

Skill Formation with Siblings

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Abstract

This paper investigates the technology of skill formation in children who grow up with siblings. To consider siblings, I introduce a novel variable, named "sibling bond", which reflects how well siblings get along. This variable is constructed using data from the Millennium Cohort Study, specifically focusing on the frequency of positive interactions between siblings, such as enjoying play time together and teasing each other. This allows me to open the black box of sibling spillovers and present evidence that differences in the quality of the sibling bond are associated with persistent inequalities across households in the United Kingdom. I document a socio-economic gradient in the quality of the sibling bond and show that a stronger sibling bond at age 5 predicts better developmental, educational and health outcomes across adolescence. Building on this motivating evidence, I formalize the joint production of skills in families with siblings and structurally estimate the contribution of the sibling bond and parental investment to the formation of the younger and older siblings' skills. The structural estimates reveal that a stronger sibling bond plays a significant role in shaping the skills of both younger and older siblings, even when accounting for parent-child interactions.

JEL codes: J24, I24, I28, J13, O15.

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1 Introduction

More than 75% of children in the United Kingdom have at least one sibling by the age of 5 according to the 2006-wave of Millennium Cohort Study (MCS) data. Similarly, in the United States, 82% of youth aged 18 and under lived with at least one sibling according to the Current Population Survey.¹ As siblings grow up together, they experience everyday interactions and extensive contacts, serving as sources of social support and role models for one another. However, relatively little attention has been devoted to how the relationship and interactions between siblings could be relevant for learning and development, in comparison to the wealth of studies on parent-child interactions (see for example, [Cunha and Heckman \(2007\)](#), [Currie and Almond \(2011\)](#), [Almond, Currie, and Duque \(2018\)](#), [Attanasio, Cattan, and Meghir \(2021\)](#)).

This paper aims to contribute to the literature by bridging two strands of work on: (i) estimating the technology of child development with a *single* child and (ii) the role of siblings. It is well established that parental skill and investment play a very important role for child development by estimating the technology of skill formation with a *single* child ([Cunha and Heckman, 2008](#); [Cunha, Heckman, and Schenbach, 2010](#); [Attanasio, Cattan, Fitzsimons, Meghir, and Rubio-Codina, 2020](#); [Attanasio, Meghir, and Nix, 2020](#); [Agostinelli and Wiswall, 2023](#)).² On the other hand, the joint production of siblings' skills within the family and the role of the relationship between siblings have been understudied.

I therefore study the joint production of human capital for the younger and older siblings during childhood in the United Kingdom. First, I explore the complementarity between siblings' skills in the technology of skill formation, which is assumed away when considering a *single*-child framework. Second, I use information about the frequency of parent-child interactions and sibling interactions to measure respectively parental investment and introduce a new variable the "sibling bond". The sibling bond measures to what extent siblings get along well with each other by combining information on the frequency of, for example, enjoying play time together and teasing each other. This information opens the black box of sibling spillovers by measuring directly quality interactions between siblings and enables me to consider parents as well as siblings in the process of development, studying their contributions to the younger and older siblings' development.

Considering the social capital siblings share via their bond is important for several reasons. For example, a stronger bond enhances siblings' cooperation and connection, fostering their pro-social behavior and effective collaboration. This facilitates the overall functioning of the family and the achievement of common goals, such as the joint development of the siblings' skills. On the other hand, a weaker bond leads siblings to take exploitative actions among themselves, which can be

¹Similar proportions of children with at least one sibling by age 5 are also found in Ethiopia (90%), India (92%), Peru (82%), and Vietnam (77%) according to the Young Lives study. [McHale, Updegraff, and Whiteman \(2012\)](#) point out that in the United States this is a higher percentage than were living in a household with a father figure (78%).

²Another strand of the literature has focused on understanding inequality among siblings, focusing on the role of family size and birth order effects (see for example, [Black, Devereux, and Salvanes \(2005\)](#)). However, it has not considered the possibility that siblings can interact and build a bond that could foster their joint development. The focus has been on parents engaging in reinforcing and compensating investment among siblings ([Behrman, Pollak, and Taubman, 1982](#); [Behrman, 1988](#)), ignoring the possibility that parents can facilitate interactions and relations between siblings through investment and in turn these can contribute to their growth.

detrimental for their human capital formation. I also present two motivating facts to highlight its importance, which suggest that differences in the quality of the sibling bond are associated with persistent inequalities across households. First, there is a socio-economic gradient in the quality of the sibling bond. Second, a stronger bond between siblings at age 5 is predictive of better developmental, educational and health outcomes across the younger sibling's adolescence. Crucially, the richness of the MCS data enables me to document that the quality of the sibling bond primarily reflects the social capital of the sibling relationship rather than capturing their home environment, skills and mother-child relationship.

Building on this motivating evidence, I formalize the joint production of the younger and older siblings' human capital. I consider carefully their multi-dimensionality and study the formation of cognitive (ability to complete tasks and learn), internalizing (ability to focus to pursue long-term goals) and externalizing (ability to collaborate with others) skills (Achenbach, 1966; Achenbach et al., 2016). Structurally estimating the joint technology of skill formation in the presence of siblings is inherently complicated and presents two main methodological challenges: (i) measurement error in the skills and inputs of the joint skill formation technology and (ii) input endogeneity. After having addressed these challenges, the technology of skill formation identifies two structural parameters of interest: the productivity of the sibling bond and parental investment. The main finding of the structural estimation is that a stronger sibling bond contributes to both younger and older siblings' skill formation, even when considering parent-child interactions.

To address the measurement error, I use the Millennium Cohort Study (MCS) data, which follow the lives of a representative sample of children born in years 2000-02 in the United Kingdom. The MCS has administered a set of questionnaires to collect information on the cohort member and the older sibling's development as well as the quality of their interactions.³ I map the information recorded in the MCS questionnaires into latent inputs and outputs of the skill formation technology through a dynamic factor model (Cunha, Heckman, and Schennach, 2010). This provides an effective way to summarize the information from the questionnaires and obtain an efficient measure of the latent inputs and outputs, while setting a metric for measurement and making the latent factors comparable over time and across siblings (Agostinelli and Wiswall, 2023; Freyberger, 2021). I additionally test the scaling assumptions needed in the factor model for comparability between the younger and older siblings' technology of skill formation through a *measurement invariance* test (Vandenberg and Lance, 2000; Putnick and Bornstein, 2016; Wu and Estabrook, 2016). This provides support for setting the same scale for the younger and older siblings, building confidence in the comparison between the structural estimates of their joint technologies of skill formation.

The second challenge is the endogeneity of parental investment and sibling bond. Parents who

³The questions about the quality of interactions between siblings are collected from each sibling pair. Similar questions about sibling interactions - measuring for example the frequency of conflicts between each sibling pair as well as how often they have fun together - are found in the Sibling Relationship Questionnaire developed in psychology by Furman and Buhrmester (1985). To structurally estimate the joint technology of skill formation with siblings, I use the information from the questionnaire about the quality of interactions between the younger and the older sibling for whom data are also collected to measure their socio-emotional development through the Strengths and Difficulties Questionnaire (SDQ) at the age-3 and 5 waves (Goodman, 1997, 2001). If there is more than one older sibling, the MCS randomly administers the SDQ to one of them.

observe a positive shock to child development, which is unobserved by the econometrician, may decide to reinforce or compensate it by changing investment. A similar reasoning applies for a high-quality bond between siblings: children experiencing a positive shock to skills, unobserved by the econometrician, may experience fewer conflicts and more enjoyable time with their siblings. Ignoring the endogeneity of the inputs would likely yield biased estimates of their productivities due to such responses to the unobserved shocks. To address this challenge, I propose two exogenous shifters - local labour market shocks and adjustment costs to housing - that affect the siblings' skills only through parental investment and the sibling bond respectively ([Carneiro, Meghir, and Parey, 2013](#); [Altonji, Cattan, and Ware, 2017](#)). The two shifters I propose are consistent with a model of parental investment, where they never enter the siblings' production function directly. In addition, the richness of the MCS data allows me to condition on a large set of household characteristics, such as household's demographics, resources, social skills and housing arrangement, reinforcing the assumption that any residual variation is quasi-random.

This paper contributes to two strands of the literature on the determinants of skill formation by bridging the work on (i) the estimation of the technology of skill formation with a *single* child and (ii) the role of siblings. In turn, it contributes to a growing evidence highlighting the role of childhood conditions in determining many life course outcomes, such as earnings, well-being and health in developed and developing countries ([Currie and Almond, 2011](#); [Almond, Currie, and Duque, 2018](#); [Attanasio, Cattan, and Meghir, 2021](#)).

First, it contributes to the literature estimating the technology of skill formation ([Cunha and Heckman, 2008](#); [Cunha, Heckman, and Schennach, 2010](#); [Attanasio, Cattan, Fitzsimons, Meghir, and Rubio-Codina, 2020](#); [Attanasio, Meghir, and Nix, 2020](#); [Agostinelli and Wiswall, 2023](#)). This literature presumes a *single* child.⁴ However, families usually have more than one child and siblings interact, as noted by [Francesconi and Heckman \(2016\)](#) and [McHale, Updegraff, and Whiteman \(2012\)](#).⁵ I extend the single-child framework and consider the younger and older siblings' joint technology of skill formation. This allows me to study how parental investment and a quality bond between siblings affect the development of each sibling. Considering parents and siblings in the development process highlights the importance of thinking carefully about the social capital and relationships within the family. Siblings can be important team players, who can help each other achieve common goals within the family, such as their joint production of human capital.⁶

Moreover, this paper thinks carefully about the multi-dimensionality of skills and identifies two

⁴Other examples of estimates for the production function with a *single* child are [Fiorini and Keane \(2014\)](#), [Attanasio, Meghir, Nix, and Salvati \(2017\)](#), [Moroni, Nicoletti, and Tominey \(2019\)](#), [Agostinelli, Saharkhiz, and Wiswall \(2019\)](#), [Attanasio, Bernal, Giannola, and Nores \(2020\)](#), [Gensowski, Landersø, Bleses, Dale, Højen, and Justice \(2020\)](#), [Houmark, Ronda, and Rosholm \(2020\)](#), [Aucejo and James \(2021\)](#), and [Carneiro, Cruz-Aguayo, Pachon, and Schady \(2022\)](#). [Pavan \(2016\)](#) estimates the production function of skill formation to understand the birth order effect in cognitive skill, but does *not* allow siblings to spend time together and interact with each other.

⁵[Del Boca, Flinn, and Wiswall \(2014\)](#) and [Gayle, Golani, and Soytas \(2015\)](#) have started moving in this direction by having a structural model with more than one child, where they allow parents to spend time with both children at the same time, but do not estimate the returns to investment and have to assume that parents know the structure of the production function. Also, [Cunha, Elo, and Culhane \(2013\)](#), [Boneva and Rauh \(2018\)](#) and [Attanasio, Cunha, and Jervis \(2019\)](#) have shown that parents have biased beliefs about the returns to investment.

⁶The importance of teamwork within the family is still understudied, while it has been shown to matter, for example, within the firm ([Weidmann and Deming, 2021](#)).

dimensions of socio-emotional skills (Heckman, Stixrud, and Urzua, 2006; Borghans, Duckworth, Heckman, and Ter Weel, 2008; Heckman, Humphries, and Veramendi, 2018; Humphries, Joensen, and Veramendi, 2019; Papageorge, Ronda, and Zheng, 2019; Attanasio, Blundell, Conti, and Mason, 2020; Attanasio, de Paula, and Toppeta, 2022). Considering cognitive, externalizing and internalizing skills highlights that the formation of skills can be quite complex and different skills can have different processes. For example, studying the contribution of one sibling's externalizing skill to the other sibling's development allows me to investigate whether one sibling is likely to have a high internalizing skill (i.e., introvert) when the other sibling has a high externalizing skill (i.e., extrovert) and vice versa.

Second, there is a growing interest in understanding the role played by siblings, which has mostly focused on quantifying spillovers among siblings, noting that their identification is complicated. For example, Altonji, Cattan, and Ware (2017) assess the extent to which the correlations in substance use between siblings are causal. Altmejd et al. (2021) provide evidence from Chile, Croatia, Sweden, and the United States that older siblings affect the college and major choice of the younger sibling.⁷ However, these papers have not attempted to measure the sibling bond directly, even if a strong sibling bond can be conducive of the sibling spillovers and contribute to development in the early years. My paper aims to fill this gap by measuring the strength of the sibling bond directly and quantifying to what extent their bond contributes to human capital development in the early years.

My estimates also complement the literature on the trade-off between the quantity and quality of children, which examines if parents decrease their investments per child when increasing the quantity of children (Becker and Lewis, 1973; Willis, 1973; Becker and Tomes, 1976). I show that a quality bond between siblings can spur development, offering another possible explanation for why there is limited evidence of such trade-off (Black, Devereux, and Salvanes, 2005, 2010; Cáceres-Delpiano, 2006; Angrist, Lavy, and Schlosser, 2010; Åslund and Grönqvist, 2010; De Haan, 2010; Briole, Le Forner, and Lepinteur, 2020). In turn, this paper also connects to the literature on intra-household inequality in human capital. I highlight the possibility that children can interact and a strong relationship can foster both siblings' skills. It is in turn plausible that parents could facilitate such interactions between siblings through investments aimed at encouraging pro-social actions between siblings. The literature has, instead, focused on parents engaging mainly in reinforcing or compensating investment for inequality among siblings (Behrman, Pollak, and Taubman, 1982;

⁷Other examples are Gurantz, Hurwitz, and Smith (2020) on taking advanced placement (AP) classes in the United States, Joensen and Nielsen (2018) on choosing advanced math and science subjects in high school, Dahl et al. (2020) on choosing a field of study, Qureshi (2018) and Nicoletti and Rabe (2019) on school achievement respectively in North Carolina (USA) and England. Spillovers have been documented also related to the older sibling's cognitive skill (Dai and Heckman, 2013), to sibling's gender considering the younger sibling's gender plausibly exogenous (Butcher and Case, 1994; Cools and Patacchini, 2019; Brenøe, 2021; Dudek et al., 2022) or the older sibling's gender plausibly exogenous (Jakiela, Ozier, Fernald, and Knauer, 2020), and to having a disabled younger sibling (Black et al., 2021).

[Behrman, 1988\)](#).⁸

The psychology and child development literature has also studied parent-child interactions by focusing on how environmental factors contribute to development, but now the focus is shifting to explore sibling relationships and interactions ([McHale, Updegraff, and Whiteman, 2012](#)).⁹ Similarly, the anthropology literature has investigated the role of interactions between siblings for child development, highlighting that the older sibling could engage in care-taking interactions with the younger sibling (see for example [Weisner et al. \(1977\)](#) and [Lancy \(2014\)](#)). Unfortunately, these studies are characterized by a small (and sometimes selected) sample and overlook the endogeneity of parental investment and sibling bond.

This paper is organised as follows. Section 2 presents some motivating evidence on the importance of the sibling bond in the study of child development. This section also presents a theoretical framework to understand parental decision and the joint production of skills in the presence of siblings. Section 3 presents the dynamic factor model to measure the latent inputs and outputs of the joint technology of skill formation. Section 4 presents the structural estimates of technology of skill formation for the younger and older siblings. Section 6 summarizes the results and concludes.

2 The Joint Production of Skills with Siblings

This section discusses the role of siblings to understand the joint production of human capital in families with siblings. First, I present some motivating evidence on the importance of the sibling bond to understand skill formation. This evidence suggests that differences in the strength of the sibling bond are associated with persistent inequalities across households. Second, I extend the theoretical framework of child development to include more than one child in the family. Siblings can interact with each other and parents can facilitate the sibling relationship through investments that encourage pro-social actions and discourage exploitation between siblings. Third, I formalize the joint production of human capital in a family with siblings. Finally, I discuss how to think about the endogeneity of the inputs.

⁸Evidence is mixed on whether parents engage in compensating or reinforcing investment, finding evidence for reinforcing behaviour ([Behrman, Rosenzweig, and Taubman, 1994](#); [Aizer and Cunha, 2012](#); [Frijters, Johnston, Shah, and Shields, 2013](#); [Adhvaryu and Nyshadham, 2016](#); [Grätz and Torche, 2016](#)), for compensating behaviour ([Frijters, Johnston, Shah, and Shields, 2009](#); [Del Bono, Ermisch, and Francesconi, 2012](#); [Bharadwaj, Eberhard, and Neilson, 2018](#)) or mixed or no effect ([Ayalew, 2005](#); [Almond and Currie, 2011](#); [Yi, Heckman, Zhang, and Conti, 2015](#)).

⁹Some examples of studies in psychology and child development on the role of sibling interaction and direct influence on children's development outcomes are [Maynard \(2002\)](#), [Howe, Rinaldi, Jennings, and Petrakos \(2002\)](#), [Stocker, Burwell, and Briggs \(2002\)](#), [Bank, Burraston, and Snyder \(2004\)](#) and [Sun, McHale, and Updegraff \(2019\)](#). The psychology literature has also proposed two alternative theories on the role of sibling interactions and bond in the context of adjustment problems and risky behaviour. On the one hand, [Patterson \(1984\)](#) argues that siblings take up risky behaviors when their relationships are aggressive and ridden with conflicts as these promote antisocial behaviour. On the other hand, [Buhrmester, Boer, and Dunn \(1992\)](#) and [Rodgers and Rowe \(1988\)](#) argue that siblings provide opportunities to each other for substance use and this channel is more likely to be present when the siblings have a positive relationship. My paper tests these two alternative hypotheses, finding supporting evidence on the former by showing that a higher quality bond between siblings at age 5 is predictive of a lower probability that the younger sibling smokes cigarettes at ages 14 and 17 and higher socio-emotional development across adolescence

2.1 Motivating Evidence on the Role of Siblings for Skill Formation

Siblings play a vital role within the family unit. As they grow, they often spend more time with their siblings than with their parents, highlighting the importance of exploring the sibling bond beyond the parent-child bond. A strong and positive bond between siblings can have numerous benefits. It can foster pro-social actions, discouraging exploitation and promoting a sense of cooperation. This, in turn, enables siblings to work together more effectively.

To measure the strength of the sibling bond, I use a unique battery of questions on the quality of the interactions between siblings contained at the age-5 wave of the Millennium Cohort Study (MCS). The MCS is a survey following a representative sample of children in the United Kingdom from their birth in 2000-02 to age 17. Parents are asked to answer the following 4 questions about how often [frequently, sometimes, never] the cohort member (i.e., the younger sibling): (i) likes to be with the older sibling, (ii) not much interested in the older sibling, (iii) has a lot of fun with the older sibling, (iv) teases or needles the older sibling. The behaviours indicating worse interactions are recoded in reverse (i.e., not much interested in older sibling and teases or needles older sibling).

As a first step, to construct an index of the sibling bond, I sum the values from all questions and standardize the index to have mean 0 and standard deviation 1. I then present evidence on two motivating facts that justify the importance of the sibling bond in the study of skill formation.

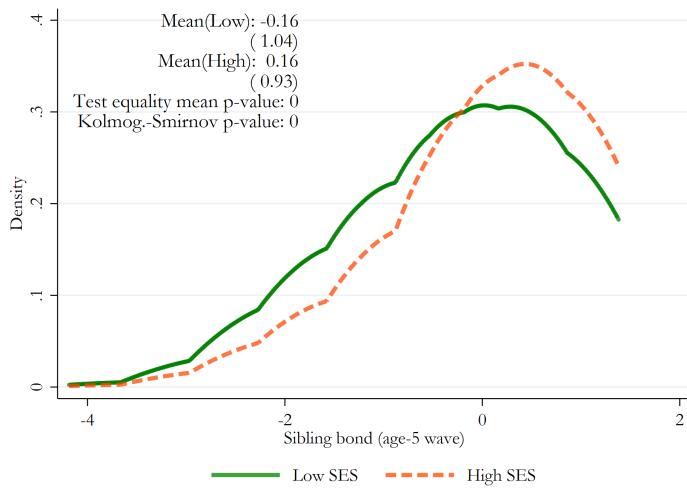
First, there is a socio-economic gradient in the quality of the sibling bond. Figure 1 defines the socioeconomic status (SES) as the mother continuing schooling past the minimum leaving age, based on her date of birth.¹⁰ Siblings from low-educated mothers experience a weaker bond than siblings from high-educated mothers. Figure 1 also shows the *p*-values from the t test on the equality of means (assuming unequal variances) and the Kolmogorov-Smirnov test on the equality of the sibling bond distributions. Both the means and the distributions of the sibling bond are statistically different by mother's education.

Second, the sibling bond at age 5 predicts the younger sibling's developmental, educational and health outcomes across adolescence as shown in Table 1 and Figure 2. This prediction exercise is robust to a large set of controls. The MCS is indeed well-suited to address this question because it contains, for example, information on demographic characteristics, such as mother's education, age, employment, housing arrangements, but also information on mother's mental health and how close the relationship is between the mother and child.

More importantly, the MCS contains very rich information on the home environment, proxied by parental investment, parenting style and joint activities done at the family level and with extended family. Finally, it has information on the socio-emotional skills of both siblings involved in the relationship, allowing me, for example, to show that the sibling bond matters over and beyond the ability of both siblings to make friends outside of the household or focus attention on at least one

¹⁰The cumulative distribution function of the sibling bond by mother's education is presented in Appendix Figure A1. A socio-economic gradient is found in each item used to measure the sibling bond (Appendix Figure A2). The socio-economic gradient is also found when the quality of the sibling bond is residualized by the older sibling's age (Appendix Figure A3). Similar results for the socio-economic gradient in the sibling bond are found if the socio-economic status is defined as a dummy equal to 1 if the mother was smoking during pregnancy (Appendix Figures A4 and A5). Appendix Figure A6 presents the socio-economic gradient in parental investment.

Figure 1: Socio-economic gradient (mother's education) in the quality of the sibling bond



Note. The Figure presents the socioeconomic gradient in the quality of the sibling bond at age 5. The socioeconomic status (SES) is the mother's education at the age-5 wave (dummy for whether the mother continued schooling past the minimum leaving age, based on her date of birth). The index of the sibling bond is constructed by summing the values from the following 4 questions about how often [frequently, sometimes, never] the cohort member (i.e., the younger sibling): (i) Likes to be with the older sibling, (ii) Not much interested in the older sibling, (iii) Has a lot of fun with the older sibling, (iv) Teases or needles the older sibling. The index of sibling bond is standardized to have mean 0 and standard deviation 1. I recode behaviours indicating worse interactions in reverse (i.e., not much interested in older sibling and teases or needles older sibling). Higher scores correspond to better quality bonds. I report the means of the quality of the sibling bond by socioeconomic gradient and their standard errors between parentheses. The distribution is estimated nonparametrically, using an Epanechnikov kernel. I report the *p*-value of a t test on the equality of means between the two groups assuming unequal variances. I report the *p*-value from the Kolmogorov-Smirnov test on the equality between the distributions by socioeconomic gradient.

good friend. The full list of controls is in the note of Table 1 and Figure 2.

Focusing on the younger sibling's educational outcomes at age 17, Panels A and B of Table 1 consider the grades in the GCSE Math and English exams, studying for an A-level qualification and educational aspiration to study at university.¹¹ Table 1 documents that a higher quality bond between siblings is predictive of better educational outcomes. In particular, a stronger sibling bond is associated with a higher grade in the English exam and a higher probability of studying for an A-level qualification, which is required to enrol in university. These results are also consistent with a higher aspiration to study at university (Column 8 of Panel B in Table 1).

Turning to the younger sibling's health outcomes at ages 14 and 17, Panel C of Table 1 documents that siblings with a stronger bond at age 5 are less likely to smoke cigarettes. The effect of the sibling bond on the probability of smoking is persistent, predicting a lower probability of smoking at ages 14 and 17. This finding is consistent with the psychology theory by Patterson (1984), who argues that siblings take up risky behaviors, such as smoking, when the sibling relationship is ridden with conflicts and aggressive as these promote antisocial behaviour.

¹¹GCSE stands for the General Certificate of Secondary Education which is a qualification in a specific subject typically taken by school students aged 14-16 and is pre-requisite to study for an A-level qualification. It corresponds to high school diploma in the United States. Students who plan to go to university study for an A-level qualification.

Table 1: Age-5 sibling bond and younger sibling's educational and health outcomes during young adulthood

Panel A:

Outcome	Grade GCSE Math				Grade GCSE English			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Sibling bond (age 5)	0.314*** (0.038)	0.157*** (0.050)	0.149*** (0.051)	0.074 (0.050)	0.282*** (0.035)	0.129*** (0.047)	0.130*** (0.048)	0.095** (0.046)
Observations	3235	2024	1963	1909	3238	2035	1970	1918
R ²	0.026	0.145	0.145	0.259	0.025	0.143	0.142	0.270
Younger & older sib's skills (age-3 wave)	✓	✓	✓		✓	✓	✓	
Parental investment (age-5 wave)		✓	✓			✓	✓	
Other controls			✓				✓	

Panel B:

Outcome	Study for an A-level qualification (age 17)				Aspiration to study at University (age 17)			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Sibling bond (age 5)	0.063*** (0.010)	0.035*** (0.013)	0.035*** (0.014)	0.019 (0.013)	5.493*** (0.858)	3.304*** (1.135)	3.339*** (1.151)	2.375** (1.133)
Observations	3475	2164	2088	2026	2651	1649	1590	1549
R ²	0.015	0.091	0.090	0.172	0.021	0.115	0.109	0.185
Younger & older sib's skills (age-3 wave)	✓	✓	✓		✓	✓	✓	
Parental investment (age-5 wave)		✓	✓			✓	✓	
Other controls			✓				✓	

Panel C:

Outcome	Smoke cigarettes (age 14)				Smoke cigarettes (age 17)			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Sibling bond (age 5)	-0.038*** (0.007)	-0.022** (0.010)	-0.021** (0.010)	-0.017* (0.010)	-0.030*** (0.010)	-0.035*** (0.013)	-0.036*** (0.014)	-0.026* (0.014)
Observations	4298	2599	2510	2435	3827	2340	2260	2192
R ²	0.011	0.036	0.033	0.057	0.003	0.012	0.015	0.035
Younger & older sib's skills (age-3 wave)	✓	✓	✓		✓	✓	✓	
Parental investment (age-5 wave)		✓	✓			✓	✓	
Other controls			✓				✓	

Note. The table presents the relationship between the age-5 sibling bond and the younger sibling's educational and health outcomes at ages 14 and 17. The index of the sibling bond is constructed by summing the values from the following 4 questions about how often [frequently, sometimes, never] the cohort member (i.e., the younger sibling): (i) Likes to be with the older sibling, (ii) Not much interested in the older sibling, (iii) Has a lot of fun with the older sibling, (iv) Teases or needles the older sibling. I recode behaviours indicating worse interactions in reverse (i.e., not much interested in older sibling and teases or needles older sibling). The index of parental investment in younger sibling is obtained by summing the values from the questions asking the parents how often [Every day, Several times a week, Once or twice a week, Once or twice a month, Less often, Not at all] they do the following activities: (i) How often do you read to the child, (ii) How often tells stories to the child, (iii) How often does musical activities with the child, (iv) How often does the child paint/draw at home, (v) How often do you play physically active games with the child?, (vi) How often play indoor games with the child? and (vii) How often play outdoor games with the child? (viii) How often family does indoor activities together (ix) How often child sees grandparents (x) How often child sees other relatives (xi) How often child spends time with friends outside school (xii) How often ignores child when naughty (xiii) How often shouts at child when naughty (xiv) How often sends child to bedroom/naughty chair (xv) How often takes away treats from child when naughty (xvi) How often tells child off when naughty (xvii) How often bribes child when naughty (xviii) How often tries to reason with child when naughty (xix) How often makes sure child obeys instruction/request (xx) how close the bond between mother and child is. The sibling bond index is standardized to have mean 0 and standard deviation 1. Other controls include younger sibling's gender, age gap between younger and older sibling, older sibling's gender, number of children in the house, mother's mental health, mother's education, mother's age, whether the household is dual or single headed, partner's employment status, home atmosphere, housing tenure, years lived in current address, region fixed effects. Internalizing skill captures the ability to focus their drive and determination to pursue a long-term goal. Externalizing skill captures the ability to engage in interpersonal activities. Robust standard errors in parentheses (***) p<0.01, ** p<0.05, * p<0.1).

Figure 2 shows that a stronger sibling bond at age 5 predicts better developmental outcomes across the younger sibling's adolescence. In this analysis, I pay particular attention to the multi-dimensionality of skills and consider three dimensions of development: *externalizing* (ability to engage in interpersonal activities), *internalizing* (ability to focus determination in pursuit of long-term goals) and *cognitive* (ability to learn and solve tasks) skills (Achenbach, 1966; Achenbach et al., 2016). I use a battery of cognitive tests administered by the interviewer to measure cognitive skills, and the Strengths and Difficulties Questionnaire (SDQ) to measure externalizing and internalizing skills (Goodman, 1997; Goodman, Lampung, and Ploubidis, 2010).

The point estimates from regressing the age-5 sibling bond on developmental outcomes across adolescence are presented in Figure 2. The blue dots are the point estimates from such regression without any controls. On the other hand, the red triangles are the point estimates after conditioning on all the controls listed in the notes of Figure 2, aiming at reducing the gap in family characteristics of siblings with different bond qualities. The sibling bond at age 5 is associated with higher externalizing, internalizing and cognitive development at ages 5, 7, 11, 14, and 17. For example, an increase in one standard deviation in the quality of the sibling bond at age 5 is associated with an increase in 0.1 standard deviation in the externalizing skill at age 17 (red triangles). Importantly, it is worth noting that the decline in the coefficient of the sibling bond is primarily driven by the the younger and older siblings' skills in the previous wave. Interestingly, even when considering other factors, such as the home environment, parental resources and the mother-child bond, these additional controls no longer have a substantial effect on the coefficient.

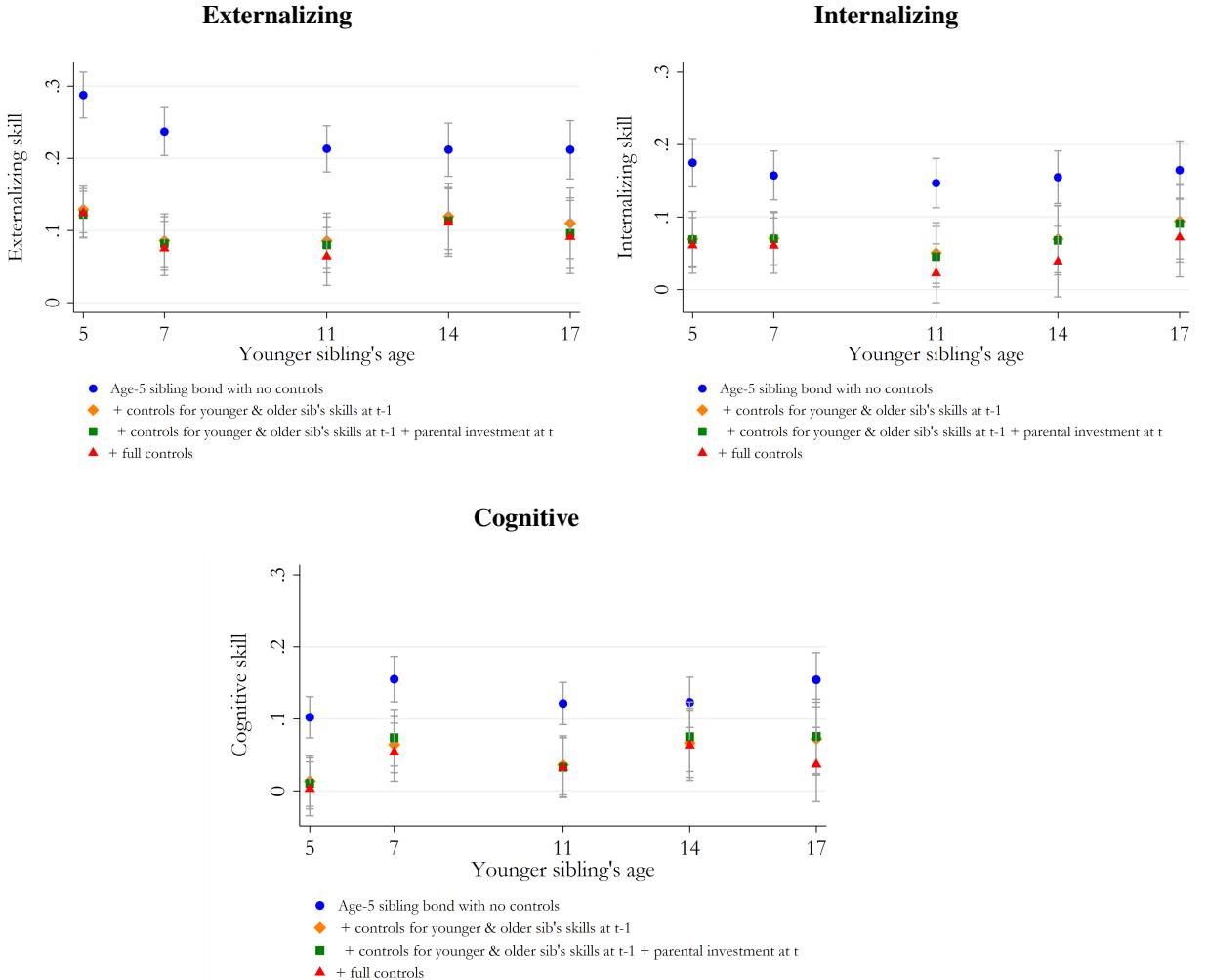
Finally, Appendix Table A1 investigates some possible mediators of these findings. I explore if younger siblings with a stronger sibling bond at age 5 are more likely to have a positive relationship and talk to their siblings in the future. Columns 4 and 5 of Appendix Table A1 show that when children are worried about something, they are more likely to speak to their sibling than to their parents. This result is suggestive that the sibling relationship at age 5 is the base for long-term relationship that is likely to last. The positive relationship between siblings also seems to spillover to other relationships. Namely, a higher quality bond with the older sibling at age 5 is predictive of fewer arguments between the younger sibling and the parents at age 14 (Column 3 of Appendix Table A1).¹²

Overall, these results suggest that younger siblings, who experience more positive interactions with their older siblings, are more likely to develop better skills over the life cycle and achieve better educational and health outcomes.¹³ This effect may also be amplified in the future as high socio-economic status parents are more likely to have more than one child (Doepke, Hannusch,

¹²A limitation of the MCS dataset is that it does not contain longitudinal data on the sibling bond. However, the results in Appendix Table A1 suggests that a strong sibling at age 5 is the base for a long-term positive relationship between siblings (Column 4).

¹³One may wonder if the result on the predictive power of the sibling bond on future outcomes presented in Table 1 is driven by the selected sample of children with siblings. Appendix Table A2 investigates such concern and reproduces Table 1 for the full sample (i.e., children with and without siblings), where observations for the sibling bond and older sibling's social skills are replaced respectively with the minimum and maximum level of the sibling bond and siblings' social skills when the child does not have a sibling. I then control for the number of siblings and a dummy variable equal to 1 if the child is a single child. The estimates presented in Appendix Table A2 are robust and similar to the ones in Table 1.

Figure 2: Age-5 sibling bond and younger sibling's development across adolescence



Note. The Figures present the point estimates and the respective confidence intervals at 95% level from regressing the age-5 sibling bond on the younger sibling's developmental outcomes at ages 5, 7, 11, 14, and 17. The point estimates on the y-axis are in standard deviation units as the sibling bond and developmental outcomes are standardized to have mean 0 and standard deviation 1. The three dimensions of development considered are: externalizing (ability to engage in interpersonal activities), internalizing (ability to focus their drive and determination to achieve long-term goal) and cognitive skills (ability to complete tasks and learn). Internalizing and externalizing skills are measured with the Strengths and Difficulties Questionnaire (SDQ) (Goodman, 1997; Goodman, Lampung, and Ploubidis, 2010). Cognitive skills are measured with a battery of tests, such as the British Ability Scales II (BAS II). The index of the sibling bond is constructed by summing the values from the following 4 questions about how often [frequently, sometimes, never] the cohort member (i.e., the younger sibling): (i) Likes to be with the older sibling, (ii) Not much interested in the older sibling, (iii) Has a lot of fun with the older sibling, (iv) Teases or needles the older sibling. I recode behaviours indicating worse interactions in reverse (i.e., not much interested in older sibling and teases or needles older sibling). The index of parental investment in younger sibling is obtained by summing the values from the questions asking the parents how often [Every day, Several times a week, Once or twice a week, Once or twice a month, Less often, Not at all] they do the following activities: (i) How often do you read to the child, (ii) How often tells stories to the child, (iii) How often does musical activities with the child, (iv) How often does the child paint/draw at home, (v) How often do you play physically active games with the child?, (vi) How often play indoor games with the child? and (vii) How often play outdoor games with the child? (viii) How often family does indoor activities together (ix) How often child sees grandparents (x) How often child sees other relatives (xi) How often child spends time with friends outside school (xii) How often ignores child when naughty (xiii) How often smacks child when naughty (xiv) How often shouts at child when naughty (xv) How often sends child to bedroom/naughty chair (xvi) How often takes away treats from child when naughty (xvii) How often tells child off when naughty (xviii) How often bribes child when naughty (xix) How often tries to reason with child when naughty (xx) how close the bond between mother and child is. Full controls include the younger and older siblings' skills at the age-3 wave, parental investment, younger sibling's gender, mother's mental health, mother's education, mother's age, whether the household is dual or single headed, partner's employment status, number of children, age gap between younger and older sibling, older sibling's gender, housing tenure, years lived in current address, home atmosphere, and region fixed effects.

(Kindermann, and Tertilt, 2022). However, a plausible concern regarding this evidence, and more generally about considering the sibling bond in the study of child development, is that the sibling bond may be capturing how stimulating the home environment is rather than what happens between siblings. Appendix A.2 exploits the richness of the MCS data and provides three pieces of evidence, summarized below, that the sibling bond measure is intrinsically related to the interactions between the siblings rather than a stimulating home environment.

First, Appendix Table A3 presents the correlations between the sibling bond and some home environment factors, such as parental investment, mother's mental health, and the quality of mother-child bond. These correlations are low and usually below 0.20. For example, the correlation between the sibling bond and the mother-child bond is 0.11, hinting that the sibling bond is not capturing the relationship that the children have with their mother. Second, I present evidence that the sibling bond is not measuring the children's social skills. Appendix Figure A7 shows that there are children with poor social skills, who still have quality interactions with their siblings, as well as siblings with good social skills, who have low quality interactions with their siblings. Third, I study the correlations among the questions used to construct the two latent measures with an exploratory factor analysis, discussed in detail in Section 3.2.1, and show that the sibling bond and parental investment are capturing two different inputs.

2.2 Theoretical Framework

This Section presents a stylized model to highlight the trade-off faced by family i when deciding how to invest in the joint production of their children's human capital. The model is useful to derive the investment functions, which support the economic restrictions consistent with the exclusion restriction discussed in detail in Section 2.4.

In standard models of parental human capital investment, it is assumed that parents care about their own consumption C_i and the development of a *single* child θ_i (see for example Attanasio (2015)). I augment this standard framework by considering parents with *two* children and allowing for the possibility that parents can create quality interactions and foster good relations between siblings. Siblings in turn can interact with each other.

I begin by defining human capital and pay particular attention to its multi-dimensionality by specifying three skill dimensions for each child c in family i at time t :

$$\theta_{cit} = H_t(\theta_{cit}^{EXT}, \theta_{cit}^{INT}, \theta_{cit}^{COG}) \quad c = Y, O$$

Where θ_{cit} is a vector with the three dimensions of human capital: internalizing (INT), Externalizing (EXT), and Cognitive (COG) skills for the younger, Y , and older, O , siblings. I formulate this problem as static and omit t from the model below to highlight the trade-off during this developmental stage.¹⁴

¹⁴It is possible to extend the model to multiple periods, where parents enjoy utility at different point at times, for example, to highlight the role of liquidity constraints or windows of opportunities in investment. I keep the model simple to stress the role of siblings in the joint production of human capital.

Parents' choices on how to invest in the younger sibling (Y) and older (O) siblings' human capital have two distinct features. First, parents invest in activities specific to one of the two siblings. Second, they can promote activities that involve both siblings and can improve their interactions and relationship. The parents of siblings Y and O can allocate their available time to work, L_i , as well as different types of activities that promote the development of the child: parental investment in the younger sibling $I_{Y,i}$, parental investment in the older sibling $I_{O,i}$ and actions SI_i aimed to foster the sibling bond SB_i (equation 1). w_i and y_i in the budget constraint are respectively the wage and the non-work income (equation 2).¹⁵

Parents' actions to facilitate sibling interactions, SI_i , do not have to always correspond to forming a strong sibling bond, SB_i (equation 3). The assumption of a deterministic relationship between parents and siblings' actions would be problematic because parents could try to facilitate relations between siblings, but siblings may decide *not* to bond for reasons outside of the parents' control. I capture this in equation (3) by defining the sibling bond SB_i as a function of parents' actions, SI_i , and an idiosyncratic shock to siblings' actions, e_i , which is outside of the parents' control.¹⁶

Parents optimize the expected utility function of consumption and siblings' human capital, while facing a resource constraint and joint technological constraints that map the investment choices, the level of skills at beginning of the period ($\theta_{i,0}$) and developmental shocks onto younger and older siblings' outcomes at the end of the period ($\theta_{Y,i,1}$ and $\theta_{O,i,1}$ in equations 4 and 5). Parents take the level of skills at beginning of the period, generated by their past investments, as given in the joint technology of skill formation.

$$\max_{C_i, I_{Y,i}, I_{O,i}, SI_i} EU(C_i, \theta_{Y,i,1}, \theta_{O,i,1})$$

Subject to

$$L_i = 1 - I_{Y,i} - I_{O,i} - SI_i \quad (1)$$

¹⁵In the current framework, I abstract from monetary investments that help children acquire skills, but the model could be easily extended to accommodate them. The budget constraint with monetary investment would become the following: $y_i + w_i L_i = C_i + p M_i$. The monetary investment M_i would then be an additional input in the production function and p is the price of the monetary investment. I abstract from monetary investment because the measures of parental investment in the MCS refer to parent-child interactions, with a focus on time investment in children rather than material investment.

¹⁶Appendix B extends the current framework, allowing siblings to interact with each other, to suggest how the sibling bond is formed. In the extension of the model, parents propose an interaction, SI_i , to the siblings with a certain payoff (for example, a drawing competition where siblings can interact over it). The sibling bond, SB_i , originates from siblings taking actions and interacting over the proposed activity, SI_i , to maximize their pay-off in a non-cooperative game where they best responding to each other. The timing of this game could be simultaneous or dynamic. It could be more reasonable to think about these interactions as a dynamic Stackelberg game where the older sibling takes the first action, acting as a leader, and then the younger sibling follows. This extension of model resembles the literature on role model (see for example Bell, Chetty, Jaravel, Petkova, and Van Reenen (2019)). A similar extension to a dynamic Stackelberg game is considered in Del Boca, Flinn, Verriest, and Wiswall (2019) who instead study a model of child development where parents and children can invest in human capital with partially altruistic parents acting as the Stackelberg leader and a child being the follower in setting their study time.

$$y_i + w_i L_i = C_i \quad (2)$$

$$SB_i = h(SI_i, e_i) \quad (3)$$

$$\theta_{Y,i,1} = f(\theta_{Y,i,0}, \theta_{O,i,0}, I_{Y,i}, SB_i, \mathbf{X}_i, v_{Y,i}) \quad (4)$$

$$\theta_{O,i,1} = g(\theta_{Y,i,0}, \theta_{O,i,0}, I_{O,i}, SB_i, \mathbf{X}_i, u_{O,i}) \quad (5)$$

To solve the parents' optimization problem, I define the parents' preferences and the functional form of the joint technology of skill formation. Regarding parents' preferences, parents are altruistic and care about their own consumption and their children human capital as follows:

$$EU(C_i, \theta_{Y,i,1}, \theta_{O,i,1}) = EU(C_i) + \alpha EU(\theta_{Y,i,1}, \theta_{O,i,1})$$

with α being a parameter capturing altruism (Becker and Tomes, 1979, 1986). The utility of siblings' skills is assumed to be Constant Elasticity of Substitution (CES) in the literature on intra-household allocation with the following specification, $U(\theta_{Y,i,1}, \theta_{O,i,1}) = (a(\theta_{Y,i,1})^\kappa + b(\theta_{O,i,1})^\kappa)^{\frac{1}{\kappa}}$, to consider the productivity-equity trade-off within the family (e.g., Behrman et al. (1982) and Behrman (1988)). If the utility is linear ($\kappa = 1$), then there are no inequality concerns between siblings. On the other hand, parents try to equalize the siblings when the utility function is Leontief ($\kappa \rightarrow \infty$). Parents will trade off between equity and efficiency concerns between these two extreme cases by compensating or reinforcing differences in siblings' skills. This theoretical framework extends previous models by allowing siblings to interact and build a bond with each other. In turn, this sibling bond could benefit both siblings' development.

From this problem, it is possible to derive the following investment policy functions, which determine parental choices:

$$I_{Y,i}^* = l_t(\theta_{Y,i,0}, \theta_{O,i,0}, y_i, w_i, \mathbf{X}_i, \epsilon_{Y,i})$$

$$I_{O,i}^* = m_t(\theta_{Y,i,0}, \theta_{O,i,0}, y_i, w_i, \mathbf{X}_i, \epsilon_{O,i})$$

$$SI_i^* = n_t(\theta_{Y,i,0}, \theta_{O,i,0}, y_i, w_i, \mathbf{X}_i, \epsilon_i)$$

The investment equations are a function of preference parameters, productivity parameters, younger and older siblings' development at the beginning of the period, income y_i , wages w_i and idiosyncratic shocks $\epsilon_{Y,i}$, $\epsilon_{O,i}$, and ϵ_i , which are a function of idiosyncratic shocks to each sibling's development. These shocks can be correlated within the family. The sibling bond, SB_i^* , is in turn a function of a shock e_i and SI_i^* , which depend among other things on the younger and older siblings'

skills, suggesting for example that the parents' ability to improve the quality of the interactions between siblings depends on how similar/close the two siblings are.

This stylized model of parental investment guides the choice of instruments that could satisfy the exogeneity condition, providing the *sufficient* conditions for the excluded instruments to be valid and consistent with economic theory. It is possible to infer from the model that the excluded instruments are variables that do not enter the child's human capital production function directly, but affect the child's human capital only through the budget constraint. These variables correspond to measures related to wages and non-labor income. These conditions are, however, only sufficient as the model cannot capture every possible response to unobserved shocks by the household. Section 2.4 discusses in detail the *necessary* conditions for the instruments to be valid and affect the child's human capital only through parental investment and the sibling bond respectively.

2.3 The Joint Technology of Skill Formation with Siblings

This Section describes the technology of skill formation for the younger (Y) and older (O) siblings estimated in the paper (equations 6 and 7). Appendix D.4 experiments with different specifications, such as a translog production function to capture different degrees of substitutability between inputs. The data, however, do not reject the Cobb-Douglas specification. I present the Cobb-Douglas functional form below.

$$\ln(\theta_{Y,it}^S) = \sum_S \beta_{1S} \ln(\theta_{Y,it-1}^S) + \sum_S \beta_{2S} \ln(\theta_{O,it-1}^S) + \beta_{3S} \ln(SB_{it}) + \beta_{4S} \ln(I_{it}) + \mathbf{X}'_{it} \eta_S + v_{Y,it}^S \quad (6)$$

Where t represents age-5 wave and $(t - 1)$ represents the age-3 wave. Skills S are internalizing (INT), Externalizing (EXT), and Cognitive (COG) skills. I_{it} and SB_{it} represent respectively parental investment and the sibling bond.¹⁷ As I am considering the joint process of skill formation with siblings, I include the younger and older siblings' internalizing and externalizing skills at time $t - 1$ on the right hand side to consider that children with higher social skills could have more positive interactions with each other. I also control for the younger sibling's cognitive skill in the previous period, while I cannot do that for the older sibling as the MCS does not collect data on the older sibling's cognitive development.¹⁸ Finally, X_{it} is a vector of environmental factors that may affect child development. These include the younger sibling's gender, age gap between younger and older sibling, older sibling's gender, number of children in the house, mother's mental health, mother's education, mother's age, whether the household is dual or single headed, housing tenure, years lived in current address, local employment at the local authority where family lives, and

¹⁷Various measures of parental investments can be constructed, each capturing different dimensions such as investment in individual children and joint activities, as explained in the model outlined in Section 2.2. For the purpose of estimation, a comprehensive measure of parental investment is constructed, encompassing multiple dimensions of the home environment, including quality interactions, parenting style, joint family activities, interactions with extended family, and the mother-child bond. This approach is adopted to avoid the need for multiple exogenous instruments, as discussed in Section 2.4, which would be necessary to identify several dimensions of investment separately.

¹⁸Data on cognitive skills are available only for the younger sibling (i.e., the cohort member of the MCS), while data on social skills were collected from one randomly-selected older sibling if there is more than one older sibling.

region fixed effects. $v_{Y,it}$ is an idiosyncratic shock observed by the parents, but unobserved by the econometrician. The parameters of interest, β_{3S} and β_{4S} , capture the productivity of the sibling bond and parental investment for each skill S .

The technology of skill formation for the older siblings can be similarly defined:

$$\ln(\theta_{O,it}^S) = \sum_S \omega_{1S} \ln(\theta_{Y,it-1}^S) + \sum_S \omega_{2S} \ln(\theta_{O,it-1}^S) + \omega_{3S} \ln(SB_{it}) + \omega_{4S} \ln(I_{it}) + \mathbf{X}'_{it} \varphi_S + u_{O,it}^S \quad (7)$$

The parameters of interest, ω_{3S} and ω_{4S} , capture the productivity of the sibling bond and parental investment for each skill S . There are two caveats to keep in mind due to data limitations. First, only two dimensions of socio-emotional development can be considered as the older sibling was not the target child of the MCS. Second, data are collected from the older siblings at different ages, so it is not possible to define a production function of child development at a specific age. The technology of child development controls for the older sibling's age.

The structural estimation of equations (6) and (7) presents two key methodological challenges discussed in Sections 2.4 and 3 respectively.

2.4 Investment Functions: Endogeneity of Parental Investment and Sibling Bond

A challenge researchers encounter when estimating the technology of child development is that inputs are likely to be correlated with unobserved shocks to child development (Cunha, Heckman, and Schennach, 2010; Attanasio, Cattan, Fitzsimons, Meghir, and Rubio-Codina, 2020; Attanasio, Meghir, and Nix, 2020).¹⁹ Parents and siblings may adjust their actions, depending on developmental shocks to human capital, making the inputs endogenous. For example, parents may adjust their investment at time t in response to unobserved shocks that affect their choices as well as the level of development, $\theta_{Y,it}^S$. Similarly, siblings experiencing a positive shock to social skills, unobserved by the econometrician, may be more likely to have positive interactions and fewer conflicts with their siblings. Ignoring this endogeneity problem would provide biased estimates of the productivity of parental investment and the sibling bond in the technology of skill formation.

Ideally, to address this problem, I would need random assignment of parental investment and the sibling bond to the child, but of course this is not always feasible. A feasible alternative is instead to resort to an instrumental variable approach motivated by the model of parental investment from Section 2.2, which derives the economic restriction consistent with the exogeneity condition.

These investment functions can in principle be computed numerically by solving the dynamic problem faced by parents, as in Del Boca, Flinn, and Wiswall (2014) and Gayle, Golan, and Soytas (2015). This approach would require stronger assumptions about parental behavior, such as requiring parents to have full knowledge of the production function. This assumption however would go against existing research, documenting that parents in both developed and developing countries have biased beliefs about the returns to investment in children (Cunha, Elo, and Culhane,

¹⁹A similar problem is faced in industrial organization when estimating production functions (see for example, Olley and Pakes (1996)).

2013; Boneva and Rauh, 2018; Attanasio, Cunha, and Jervis, 2019). Instead, approximating these investment functions does not require to take a stance on whether parents know the true production function reflected in the structure of the skill formation technology (Attanasio, Meghir, and Nix, 2020; Attanasio, Cattan, Fitzsimons, Meghir, and Rubio-Codina, 2020). I therefore follow the latter approach: I derive the investment functions from the parental investment model and approximate them with the following log-linear equations.

$$\ln(SB_{it}) = \sum_S \delta_{1S} \ln(\theta_{Y,it-1}^S) + \sum_S \delta_{2S} \ln(\theta_{O,it-1}^S) + \delta_3 Z_{1,it} + \delta_4 Z_{2,it} + \mathbf{X}'_{it} \phi_S + \epsilon_{it}^{SB} \quad (8)$$

$$\ln(I_{it}) = \sum_S \gamma_{1S} \ln(\theta_{Y,it-1}^S) + \sum_S \gamma_{2S} \ln(\theta_{O,it-1}^S) + \gamma_3 Z_{1,it} + \gamma_4 Z_{2,it} + \mathbf{X}'_{it} \phi_I + \epsilon_{it}^I \quad (9)$$

The investment functions in equations (8) and (9) depend on the younger and older siblings' skills at $t - 1$, parental background and household characteristics. The variables $Z_{1,it}$ and $Z_{2,it}$ are respectively the instruments for parental investment and the sibling bond. These variables must affect the child's skills only through one of the endogenous variables. As hinted in the theoretical model in Section 2.2, these variables enter the budget constraint and are related to wages and non-labor income, while they never enter the child's human capital production function directly. I will discuss both of them in detail in the next paragraphs.

To deal with the endogeneity of parental investment, I use a local female employment shock, $Z_{i,1t}$, proxied by the local female employment rate at the local authority where the household lives at the age-5 wave, using geocoded data. The richness of the MCS builds confidence that this shock is quasi-exogenous as I can condition on a large set of controls, \mathbf{X}_{it} , such as, for example, local employment at the local authority, partner being present in the household and other variables capturing household's resources. The residual variation in the female employment shock should then not be related directly to child development, but only through parental investment (Carneiro, Meghir, and Parey, 2013). The female employment shock is a relevant instrument because a positive female employment shock could lead the mother to be more likely to work, affecting the amount of parental investment investment.

To deal with the endogeneity of the sibling bond, I look for the exogenous variation that can increase the sibling bond without affecting child development directly. I use an adjustment cost to housing, $Z_{2,it}$, proxied by the number of rooms in the house at age-3 wave. To strengthen the credibility of the instrument and make sure that its residual variation is quasi-exogenous, I condition on the same large set of controls, \mathbf{X}_{it} . Therefore, the residual variation left in the instrument should capture the adjustment cost to housing, which affects level of skills only through the sibling bond.

Using the number of rooms as an instrument to capture the adjustment cost to housing could

raise some concerns about violating the exclusion restriction.²⁰ For example, the number of rooms might affect the ability to focus the children's drive and determination to complete an assignment or sleep patterns. It is important to keep in mind that the MCS has very rich information on siblings' social skills, household and housing characteristics whose I can control for to exploit the residual variation that is plausibly exogenous and should affect development only through the sibling bond. Thinking about the aforementioned violations of the exclusion restriction, controlling for both siblings' internalizing skills would capture variables that are usually unobserved, such as the siblings' ability to focus their drive and determination, for example, to complete assignment.

The idea behind the instrument for the sibling bond is similar to the one that has been employed in the studies of peer effects, that use quasi-random assignment of roommates to students in college dorms (see for example, [Sacerdote \(2001\)](#) and [Stinebrickner and Stinebrickner \(2006\)](#)). This is of course not available within the same household. But the instrument tries to mimic this by quasi-randomly dividing the siblings in different rooms "by building a wall", as I consider similar households, who live in similar homes, where sometimes siblings quasi-randomly do not share the same bedroom.

To understand the relevance of the instrument, it is important to keep in mind the questions used to measure the latent sibling bond, which contain information about teasing the sibling and spending enjoyable time together. Intuitively, the instrument is relevant because if both siblings have their own room, they could fight less and have higher quality interactions without stepping on each other toes and invading each other's privacy. If both siblings share the same bedroom, they would have harder time finding space for regaining control of emotions during a discussion, ending up exacerbating the conflicts.²¹

The literature has adopted a similar strategy to deal with the endogeneity of parental investment when estimating the technology of child development with a single child. Some examples of exogenous shifters for parental investment are: innovations in income ([Cunha, Heckman, and Schennach, 2010](#)), variation in prices ([Attanasio, Meghir, and Nix, 2020](#)), and variation in prices and exposure to conflicts ([Attanasio, Cattan, Fitzsimons, Meghir, and Rubio-Codina, 2020](#)). In all these instances, a theoretical framework is helpful to derive the *sufficient* conditions for the excluded instruments to be valid and consistent with economic theory. However, these conditions are only sufficient as the model cannot capture every possible response to unobserved shocks by the household.

[Cunha, Nielsen, and Williams \(2021\)](#) argue that the *necessary* conditions for the instrument to be valid depend on the nature of the unobserved shocks. For example, if the unobserved shocks capture omitted inputs, then the exclusion restriction would be difficult to satisfy as unobserved inputs could change in response, for example, to the female employment shock and the adjustment cost to housing. On the other hand, if the omitted inputs can only change at significant cost, such

²⁰I could also use the local house prices to measure the adjustment cost to housing or use the tax simulator tool to simulate the amount of housing subsidy households are entitled to after controlling for all the variables that define how the subsidy is allocated.

²¹For example, [Dickinson and Masclet \(2015\)](#) show in a public good experiment that venting emotions can reduce (excessive) punishment, and could increase final payoffs to the group.

as moving to a different neighborhood, then the female employment shock and the adjustment cost to housing would satisfy the exclusion restriction.

3 Latent Factors and Measurement System

This Section describes the available data from the Millennium Cohort Study in the United Kingdom and the measurement system adopted to map the questionnaires into the latent constructs of interest: skills, parental investment and sibling bond. [Cunha, Heckman, and Schennach \(2010\)](#) provide a framework to allow researchers to spell out the assumptions through a measurement system on how the available observable responses to the questionnaires map into the latent constructs that researchers are interested in. The measurement system provides an effective way to summarize the available information from the questionnaire and obtain an efficient measure of the latent factors, while allowing to set a metric for measurement and making the measures comparable over time and across siblings ([Agostinelli and Wiswall, 2023](#); [Freyberger, 2021](#)). This section also adopts advances from psychometrics to test for measurement invariance in skills across siblings. This test provides support for setting the same metric for the younger and older siblings' socio-emotional skills and compare the structural estimates of the technologies of skill formation. Finally, I outline the estimation technique adopted to estimate the entire measurement system in one step.

3.1 Data: Millennium Cohort Study

The Millennium Cohort Study (MCS) follows the lives of a representative sample of children born in United Kingdom in 2000-02. Multiple measures of the cohort members' socio-emotional and cognitive development as well as detailed information on their daily life, economic circumstances, parenting, relationships and family life have been collected from birth to age 17.²² It also contains longitudinal information on siblings' skills as well as information on the quality of the interactions between siblings and between the parent and child.

Information on the younger and older siblings' socio-emotional skills comes from the Strengths and Difficulties Questionnaire (SDQ) administered at the age-3 and age-5 waves ([Goodman, 1997, 2001](#)). The SDQ is made up of 5 scales of 5 items each: (i) Emotional symptoms, (ii) Conduct problems, (iii) Hyperactivity/inattention, (iv) Peer relationship problems and (v) Prosocial behaviour. Parents are asked if the cohort member and the older sibling exhibit 25 personality attributes, rating them on three levels: 'Does not apply', 'Somewhat applies', 'Certainly applies' (Appendix Table C5). Since they are all behaviours indicating lower skills, I recode all of them in reverse. So higher scores correspond to higher skills. [Goodman \(1997\)](#), [Goodman \(2001\)](#), and [Goodman, Lamping, and Ploubidis \(2010\)](#) propose adding the responses from the Conduct and Hyperactivity scales to obtain an externalizing score, and adding the responses of the Emotional

²²Data are publicly available through the UK data service. Interviews have taken place at birth, and ages 3, 5, 7, 11, 14 and 17. The MCS longitudinal study is still ongoing with the age 22 wave taking place in 2022. Descriptive statistics for the estimation sample are presented in Appendix Table C4.

and Peer problem scales to produce an internalizing score (Achenbach, 1966; Achenbach et al., 2016).²³

In addition, the interviewers administer a battery of tests to the younger sibling (i.e., the cohort member child in the MCS) at ages 3 and 5, which can be used to measure cognitive skills. The tests administered at age 3 are: the Naming Vocabulary from the British Ability Scales II and the Bracken School Readiness Assessment-Revised (BSRA-R). The BSRA-R is divided in the following 6 subtests: (i) Colours (represents both primary colours and basic colour terms), (ii) Letters (measures knowledge of both upper- and lower-case letters), (iii) Numbers/Counting (measures recognition of single- and double-digit numbers and assign a number value to a set of objects), (iv) Sizes (describes concepts of one, two, and three dimensions), (v) Comparisons (measures ability to match and/or differentiate objects based on one or more of their salient characteristics), and (vi) Shapes (includes one, two, and three-dimensional shapes, such as linear shapes, circles, squares, triangles, cubes and pyramids). The age-5 tests comprise: (i) the naming vocabulary, (ii) pattern construction and (iii) picture similarities from the British Ability Scales II.

Information on the sibling bond is collected at the age-5 wave by asking parents how often [frequently, sometimes, never] the cohort member (i.e., the younger sibling): (i) Likes to be with the older sibling, (ii) Not much interested in the older sibling, (iii) Has a lot of fun with the older sibling and (iv) Teases or needles the older sibling.

Parental investment is measured at the age-5 wave by asking parents how often [Every day, Several times a week, Once or twice a week, Once or twice a month, Less often, Not at all] they do the following activities: (i) How often do you read to the child, (ii) How often tells stories to the child, (iii) How often does musical activities with the child, (iv) How often does the child paint/draw at home, (v) How often do you play physically active games with the child?, (vi) How often play indoor games with the child? (vii) How often play outdoor games with the child? (viii) How often family does indoor activities together? (ix) How often child sees grandparents? (x) How often child sees other relatives? (xi) How often child spends time with friends outside school? (xii) How often ignores child when naughty? (xiii) How often smacks child when naughty? (xiv) How often shouts at child when naughty? (xv) How often sends child to bedroom/naughty chair? (xvi) How often takes away treats from child when naughty? (xvii) How often bribes child when naughty? (xviii) How often tries to reason with child when naughty? (xix) How often makes sure child obeys instruction/request? (xx) how close the bond between mother and child is.

Finally, the UK dataservice has provided access to the restricted MCS data with the geo-coded location of each household via the secure lab. Each household is linked to the local employment rate between October 2004 and September 2005 at the local authority, where the household lives.²⁴ Unfortunately, data on the local employment at the age-5 wave are not available for Northern Ireland.

²³The note of Table C5 reports to which scale each questionnaire item belongs to. Items with no variation are not used. These are the items with less than 5% variation in two of the categories combined (i.e., item where more than 95% of the responses in only one category). These are the items 8, 13, 19 and 22.

²⁴Source: University of London. Institute of Education. Centre for Longitudinal Studies. (2017). Millennium Cohort Study: Geographical Identifiers, Third Survey: Secure Access. [data collection]. 2nd Edition. UK Data Service. SN: 7760, <http://doi.org/10.5255/UKDA-SN-7760-2>.

3.2 Measurement System

3.2.1 Exploratory Factor Analysis

The psychometric literature identifies two dimensions of socio-emotional development: internalizing (ability to focus their drive and determination) and externalizing (ability to engage in interpersonal activities) skills (Achenbach, 1966; Achenbach, Ivanova, Rescorla, Turner, and Althoff, 2016; Goodman, 1997, 2001; Goodman, Lamping, and Ploubidis, 2010). The conduct and hyperactivity scales from the SDQ can be employed to obtain a measure of externalizing skill, while the emotional and peer problem scales to obtain a measure of internalizing skill (Goodman, 1997, 2001; Goodman, Lamping, and Ploubidis, 2010). Goodman, Lamping, and Ploubidis (2010) suggest using these two dimensions of socio-emotional development in low-risk samples, such as the MCS, while using the five separate SDQ subscales in high-risk children.

I investigate this division in internalizing and externalizing skills and confirm it in my dataset with an exploratory factor analysis. I estimate the factor loadings from the exploratory factor analysis, based on decomposing the polychoric correlation matrix of the items and using weighted least squares (Olsson, 1979). The polychoric correlation is an estimate for the correlation between two standard normal latent factors underlying ordinal responses. The solution of the exploratory factor analysis is finally rescaled using oblique factor rotation (Hendrickson and White, 1964). The exploratory factor analysis of the SDQ shows a clear separation between items and support the division in internalizing and externalizing skills proposed by theory (Appendix Table C6). The factor loadings have also a similar magnitudes across siblings, highlighting the similar association between the items and the factors across the younger and older siblings.

I also perform an exploratory factor analysis to verify if parental investment and the sibling bond are capturing only one latent factor, namely the "home environment", as discussed in Section 2.1. The exploratory factor analysis in Table 2 supports the existence of two distinct latent factors and shows a clear separation between items. The question items related to parental investment are highly correlated with the first latent factor (parental investment) and the items related to the sibling bond are highly correlated with the second latent factor (sibling bond). Appendix Table C7 reproduces Table 2 using the questionnaire items residualized by the set of controls previously described. Results are even more pronounced. The correlation between the two latent factors is 0.15 and reduces to 0.06 when residualizing the questionnaire items.

As a robustness check, I also perform an exploratory factor analysis of the questions meant to measure parental investment, sibling bond and younger sibling's internalizing and externalizing skills at age 5. This is meant to investigate if the questionnaires are capturing four different latent constructs. Appendix Table C7 shows that questionnaire items meant to measure a certain latent factor load mostly on that specific latent factor, while being uncorrelated with the other factors.

Finally, Appendix Table C9 reports Cronbach's alpha, which measures how closely related a set of items are for each latent factor (Cronbach, 1951). Cronbach's alpha is a measure of internal consistency for scale reliability and can take values between 0 and 1, where values closer to 1 correspond to higher reliability. Values above 0.50 are considered acceptable (Taber, 2018).

Table 2: Exploratory factor analysis of the sibling bond and parental investment questions

Item	Parental investment	Sibling bond
Younger sib likes to be with older sib	-0.048	0.872
Younger sib interested in older sib	-0.061	0.657
Younger sib has fun with older sib	-0.003	0.832
Younger sib does not tease older sib	-0.016	0.355
How often do you read to child	0.415	0.027
How often tells stories to child	0.501	-0.041
How often does musical activities with child	0.527	-0.022
How often does child paint/draw at home	0.612	-0.054
How often do you play physically active games with child?	0.529	0.055
Frequency play indoor games with child	0.644	-0.051
Frequency take child to park or playground	0.379	-0.065
How often family does indoor activities together	0.335	0.029
How often child sees grandparents	0.071	-0.049
How often child sees other relatives	0.136	-0.130
How often child spends time with friends outside school	0.194	-0.002
How often ignores child when naughty	-0.049	0.066
How often smacks child when naughty	-0.195	-0.054
How often shouts at child when naughty	0.178	0.142
How often sends child to bedroom/naughty chair	-0.028	0.098
How often takes away treats from child when naughty	-0.009	0.084
How often tells child off when naughty	0.161	0.108
How often bribes child when naughty	-0.048	-0.008
How often tries to reason with child when naughty	0.025	-0.046
How often makes sure child obeys instruction/reques	0.092	0.158
How close bond between mother and child	0.243	0.186

Note. The table displays the factors loadings obtained from exploratory factor analysis (EFA) of the sibling bond and parental investment questions. The EFA is based on the decomposition of the correlation matrix. The solution is rescaled using oblique factor rotation obtained via the PROMAX protocol (with $k = 3$). I recode behaviours indicating worse interactions in reverse (i.e., not much interested in older sibling and teases or needles older sibling).

Appendix Table C9 documents a good reliability for each latent factor.

3.2.2 Confirmatory Factor Analysis

I use a measurement system with categorical items to measure the latent factors. The measurement system with categorical items exploits, for example, the variation from each item of the SDQ - instead of aggregating their responses in continuous subscales to estimate a factor model with continuous items.²⁵ This allows me to look deeper into the multi-dimensionality of skills and study two dimensions of socio-emotional development as previously discussed.

The categorical response, m_{cijt} , to the questionnaire item j for child c (i.e., the younger or the older sibling) in family i at time t is assumed to be a manifestation of a latent item m_{cijt}^* , which in turn depends linearly on the logarithm of the latent factors $\ln\theta_{cit}$ by item-specific intercepts α_{jt} and loadings λ_{jt} and an independent measurement error term ε_{cijt} . For ease of notation, I omit the subscripts c in the factor model for the younger and older sibling in equations (10) and (11).²⁶

$$m_{ijt}^* = \alpha_{jt} + \lambda_{jt}^\top \ln\theta_{it} + \varepsilon_{ijt} \quad (10)$$

Specifically, m_{ijt}^* maps into m_{ijt} via a threshold model:

²⁵Cunha, Heckman, and Schennach (2010), Attanasio, Cattan, Fitzsimons, Meghir, and Rubio-Codina (2020), Attanasio, Meghir, and Nix (2020), and Agostinelli and Wiswall (2023) use a measurement system with continuous items and explore fewer dimensions of human capital. For example, they explore only one dimension of socio-emotional development - instead of considering two dimensions of socio-emotional skills (i.e., internalizing and externalizing).

²⁶I test for the invariance of the model between younger and older sibling in Appendix C.5 and find support for such invariance.

$$m_{ijt} = \begin{cases} 0 & \text{if } m_{ijt}^* < \tau_{1,jt} \\ 1 & \text{if } m_{ijt}^* \in [\tau_{1,jt}, \tau_{2,jt}] \\ 2 & \text{if } m_{ijt}^* > \tau_{2,jt} \end{cases} \quad (11)$$

Where τ_{jt} is the threshold, for example, for showing a certain behaviour in the SDQ scale or an interaction in the sibling bond scale. I consider a dedicated factor structure, where each item loads only on one latent dimension, following the structure found in the exploratory factor analysis in Section 3.2.1 (Conti, Heckman, and Urzua, 2010; Heckman, Pinto, and Savelyev, 2013).

Latent factors and the measurement error terms are usually assumed to be normally distributed: $ln\theta_{it} \sim \mathcal{N}(\mu_{\theta,t}, \sigma_{\theta,t})$ and $\varepsilon_{ijt} \sim \mathcal{N}(0, \sigma_{\varepsilon,jt})$. Some normalizations are also needed in equations (10) and (11) for the parameters to be identified. First, as the intercepts and the thresholds cannot be jointly identified in a factor model with categorical items, intercepts are assumed zero, $\alpha_{jt} = 0, \forall j, t$. Second, following Agostinelli and Wiswall (2023), I normalize $\lambda_{jt} = 1$ and $\tau_{1,jt} = 0$ $\forall t = \{age - 3, age - 5\}$ wave for the younger and older sibling on the SDQ item: (i) "*Often complaining of headaches, stomach-aches or sickness*" to measure the internalizing skill, and (ii) "*Has often had temper tantrums or hot tempers*" to measure the externalizing skill. These questions are chosen as their mapping from m_{ijt}^* to m_{ijt} can reasonably be assumed to be invariant.

The normalization of the factors is a critical step to be able to compare the objective parameters of the production function over time and across siblings. Other normalizations are conceivable too as described in Appendix C.4, however they are not recommended as they do not allow me to compare the evolution of the factors over time and across siblings. Appendix C.5 uses advances from psychometrics and presents a test for measurement invariance (Vandenberg and Lance, 2000; Putnick and Bornstein, 2016; Wu and Estabrook, 2016). This test enables me to confirm that the latent socio-emotional skills are invariant to the younger and older siblings and are measured on the same scale across the two groups. This test builds confidence in the comparison of the structural estimates of the younger and older siblings' skill formation technology.

To measure cognitive skills, I use a factor model with continuous items (Appendix C.6). I set the constant α_{jt} to 0 and the loading to λ_{jt} to 1 for the "naming vocabulary test", which has been administered at age-3 and 5 waves for the younger sibling, and let the mean and the variance of the latent factor to be estimated (Agostinelli and Wiswall, 2023).

To measure the latent factors capturing parental investment and the sibling bond, I use the factor model outlined in this section and set the mean to 0 and the standard deviation to 1 for the identification of each latent factor. This normalization allows me to specify the underlying assumptions for the comparison of the productivity of these inputs. If I were to have a common question in the parental investment and sibling bond questionnaire (e.g. "how frequently parent and child play indoor activity" in the parent's questionnaire and "how frequently siblings play indoor activity together" in the sibling's questionnaire), then I could do the normalization on that questionnaire item by setting its constant to 0 and factor loading to 1. This would be slightly preferred because the normalization done on a common question would set the metric on that

question. Nevertheless, it could still be difficult to justify this normalization because, for example, an indoor activity with siblings may be completely different from an indoor activity with parents.

3.3 Estimation

The factor model, the production function and the investment function are estimated in one step. A more intuitive procedure would follow two steps. In a first step, the factor model is estimated and the factors are predicted. Then in the second step, the factor scores predicted in the previous step are used to estimate the production function. This method is however not recommended as the first step involves measurement error from the prediction, which could lead to attenuation bias in the second step ([Cunha, Nielsen, and Williams, 2021](#)).

I use the one-step estimation strategy developed in the psychometrics literature by [Muthén \(1984\)](#) and [Muthén \(1983\)](#). This estimation method is well-suited to estimate factor models with *categorical* items in one step (more details on the estimation strategy can be found in Appendix [C.7](#)). This estimation strategy is also used to estimate intergenerational mobility in socio-emotional skills in [Attanasio, de Paula, and Toppeta \(2022\)](#).

Other estimation methods commonly used in the literature are instead well-suited to estimate factor models with *continuous* items: a non-linear filtering method ([Cunha, Heckman, and Schenbach, 2010](#)), a three-step simulation algorithm ([Attanasio, Meghir, and Nix, 2020](#)), a generalized method of moments ([Agostinelli and Wiswall, 2023](#)) or [Croon \(2002\)](#)'s bias-correction method for the two-step estimation as in, for example, [Heckman, Pinto, and Savelyev \(2013\)](#).²⁷

4 Results

This Section presents the estimates for the investment and production functions for externalizing, internalizing and cognitive skills for the younger and older siblings during childhood. The younger sibling's development is measured at age 5 for every child, while the older sibling's development is measured at different ages. The older sibling's technology is conditional on the older sibling's age. The factor model, the production function and the investment function are estimated in one step. The coefficients in the Tables are elasticities as all the variables are in logs, except for the dummies and the categorical variables.

4.1 Investment Function Estimates

The estimates of the investment functions are presented in Table [3](#), where Column 1 focuses on the sibling bond and Column 2 on parental investment. Studying the determinants of these two inputs is relevant for understanding the origin of disadvantage and in turn understand how to intervene to break its intergenerational transmission.

²⁷The three steps of the simulation algorithm are: (i) estimating the moments of observed measures, (ii) matching the moments of the observed measures to the moments defined by the factor structure and (iii) drawing factors from a distribution to estimate the production function parameters.

Table 3: Investment function: Sibling bond and parental investment

Outcome	Sibling bond	Parental investment
Number of rooms (t-1)	0.066*** (0.017)	0.011 (0.012)
Local female employment rate	-0.019 (0.013)	0.046*** (0.009)
Younger sib's EXT skill (t-1)	0.180*** (0.032)	0.190*** (0.024)
Younger sib's INT skill (t-1)	0.039 (0.089)	0.304*** (0.070)
Younger sib's COG skill (t-1)	0.061** (0.058)	-0.032 (0.021)
Older sib's EXT skill (t-1)	0.304*** (0.028)	0.119*** (0.019)
Older sib's INT skill (t-1)	0.136** (0.058)	-0.048 (0.043)
Test of joint significance: F-statistic (<i>p</i> -value)	14.867 (0.000)	
Number of rooms		25.211 (0.000)
Mother's employed		
Observations	2558	2558
Other controls	Yes	Yes

Note. The Table presents the structural estimates of the investment functions. Measurement system and equations are estimated jointly (Muthén, 1984). Other controls include mother's mental health, mother's education, mother's age, whether the household is dual or single headed, number of children, age gap between younger and older sibling, siblings' gender, housing tenure, years lived in current address, local employment, region fixed effects. Source: University of London. Institute of Education. Centre for Longitudinal Studies. (2017). Millennium Cohort Study: Geographical Identifiers, Third Survey: Secure Access. [data collection]. 2nd Edition. UK Data Service. SN: 7760, <http://doi.org/10.5255/UKDA-SN-7760-2>. Standard errors computed based on inverting information matrix in parentheses (***($p < 0.01$), **($p < 0.05$), *($p < 0.1$)).

First, Column 1 presents the estimates of the determinants of the sibling bond. The younger and older siblings' externalizing skills, not surprisingly, are important determinants of the sibling bond. Children with a higher ability to engage in interpersonal activities at time $t - 1$ are more likely to enjoy a stronger bond at time t . Turning attention to the excluded instrument, the number of rooms is positively and significantly associated with the sibling bond, as shown by the F-statistic and p-values (Column 1 of Table 3). Intuitively, if siblings share the same bedroom, it would be harder for them to find space to regain control of their emotions during a heated debate, ending up exacerbating the conflicts. On the other hand, having their own bedroom would allow them to have their privacy and interact with each other when they desire to do so.

Thinking about possible violations of the exclusion restriction, it is important to keep in mind that the MCS has very rich information on background characteristics for which I can condition on. This enables me to consider similar households with similar family compositions who live in homes that are approximately the same size where quasi-randomly siblings share their bedroom in some instances, while they do not in others. The residual variation of the excluded instrument can be plausibly considered exogenous and should affect child development only through the sibling bond. Table 3 shows indeed that the adjustment cost to housing, proxied by the number of rooms at time $t - 1$, appears to affect the child's human capital only through the sibling bond (Column 1),

but not through parental investment (Column 2).²⁸

Second, Column 2 presents the estimates of the determinants of the parental investment. The excluded instrument is the female local employment rate in the local authority where the household lives ([Carneiro, Meghir, and Parey, 2013](#)). The key justification for this excluded instrument is that the residual variation should capture the plausibly exogenous variation that affects the child's human capital only through parental investment. Again an important point to highlight is the extensive set of controls used, which includes factors such as local employment in the local authority and the mother's employment status. These controls serve as essential variables to account for additional influences on the outcomes of interest. By incorporating them, I can more accurately examine the specific effects of the variables under investigation, while mitigating the potential confounding effects of other factors. Indeed, the residual variation in the female local employment appears to affect child development only through parental investment (Column 2), but not through the sibling bond (Column 1).

The female local employment is a relevant instrument as reported by the F-statistics and p-values in Table 3. Intuitively, the positive association between the local female employment rate and parental investment implies that the income effect outweighs the substitution effect. When a family lives in a local authority with higher local female employment rate, it is likely that the family may have higher quality interactions with their children. This suggests that despite potential time constraints due to work commitments, the increased resources from employment allows for a higher level of parental investment in terms of quality interactions with the children.

4.2 Production Function Estimates

This Section discusses the estimates of the joint technology of skill formation for the younger and older siblings (Table 4). Outputs are externalizing, internalizing and cognitive skills. Studying these different dimensions of human capital provides valuable insights into the complexity of the development process and the interplay between each skill dimension. Columns 1-4 of Table 4 present the estimates for the externalizing skill, Columns 5-8 for the internalizing skill, and Columns 9-10 for the cognitive skill. Odd Columns present the estimates of the skill formation technology, when assuming a single child and restricting the sibling bond to have a productivity of zero ([Cunha and Heckman, 2008](#); [Cunha, Heckman, and Schennach, 2010](#); [Attanasio, Cattan, Fitzsimons, Meghir, and Rubio-Codina, 2020](#); [Attanasio, Meghir, and Nix, 2020](#); [Agostinelli and Wiswall, 2023](#)), while Even Columns present the estimates, when allowing for the possibility of the sibling bond to be productive.

There are two general considerations to highlight before turning to the productivity of the sibling bond and parental investment. First, skills are self-productive ([Cunha, Heckman, and Schennach, 2010](#)). This holds true for each skill dimension and sibling. For example, a 10% increase in

²⁸Another instrument that could be used for the sibling bond is the siblings' gender composition, which has been assumed to be a source of exogenous variation for fertility decisions (see for example, [Angrist and Evans \(1998\)](#) and [Glynn and Sen \(2015\)](#)). I try to estimate a specification where I use the siblings' gender composition as an instrument. However, this instrument fails to satisfy the exogeneity condition, affecting the child's human capital through the sibling bond as well as parental investment, and appears to covary with female employment.

Table 4: Joint technology of skill formation: younger and older siblings

Outcome	Externalizing (EXT)				Internalizing (INT)				Cognitive (COG)		
	Younger		Older		Younger		Older		Younger		
	Restricted (1)	Unrestricted (2)	Restricted (3)	Unrestricted (4)	Restricted (5)	Unrestricted (6)	Restricted (7)	Unrestricted (8)	Restricted (9)	Unrestricted (10)	
Younger sib's EXT skill (t-1)	0.572*** (0.064)	0.500*** (0.076)	-0.203*** (0.044)	-0.277*** (0.071)	-0.050* (0.029)	-0.107** (0.047)	-0.041 (0.033)	-0.099* (0.053)	0.004 (0.046)	-0.068 (0.068)	
Younger sib's INT skill (t-1)	-0.324*** (0.083)	-0.282*** (0.091)	-0.259*** (0.098)	-0.260** (0.109)	0.775*** (0.103)	0.750*** (0.108)	-0.285** (0.084)	-0.313*** (0.093)	-0.139 (0.095)	-0.127 (0.109)	
Younger sib's COG skill (t-1)	0.121*** (0.024)	0.089*** (0.027)	0.061* (0.025)	0.038 (0.029)	-0.013 (0.017)	-0.038* (0.022)	0.057** (0.024)	0.046* (0.026)	0.599*** (0.031)	0.568*** (0.035)	
Older sib's EXT skill (t-1)	-0.064** (0.031)	-0.176** (0.065)	0.706*** (0.041)	0.595*** (0.078)	-0.067*** (0.021)	-0.166*** (0.051)	-0.137*** (0.026)	-0.219*** (0.060)	-0.035 (0.032)	-0.172** (0.075)	
Older sib's INT skill (t-1)	0.062 (0.041)	0.000 (0.047)	0.048 (0.044)	-0.007 (0.055)	0.032 (0.030)	-0.015 (0.039)	0.973*** (0.088)	0.943*** (0.088)	-0.022 (0.046)	-0.093 (0.059)	
Parental investment (t)	0.564*** (0.186)	0.460** (0.196)	0.647*** (0.191)	0.624*** (0.281)	0.232* (0.122)	0.194 (0.150)	0.170 (0.134)	0.225 (0.159)	0.426** (0.208)	0.331 (0.242)	
Sibling bond (t)		0.406** (0.172)		0.397** (0.195)		0.344** (0.133)		0.242* (0.145)		0.491** (0.200)	
Observations	2558	2558	2475	2475	2558	2558	2475	2475	2558	2558	
Other controls	Yes	Yes	Yes								

Note. Younger sibling at age 5, older sibling between age 6 and 15. Measurement system and equations are estimated jointly (Muthén, 1984). Other controls include mother's mental health, mother's education, mother's age, whether the household is dual or single headed, number of children, age gap between younger and older sibling, siblings' gender, housing tenure, years lived in current address, local employment, region fixed effects. Source: University of London. Institute of Education. Centre for Longitudinal Studies. (2017). Millennium Cohort Study: Geographical Identifiers, Third Survey: Secure Access. [data collection]. 2nd Edition. UK Data Service. SN: 7760, <http://doi.org/10.5255/UKDA-SN-7760-2>. Standard errors computed based on inverting information matrix in parentheses (***) p<0.01, ** p<0.05, * p<0.1).

the externalizing skill at time $t - 1$ translates into a 5.0% and 5.95% increase respectively in the younger and older siblings' externalizing skill at time t (Columns 2 and 4). The more persistent dimension of development is the internalizing skill, where a 10% increase in the internalizing skill at time $t - 1$ translates into a 7.8% and 9.4% increase respectively in the younger and older siblings' internalizing skill at time t (Columns 6 and 8). It would be interesting to consider additional lags of development as done in [Attanasio, Bernal, Giannola, and Nores \(2020\)](#) and [Attanasio, de Paula, and Toppeta \(2020\)](#) and study how persistent the development process is, questioning whether it follows a first-order Markov chain. Unfortunately, this is not possible in my setting due to data limitation as the $t - 2$ wave is at birth.

Second, the siblings' socio-emotional development matters too. [Cunha, Heckman, and Schenbach \(2010\)](#), [Attanasio, Cattan, Fitzsimons, Meghir, and Rubio-Codina \(2020\)](#), [Attanasio, Meghir, and Nix \(2020\)](#) and [Agostinelli and Wiswall \(2023\)](#) do not consider this as they focus on a single child. I show that an increase in the older (younger) sibling's externalizing skill at $t - 1$ is negatively associated with the younger (older) sibling development. The psychology literature has theorized that if one sibling has a high externalizing skill (i.e., extrovert), then the other one is likely to have a high internalizing skill (i.e., introvert) and viceversa ([Plomin and Daniels, 1987](#)). This could, for example, be because a sibling with a strong externalizing skill, which corresponds to a high ability to engage in interpersonal activity, might overshadow the other sibling and push her/him to develop another dimension of skill where s/he could have a comparative advantage.

For example, my estimates suggest that a 10% increase in the older sibling's externalizing skill at time $t - 1$ translates into a 1.8% decrease in the younger sibling's externalizing skill at time t (Column 2). This effect would correspond to a spillover from the older sibling's externalizing skill to the younger sibling under the assumption of unidirectional influence from the older to the younger sibling and a timing restriction. Unfortunately, I cannot control for the endogeneity of

such spillover. Finding another instrument for the siblings' socio-emotional development within the family is quite demanding. The influence from the older to younger sibling is, however, supported by several studies in the psychology as a first approximation ([Buhrmester, Boer, and Dunn, 1992](#); [Rodgers and Rowe, 1988](#)). This result calls for additional investigation, as a negative spillover could have implications for policies aimed at improving only one sibling's interpersonal skills.

Turning to the sibling bond and parental investment, the sibling bond is productive and increases child development for younger and older siblings with a significant coefficient for each of three skill dimensions.²⁹ A comparison between the Odd and Even Columns in Table 4 sheds light on the importance of the sibling bond.³⁰ Disregarding the sibling bond would overlook a crucial factor in children's development. As siblings grow up together, they tend to spend more time interacting together rather than solely relying on parental interactions. Consequently, many parental actions are mediated through sibling interactions. This is more likely to occur when siblings are more connected, namely when they have a strong sibling bond. This mediation can be observed by comparing Even and Odd Columns.

The estimates presented in Table 4 assumes a Cobb-Douglas specification. Appendix D.4 experiments with different functional form assumptions for the production function, such as a translog production function, where the elasticity of substitution between inputs can be different from 1. The translog specification allows me to investigate if the sibling bond interacted by lag of the siblings' skills has an effect on their development. The estimates for the translog production function are presented in Appendix Table D15. The restrictions implied by the Cobb-Douglas specification do not seem to be rejected, suggesting that the Cobb-Douglas constitutes a good approximation in my dataset. This is consistent with [Attanasio, Cattan, Fitzsimons, Meghir, and Rubio-Codina \(2020\)](#) and [Attanasio, Meghir, and Nix \(2020\)](#).

Appendix D.5 exploits the data on the younger sibling's socio-emotional development as reported by the teachers - instead of the parents - to address any concerns about misreporting bias regarding the estimates of the externalizing and internalizing production functions.³¹ [Del Bono, Kinsler, and Pavan \(2020\)](#) show that socio-emotional skill measures can suffer from misreporting bias when parents answer these questions. They use the responses to two different questionnaires, administered respectively to the parents and the teachers, in a factor model with continuous items

²⁹Table 4 uses the data on the sibling bond between the cohort member (i.e., younger sibling) and the randomly-selected older sibling whose data on social skills have been collected. This allows me to condition on the younger and older siblings' social skills and capture the productivity of the sibling bond conditional, for example, on their ability to engage in interpersonal activities and focus drive their determination. Appendices D.1 and D.2 present evidence that the estimates of the sibling bond productivity in Table 4 are robust to the using the average sibling bond in families with at least two older siblings and to family size. First, Appendix Table D12 reproduces Table 4 by using the average of the sibling bonds from different younger and older siblings' combinations when the younger sibling has at least two older siblings, and finds similar estimates for the productivity of the sibling bond (50% of children with siblings have at least two older siblings). Second, Appendix Table D13 reproduces the estimates for Table 4, instrumenting family size with the siblings' gender composition, and provides suggestive evidence that the estimates are robust. It is important to highlight that the instrument for family size (i.e., siblings' gender composition) is weak, estimates must therefore be taken with caution. Appendix Table D14 presents the estimates for Table 4 when treating investment as exogenous.

³⁰The estimates of the productivity of parental investment are similar to the ones found in [Cunha, Heckman, and Schennach \(2010\)](#).

³¹The estimates of the technology of cognitive skill do not present this concern as the MCS interviewers collect the responses to the cognitive tests.

to address the concerns of misreporting bias of socio-emotional skills. However, comparing responses given to different questionnaires does not allow to disentangle if these differences are due to different respondents or different questionnaires.

I therefore use the individual items from the teacher's socio-emotional questionnaire that are similarly worded to the ones in the parent's questionnaire (i.e., Strengths and Difficulties Questionnaire). I then use these items to estimate a factor model with categorical items and measure externalizing skill as reported by the teachers and the parents respectively. This provides a measure of the latent externalizing skill at age 5 that differs only by the nature of the respondent as similar survey questions are used across parents and teachers.³² Appendix Table D16 reports the structural estimates from estimating the production function with the externalizing skill as reported by the teacher - instead of the parents - and finds similar structural estimates for the self-productivity of skills and the productivity of the inputs as the ones obtained when using the information about the socio-emotional skills as reported by the parents.

Finally, Appendix D.6 explores two possible sources of heterogeneity in the structural estimates of younger sibling's skill formation technology: the siblings' gender and age. Unfortunately, the structural estimates become unreliable because the instruments become weak when the sample is split and investments are allowed to be endogenous. The estimates are reported in Appendix Tables D17-D20. Appendix Table D19 provides some suggestive evidence that the sibling bond could be more productive for same-sex than mixed-sex siblings.

5 Using the Structural Estimates

5.1 Marginal Productivity of Parental Investment and Sibling Bond

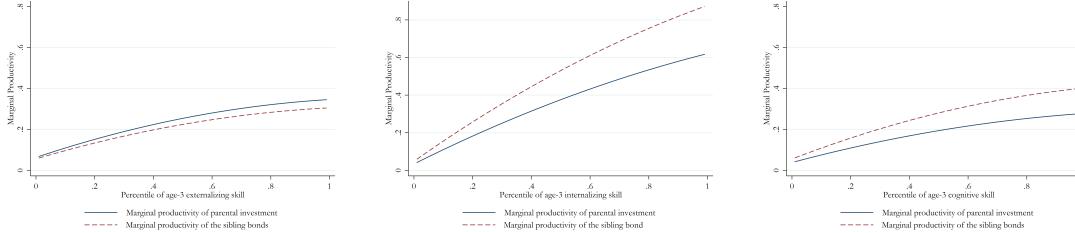
The Figure 3 presents the marginal productivity of parental investment and the sibling bond by age-3 skill levels. The marginal productivity of parental investment (sibling bond) is constructed using the estimates of the production function, evaluated at each percentile of the age-3 skill, while holding the sibling bond (parental investment) at zero (i.e., its mean) and the other inputs at the median in the sample. The marginal productivity of the input is in standard deviation units, corresponding to an increase in one standard deviation of the input.

The marginal productivity of the input by the age-3 skill level is useful to illustrate two points. First, there is a complementarity between the age-5 input and the age-3 skill for each skill dimension. This complementarity reiterates the point that difference in the sibling bond are associated with persistent inequality across households. Indeed, a stronger sibling bond would amplify inequality even more. High-SES children are more likely to experience higher skills and higher quality bond with their siblings (Section 2.1), while at the same time they would benefit from a higher productivity of the sibling bond (Figure 3). Second, the marginal productivity of the

³²Appendix D.5 presents the similarly-worded items across questionnaires. There are two caveats. First, the teachers' questionnaire was administered to teachers only in Northern Ireland, Wales and Scotland. This results in a smaller sample size. Second, similarly-worded items are available to measure only the externalizing skill. This is confirmed by an exploratory factor analysis on the items from the teachers' questionnaire that points out the existence of just one latent skill in the teacher's questionnaire.

inputs describes the differences in productivity between parental investment and the sibling bond. The sibling bond is more productive than parental investment for each skill level at age 5. The gap in productivities appears to be larger for the internalizing skill.

Figure 3: Marginal productivity of investment and sibling bond



Note. The Figures present the marginal productivity of parental investment and sibling bond at age 5 by the age-3 skill levels. The marginal productivity of parental investment (sibling bond) is constructed using the estimates of the production function, evaluated at each percentile of the age-3 skill, while holding sibling bond (parental investment) at zero (i.e., its mean) and the other inputs at the median in the sample. The y-axis represents the marginal productivity of the input, in standard deviation units, of increasing the input by one standard deviation.

5.2 Counterfactual Simulations

The structural model is useful to perform some counterfactual simulations of hypothetical interventions aimed at stimulating parental investment and the sibling bond and in turn understand how these policies would affect skill formation. So far policies have mostly focused on stimulating parent-child interactions, while not considering siblings (e.g., [Evans, Jakielo, and Knauer \(2021\)](#)).

I do not focus on practical aspects of the policy implementation, but refer to [Leijten, Melendez-Torres, and Oliver \(2021\)](#), who review randomized control trials to improve sibling interactions and identify only 8 studies that test such interventions with promising results.³³ Unfortunately, these interventions have looked only at the sibling relationship as an outcome without trying to understand their effect on child development. In addition, they have a small sample with an average of less than 55 households. Therefore, my counterfactual simulations offer some novel insights on how a hypothetical intervention aimed at stimulating the sibling bond and/or parental investment would affect skills.

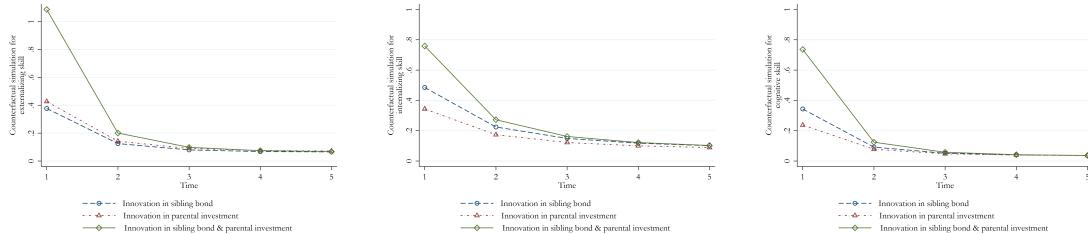
Before proceeding with the counterfactual simulations, I perform a validation exercise to check how well the model does in terms of out-of-sample prediction. I use the structural estimates of younger sibling's skill formation technology at age 5 to simulate their skills over the life-cycle at ages 5, 7, 11, 14 and 17, iterating the model for each younger sibling i , based on the baseline inputs and skills. Appendix Figure E8 presents the binscatter plot of the realized skill against the simulated skill from the structural model, showing that the model performs well in terms of the out-of-sample data across adolescence and building some confidence in the counterfactual exercises presented below.

³³Some examples are [Siddiqui and Ross \(2004\)](#), [Kramer \(2004\)](#) and [Kennedy and Kramer \(2008\)](#). The design of such interventions draws from behavior management and mediation, such as directing children's behavior using reinforcement practices or maintaining impartiality and facilitating communication between siblings.

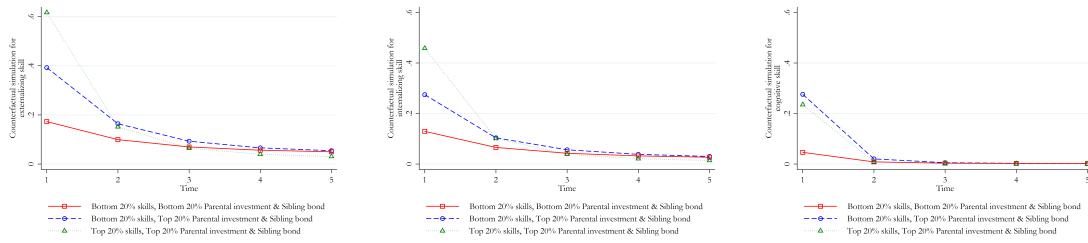
The first thought experiment increases only parental investment, then only the sibling bond and finally both parental investment and the sibling bond at time 1. For each simulation, the increase is by one standard deviation and occurs only at time 1, while fixing all the other inputs at their median values in the sample. For the remaining 4 periods (times 2-5), parental investment and the sibling bond are set equal to their mean 0. I then trace the evolution of skills from time 1 to 5, while assuming that the production function has the same parameters at each time t. Holding the parameters of the production function fixed at different developmental stages is a strong assumption, but is reasonably supported in this instance by the validation exercise presented above. The counterfactual simulations are presented in Panel A of Figure 4. The solid line shows that the hypothetical intervention aimed at stimulating parental investment and the sibling bond would have a larger effect on skill formation.

Figure 4: Counterfactual simulations

Panel A



Panel B



Note. The Figures in Panel A present the counterfactual simulation of an intervention to improve parental investment and the sibling bond on skills by 1 standard deviation only at time 1, as implied by the estimated production functions. Parental investment and sibling bond are set equal to their mean 0 from time 2 to 5. The Figures in Panel B present the counterfactual simulation of assigning the level of the top 20% of parental investment and the sibling bond distributions to the children with skills at the bottom 20% of the distribution at time 1, as implied by the estimated production functions. Parental investment and sibling bond are set equal to their mean 0 from time 2 to 5. The production function is assumed to have the same parameters in each time t.

The second thought experiment considers children at the bottom 20% of the skill distribution and assigns them the top 20% level of parental investment and sibling bond at time 1. I compare this counterfactual simulation to a scenario where the children in the bottom 20% of the skill distribution receive the bottom 20% level of parental investment and sibling bond at time 1 (i.e., status quo). For the remaining 4 periods (times 2-5), parental investment and the sibling bond are set equal to their mean 0. Again, to trace the evolution of skills, the production function is assumed to have the same parameters at each time t. The counterfactual simulations are presented in Panel B of Figure 4, which shows that if children at the bottom of the distribution would have

the opportunity to receive the parental investment and engage in higher quality relations with their siblings as the top of the distribution, then their skills would be twice as large.

6 Conclusion

Understanding the technology of skill formation is at the core of labor economics. Several actors, ranging from parents to policy makers, benefit from understanding how skills are formed to invest more effectively in them. Parents can use their knowledge of the technology of skill formation to break the intergenerational transmission of disadvantage by engaging in actions to increase their children's human capital. Similarly, policy makers can use this knowledge to design effective interventions to boost human capital formation.

The literature has established that parent-child interactions and parents' skills are central in the human capital formation process during childhood by estimating the technology of skill formation with a *single* child. On the other hand, the role of siblings and their interactions for human capital formation have been understudied so far, even if the majority of children in most countries have at least one sibling. As siblings grow up together, they have everyday interactions and build a bond that is likely to last longer than any other ones. In turn, a strong bond can help them to work together effectively to achieve common goals, while serving as sources of social support and role models for one another.

This paper formalizes and structurally estimates the joint technology of skill formation for the younger and older siblings, allowing both parental investment and the sibling bond to be productive. I use the data from the Millennium Cohort Study to open the black box of sibling spillovers by using information on the frequency of the quality of the interactions between siblings, such as experiencing enjoyable time together. This allows me to use a factor model to introduce a novel variable, the sibling bond, capturing how well siblings get along.

Two sets of results are presented when siblings are incorporated in the study of skill formation. First, I present reduced-form evidence on the importance of the sibling bond to understand inequality across households. I document a socio-economic gradient in the quality of the sibling bond and show that the sibling bond at age 5 predicts better developmental, educational and health outcomes during adolescence and young adulthood. Second, I structurally estimate the joint technology of skill formation for the younger and older siblings and show that a strong sibling bond contributes to both siblings' human capital formation, even after considering parent-child interactions.

This paper provides a fertile ground to think about novel interventions and policies where we target the whole family. For example, [Evans, Jakielo, and Knauer \(2021\)](#) review early childhood development interventions (ECD) in low-medium income countries and find only 7 studies out of 478 ECD reporting impacts on older siblings. [Leijten, Melendez-Torres, and Oliver \(2021\)](#) review randomized control trials to improve sibling relations and find only 8 studies with some limitations, such as no measures on children's outcomes. My counterfactual simulations highlight the importance of thinking about the child as part of a family system and focusing both on parent-child as well as sibling interactions.

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Appendices to "Skill Formation with Siblings"

A Motivating evidence: additional results

A.1 Sibling bond and future outcomes

Table A1: Age-5 sibling bond and younger sibling's age-14 relational outcomes

Outcome	Time on social network websites (1)	without controls			
		Wellbeing (2)	Argue with parents (3)	Talk to sibling if worried (4)	Talk to parents if worried (5)
Sibling bond (age 5)	-0.119*** (0.036)	0.048*** (0.015)	-0.091*** (0.033)	0.026*** (0.008)	-0.003 (0.009)
Observations	4377	4208	4003	4301	4301
R ²	0.003	0.003	0.003	0.003	0.000
Younger & older sib's skills (age-3 wave)	No	No	No	No	No
Parental investment (age-5 wave)	No	No	No	No	No
Other controls	No	No	No	No	No

Outcome	Time on social network websites (1)	with controls			
		Wellbeing (2)	Argue with parents (3)	Talk to sibling if worried (4)	Talk to parents if worried (5)
Sibling bond (age 5)	-0.059 (0.040)	0.018 (0.017)	-0.128*** (0.038)	0.019** (0.009)	-0.008 (0.011)
Observations	3780	3645	3477	3721	3721
R ²	0.103	0.103	0.043	0.026	0.009
Younger & older sib's skills (age-3 wave)	Yes	Yes	Yes	Yes	Yes
Parental investment (age-5 wave)	Yes	Yes	Yes	Yes	Yes
Other controls	Yes	Yes	Yes	Yes	Yes

Note. The table presents the relationship between the age-5 sibling bond and the younger sibling's relational outcomes at age 14. The index of the sibling bond is constructed by summing the values from the following 4 questions about how often [frequently, sometimes, never] the cohort member (i.e., the younger sibling): (i) Likes to be with the older sibling, (ii) Not much interested in the older sibling, (iii) Has a lot of fun with the older sibling, (iv) Teases or needles the older sibling. I recode behaviours indicating worse interactions in reverse (i.e., not much interested in older sibling and teases or needles older sibling). The index of parental investment in younger sibling is obtained by summing the values from the questions asking the parents how often [Every day, Several times a week, Once or twice a week, Once or twice a month, Less often, Not at all] they do the following activities: (i) How often do you read to the child, (ii) How often tells stories to the child, (iii) How often does musical activities with the child, (iv) How often does the child paint/draw at home, (v) How often do you play physically active games with the child?, (vi) How often play indoor games with the child? and (vii) How often play outdoor games with the child? (viii) How often family does indoor activities together (ix) How often child sees grandparents (x) How often child sees other relatives (x) How often child spends time with friends outside school (xi) How often ignores child when naughty (xii) How often smacks child when naughty (xiii) How often shouts at child when naughty (xiv) How often sends child to bedroom/naughty chair (xv) How often takes away treats from child when naughty (xvi) How often tells child off when naughty (xvii) How often bribes child when naughty (xviii) How often tries to reason with child when naughty (xix) How often makes sure child obeys instruction/request (xx) how close the bond between mother and child is. The sibling bond index is standardized to have mean 0 and standard deviation 1. Other controls include younger sibling's gender, age gap between younger and older sibling, older sibling's gender, number of children in the house, mother's mental health, mother's education, mother's age, whether the household is dual or single headed, housing tenure, years lived in current address, region fixed effects. Internalizing skill captures the ability to focus their drive and determination to pursue a long-term goal. Externalizing skill captures the ability to engage in interpersonal activities. Robust standard errors in parentheses (** p<0.01, ** p<0.05, * p<0.1).

Table A2: Age-5 sibling bond and younger sibling's future educational and health outcomes (full sample - i.e., children with and without siblings)

Panel A:

	Grade GCSE Math		Grade GCSE English	
	(1)	(2)	(3)	(4)
Sibling bond (worst interaction for single child)	0.207*** (0.071)		0.104 (0.064)	
Sibling bond (best interaction for single child)		0.076 (0.051)		0.109** (0.047)
Observations	2514	2514	2519	2519
R ²	0.236	0.233	0.256	0.257
Younger & older sib's skills (age-3 wave)	✓	✓	✓	✓
Parental investment (age-5 wave)	✓	✓	✓	✓
Other controls	✓	✓	✓	✓

Panel B:

	Study for A-level qualification (age 17)		Aspiration to study at University (age 17)	
	(1)	(2)	(3)	(4)
Sibling bond (worst interaction for single child)	0.032* (0.019)		2.480 (1.591)	
Sibling bond (best interaction for single child)		0.022 (0.014)		2.433** (1.159)
Observations	2685	2685	2027	2027
R ²	0.167	0.167	0.178	0.179
Younger & older sib's skills (age-3 wave)	✓	✓	✓	✓
Parental investment (age-5 wave)	✓	✓	✓	✓
Other controls	✓	✓	✓	✓

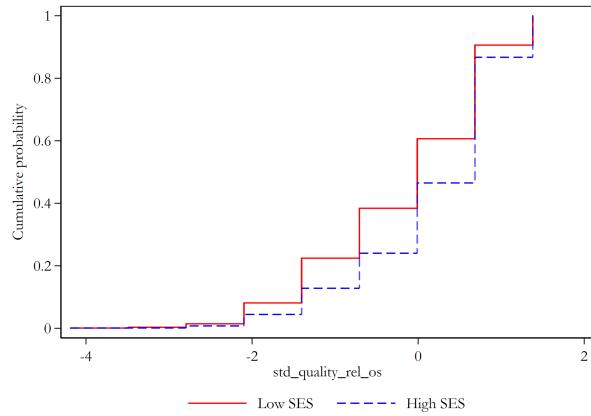
Panel C:

	Smoke cigarettes (age 14)		Smoke cigarettes (age 17)	
	(1)	(2)	(3)	(4)
Sibling bond (worst interaction for single child)	-0.024* (0.013)		-0.056*** (0.020)	
Sibling bond (best interaction for single child)		-0.018* (0.010)		-0.023 (0.015)
Observations	3259	3259	2910	2910
R ²	0.047	0.047	0.030	0.027
Younger & older sib's skills (age-3 wave)	✓	✓	✓	✓
Parental investment (age-5 wave)	✓	✓	✓	✓
Other controls	✓	✓	✓	✓

Note. The table presents the relationship between the age-5 sibling bond and the younger sibling's educational and health outcomes at ages 14 and 17 for the full sample (children with and without siblings). Observations for the sibling bond and the older sibling's social skills are replaced with the worst and best sibling bond level when the child is a single child. Then in the regression, I control for the number of siblings and a dummy variable equal to 1 if the child is a single child. The index of the sibling bond is constructed by summing the values from the following 4 questions about how often [frequently, sometimes, never] the cohort member (i.e., the younger sibling): (i) Likes to be with the older sibling, (ii) Not much interested in the older sibling, (iii) Has a lot of fun with the older sibling, (iv) Teases or needles the older sibling. I recode behaviours indicating worse interactions in reverse (i.e., not much interested in older sibling and teases or needles older sibling). The index of parental investment in younger sibling is obtained by summing the values from the questions asking the parents how often [Every day, Several times a week, Once or twice a week, Once or twice a month, Less often, Not at all] they do the following activities: (i) How often do you read to the child, (ii) How often tells stories to the child, (iii) How often does musical activities with the child, (iv) How often does the child paint/draw at home, (v) How often do you play physically active games with the child?, (vi) How often play indoor games with the child? and (vii) How often play outdoor games with the child? (viii) How often family does indoor activities together (ix) How often child sees grandparents (x) How often child sees other relatives (xi) How often child spends time with friends outside school (xii) How often ignores child when naughty (xiii) How often smacks child when naughty (xiv) How often shouts at child when naughty (xv) How often sends child to bedroom/naughty chair (xvi) How often takes away treats from child when naughty (xvii) How often bribes child when naughty (xviii) How often tries to reason with child when naughty (xix) How often makes sure child obeys instruction/request (xx) how close the bond between mother and child is. The sibling bond index is standardized to have mean 0 and standard deviation 1. Other controls include younger sibling's gender, age gap between younger and older sibling, older sibling's gender, number of children in the house, mother's mental health, mother's education, mother's age, whether the household is dual or single headed, housing tenure, years lived in current address, region fixed effects. Internalizing skill captures the ability to focus their drive and determination to pursue a long-term goal. Externalizing skill captures the ability to engage in interpersonal activities. Robust standard errors in parentheses (** p<0.01, ** p<0.05, * p<0.1).

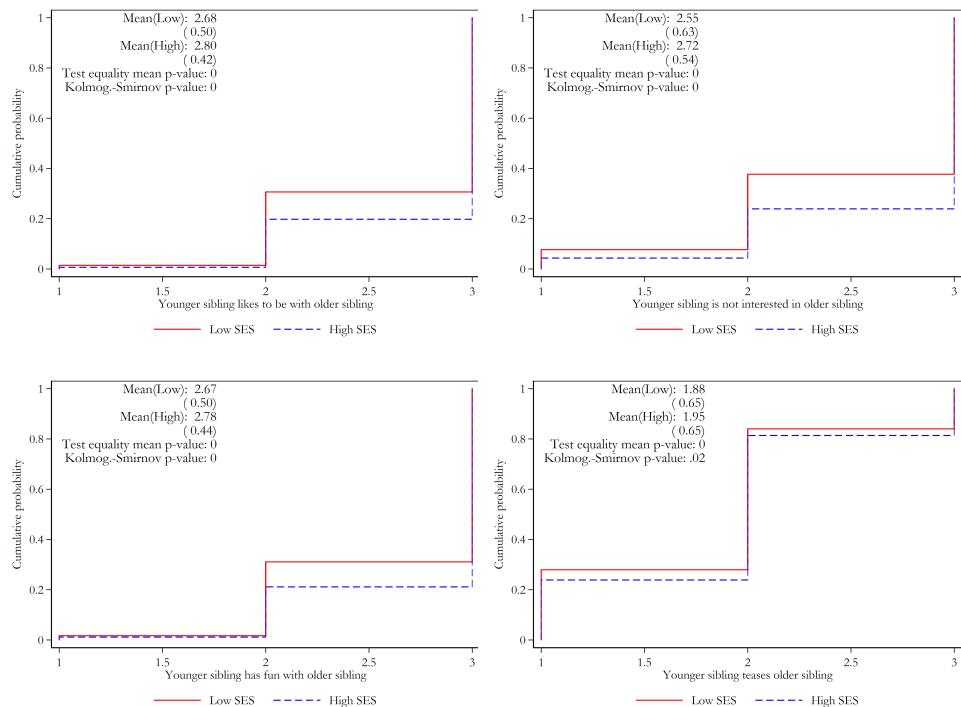
A.2 Determinants of the Sibling Bond and parental investment

Figure A1: Cumulative distribution function: socio-economic gradient (mother's education) in the sibling bond



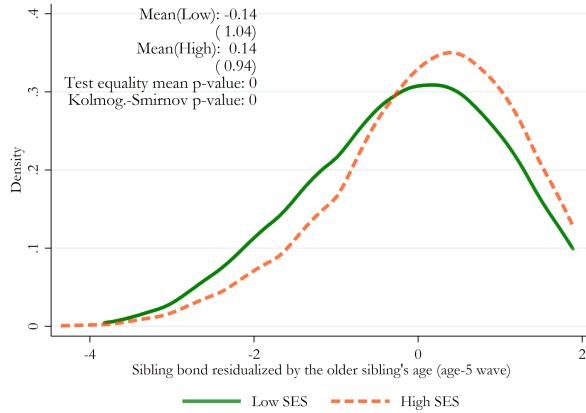
Note. The Figure presents the socioeconomic gradient in the quality of sibling bond at the age-5 wave. The socioeconomic status is the mother's education at the age-5 wave (dummy for whether the mother continued schooling past the minimum leaving age, based on her date of birth). The index of the sibling bond is constructed by summing the values from the following 4 questions about how often [frequently, sometimes, never] the cohort member (i.e., the younger sibling): (i) Likes to be with the older sibling, (ii) Not much interested in the older sibling, (iii) Has a lot of fun with the older sibling, (iv) Teases or needles the older sibling. The index of sibling bond is standardized to have mean 0 and standard deviation 1. I recode behaviours indicating worse interactions in reverse (i.e., not much interested in older sibling and teases or needles older sibling). Higher scores correspond to better quality interactions.

Figure A2: Cumulative distribution function: socio-economic gradient (mother's education) for each item used to measure sibling bond



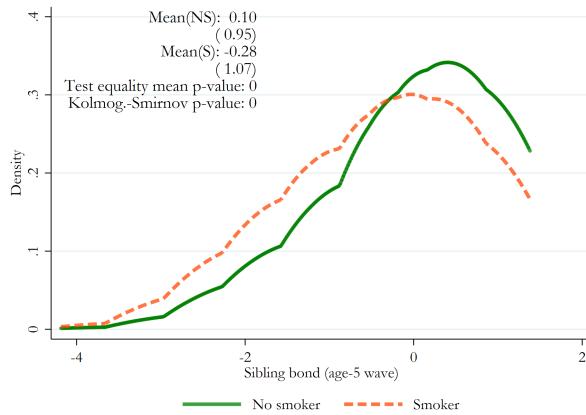
Note. The Figure presents the socioeconomic gradient in each item used to measure the quality of sibling interactions at the age-5 wave. The socioeconomic status is the mother's education at the age-5 wave (dummy for whether the mother continued schooling past the minimum leaving age, based on her date of birth). The mother is asked to answer the following 4 questions about how often [never, sometimes, frequently] the cohort member (i.e., the younger sibling): (i) Likes to be with the older sibling, (ii) Not much interested in the older sibling, (iii) Has a lot of fun with the older sibling, (iv) Teases or needles the older sibling. I recode behaviours indicating worse interactions in reverse (i.e., not much interested in older sibling and teases or needles older sibling). Higher scores correspond to a higher quality bond between siblings.

Figure A3: Socio-economic gradient (mother's education) in the sibling bond residualized by the older sibling's age



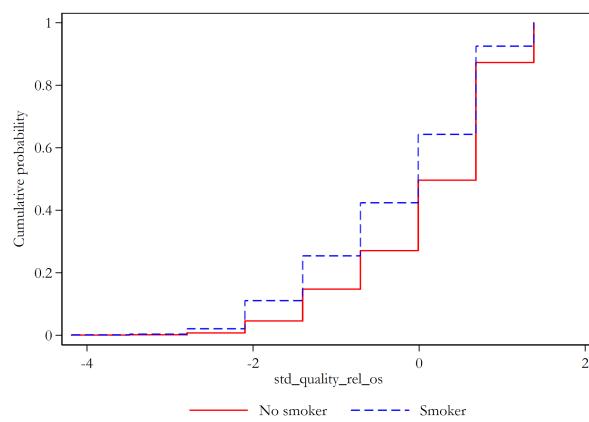
Note. The Figure presents the socioeconomic gradient in the quality of the sibling bond residualized by the older sibling's age at the age-5 wave. The socioeconomic status is the mother's education at the age-5 wave (dummy for whether the mother continued schooling past the minimum leaving age, based on her date of birth). The index of the sibling bond is constructed by summing the values from the following 4 questions about how often [frequently, sometimes, never] the cohort member (i.e., the younger sibling): (i) Likes to be with the older sibling, (ii) Not much interested in the older sibling, (iii) Has a lot of fun with the older sibling, (iv) Teases or needles the older sibling. The index of sibling bond is standardized to have mean 0 and standard deviation 1. I recode behaviours indicating worse interactions in reverse (i.e., not much interested in older sibling and teases or needles older sibling). Higher scores correspond to better quality interactions. I report the means of the quality of interactions by socioeconomic gradient and their standard errors between parentheses. The distribution is estimated nonparametrically, using an Epanechnikov kernel. I report the p -value of a t tests on the equality of means between the two groups assuming unequal variances. I report the p -value from Kolmogorov-Smirnov tests on the equality between the distributions by socioeconomic gradient.

Figure A4: Socio-economic gradient (mother was smoking during pregnancy) in the sibling bond



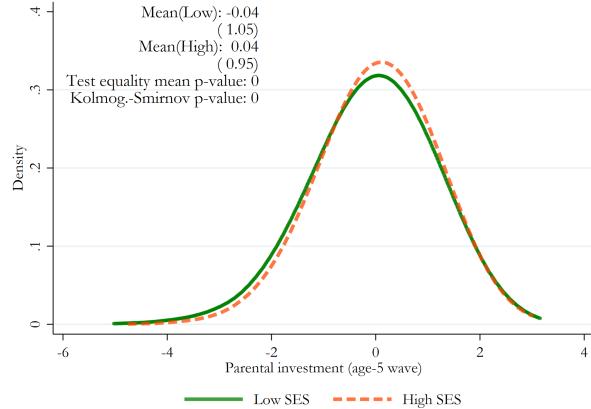
Note. The Figure presents the socioeconomic gradient in the quality of the sibling bond at the age-5 wave. The socioeconomic status is a dummy equal to 1 if the mother was smoking during pregnancy. The index of the sibling bond is constructed by summing the values from the following 4 questions about how often [frequently, sometimes, never] the cohort member (i.e., the younger sibling): (i) Likes to be with the older sibling, (ii) Not much interested in the older sibling, (iii) Has a lot of fun with the older sibling, (iv) Teases or needles the older sibling. The index of sibling bond is standardized to have mean 0 and standard deviation 1. I recode behaviours indicating worse interactions in reverse (i.e., not much interested in older sibling and teases or needles older sibling). Higher scores correspond to better quality interactions. I report the means of the quality of interactions by socioeconomic gradient and their standard errors between parentheses. The distribution is estimated nonparametrically, using an Epanechnikov kernel. I report the p -value of a t tests on the equality of means between the two groups assuming unequal variances. I report the p -value from Kolmogorov-Smirnov tests on the equality between the distributions by socioeconomic gradient.

Figure A5: Cumulative distribution function: socio-economic gradient (mother was smoking during pregnancy) in the sibling bond



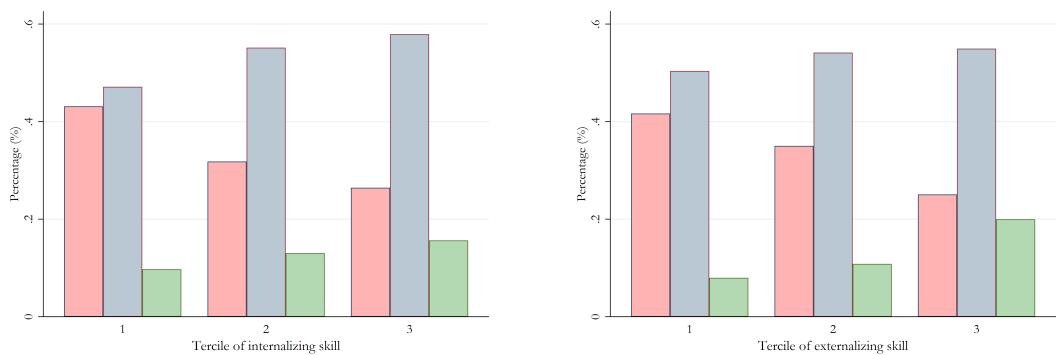
Note. The Figure presents the socioeconomic gradient in the quality of sibling interactions at the age-5 wave. The index of the sibling bond is constructed by summing the values from the following 4 questions about how often [frequently, sometimes, never] the cohort member (i.e., the younger sibling): (i) Likes to be with the older sibling, (ii) Not much interested in the older sibling, (iii) Has a lot of fun with the older sibling, (iv) Teases or needles the older sibling. The index of sibling bond is standardized to have mean 0 and standard deviation 1. I recode behaviours indicating worse interactions in reverse (i.e., not much interested in older sibling and teases or needles older sibling). Higher scores correspond to better quality interactions.

Figure A6: Socio-economic gradient (mother's education) in parental investment



Note. The Figure presents the socioeconomic gradient in the quality of the sibling bond at the age-5 wave. The socioeconomic status is the mother's education at the age-5 wave (dummy for whether the mother continued schooling past the minimum leaving age, based on her date of birth). The index of parental investment in younger sibling is obtained by summing the values from the questions asking the parents how often [Every day, Several times a week, Once or twice a week, Once or twice a month, Less often, Not at all] they do the following activities: (i) How often do you read to the child, (ii) How often tells stories to the child, (iii) How often does musical activities with the child, (iv) How often does the child paint/draw at home, (v) How often do you play physically active games with the child?, (vi) How often play indoor games with the child? and (vii) How often play outdoor games with the child? (viii) How often family does indoor activities together (ix) How often child sees grandparents (x) How often child sees other relatives (xi) How often ignores child when naughty (xii) How often smacks child when naughty (xiii) How often shouts at child when naughty (xiv) How often sends child to bedroom/naughty chair (xv) How often takes away treats from child when naughty (xvi) How often tells child off when naughty (xvii) How often bribes child when naughty (xviii) How often tries to reason with child when naughty (xix) How often makes sure child obeys instruction/request (xx) how close the bond between mother and child is. Higher scores correspond to higher parental investment. I report the means of the quality of interactions by socioeconomic gradient and their standard errors between parentheses. The distribution is estimated nonparametrically, using an Epanechnikov kernel. I report the p -value of a t tests on the equality of means between the two groups assuming unequal variances. I report the p -value from Kolmogorov-Smirnov tests on the equality between the distributions by socioeconomic gradient.

Figure A7: Sibling bond by each skill tercile



Note. The Figure shows that there are younger siblings with high social skills who still experience low quality bond with the older sibling and viceversa. The Figure presents the proportion of the quality of interactions between siblings in each skill (internalizing and externalizing) tercile of the younger sibling. The sibling' quality interactions is divided in tercile that are plotted in the figure against the tercile of the skill distribution. The index of the sibling bond is constructed by summing the values from the following 4 questions about how often [frequently, sometimes, never] the cohort member (i.e., the younger sibling): (i) Likes to be with the older sibling, (ii) Not much interested in the older sibling, (iii) Has a lot of fun with the older sibling, (iv) Teases or needles the older sibling. I recode behaviours indicating worse interactions in reverse (i.e., not much interested in older sibling and teases or needles older sibling).

Table A3: Correlation between the sibling bond and "home environment" variables

	Sibling bond	Parental investment	Calm home atmosphere	Close relationship mother and child	Mother's mental health	Household dual or single headed
Sibling bond	1.000					
Parental investment	0.074***	1.000				
Calm home atmosphere	0.126***	0.123***	1.000			
Close relationship mother and child	0.113***	0.170***	0.048**	1.000		
Mother's mental health	-0.223***	-0.100***	-0.187***	-0.090***	1.000	
Household dual or single headed	-0.120***	0.001	-0.013	-0.011	0.138***	1.000

Note. Table shows the correlation between the sibling bond and parental investment, how calm the home atmosphere is, close relationship between mother and child, whether the household is dual or single head. The index of the sibling bond is constructed by summing the values from the following 4 questions about how often [frequently, sometimes, never] the cohort member (i.e., the younger sibling): (i) Likes to be with the older sibling, (ii) Not much interested in the older sibling, (iii) Has a lot of fun with the older sibling, (iv) Teases or needles the older sibling. I recode behaviours indicating worse interactions in reverse (i.e., not much interested in older sibling and teases or needles older sibling). The index of parental investment in younger sibling is obtained by summing the values from the questions asking the parents how often [Every day, Several times a week, Once or twice a week, Once or twice a month, Less often, Not at all] they do the following activities: (i) How often do you read to the child, (ii) How often tells stories to the child, (iii) How often does musical activities with the child, (iv) How often does the child paint/draw at home, (v) How often do you play physically active games with the child?, (vi) How often play indoor games with the child? and (vii) How often play outdoor games with the child? (viii) How often family does indoor activities together (ix) How often child sees grandparents (x) How often child sees other relatives (xi) How often child spends time with friends outside school (xii) How often ignores child when naughty (xiii) How often smacks child when naughty (xiv) How often shouts at child when naughty (xv) How often sends child to bedroom/naughty chair (xvi) How often takes away treats from child when naughty (xvii) How often tells child off when naughty (xviii) How often bribes child when naughty (xix) How often tries to reason with child when naughty (xx) how close the bond between mother and child is Both indexes of the sibling bond and parental investment are standardized to have mean 0 and standard deviation 1. *** p<0.01, ** p<0.05, * p<0.1.

B Extension to the Theoretical Framework

This section discuss a possible extensions to the theoretical framework where parents propose an interaction SI_i to the two siblings which is associated with a certain payoff (for example, a drawing competition with a prize). Then siblings interact over the proposed activity to try to win it in a non-cooperative way by best responding to each other. The sibling bond depends on siblings' actions, $SB_i = h(A, SI_i)$, where A corresponds to the actions of the siblings and a shock ξ outside of the parents' control ($A = a_{YS} + a_{OS} + \xi_{YS} + \xi_{OS}$). Each sibling maximizes the following utility which depends on the other sibling's actions and is linear in the cost incurred for taking each action.

$$U^{YS}(a_{YS}, a_{OS}, \xi_{YS}) = (SB_i - c_{YS}) * (a_{YS} + \xi_{YS}) \quad (12)$$

$$U^{OS}(a_{YS}, a_{OS}, \xi_{OS}) = (SB_i - c_{OS}) * (a_{OS} + \xi_{OS}) \quad (13)$$

To complete the game, I need to define the timing of the game. It is possible to consider either a simultaneous or dynamic game. A dynamic game where the older sibling takes the first action and the younger sibling is the follower allows for role model consideration of the older sibling. The solution to this game can be found via Nash equilibrium where each sibling is best responding to each other and the best responses generate the sibling bond.

C Measurement

C.1 Descriptive Statistics

Table C4: Descriptive statistics on sample characteristics.

	Mean	St.Dev.	N
Younger sib's sex	0.51	0.50	2558
Older sib's Sex	0.48	0.50	2558
Older sib's Age	8.46	2.15	2558
Number of sibs (age-3 wave)	1.60	0.75	2558
Mother's age at birth	30.51	5.03	2555
Mother education past compulsory (age-5 wave)	0.56	0.50	2558
Mother's mental health Kessler K6 Scale	2.77	3.48	2558
Years in current address	6.79	4.45	2558
Number of rooms in the house (age-3 wave)	6.18	1.59	2558

Note. The table presents the descriptive statistics on the sample. Mean (%) is reported in column 1, standard deviation is reported in column 2, and number of observations in column 3. Mother's mental health is measured with the Kessler 6.

C.2 Strengths and Difficulties Questionnaire (SDQ)

Table C5: Strengths and Difficulties Questionnaire (SDQ)

Strengths and Difficulties Questionnaire (SDQ) administered to the cohort member child and older sibling	
1. Considerate of other people's feelings ⁺	2. Restless, overactive and not able to sit still for long
3. Often complaining of headaches, stomach-aches or sickness	4. Sharing readily with other children (treats, toY, pencils etc.) ⁺
5. Has often had temper tantrums or hot tempers	6. Rather solitary, tending to play alone
7. Generally obedient, usually doing what adults requested ⁺	8. Many worries, often seeming worried
9. Helpful if someone was hurt, upset or feeling ill ⁺	10. Constantly fidgeting and squirming
11. Has had at least one good friend ⁺	12. Has often had fights with other children or bullies them
13. Often unhappy, downhearted or tearful	14. Generally liked by other children ⁺
15. Easily distracted, concentration wandered	16. Nervous or clingy in new situations, easily loses confidence
17. Kind to younger children ⁺	18. Often lies or cheats
19. Picked on or bullied by other children	20. Often volunteer to help (parents, teachers, other children) ⁺
21. Able to think things out before acting ⁺	22. Stole from home, school or elsewhere
23. Getting on better with adults than with other children	24. Many fears, easily scared
25. Has seen tasks through to the end, good attention span ⁺	

Note. The Strengths and Difficulties Questionnaire items are rated on three levels: 'Does not apply', 'Somewhat applies', 'Certainly applies'. Since they are all behaviours indicating lower skills, I recode all of them in reverse, i.e. 'Certainly applies' = 0, 'Somewhat applies' = 1, 'Does not apply' = 2. Items denoted by ⁺ are positively coded in the original scale. The items measuring Emotional symptoms are 3, 8, 13, 16 and 24. The items measuring Conduct problems are 5, 7, 12, 18 and 21. The items measuring Hyperactivity/inattention are 2, 10, 15, 21 and 25. The items measuring Peer relationship problem are 6, 11, 14, 19 and 23. The items measuring Prosocial behaviour are 1, 4, 9, 17 and 20.

C.3 Exploratory Factor Analysis

Table C6: Exploratory factor analysis of the siblings' socio-emotional skill questions

Item	Younger sibling (age 3)		Younger sibling (age 5)		Older sibling (age-3 wave)	
	Externalizing	Internalizing	Externalizing	Internalizing	Externalizing	Internalizing
Has at least one good friend	-0.052	0.480	0.060	0.450	0.135	0.496
Generally liked by other children	0.047	0.482	0.187	0.485	0.330	0.507
Often complains of headaches/sickness	0.144	0.287	-0.003	0.369	0.132	0.325
Nervous/clingy in new situations	-0.009	0.495	-0.068	0.581	-0.158	0.646
Has many fears, is easily scared	-0.060	0.461	0.017	0.581	-0.126	0.671
Solitary, plays alone	-0.078	0.636	-0.183	0.640	-0.089	0.680
Gets on better with adults than children	-0.038	0.552	0.013	0.535	0.027	0.527
Temper tantrums	0.537	0.105	0.436	0.253	0.549	0.151
Is generally obedient	0.529	0.092	0.636	-0.014	0.655	0.025
Fights with or bullies other children	0.463	0.186	0.465	0.263	0.599	0.171
Often lies or cheats	0.536	0.084	0.451	0.116	0.473	0.170
Restless, overactive, cannot stay still	0.796	-0.051	0.748	0.056	0.854	-0.109
Constantly fidgeting or squirming	0.759	-0.051	0.649	0.105	0.794	-0.015
Easily distracted, concentration wanders	0.797	-0.090	0.805	-0.055	0.821	-0.024
Thinks things out before acting	0.334	0.019	0.654	-0.120	0.739	-0.093
Sees tasks through to the end	0.651	-0.059	0.773	-0.156	0.791	-0.052

Note. The table displays the factors loadings obtained from exploratory factor analysis (EFA) of the siblings' socio-emotional skill questions. Two dimensions of socio-emotional skills are found: internalizing and externalizing, linked respectively to the ability to focus their drive and determination to pursue long-term goals and the ability to engage in interpersonal activities. The EFA is based on the decomposition of the polychoric correlation matrix. The polychoric correlation is an estimate for the correlation between two normally distributed continuous random variables observed as ordinal variables. The solution is rescaled using oblique factor rotation obtained via the PROMAX protocol outlined in [Hendrickson and White \(1964\)](#) (with $k = 3$). Since they are all behaviours indicating lower skills, we recode all of them in reverse, i.e. 'Certainly applies' = 0, 'Somewhat applies' = 1, 'Does not apply' = 2.

Table C7: Exploratory factor analysis of the sibling bond and parental investment residualized questions

Item	Parental investment	Sibling bond
Younger sib likes to be with older sib	-0.010	0.668
Younger sib interested in older sib	0.005	0.444
Younger sib has fun with older sib	0.026	0.649
Younger sib does not tease older sib	-0.034	0.199
How often do you read to child	0.385	-0.027
How often tells stories to child	0.456	0.022
How often does musical activities with child	0.470	0.045
How often does child paint/draw at home	0.565	-0.013
How often do you play physically active games with child?	0.525	0.032
Frequency play INDOOR games with child	0.580	-0.014
Frequency take child to park or playground	0.382	-0.031
How often family does indoor activities together	0.272	-0.003
How often child sees grandparents	0.020	0.004
How often child sees other relatives	0.057	-0.059
How often child spends time with friends outside school	0.171	-0.012
How often ignores child when naughty	-0.014	0.027
How often smacks child when naughty	-0.100	0.014
How often shouts at child when naughty	0.090	0.025
How often sends child to bedroom/naughty chair	-0.025	-0.007
How often takes away treats from child when naughty	-0.025	0.006
How often tells child off when naughty	0.038	-0.002
How often bribes child when naughty	-0.022	-0.033
How often tries to reason with child when naughty	0.096	-0.016
How often makes sure child obeys instruction/requs	0.041	0.048
How close bond between mother and child	-0.007	-0.052

Note. The table displays the factors loadings obtained from exploratory factor analysis (EFA) with the residualized items. The EFA is based on the decomposition of the correlation matrix. The solution is rescaled using oblique factor rotation obtained via the PROMAX protocol (with $k = 3$). The solution is rescaled using oblique factor rotation obtained via the PROMAX protocol (with $k = 3$). I recode behaviours indicating worse interactions in reverse (i.e., not much interested in older sibling and teases or needles older sibling).

Table C8: Exploratory factor analysis of the sibling bond, parental investment, age-5 younger sibling's internalizing and externalizing skill questions

Item	Sibling bond	Parental investment	Internalizing	Externalizing
Younger sib likes to be with older sib	0.846	0.004	-0.064	0.067
Younger sib interested in older sib	0.663	-0.025	-0.018	0.066
Younger sib has fun with older sib	0.816	0.052	-0.091	0.071
Younger sib does not tease older sib	0.196	-0.054	-0.075	0.396
How often do you read to child	0.039	0.406	0.037	0.053
How often tells stories to child	0.001	0.510	-0.030	-0.065
How often does musical activities with child	0.021	0.541	-0.016	-0.033
How often does child paint/draw at home	-0.036	0.606	-0.017	0.026
How often do you play physically active games with child?	0.090	0.542	0.057	-0.045
Frequency play indoor games with child	-0.011	0.639	-0.049	0.039
Frequency take child to park or playground	0.000	0.390	0.020	-0.096
How often family does indoor activities together	0.023	0.340	-0.028	0.051
How often child sees grandparents	-0.097	0.072	0.068	-0.022
How often child sees other relatives	-0.180	0.141	0.079	-0.061
How often child spends time with friends outside school	0.007	0.206	0.120	-0.052
How often ignores child when naughty	0.020	-0.054	-0.037	0.075
How often smacks child when naughty	0.062	-0.165	0.001	-0.213
How often shouts at child when naughty	-0.132	0.115	-0.038	0.439
How often sends child to bedroom/naughty chair	-0.021	-0.070	-0.044	0.253
How often takes away treats from child when naughty	-0.063	-0.050	-0.026	0.242
How often tells child off when naughty	-0.253	0.076	-0.114	0.597
How often bribes child when naughty	0.014	-0.050	0.018	-0.046
How often tries to reason with child when naughty	0.239	0.088	0.030	-0.401
How often makes sure child obeys instruction/reques	0.163	0.100	0.064	0.040
How close bond between mother and child	0.098	0.237	0.100	0.164
Child often complains of headaches/sickness	-0.081	0.064	0.448	0.046
Child has many worries, often seems worried	-0.085	0.005	0.787	0.005
Child often unhappy/downhearted, tearful	-0.071	-0.009	0.710	0.078
Child nervous/clingy in new situations	-0.141	-0.039	0.586	-0.001
Child has many fears, is easily scared	-0.058	-0.002	0.649	0.054
Child is rather solitary, plays alone	0.110	0.043	0.558	-0.170
Child has at least one good friend	0.091	0.029	0.322	0.088
Child generally liked by other children	0.062	0.032	0.453	0.198
Child picked on or bullied by other children	0.055	-0.074	0.474	0.115
Child gets on better with adults than children	0.227	-0.080	0.395	0.054
Child often has temper tantrums	-0.026	-0.015	0.228	0.540
Child is generally obedient	0.111	0.041	-0.055	0.623
Child fights with or bullies other children	0.069	-0.095	0.275	0.543
Child often lies or cheats	-0.050	-0.001	0.113	0.556
Child steals from home, school, elsewhere	-0.011	0.051	-0.046	0.460
Child is restless, overactive, cannot stay still	0.137	-0.056	0.096	0.640
Child constantly fidgeting or squirming	0.043	-0.050	0.166	0.569
Child is easily distracted, concentration wanders	0.064	-0.020	0.042	0.675
Child thinks things out before acting	0.048	0.055	-0.113	0.590
Child sees tasks through to the end	0.064	0.049	-0.110	0.660

Note. The table displays the factors loadings obtained from exploratory factor analysis (EFA) with the residualized items. The EFA is based on the decomposition of the correlation matrix. The solution is rescaled using oblique factor rotation obtained via the PROMAX protocol (with $k = 3$). The solution is rescaled using oblique factor rotation obtained via the PROMAX protocol (with $k = 3$). I recode behaviours indicating worse interactions in reverse (i.e., not much interested in older sibling and teases or needles older sibling).

Table C9: Scale reliability: Cronbach's alpha

Latent factor	Cronbach's alpha
Younger sib's internalizing (age 3)	0.532
Younger sib's internalizing (age 5)	0.563
Older sibling's internalizing (age-3 wave)	0.629
Younger sib's externalizing (age 3)	0.776
Younger sib's externalizing (age 5)	0.792
Older sibling's externalizing (age-3 wave)	0.835
Parental investment	0.581
Sibling bond	0.584

Note. The table presents Cronbach's alpha which measures how closely related a set of items are as a group for each latent factor. The Cronbach's alpha is computed as follows: $\frac{Nc}{(v+(N-1)c)}$ where N corresponds to the number of items, v is average variance of the items and c is the average inter-item correlation of the items. Cronbach's alpha can take values between 0 and 1 where values closer to 1 correspond to higher reliability. Values above 0.50 are considered acceptable ([Taber, 2018](#)).

C.4 Identification of a Factor Model with Categorical Items

The model assumes that the relationship between the logarithm of latent factors $\ln\theta_{cit}$ for child c in family i at time t and the available measures m_{cijt} for item j are characterised by item-specific intercepts α_{cjt} and loadings λ_{cjt} and are affected by an independent measurement error term ε_{cijt} . I omit c for ease of notation in equations (17) and (18).

$$m_{ijt}^* = \alpha_{jt} + \lambda_{jt}^\top \ln\theta_{it} + \varepsilon_{ijt} \quad (14)$$

Given that m_{ijt}^* is unobserved, a threshold model is added to equation 17 to accommodate the categorical nature of the observed response, m_{ijt} such that:

$$m_{it}^j = \begin{cases} 0 & \text{if } m_{ijt}^* < \tau_{1,jt} \\ 1 & \text{if } m_{ijt}^* \in [\tau_{1,jt}, \tau_{2,jt}] \\ 2 & \text{if } m_{ijt}^* > \tau_{2,jt} \end{cases} \quad (15)$$

Where τ_{jt} is the threshold, for example, for showing a certain behaviour in the SDQ scale or an interaction in the quality of interactions between siblings scale. In a measurement system, latent factors and the measurement error terms are usually assumed to be normally distributed as follows $\ln\theta_{it} \sim \mathcal{N}(\mu_{\theta,t}, \sigma_{\theta,t})$ and $\varepsilon_{ijt} \sim \mathcal{N}(0, \sigma_{\varepsilon,jt})$. The measurement system defined in equations (10) and (11) needs some normalizations to be identified. The intercepts and the thresholds cannot be jointly identified in a factor model with categorical items, therefore intercepts are assumed zero. I need to make an additional normalization for the parameters λ_{jt} and τ_{jt} to be identified. Namely, two choices must be made to achieve identification: (i) scaling the latent response variables m_{ijt}^* , (ii) scaling the common factors.

The first choice deals with the conditional distribution of the continuous latent variable, so I refer to it as *conditional parametrization*. One possibility is to constrain the variance of m_{ijt}^* to be 1 for all the items to obtain the $V(\varepsilon_{ijt}) = 1 - \lambda_{jt}^2 V(\ln\theta_{it})$ as the remainder. Another possibility is to constrain the residuals $V(\varepsilon_{ijt})$ to be 1 and obtain $y_{jt}^* = \lambda_{jt}^2 V(\ln\theta_{it}) + 1$.²

Second, a choice must be made on how to scale the common factor. Two frequently used scaling conventions are either to choose a reference indicator or to standardize the common factor. In the former approach, it is usually assumed $\lambda_{1t} = 1$ and $\tau_{1t} = 0$ to allows me to estimate the mean and the variance of the factor $\ln\theta_{it}$. In the latter approach, λ_{jt} and τ_{jt} are freely estimated by fixing $E(\ln\theta_{it}) = 0$ and $V(\ln\theta_{it}) = 1$.³ By the combinations of the two types of scaling choices, four possible parametrizations are possible, as shown in Table C10. Other parametrizations are conceivable as well, these seem to be the most commonly used.

²This latter possibility is more familiar to the one used in IRT probit model, but is less commonly used in factor model with categorical items.

³Similar choices are made in continuous factor model with reference to the intercept - instead of the threshold.

Table C10: Normalization for identification

	Reference Indicator	Standardized Factor
Marginal	$\lambda_{jt} = 1$ and $\tau_{jt} = 0$	$E(\ln(\theta_{it})) = 0, V(\ln(\theta_{it})) = 1$
	$V(m_{ijt}^*) = 1$	$V(m_{ijt}^*) = 1$
Conditional	$\lambda_{jt} = 1$ and $\tau_{jt} = 0$	$E(\ln(\theta_{it})) = 0$ and $V(\ln(\theta_{it})) = 1$
	$V(\varepsilon_{ijt}) = 1$	$V(\varepsilon_{ijt}) = 1$

C.5 Measurement Invariance between Siblings' Skill Measures

This section outlines a novel measurement challenge faced when estimating the joint technology of skill formation with siblings. As I am estimating the joint technology of the younger and older siblings' skills, I would like to set the same metric to compare the structural estimates of the joint technologies of skill formation for the younger and older siblings. I also need to assure that I can control for comparable measures of the younger and older siblings' socio-emotional skills. This requires the socio-emotional questionnaire items to have the same relationship with the latent constructs across the younger and older siblings. In other words, socio-emotional questionnaire items in the factor model must be invariant to the group, in this instance across the younger and older siblings. Specifically, the younger and older siblings' SDQ items must measure internalizing and externalizing in the same way. If invariance is not achieved, this would mean that the measures of the siblings' latent social skills are on different scales and therefore incomparable. For example, this happens when some questions contribute more to the younger sibling's socio-emotional skills, while at the same time these questions contribute less to the older sibling's socio-emotional skills.

Fortunately, this is a testable property in psychometrics. [Vandenberg and Lance \(2000\)](#), [Putnick and Bornstein \(2016\)](#), and [Wu and Estabrook \(2016\)](#) have developed a test for measurement invariance. This test involves the estimation of a series of more restrictive measurement systems and the comparison of their fits to investigate whether questions are answered consistently across groups and therefore are invariant to the group.⁴ Following the assumptions introduced by [Wu and Estabrook \(2016\)](#), the test compares the baseline model, namely the maximal identifiable model, with a series of models with stronger restrictions on the item- and sibling-specific intercepts and loadings, requiring them to be the same across groups. Their fit is then compared to see if the models with stronger restrictions have a worse fit. If the fit is not worse, then measurement invariance is not rejected.

I estimate three models with additional restrictions to compare their relative fit with respect to the baseline model. First, a threshold invariant model is estimated where the threshold are restricted to be the same across younger and older sibling ($\tau_{1,YSjt} = \tau_{1,OSjt}, \tau_{2,YSjt} = \tau_{2,OSjt}, \mu_{\theta,YSjt} = \mu_{\theta,OSjt} = 0, \sigma_{\theta,YSjt} = \sigma_{\theta,OSjt} = 1 \forall j, t$). This is observationally equivalent to the baseline model when each item is a categorical variable with three categories ([Wu and Estabrook, 2016](#)). Second, the loading- and threshold-invariant model is estimated, imposing stronger restrictions

⁴Versions of this test have now been used in economics by [Attanasio, Blundell, Conti, and Mason \(2020\)](#), [Attanasio, de Paula, and Toppeta \(2022\)](#), and [Heckman and Zhou \(2022\)](#).

on the factor loadings and the thresholds on the items, which must be the same across siblings ($\tau_{1,YSjt} = \tau_{1,OSjt}$, $\tau_{2,YSjt} = \tau_{2,OSjt}$, $\lambda_{YSjt} = \lambda_{OSjt}$, $\mu_{\theta,YSjt} = \mu_{\theta,OSjt} = 0$, $\sigma_{\theta,YSjt} = 1 \forall j, t$). This requires that the SDQ items to have the same relationship with the latent skill across groups. Third, a loading-, threshold-, and intercept-invariant model is estimated. This model imposes the factor loadings, the intercepts and the thresholds to be the same across siblings ($\tau_{1,YSjt} = \tau_{1,OSjt}$, $\tau_{2,YSjt} = \tau_{2,OSjt}$, $\lambda_{YSjt} = \lambda_{OSjt}$, $\alpha_{YSjt} = \alpha_{OSjt} = 0$, $\mu_{\theta,YSjt} = 0$, $\sigma_{\theta,YSjt} = 1 \forall j, t$).

The measurement invariance test involves the comparison of models' fits after the inclusion of these additional restrictions. The comparison of χ^2 across models is however not recommended because tests based on $\Delta\chi^2$ are known to display high Type I error rates with large sample size and complex models (Sass, Schmitt, and Marsh, 2014). The psychometric literature recommends a holistic approach by using approximate fit indices (AFIs). These indices successfully adjust for model complexity (Cheung and Rensvold, 2002), but they do not have a known sampling distribution. Therefore, it is necessary to rely on simulation studies to derive the rule of thumb indicating what level of ΔAFI is compatible with invariance.

The recommendation is to present a range of fit indices for a more comprehensive assessment. Therefore, I first present the χ^2 statistic, but also other alternative goodness-of-fit indices commonly used, such as the root mean squared error of approximation (RMSEA), standardised root mean square residual (RMSR), the comparative fit index (CFI), and the Tucker-Lewis index (TLI).⁵

Commonly used rules of thumb for comparison of fit are Chen (2007) who suggests the following thresholds for *rejecting* measurement invariance: $\Delta\text{RMSEA} > 0.015$, $\Delta\text{CFI} < -0.010$, and $\Delta\text{RMSR} > 0.010$. Chen (2007) computes these rules of thumb from simulations with continuous measures and may not adjust well to the categorical case as suggested by Lubke and Muthén (2004). Rutkowski and Svetina (2017) find that a ΔRMSEA threshold of 0.010 is appropriate for testing equality of slopes and thresholds.

Table C11 compares the fit of each model. The baseline model fits the data well. Restricting the thresholds and loadings to be the same across siblings yields a fit comparable to the baseline model. The fit however does worsen when I also restrict the intercepts to be the same, but still provides comparable fit according to the measures above. These results reassure that the latent socio-emotional skills are invariant to the younger and older siblings and are measured on the same scale across the two groups, building confidence in the comparison of the estimates of the joint technology of skills for the younger and older siblings.

⁵The RMSEA is defined as $\sqrt{(\chi^2 - df)/df(N - 1)}$, where df are the degrees of freedom and N is the sample size. Lower values imply a better fit and MacCallum et al. (1996) suggest measures between 0.05 and 0.08 to be fair. On the other hand, CFI and TLI determine how far our model is from the model with the model where the variables have no correlation across them). The CFI is defined as $(\epsilon_{\text{Null Model}} - \epsilon_{\text{Alternative Model}})/\epsilon_{\text{Null Model}}$, where $\epsilon = \chi^2 - df$, whereas the TLI is defined as $(\epsilon_{\text{Null Model}} - \epsilon_{\text{Alternative Model}})/(\epsilon_{\text{Null Model}} - 1)$, where now $\epsilon = \chi^2/df$. Both indices are between 0 and 1 and a higher value corresponds to a better fit for the alternative model.

Table C11: Comparison of models' fit for measurement invariance

	N of Parameters	χ^2	Absolute fit			
			RMSEA	RMSR	CFI	TLI
Baseline model/ Threshold Invariance	98	2557.8760	0.0612	0.0841	0.9481	0.9396
Threshold and loading invariance	84	2915.3940	0.0634	0.0889	0.9405	0.9351
Threshold, loading, and intercept invariance	70	3567.5550	0.0684	0.0918	0.9265	0.9246
Relative Fit to the Baseline model/Threshold Invariance						
	P-value	Δ RMSEA	Δ RMSR	Δ CFI	Δ TLI	
Threshold and loading invariance	0.0000	0.0022	0.0048	-0.0076	-0.0044	
Threshold, loading, and intercept invariance	0.0000	0.0072	0.0078	-0.0217	-0.0150	

Note. RMSEA stands for the root mean squared error of approximation, SRMR for the standardised root mean square residual, CFI for the comparative fit index, and TLI for the Tucker-Lewis index.

C.6 Measurement System with Binary, Categorical and Continuous items

This section specifies a measurement system when the items are continuous, binary or categorical. The measurement system assumes that the relationship between the logarithm of latent factors $\ln\theta_{cit}$ for child c in family i at time t and the available measures m_{cijt}^* for item j are characterised by item-specific intercepts α_{cjt} and loadings λ_{cjt} and are affected by an independent measurement error term ε_{cijt} . I omit c for ease of exposition.

$$m_{cijt}^* = \alpha_{cjt} + \lambda_{cjt}^\top \ln\theta_{it} + \varepsilon_{cijt} \quad (16)$$

Depending on the nature of the item, m_{cijt}^* , we can specify the following models:

- (i) Continuous items: $m_{cijt} = m_{cijt}^*$;
- (ii) Binary items: $m_{cijt} \in \{0, 1\}$: $\text{Prob}\{m_{cijt} = 1\} = \text{Pr}\{m_{cijt}^* \geq 0\}$;
- (iii) Categorical items: $m_{cijt} \in \{1, 2, \dots, L\}$: $\text{Prob}\{m_{cijt} = l\} = \text{Pr}\{\tau_{l-1,jt} \leq m_{cijt} \leq \tau_{l,jt}\}$, where $\tau_{0,jt} = -\infty$;

Model (i) is the one used in [Cunha, Heckman, and Schennach \(2010\)](#), [Attanasio, Cattan, Fitzsimons, Meghir, and Rubio-Codina \(2020\)](#) and [Attanasio, Meghir, and Nix \(2020\)](#). Model (ii) can be shown to be equivalent to an Item Response Theory (IRT) model. Model (iii) is the one used in this paper.

C.7 Estimation of Measurement Systems with Categorical Items

This section outlines the estimation strategy developed by [Muthén \(1983\)](#) and [Muthén \(1984\)](#) to estimate the measurement system with categorical items in one step. I begin to outline the derivation of the likelihood function for the measurement system with categorical items, which in principle, can be estimated by maximum likelihood estimation (MLE). However, the problem is computationally intensive. Therefore, I describe the estimation strategy based on generalized method of moments (GMM), which is more computationally tractable.

The measurement system with categorical items assumes that the relationship between the logarithm of latent factors $\ln\theta_{it}$ for individual i at time t and the available measures m_{ijt} for item j are characterised by item-specific intercepts α_{jt} and loadings λ_{jt} and are affected by an independent measurement error term ε_{ijt} .

$$m_{ijt}^* = \alpha_{jt} + \lambda_{jt}^\top \ln\theta_{it} + \varepsilon_{ijt} \quad (17)$$

Given that m_{ijt}^* is unobserved, a threshold model is added to equation 10 to accommodate the categorical nature of the observed response, m_{ijt} such that:

$$m_{ijt} = \begin{cases} 0 & \text{if } m_{ijt}^* < \tau_{1,jt} \\ 1 & \text{if } m_{ijt}^* \in [\tau_{1,jt}, \tau_{2,jt}] \\ 2 & \text{if } m_{ijt}^* > \tau_{2,jt} \end{cases} \quad (18)$$

Where τ_j is the threshold for showing a certain behaviour in the SDQ scale.

Assuming that the error term $\varepsilon_{ijt} \sim \mathcal{N}(0, \sigma_{\varepsilon, jt})$ and $E[\varepsilon_{ijt}\varepsilon_{i'j't'}] = 0 \quad \forall j, t, j' : j \neq j'$ or $t \neq t'$, we have:

$$\begin{aligned} Pr[m_{ijt} = 0 | \ln\theta_{it}] &= Pr[m_{ijt}^* < \tau_{1,jt} | \ln\theta_{it}] \\ &= Pr[\varepsilon_{ijt} < \tau_{1,jt} - \alpha_{jt} - \lambda_{jt} \ln\theta_{it} | \ln\theta_{it}] \\ &= \Phi\left(\frac{\tau_{1,jt} - \alpha_{jt} - \lambda_{jt} \ln\theta_{it}}{\sigma_{\varepsilon, jt}} | \ln\theta_{it}\right) \end{aligned} \quad (19)$$

$$\begin{aligned} Pr[m_{ijt} = 1 | \ln\theta_{it}] &= \Phi\left(\frac{\tau_{2,jt} - \alpha_{jt} - \lambda_{jt} \ln\theta_{it}}{\sigma_{\varepsilon, jt}} | \ln\theta_{it}\right) \\ &\quad - \Phi\left(\frac{\tau_{1,jt} - \alpha_{jt} - \lambda_{jt} \ln\theta_{it}}{\sigma_{\varepsilon, jt}} | \ln\theta_{it}\right) \end{aligned} \quad (20)$$

$$\begin{aligned} Pr[m_{ijt} = 2 | \ln\theta_{it}] &= Pr[m_{ijt}^* > \tau_{2,jt} | \ln\theta_{it}] \\ &= Pr[\varepsilon_{ijt} > \tau_{2,jt} - \alpha_{jt} - \lambda_{jt} \ln\theta_{it} | \ln\theta_{it}] \\ &= 1 - \Phi\left(\frac{\tau_{2,jt} - \alpha_{jt} - \lambda_{jt} \ln\theta_{it}}{\sigma_{\varepsilon, jt}} | \ln\theta_{it}\right) \end{aligned} \quad (21)$$

$\sigma_{\varepsilon, jt}$ is set to one and all intercepts are set to zero because the intercepts and thresholds (jointly) cannot be identified as evident from 19, 20, and 21.

$$Pr[m_{ijt} = 0 | \ln\theta_{it}] = \Phi(\tau_{1,jt} - \lambda_{jt} \ln\theta_{it} | \ln\theta_{it}) \quad (22)$$

$$Pr[m_{ijt} = 1 | \ln\theta_{it}] = \Phi(\tau_{2,jt} - \lambda_{jt} \ln\theta_{it} | \ln\theta_{it}) - \Phi(\tau_{1,jt} - \lambda_{jt} \ln\theta_{it} | \ln\theta_{it}) \quad (23)$$

$$Pr[m_{ijt} = 2 | \ln\theta_{it}] = 1 - \Phi(\tau_{2,jt} - \lambda_{jt} \ln\theta_{it} | \ln\theta_{it}) \quad (24)$$

Define $m_{it} = [m_{i1t} \ m_{i2t} \ \dots \ m_{iJt}]$ and \mathcal{L}_t as the likelihood function for the wave t . Assuming iid sampling:

$$\mathcal{L}_t = \prod_{i=1}^N \mathcal{L}_{i,t}$$

Then, the likelihood function for a individual i is defined as:

$$\begin{aligned}\mathcal{L}_{i,t} &= E_{\ln\theta_{it}} [\mathcal{L}_{i,t} | \ln\theta_{it}] \\ &= E_{\ln\theta_{it}} [f(m_{it} | \ln\theta_{it})]\end{aligned}$$

As the ε_{ijt} are independent of each other, then, conditional on $\ln\theta_{it}$, the items m_{ijt} are independent of each other:

$$\begin{aligned}\mathcal{L}_{i,t} &= E_{\ln\theta_{it}} \left[\prod_{j=1}^J \{f(m_{ijt} | \ln\theta_{it})\} \right] \\ &= E_{\ln\theta_{it}} \left[\prod_{j=1}^J \left\{ Pr[m_{ijt} = 0 | \ln\theta_{it}]^{1[m_{ijt}=0]} \times Pr[m_{ijt} = 1 | \ln\theta_{it}]^{1[m_{ijt}=1]} \right. \right. \\ &\quad \left. \left. \times Pr[m_{ijt} = 2 | \ln\theta_{it}]^{1[m_{ijt}=2]} \right\} \right] \\ &= E_{\ln\theta_{it}} \left[\prod_{j=1}^J \left\{ \Phi(\tau_{1,jt} - \lambda_{jt} \ln\theta_{it} | \ln\theta_{it})^{1[m_{ijt}=0]} \right. \right. \\ &\quad \left. \left. \times (\Phi(\tau_{2,jt} - \lambda_{jt} \ln\theta_{it} | \ln\theta_{it}) - \Phi(\tau_{1,jt} - \lambda_{jt} \ln\theta_{it} | \ln\theta_{it}))^{1[m_{ijt}=1]} \right. \right. \\ &\quad \left. \left. \times (1 - \Phi(\tau_{2,jt} - \lambda_{jt} \ln\theta_{it} | \ln\theta_{it}))^{1[m_{ijt}=2]} \right\} \right] \quad (25)\end{aligned}$$

If we assume that $\ln\theta_{it} \sim \mathcal{N}(\mu_{\theta,t}, \sigma_{\theta,t})$, then 25 can be written as:

$$\begin{aligned}\mathcal{L}_{i,t} &= \int_{-\infty}^{\infty} \left[\prod_{j=1}^J \left\{ \Phi(\tau_{1,jt} - \lambda_{jt} \ln\theta_{it} | \ln\theta_{it})^{1[m_{ijt}=0]} \right. \right. \\ &\quad \left. \left. \times (\Phi(\tau_{2,jt} - \lambda_{jt} \ln\theta_{it} | \ln\theta_{it}) - \Phi(\tau_{1,jt} - \lambda_{jt} \ln\theta_{it} | \ln\theta_{it}))^{1[m_{ijt}=1]} \right. \right. \\ &\quad \left. \left. \times (1 - \Phi(\tau_{2,jt} - \lambda_{jt} \ln\theta_{it} | \ln\theta_{it}))^{1[m_{ijt}=2]} \right\} \times \frac{\exp\left(\frac{1}{2\sigma_{\theta,t}^2}(\ln\theta_t - \mu_{\theta,t})^2\right)}{\sigma_{\theta,t} \sqrt{2\pi}} \right] d\ln\theta \quad (26)\end{aligned}$$

After setting the scale and the location as illustrated in Section 3.2, it is possible to estimate the parameters of interest by MLE. However, this problem is computationally intensive to solve. Another possibility is to adopt the method developed by [Muthén \(1983\)](#) and [Muthén \(1984\)](#) in the psychometrics literature to estimate structural equation models (SEM) with categorical items in one step. This strategy estimates the parameters of the measurement system (e.g., factor loadings and latent regression coefficients) by using a GMM strategy where the moments are built based on the (polychoric) correlations ρ between the items m_{it}^j . The moment conditions are constructed by first estimating each threshold for each item from the data, yielding $\hat{\tau}$.⁶ Then the correlations between any two items can be computed by maximum likelihood, treating $\hat{\tau}$ as fixed, obtaining the matrix of estimated polychoric correlations, $\hat{\rho}$. The remaining parameters can be estimated by minimizing a weighted least squares (WLS) function of the polychoric correlation moments and the other moments obtained from the outcome equations. Formally, let the q free parameters be collected in the vector B , and let $\rho(B)$ represent the model-implied correlations. Then, the estimator \hat{B} is obtained by minimizing

$$F_W(B) = (\rho(B) - \hat{\rho})^\top W^{-1}(\rho(B) - \hat{\rho}), \quad (27)$$

for a weight matrix W , to be minimised with respect to B . [Muthén \(1978\)](#) suggests using a consistent estimator for asymptotic covariance matrix of $\hat{\rho}$ as W . This is referred to as the Weighted Least Squares (WLS) estimator in the psychometrics literature. In practice this weight matrix is not used because it tends to perform poorly if the N is not very large. Alternative weight matrices, computationally more tractable and often better performing statistically in small samples, are instead: (1) the diagonal of W (Diagonally Weighted Least Squares, DWLS) ([Muthén, 1997](#)) or the (2) the identity matrix (Unweighted Least Squares, ULS). I adopt the DWLS weight matrix in the estimation.

⁶Polychoric assumes standard normal factors, so thresholds are estimated from the proportion of responses in each category. For example, $Pr(m_{ijt} = 0) = Pr(m_{ijt} < \tau_1) = \Phi(\tau_1) \iff \hat{\tau}_1 = \Phi^{-1}(Pr(m_{ijt} = 0))$.

D Additional Estimates of Joint Technology of Skill Formation

D.1 Robustness: families with more than two siblings

Table D12: Joint technology of skill formation: average sibling bond in families with more than two siblings

Outcome	Externalizing (EXT)		Internalizing (INT)		Cognitive (COG)
	(1) Younger	(2) Older	(3) Younger	(4) Older	(5) Younger
Younger sibling's EXT skill (t-1)	0.499*** (0.091)	-0.013 (0.057)	-0.111** (0.053)	-0.100* (0.054)	-0.096 (0.085)
Younger sibling's INT skill (t-1)	-0.325*** (0.105)	-0.268** (0.112)	0.751*** (0.115)	-0.318*** (0.094)	-0.205 (0.134)
Younger sibling's COG skill (t-1)	0.083*** (0.029)	0.039 (0.029)	-0.033 (0.021)	0.048* (0.026)	0.589*** (0.037)
Older sibling's EXT skill (t-1)	-0.188** (0.078)	0.592*** (0.081)	-0.164*** (0.058)	-0.221*** (0.062)	-0.225** (0.094)
Older sibling's INT skill (t-1)	-0.010 (0.052)	-0.013 (0.057)	-0.020 (0.041)	0.940*** (0.089)	-0.076 (0.068)
Average sibling bond (t)	0.461** (0.212)	0.461** (0.233)	0.397** (0.167)	0.284 (0.173)	0.657** (0.283)
Parental investment (t)	0.480** (0.220)	0.627*** (0.222)	0.200 (0.162)	0.227 (0.162)	0.415 (0.277)
Observations	2558	2475	2558	2475	2558
Other controls	Yes	Yes	Yes	Yes	Yes

Note. Younger sibling at age 5, older sibling between age 6 and 15. The average sibling bond is the average of the siblings bonds in families with more than two siblings. Columns 1-2 present the structural estimates for externalizing skill (ability to engage in interpersonal activities), Columns 3-4 for internalizing skill (ability to focus their drive and determination to achieve long-term goals), and Columns 5 for cognitive skill (ability to learn and solve tasks). The measurement system and the outcome equation are estimated jointly (Muthén, 1984). The F-stat on sibling bond is 10.896, F-stat on parental investment is 24.550. Other controls include mother's mental health, mother's education, mother's age, whether the household is dual or single headed, number of children, age gap between younger and older sibling, siblings' gender, housing tenure, years lived in current address, local employment, region fixed effects. Source: University of London. Institute of Education. Centre for Longitudinal Studies. (2017). Millennium Cohort Study: Geographical Identifiers, Third Survey: Secure Access. [data collection]. 2nd Edition. UK Data Service. SN: 7760, <http://doi.org/10.5255/UKDA-SN-7760-2>. Standard errors computed based on inverting information matrix in parentheses (** p<0.01, ** p<0.05, * p<0.1).

D.2 Robustness: family size & fertility

Table D13: Joint technology of skill formation: family size & fertility

Outcome	Externalizing (EXT)		Internalizing (INT)		Cognitive (COG)
	(1) Younger	(2) Older	(3) Younger	(4) Older	(5) Younger
Younger sibling's EXT skill (t-1)	0.551*** (0.066)	-0.350*** (0.071)	-0.029 (0.036)	-0.042 (0.041)	-0.050 (0.059)
Younger sibling's INT skill (t-1)	-0.324*** (0.105)	-0.398** (0.168)	0.839*** (0.122)	-0.240** (0.095)	-0.172 (0.128)
Younger sibling's COG skill (t-1)	0.088** (0.043)	-0.098 (0.072)	0.046 (0.032)	0.108*** (0.037)	0.593*** (0.050)
Older sibling's EXT skill (t-1)	-0.177*** (0.062)	0.360*** (0.118)	0.051 (0.049)	-0.067 (0.055)	-0.160** (0.081)
Older sibling's INT skill (t-1)	-0.010 (0.050)	-0.090 (0.097)	0.011 (0.040)	0.961*** (0.091)	-0.074 (0.061)
Sibling bond (t)	0.418*** (0.140)	1.139*** (0.286)	-0.135 (0.106)	-0.121 (0.115)	0.454** (0.178)
Parental investment (t)	0.408** (0.177)	0.510*** (0.177)	0.107 (0.117)	0.166 (0.136)	0.290 (0.214)
Number of siblings (t)	0.098 (0.238)	-0.671* (0.343)	0.491*** (0.169)	0.416** (0.188)	0.079 (0.278)
Observations	2558	2475	2558	2475	2558
Other controls	Yes	Yes	Yes	Yes	Yes

Note. Younger sibling at age 5, older sibling between age 6 and 15. Columns 1-2 present the structural estimates for externalizing skill (ability to engage in interpersonal activities), Columns 3-4 for internalizing skill (ability to focus their drive and determination to achieve long-term goals), and Columns 5 for cognitive skill (ability to learn and solve tasks). The measurement system and the outcome equation are estimated jointly (Muthén, 1984). Family size is instrumented for the gender composition of the siblings Angrist et al. (2010). The F-stat on sibling bond is 9.485, F-stat on parental investment is 25.188, F-stat on number of siblings is 0.465 . Other controls include mother's mental health, mother's education, mother's age, whether the household is dual or single headed, number of children, age gap between younger and older sibling, siblings' gender, housing tenure, years lived in current address, local employment, region fixed effects. Source: University of London. Institute of Education. Centre for Longitudinal Studies. (2017). Millennium Cohort Study: Geographical Identifiers, Third Survey: Secure Access. [data collection]. 2nd Edition. UK Data Service. SN: 7760, <http://doi.org/10.5255/UKDA-SN-7760-2>. Standard errors computed based on inverting information matrix in parentheses (** p<0.01, ** p<0.05, * p<0.1).

D.3 Joint technology of skill formation with siblings: Exogenous investments

Table D14: Joint technology of skill formation: younger and older siblings - exogenous investment

Outcome	Externalizing (EXT)				Internalizing (INT)				Cognitive (COG)		
	Younger		Older		Younger		Older		Younger		
	Restricted (1)	Unrestricted (2)	Restricted (3)	Unrestricted (4)	Restricted (5)	Unrestricted (6)	Restricted (7)	Unrestricted (8)	Restricted (9)	Unrestricted (10)	
Younger sib's EXT skill (t-1)	0.696*** (0.037)	0.681*** (0.037)	-0.092*** (0.018)	-0.096*** (0.019)	0.005 (0.015)	-0.004 (0.015)	-0.020 (0.021)	-0.020 (0.021)	-0.036* (0.022)	0.082*** (0.022)	0.085*** (0.022)
Younger sib's INT skill (t-1)	-0.134*** (0.051)	-0.134*** (0.051)	-0.057 (0.054)	-0.052 (0.053)	0.831*** (0.100)	0.806*** (0.097)	-0.233*** (0.068)	-0.233*** (0.067)	-0.005 (0.063)	-0.005 (0.062)	-0.005 (0.062)
Younger sib's COG skill (t-1)	0.089*** (0.018)	0.084*** (0.018)	0.029 (0.018)	0.031* (0.019)	-0.019 (0.016)	-0.022 (0.016)	0.055** (0.022)	0.055** (0.022)	0.051** (0.028)	0.590*** (0.028)	0.594*** (0.028)
Older sib's EXT skill (t-1)	0.004 (0.015)	-0.023 (0.015)	0.770*** (0.034)	0.766*** (0.034)	-0.032** (0.013)	-0.044*** (0.014)	-0.116*** (0.020)	-0.116*** (0.020)	-0.138*** (0.018)	0.015 (0.019)	0.022 (0.019)
Older sib's INT skill (t-1)	0.008 (0.031)	-0.003 (0.032)	0.012 (0.034)	0.011 (0.034)	0.020 (0.028)	0.015 (0.029)	0.987*** (0.088)	0.987*** (0.087)	0.969*** (0.042)	-0.044 (0.042)	-0.040 (0.042)
Parental investment (t)	0.052*** (0.010)	0.049*** (0.014)	0.068*** (0.014)	0.013 (0.010)	-0.026*** (0.009)	-0.028*** (0.009)	0.020 (0.012)	0.017 (0.012)	0.013 (0.012)	0.014 (0.012)	0.014 (0.012)
Sibling bond (t)	0.099*** (0.011)		0.067*** (0.014)		0.046*** (0.013)		0.079*** (0.018)		0.079*** (0.018)	-0.025 (0.018)	-0.025 (0.018)
Observations	2558	2558	2475	2475	2558	2558	2475	2475	2558	2558	
Other controls	Yes										

Note. Younger sibling at age 5, older sibling between age 6 and 15. Measurement system and equations are estimated jointly (Muthén, 1984). Other controls include mother's mental health, mother's education, mother's age, whether the household is dual or single headed, mother's employment status, number of children, age gap between younger and older sibling, siblings' gender, housing tenure, years lived in current address, how close the bond between mother and child is, local employment, region fixed effects. Source: University of London. Institute of Education. Centre for Longitudinal Studies. (2017). Millennium Cohort Study: Geographical Identifiers, Third Survey: Secure Access. [data collection]. 2nd Edition. UK Data Service. SN: 7760, <http://doi.org/10.5255/UKDA-SN-7760-2>. Standard errors computed based on inverting information matrix in parentheses (** p<0.01, ** p<0.05, * p<0.1).

D.4 Translog production function

Table D15: Translog joint technology of skill formation

	Younger (1)	Externalizing (EXT)			Internalizing (INT)			Cognitive (COG)		
	Younger (1)	Younger (2)	Older (3)	Older (4)	Younger (5)	Younger (6)	Older (7)	Older (8)	Younger (9)	Younger (10)
Younger sib's EXT skill (t-1)	1.086*** (0.102)	1.086*** (0.102)	0.004 (0.232)	0.006 (0.232)	0.035 (0.039)	0.035 (0.039)	0.004 (0.151)	0.005 (0.151)	0.181 (0.155)	0.180 (0.155)
Younger sib's INT skill (t-1)	-0.192* (0.103)	-0.190* (0.103)	-0.063 (0.265)	-0.058 (0.265)	0.837*** (0.042)	0.838*** (0.042)	-0.069 (0.172)	-0.066 (0.173)	-0.187 (0.156)	-0.189 (0.157)
Younger sib's COG skill (t-1)	0.116 (0.076)	0.134 (0.091)	0.332* (0.199)	0.380* (0.224)	-0.057* (0.030)	-0.049 (0.037)	0.006 (0.134)	0.038 (0.154)	0.675*** (0.134)	0.651*** (0.133)
Older sib's EXT skill (t-1)	-0.059 (0.083)	-0.074 (0.089)	0.533*** (0.191)	0.496** (0.211)	-0.072** (0.032)	-0.078** (0.034)	-0.104 (0.120)	-0.130 (0.134)	-0.082 (0.137)	-0.063 (0.158)
Older sib's INT skill (t-1)	0.026 (0.112)	0.034 (0.114)	0.281 (0.295)	0.302 (0.299)	-0.018 (0.046)	-0.015 (0.046)	0.537*** (0.202)	0.550*** (0.203)	0.064 (0.157)	0.053 (0.161)
Parental investment (t)	0.069*** (0.014)	0.068*** (0.014)	0.080** (0.033)	0.079** (0.034)	-0.025*** (0.005)	-0.025*** (0.005)	0.040* (0.022)	0.039* (0.022)	0.017 (0.018)	0.018 (0.018)
Sibling bond (t)	0.078 (0.236)	0.043 (0.261)	-0.197 (0.563)	-0.291 (0.607)	0.170* (0.098)	0.154 (0.108)	0.021 (0.356)	-0.042 (0.394)	0.356 (0.328)	0.403 (0.343)
Parental investment (t) * Sibling bond (t)		-0.075 (0.203)		-0.197 (0.478)		-0.033 (0.079)		-0.133 (0.062)		0.099 (0.336)
Younger sib's EXT skill (t-1) *	0.063 (0.080)	0.096 (0.116)	-0.094 (0.219)	-0.005 (0.310)	0.028 (0.032)	0.043 (0.048)	0.062 (0.137)	0.123 (0.209)	0.166 (0.126)	0.121 (0.174)
Younger sib's INT skill (t-1) *	-0.152 (0.164)	-0.141 (0.167)	-0.136 (0.402)	-0.108 (0.409)	-0.043 (0.064)	-0.038 (0.065)	0.155 (0.268)	0.174 (0.274)	-0.293 (0.257)	-0.307 (0.268)
Younger sib's COG skill (t-1) *	0.112 (0.105)	0.131 (0.117)	0.473* (0.272)	0.522* (0.289)	-0.001 (0.042)	0.007 (0.047)	-0.014 (0.182)	0.019 (0.197)	0.043 (0.181)	0.019 (0.177)
Older sib's EXT skill (t-1) * Sibling bond (t)	-0.078 (0.092)	-0.091 (0.096)	-0.386* (0.200)	-0.420** (0.212)	-0.000 (0.035)	-0.006 (0.037)	-0.183 (0.133)	-0.205 (0.142)	-0.080 (0.129)	-0.063 (0.143)
Older sib's INT skill (t-1) * Sibling bond (t)	0.012 (0.153)	0.013 (0.153)	0.175 (0.392)	0.179 (0.393)	0.004 (0.062)	0.004 (0.062)	-0.034 (0.261)	-0.032 (0.261)	0.167 (0.222)	0.165 (0.223)
Observations	2558	2558	2475	2475	2558	2558	2475	2475	2558	2558
Other controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Note. The table presents the estimates for the translog production function. A control function approach is adopted to deal with the endogeneity of parental investment and sibling bond. Other controls include younger sibling's gender, age gap between younger and older sibling, older sibling's gender, number of children in the house, mother's mental health, mother's education, mother's age, whether the household is dual or single headed, how close the bond between mother and child is, housing tenure, years lived in current address, local employment at the local authority level, region fixed effects. Robust standard errors in parentheses (** p<0.01, *** p<0.005, * p<0.1).

D.5 Misreporting Bias

This Section exploits the data about socio-emotional development as reported by the teachers to address any concerns about misreporting bias regarding the socio-emotional skill measures. I use the data from the Foundation Stage Profile (FSP) questionnaire administered to teachers in Northern Ireland, Wales and Scotland and select the items that are similarly worded to the questionnaires administered to the parents. The comparable items are the following questions [Yes, No]: (i) Maintains attention and concentrates, (ii) Sustains involvement and perseveres, particularly problems, (iii) Considers the consequences of words and actions. There are two caveats to keep in mind. First, the responses to the teachers' questionnaire are not available in disaggregated form for England. Second, similarly-worded items are available to measure only the externalizing skill. Namely, an exploratory factor analysis on the items from the teachers' questionnaire points out to the existence of just one latent skill being captured by the teacher's questionnaire.

I therefore estimate jointly the factor model with categorical items for externalizing skill, where I use the responses as reported by the teachers - instead of the parents - to measure the externalizing

skill at age 5, and its production function. This provides a measure of the latent externalizing skill at age 5 that differs only by the nature of the respondent as similar survey questions are used across parents and teachers. Appendix Table D16 reports similar structural estimates for the self-productivity of skills and the productivity of the inputs to the ones obtained when using the information about the socio-emotional skills as reported by the parents (Table 4). Unfortunately, the standard errors are quite large as only data from Northern Ireland, Wales and Scotland are available.

Table D16: Joint technology of externalizing skill with siblings: using socio-emotional skills as reported by teachers

Outcome	Externalizing (EXT) (1)
Younger sibling's EXT skill (t-1)	0.411*** (0.143)
Younger sibling's INT skill (t-1)	0.045 (0.123)
Younger sibling's COG skill (t-1)	0.340*** (0.067)
Older sibling's EXT skill (t-1)	-0.024 (0.049)
Older sibling's INT skill (t-1)	-0.131* (0.070)
Sibling bond (t)	0.137*** (0.049)
Parental investment (t)	0.038 (0.031)
Observations	646
Other controls	Yes

Note. The table presents the estimate of the externalizing skill production function when the externalizing skill is reported by the teachers - instead of the parents. Investments are treated as exogenous. The teacher's questionnaire was administered in Northern Ireland, Wales and Scotland. The measurement system and the outcome equation are estimated jointly. Other controls include younger sibling's gender, age gap between younger and older sibling, older sibling's gender, number of children in the house, mother's mental health, mother's education, mother's age, whether the household is dual or single headed, how close the bond between mother and child is, housing tenure, years lived in current address, region fixed effects. Standard errors computed based on inverting information matrix in parentheses (** p<0.01, ** p<0.05, * p<0.1).

D.6 Heterogeneity: Joint Technology of Skill Formation

This section explores two possible source of heterogeneity in the joint technology of child development: the siblings' gender and the age. Unfortunately, the structural estimates become unreliable when the sample is split and investments are allowed to be endogenous.

Appendix Tables D17, D18 and D19 present the estimates for joint skill formation technology by the older sibling's gender, younger sibling's gender and siblings' gender composition. I do not detect any big differences in the estimates. Appendix Table D19 provides some suggestive evidence that the sibling bond is more productive for same-sex than mixed-sex siblings. This hint that same-sex siblings may have more possibilities to interact while sharing similar interests and toys.

Finally, Appendix Tables D20 presents the estimates for the joint skill formation technology by the siblings' age gap. The sample is split at the median age gap which corresponds to 3 years.

Table D17: Joint technology of skill formation by older sibling's gender

Outcome	Externalizing (EXT)				Internalizing (INT)				Cognitive (COG)		
	Younger		Older		Younger		Older		Younger		
Older sib's gender	Female (1)	Male (2)	Female (3)	Male (4)	Female (5)	Male (6)	Female (7)	Male (8)	Female (9)	Male (10)	
Younger sib's EXT skill (t-1)	0.232 (0.237)	0.629*** (0.076)	-0.459** (0.192)	-0.239** (0.101)	-0.091 (0.117)	-0.082 (0.093)	-0.526* (0.310)	-0.055 (0.125)	-0.080 (0.073)	-0.074 (0.083)	
Younger sib's INT skill (t-1)	-0.429** (0.201)	-0.024 (0.056)	-0.208 (0.174)	-0.150* (0.078)	0.579*** (0.132)	0.889*** (0.132)	-0.868*** (0.330)	-0.250** (0.127)	-0.148 (0.128)	0.065 (0.087)	
Younger sib's COG skill (t-1)	0.327** (0.131)	0.048 (0.038)	0.096 (0.087)	0.000 (0.060)	0.108 (0.068)	-0.208*** (0.078)	0.216 (0.146)	0.113 (0.081)	0.625*** (0.073)	0.513*** (0.063)	
Older sib's EXT skill (t-1)	-0.356* (0.185)	-0.037 (0.049)	0.436*** (0.190)	0.674*** (0.086)	-0.259** (0.110)	-0.228** (0.111)	-0.810** (0.331)	-0.285*** (0.110)	-0.172 (0.115)	-0.163* (0.097)	
Older sib's INT skill (t-1)	0.028 (0.113)	-0.074 (0.054)	0.002 (0.134)	-0.056 (0.106)	0.101 (0.082)	-0.064 (0.115)	1.622*** (0.230)	1.313*** (0.154)	-0.119 (0.087)	-0.128 (0.096)	
Parental investment (t)	0.732* (0.433)	0.292 (0.271)	0.637*** (0.338)	0.816* (0.481)	0.105 (0.229)	0.573 (0.524)	0.869* (0.514)	-0.207 (0.609)	0.297 (0.258)	0.352 (0.490)	
Sibling bond (t)	0.791* (0.433)	0.137 (0.154)	0.724 (0.475)	0.221 (0.229)	0.384 (0.268)	0.424 (0.287)	1.191 (0.795)	0.185 (0.291)	0.453 (0.258)	0.456* (0.256)	
Observations	1216	1342	1170	1305	1216	1342	1170	1305	1216	1342	
Other controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	

Note. Younger sibling at age 5, older sibling between age 6 and 15. Measurement system and equations are estimated jointly (Muthén, 1984). Other controls include mother's mental health, mother's education, mother's age, whether the household is dual or single headed, mother's employment status, number of children, age gap between younger and older sibling, siblings' gender, housing tenure, years lived in current address, how close the bond between mother and child is, local employment, region fixed effects. F-stat for sibling bond and parental investment are respectively 6.351 and 16.507 when female older sibling and 8.594 and 6.549 when female older sibling. Source: University of London. Institute of Education. Centre for Longitudinal Studies. (2017). Millennium Cohort Study: Geographical Identifiers, Third Survey: Secure Access. [data collection]. 2nd Edition. UK Data Service. SN: 7760, <http://doi.org/10.5255/UKDA-SN-7760-2>. Standard errors computed based on inverting information matrix in parentheses *** p<0.01, ** p<0.05, * p<0.1.

Table D18: Joint technology of skill formation by younger sibling's gender

Outcome	Externalizing (EXT)				Internalizing (INT)				Cognitive (COG)		
	Younger		Older		Younger		Older		Younger		
Younger sib's gender	Female (1)	Male (2)	Female (3)	Male (4)	Female (5)	Male (6)	Female (7)	Male (8)	Female (9)	Male (10)	
Younger sib's EXT skill (t-1)	0.449*** (0.076)	0.783*** (0.144)	-0.259*** (0.091)	-0.333** (0.150)	-0.108* (0.061)	-0.123 (0.090)	-0.177 (0.121)	-0.201 (0.213)	-0.029 (0.089)	-0.133 (0.146)	
Younger sib's INT skill (t-1)	-0.308** (0.122)	0.078 (0.139)	-0.176 (0.132)	-0.067 (0.120)	0.603*** (0.123)	0.900*** (0.184)	-0.779*** (0.240)	-0.215 (0.182)	0.027 (0.124)	-0.043 (0.207)	
Younger sib's COG skill (t-1)	0.122*** (0.036)	0.031 (0.046)	0.062 (0.044)	-0.012 (0.073)	-0.045* (0.027)	0.022 (0.035)	0.122 (0.075)	0.014 (0.107)	0.570*** (0.042)	0.526*** (0.056)	
Older sib's EXT skill (t-1)	-0.177** (0.074)	-0.053 (0.085)	0.636*** (0.095)	0.646*** (0.120)	-0.161*** (0.054)	-0.150* (0.088)	-0.462** (0.137)	-0.462** (0.178)	-0.032 (0.074)	-0.267* (0.142)	
Older sib's INT skill (t-1)	-0.003 (0.080)	-0.112 (0.083)	-0.110 (0.096)	-0.122 (0.186)	0.050 (0.049)	-0.003 (0.073)	1.451*** (0.174)	1.279*** (0.221)	-0.070 (0.069)	-0.132 (0.121)	
Parental investment (t)	0.669*** (0.194)	-0.415* (0.229)	0.746** (0.345)	0.400 (0.306)	0.186 (0.222)	0.189 (0.196)	0.696 (0.456)	0.228 (0.414)	0.107 (0.346)	0.400 (0.327)	
Sibling bond (t)	0.277* (0.157)	0.334 (0.237)	0.282 (0.205)	0.632 (0.431)	0.188** (0.085)	0.296 (0.206)	0.352 (0.291)	0.590 (0.624)	0.137 (0.118)	0.573* (0.335)	
Observations	1312	1245	1272	1203	1312	1245	1272	1203	1312	1245	
Other controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	

Note. Younger sibling at age 5, older sibling between age 6 and 15. Measurement system and equations are estimated jointly (Muthén, 1984). Other controls include mother's mental health, mother's education, mother's age, whether the household is dual or single headed, mother's employment status, number of children, age gap between younger and older sibling, siblings' gender, housing tenure, years lived in current address, how close the bond between mother and child is, local employment, region fixed effects. F-stat for sibling bond and parental investment are respectively 13.105 and 7.407 when female younger sibling and 4.984 and 18.183 when female younger sibling. Source: University of London. Institute of Education. Centre for Longitudinal Studies. (2017). Millennium Cohort Study: Geographical Identifiers, Third Survey: Secure Access. [data collection]. 2nd Edition. UK Data Service. SN: 7760, <http://doi.org/10.5255/UKDA-SN-7760-2>. Standard errors computed based on inverting information matrix in parentheses *** p<0.01, ** p<0.05, * p<0.1.

Table D19: Joint technology of skill formation by siblings' gender composition

Outcome	Externalizing (EXT)				Internalizing (INT)				Cognitive (COG)	
	Younger		Older		Younger		Older		Younger	Same
Gender composition	Mixed (1)	Same (2)	Mixed (3)	Same (4)	Mixed (5)	Same (6)	Mixed (7)	Same (8)	Mixed (9)	Same (10)
Younger sib's EXT skill (t-1)	0.539*** (0.078)	0.497*** (0.180)	-0.186*** (0.051)	-0.719 (0.651)	-0.045 (0.063)	-0.276 (0.283)	-0.131 (0.102)	-0.363 (0.440)	-0.046 (0.063)	-0.002 (0.157)
Younger sib's INT skill (t-1)	-0.251 (0.204)	-0.141 (0.087)	0.031 (0.128)	-0.032 (0.127)	0.663*** (0.199)	0.872*** (0.190)	-0.755** (0.309)	-0.449* (0.265)	-0.043 (0.210)	0.051 (0.097)
Younger sib's COG skill (t-1)	0.097 (0.098)	0.149** (0.041)	0.131** (0.065)	0.042 (0.115)	0.011 (0.106)	-0.071 (0.072)	0.176 (0.132)	0.096 (0.095)	0.548*** (0.100)	0.588*** (0.046)
Older sib's EXT skill (t-1)	-0.159*** (0.053)	-0.154 (0.166)	0.683*** (0.060)	0.198 (0.673)	-0.257*** (0.079)	-0.412 (0.287)	-0.460*** (0.113)	-0.664 (0.477)	-0.143* (0.075)	-0.103 (0.158)
Older sib's INT skill (t-1)	-0.018 (0.156)	-0.012 (0.044)	0.031 (0.128)	-0.032 (0.127)	-0.056 (0.171)	0.053 (0.090)	1.648*** (0.257)	1.302*** (0.145)	-0.209 (0.173)	-0.044 (0.049)
Parental investment (t)	0.625 (0.502)	0.363 (0.273)	0.464 (0.391)	1.238 (1.251)	-0.052 (0.549)	0.556 (0.519)	0.907 (0.693)	0.543 (0.843)	0.467 (0.576)	0.108 (0.298)
Sibling bond (t)	0.298 (0.358)	0.342 (0.318)	0.106 (0.272)	1.293 (1.325)	0.531 (0.399)	0.815 (0.592)	0.039 (0.544)	0.825 (0.900)	0.449 (0.411)	0.243 (0.319)
Observations	1266	1292	1222	1253	1266	1292	1222	1253	1266	1292
Other controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Note. Younger sibling at age 5, older sibling between age 6 and 15. Measurement system and equations are estimated jointly (Muthén, 1984). Other controls include mother's mental health, mother's education, mother's age, whether the household is dual or single headed, mother's employment status, number of children, age gap between younger and older sibling, siblings' gender, housing tenure, years lived in current address, how close the bond between mother and child is, local employment, region fixed effects. F-stat for sibling bond and parental investment are respectively 10.564 and 3.910 when mixed-sex siblings and 5.772 and 25.927 when same-sex siblings. Source: University of London. Institute of Education. Centre for Longitudinal Studies. (2017). Millennium Cohort Study: Geographical Identifiers, Third Survey: Secure Access. [data collection]. 2nd Edition. UK Data Service. SN: 7760, <http://doi.org/10.5255/UKDA-SN-7760-2>. Standard errors computed based on inverting information matrix in parentheses (** p<0.01, ** p<0.05, * p<0.1).

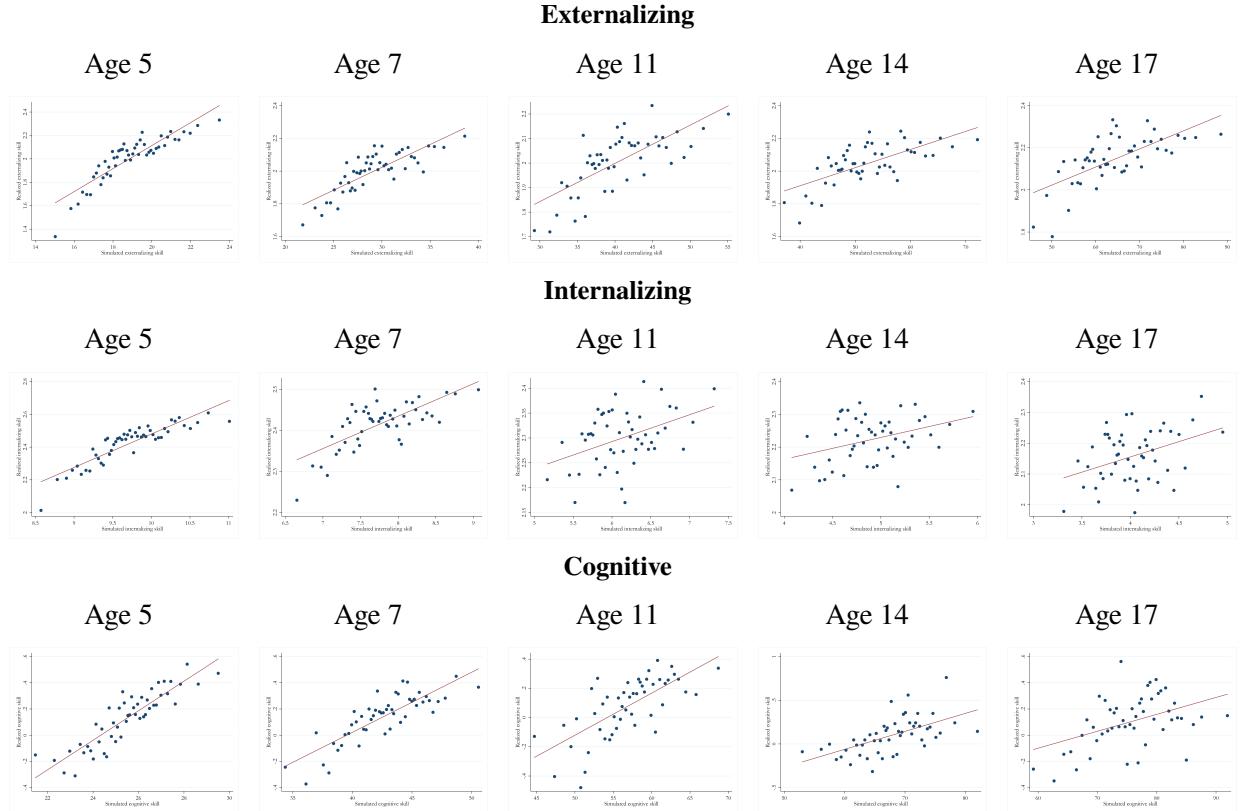
Table D20: Joint technology of skill formation by siblings' age gap

Outcome	Externalizing (EXT)				Internalizing (INT)				Cognitive (COG)	
	Younger		Older		Younger		Older		Younger	Same
Age gap	Small (1)	Large (2)	Small (3)	Large (4)	Small (5)	Large (6)	Small (7)	Large (8)	Small (9)	Large (10)
Younger sib's EXT skill (t-1)	0.476*** (0.101)	0.605*** (0.103)	-0.240*** (0.068)	-0.281** (0.108)	-0.110 (0.077)	-0.146 (0.137)	-0.230** (0.112)	-0.072 (0.121)	-0.125 (0.102)	-0.017 (0.085)
Younger sib's INT skill (t-1)	-0.145* (0.086)	-0.217* (0.116)	-0.149** (0.071)	-0.177 (0.134)	0.824*** (0.114)	0.902*** (0.183)	-0.505*** (0.150)	-0.240 (0.172)	-0.067 (0.101)	-0.046 (0.129)
Younger sib's COG skill (t-1)	0.160*** (0.034)	0.054 (0.046)	0.040 (0.033)	0.056 (0.048)	-0.039 (0.037)	-0.064 (0.063)	0.124* (0.066)	0.040 (0.062)	0.592*** (0.044)	0.593*** (0.054)
Older sib's EXT skill (t-1)	-0.185** (0.083)	-0.073 (0.067)	0.676*** (0.094)	0.573*** (0.081)	-0.163* (0.092)	-0.289*** (0.098)	-0.338** (0.153)	-0.379*** (0.099)	-0.225* (0.116)	-0.123 (0.080)
Older sib's INT skill (t-1)	0.029 (0.071)	-0.124* (0.067)	0.064 (0.065)	-0.163* (0.099)	0.019 (0.068)	0.010 (0.112)	1.410*** (0.149)	1.126*** (0.146)	-0.069 (0.085)	-0.100 (0.074)
Parental investment (t)	0.456* (0.264)	0.376 (0.277)	0.509** (0.235)	0.608* (0.321)	0.350 (0.265)	-0.095 (0.404)	0.396 (0.383)	0.371 (0.356)	0.407 (0.321)	0.335 (0.331)
Sibling bond (t)	0.269* (0.161)	0.473* (0.278)	0.317* (0.183)	0.375 (0.296)	0.283 (0.182)	0.779** (0.390)	0.493 (0.303)	0.208 (0.338)	0.516** (0.216)	0.184 (0.288)
Observations	1573	985	1531	994	1573	985	1531	994	1573	985
Other controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Note. Younger sibling at age 5, older sibling between age 6 and 15. Small age gap corresponds to siblings with an age gap below or equal to 3 years old (median age gap), age gap corresponds to siblings with an age gap above 3 years old. Measurement system and equations are estimated jointly (Muthén, 1984). Other controls include mother's mental health, mother's education, mother's age, whether the household is dual or single headed, mother's employment status, number of children, age gap between younger and older sibling, siblings' gender, housing tenure, years lived in current address, how close the bond between mother and child is, local employment, region fixed effects. F-stat for sibling bond and parental investment are respectively 10.117 and 13.599 when small siblings' age gap and 7.254 and 11.201 when large siblings' age gap. Source: University of London. Institute of Education. Centre for Longitudinal Studies. (2017). Millennium Cohort Study: Geographical Identifiers, Third Survey: Secure Access. [data collection]. 2nd Edition. UK Data Service. SN: 7760, <http://doi.org/10.5255/UKDA-SN-7760-2>. Standard errors computed based on inverting information matrix in parentheses (** p<0.01, ** p<0.05, * p<0.1).

E Validating the structural estimates

Figure E8: Validation exercise: future realized development and *simulated* development, as implied by the structural estimates of the joint skill formation technology.



Note. The Figures present the binscatter plot of the association between the future realized development (y-axis) and the simulated development (x-axis), as implied by the structural estimates of the technology of skill formation, for the younger sibling at ages 5, 7, 11, 14 and 17. The unit of the y-axis is in standard deviation units. Three dimensions of development are considered: externalizing (ability to engage in interpersonal activities), internalizing (ability to focus their drive and determination to achieve long-term goal) and cognitive skills (ability to complete tasks and learn).