (% of correct answers)	55.05	22.53	0.00	100.00	5631
Matrices (BSA)	116.68	18.03	10.00	161.00	5631
Cognitive ability 1	0.14	1.33	-4.25	3.32	5631
Cognitive ability 2	100.00	15.00	36.25	136.40	5631
Independent variables: Noncognition (SDQ scale)					
Emotional resilience	8.29	1.87	0.00	10.00	5631
Good conduct	8.97	1.31	0.00	10.00	5631
Focused behaviour	7.56	2.26	0.00	10.00	5631
Positive peer relationships	8.96	1.41	0.00	10.00	5631
Independent variables: Noncognition (TIPI scale)					
Agreeable	5.01	1.95	0.50	7.00	5631
Conscientious	4.33	2.07	0.50	7.00	5631
Emotional stability	4.40	1.99	0.50	7.00	5631
Extravert	3.98	1.98	0.50	7.00	5629
Openness	4.73	1.83	0.50	7.00	5627

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Descriptive Statistics - Control Variables

Table: Descriptive Statistics - Control Variables

Variable	Mean	Std. Dev.	Min	Max	N
Controls (SES characteristics)					
Gender (Male = 1)	0.49	0.50	0.00	1.00	5468
Primary caregiver education level	3.97	1.24	1.00	6.00	5631
Secondary caregiver education level	3.86	1.36	1.00	6.00	4440
Income quintile (equivalized)	3.33	1.39	1.00	5.00	5241
Controls (School characteristics, binary)					
DEIS (Delivering Equality of Opportunity In Schools)	0.12	0.33	0.00	1.00	5452
Fee-paying	0.10	0.30	0.00	1.00	5452
Mixed-school	0.54	0.50	0.00	1.00	5317

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Notes I

- For the analysis, I used the Junior Certificate Overall Performance Scale (OPS), which converts letter grades from different exam levels to a standardized 12-point numerical scale. This scale has been validated in previous research by Nick Sofroniou, Gerry Shiel and Judith Cosgrove (2000), and it provides a comprehensive measure that accounts for both grade and exam level.
- TIPI scale scores on a 1-7 scale in intervals of 0.5, and the original SDQ scales, ranging from 0 to 10, have been inverted (higher scores typically indicate more problems on the original SDQ scale).
- "Cognitive ability 1" was used in the first part of the production function estimation and was standardized to have mean = 0 and standard deviation = 1. "Cognitive ability 2" is to be used in the second part of the analysis as a measure of cognition in non-linear production function estimation, with a mean of 100 and standard deviation = 15 as is standard in the literature.
- Education levels are coded from 1 (Primary or less) to 6 (Postgraduate/Higher degree) in the Growing Up in Ireland caregiver questionnaire. The mean values for both primary (3.97) and secondary (3.86) caregivers indicate an average education level between Leaving Certificate and Diploma/Certificate, suggesting a higher proportion of educated caregivers in the sample.
- Income is reported in quintiles, where 1 represents the lowest 20% and 5 the highest 20% of incomes. The mean of 3.33 suggests that the sample is slightly skewed towards higher income levels, with families on average being just above the median income quintile.
- The sample includes 12% DEIS schools (schools in disadvantaged areas), 10% fee-paying schools, and 54% mixed-gender schools. This suggests a diverse range of school types, with a notably high proportion of fee-paying schools and a relatively low proportion of DEIS schools.

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Notes II

Table: Junior Certificate Overall Performance Scale (OPS)

Higher Level	Ordinary Level	Foundation Level	OPS Score
A			12
B			11
C			10
D	A		9
E	B		8
F	C		7
	D	A	6
	E	B	5
	F	C	4
		D	3
		E	2
		F	1

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Key Concepts

Marginal Products (MPs) indicate how output changes with a small increase in one input, holding others constant. In the Translog model, these effects reflect not just the input level, but also how inputs interact.
Output Elasticities (OEs) capture the percentage change in output from a 1% change in an input. Unlike linear models, Translog allows these elasticities to vary depending on input combinations.
Marginal Rate of Technical Substitution (MRTS) shows how much of one input is needed to offset a reduction in another. In Translog, this rate is flexible — adapting to student skill profiles.
Elasticity of Substitution (ES) measures how easily inputs can replace each other. Translog allows this substitutability to shift depending on the balance of skills.

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Definitions

$$MP_C = A\alpha C^{\alpha-1} N_0^{\beta} \exp\left\{\frac{1}{2}\gamma_1 [\ln(C)]^2 + \frac{1}{2}\gamma_2 [\ln(N_0)]^2 + \gamma_{12} \ln(C)\ln(N_0)\right\}\left[\gamma_1 \ln(C)\frac{1}{C} + \gamma_{12}\frac{\ln(N_0)}{C}\right] \tag{1}$$

$$MP_N = A\beta C_0^{\alpha} N^{\beta-1} \exp\left\{\frac{1}{2}\gamma_1 [\ln(C_0)]^2 + \frac{1}{2}\gamma_2 [\ln(N)]^2 + \gamma_{12} \ln(C_0)\ln(N)\right\}\left[\gamma_2 \ln(N)\frac{1}{N} + \gamma_{12}\frac{\ln(C_0)}{N}\right] \tag{2}$$

$$OE_C = \left.\frac{\partial \ln(Y)}{\partial \ln(C)}\right|_{N=N_0} = \alpha + \gamma_1 \ln(C) + \gamma_{12}\ln(N_0) \tag{3}$$

$$OE_N = \left.\frac{\partial \ln(Y)}{\partial \ln(N)}\right|_{C=C_0} = \beta + \gamma_2 \ln(N) + \gamma_{12}\ln(C_0) \tag{4}$$

$$MRTS_{CN} = \frac{\alpha + \gamma_1 \ln(C) + \gamma_{12}\ln(N)}{\beta + \gamma_2 \ln(N) + \gamma_{12}\ln(C)} \cdot \frac{N}{C} \tag{5}$$

$$\sigma = \frac{OE_C + OE_N}{OE_C + OE_N - \gamma_{12}\left(\frac{OE_C}{OE_N} + \frac{OE_N}{OE_C}\right)} \tag{6}$$

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Theoretical Explanations for Negative Interaction

- **Skill Complementarity with Diminishing Returns**: Skills enhance each other but with decreasing marginal effects at higher levels (Heckman, Stixrud, & Urzua, 2006)
- **Self-Regulatory Resource Theory**: Brain has finite self-regulatory resources; allocation efficiency varies by skill profile (Blair & Raver, 2015)
- **Developmental Compensation Hypothesis**: Students develop compensatory strategies that are especially valuable when one skill domain is weaker (Duckworth & Seligman, 2005)
- **Specialized Skill Utilization**: Students with balanced high skills may not fully utilize both simultaneously in standard academic tasks (Almlund et al., 2011)

Economic and Policy Implications

- **Human Capital Formation Models**: Negative interactions suggest optimal investment strategies should be personalized based on existing skill profiles (Heckman & Kautz, 2012)
- **Critical Periods in Skill Development**: Different skill types may have distinct developmental windows, affecting their interaction efficiency (Moffitt et al., 2011)
- **Differential Returns by Context**: The substitutability between skill types varies by academic domain and demographic factors (Duckworth & Gross, 2014)
- **Policy Implications**: Educational interventions should target specific skill deficits rather than applying uniform approaches; optimal strategy depends on both subject domain and student characteristics

Neurological Perspectives and Implications

- **Neural Efficiency Hypothesis**: Different skill profiles show distinct patterns of brain activation; negative interaction reflects different neural strategies (Posner & Rothbart, 2007)
- **Integration of Emotional and Cognitive Systems**: Neurobiological integration explains trade-offs between skill types (Immordino-Yang & Damasio, 2007)
- **Executive Function as Mediator**: Executive functions mediate how cognitive abilities translate to performance (Zelazo, Blair, & Willoughby, 2016)

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