Skill Formation with Siblings

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Abstract

This paper structurally estimates the technology of skill formation in children who grow up with 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 in the United Kingdom, focusing on the frequency of positive interactions between siblings, such as enjoying play time together and teasing each other. The structural estimates reveal that a stronger sibling bond plays a significant role in shaping both younger and older siblings' skills, even when accounting for parent-child interactions.

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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 (2022)).

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 an important role for child development by estimating the technology of skill formation with a *single* child (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).[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 siblings' human capital 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.

Measuring directly the quality of interactions between siblings enables me to open the black box of sibling spillovers and consider the social capital siblings share via their bond. This is important for several reasons. For example, a stronger bond enhances siblings' cooperation and connection, fostering their pro-social behavior and effective collaboration as well as reducing free-riding. 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 detrimental for their

[1] Similar 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 those living in a household with a father figure (78%).

[2] Another 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.

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 siblings' skills, personality, mother-child relationship and, more generally, the home environment (proxied by parental investment, parenting style and joint activities done at the family level and with extended family).

Building on this motivating evidence, I formalize the joint production of the younger and older siblings' skills. I consider carefully the multi-dimensionality of skills 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 the 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

[3]The 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.

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 observe a positive shock to child development, which is unobserved by the econometrician, may decide to reinforce or compensate it by adjusting their 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, 2022).

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

[4]Other 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, Golan, 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.

the social capital and relationships within the family.[6] Siblings can indeed be important team players, who can help each other achieve common goals within the family, such as their joint production of human capital.[7]

Moreover, this paper thinks carefully about the multi-dimensionality of skills and identifies two 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, when studying the impact of one sibling's externalizing skill on the development of the other sibling, I can investigate whether one sibling tends to specialize in high internalizing skills, when the other has high externalizing skills, 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.[8] However, these papers have not made direct attempts to measure the strength of the sibling bond, even though a strong sibling bond could promote sibling spillovers and contribute to early childhood development. This 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 strong 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;

[6]Dunifon, Fomby, and Musick (2017) show that children with siblings spend more time in *unstructured play* with the siblings (almost 2 hours more per week), using the Child Development Supplement in the United States. unstructured play enables children to explore, create and discover without predetermined rules or guidelines and can foster cognitive, social and emotional development, while boosting physical development (e.g., Dankiw et al. (2020) and Lee et al. (2020)).

[7]The 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).

[8]Other 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). Other papers have looked at sibling correlations to understand the transmission of inequality, noticing that sibling correlations are higher than parent-child correlations (Björklund et al., 2010; Vladasel et al., 2021; Björklund and Jäntti, 2020).

De Haan, 2010; Briole, Le Forner, and Lepinteur, 2020). Additionally, my estimates complement the literature on the birth order effects, which has been shown to explain differences in human capital among siblings (Black et al., 2005; Pavan, 2016; Lehmann et al., 2018; Breining et al., 2020). While this literature has mostly focused on showing that differences in parental investment are responsible for a birth order effect, my paper offers another explanation, emphasising that sibling interactions are another important mechanism to understand human capital formation.

In turn, this paper 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 therefore 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; Behrman, 1988).[9]

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).[10] 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 5 presents the counterfactual simulations, based on the structural estimates. Section 6 summarizes the results and concludes.

[9]Evidence 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).

[10]Some 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 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 and take a first step to understand what the sibling bond is capturing. This evidence suggests that differences in the strength of the sibling bond are associated with persistent inequalities across households. 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, Kindermann, and Tertilt, 2023). Second, I extend the theoretical framework of child development to include more than one child in the family and formalize their joint production of human capital, discussing how to think about the endogeneity of the inputs.

2.1 Motivating Evidence on the Role of Siblings for Skill Formation

Siblings play a vital role within the family unit and often spend more time with each other than with their parents, as they grow up together (Dunifon, Fomby, and Musick, 2017). This calls for exploring the sibling bond beyond the parent-child bond as a strong sibling bond can have numerous benefits. For example, it can foster pro-social actions, discourage free-riding, and promote 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 survey follows 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 [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.[11]

As a first step, to construct an index of the sibling bond, I sum the values from every questionnaire item and standardize the sum 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.

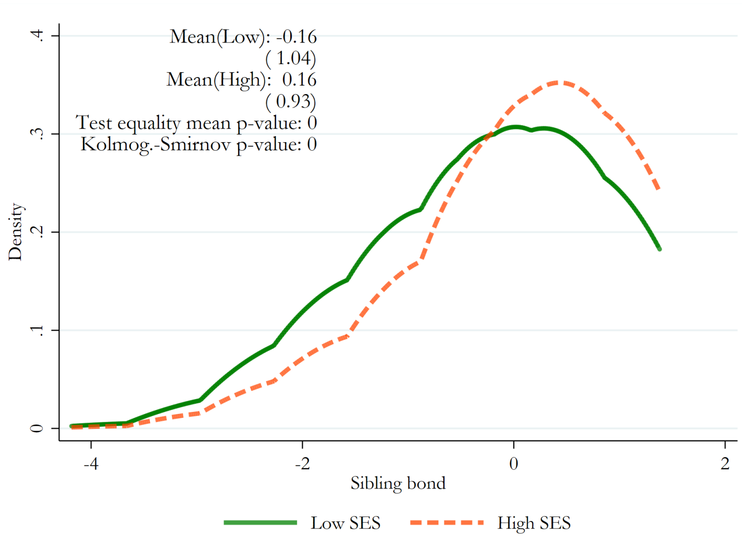
First, Figure 1 documents a socio-economic gradient in the quality of the sibling bond, where the socioeconomic status (SES) is defined as the mother continuing schooling past the minimum leaving age, based on her date of birth.[12] Siblings from low-educated mothers experience a weaker bond than siblings from high-educated mothers. Figure 1 also shows the p-values from the t test on the equality of the means (assuming unequal variances) and the Kolmogorov-Smirnov

[11] The behaviours indicating worse interactions are recoded in reverse (i.e., not much interested in older sibling and teases or needles older sibling).

[12] The 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.

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.

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 sibling bond index 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.

Second, Table 1 and Figure 2 show that the sibling bond at age 5 predicts the younger sibling's developmental, educational and health outcomes across adolescence. 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 the mother's education, age, employment, household structure and housing arrangements, but also information on mother's mental health and how close the relationship is between the mother and child. This rich information, for example, enables me to consider how the sibling bond may vary in two/one parent household, or when the mother-child bond is weak.

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. It also has information on the socio-emotional skills of both siblings involved in the relationship. This enables me to show that the sibling bond matters over and beyond the home home environment and the ability of both siblings to make friends outside of the household or focus attention on at least one good friend. The full list of controls is in the note of Table 1 and Figure 2.[13]

Before discussing the results in Table 1 and Figure 2 more carefully, it is worth investigating a plausible concern regarding this evidence, and more generally about considering the sibling bond in the study of child development. Namely, the sibling bond may be capturing how stimulating the home environment is rather than what happens between siblings. Appendix A exploits the richness of the MCS data and provides three pieces of evidence, summarized below, that the sibling bond is intrinsically related to the interactions and social capital siblings share via their relationship rather than a stimulating home environment, other relationships and their personalities.

First, Appendix Table A1 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 questionnaire items are capturing two different inputs.

More importantly, Table 1 documents that a stronger sibling bond is predictive of better educational outcomes and health outcomes at age 17 conditional on the environmental factors discussed above. Specifically, I consider the grades in the GCSE Math and English exams, studying for an A-level qualification, educational aspiration to study at university and smoking cigarettes.[14] I observe that 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). Additionally, Panel C of Table 1 documents that siblings with a stronger bond at age 5 are less likely to smoke cigarettes 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 as these promote antisocial behaviour.

One may also 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 Appendix Table 1 for the full sample (i.e., children with and without siblings), where observations for the sibling bond and

[13]The full list of controls includes younger and older siblings' skills, 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, region fixed effects.

[14]GCSE 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. The GCSE 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***	0.157***	0.149***	0.074	0.282***	0.129***	0.130***	0.095**
	(0.038)	(0.050)	(0.051)	(0.050)	(0.035)	(0.047)	(0.048)	(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***	0.035***	0.035***	0.019	5.493***	3.304***	3.339***	2.375**
	(0.010)	(0.013)	(0.014)	(0.013)	(0.858)	(1.135)	(1.151)	(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***	-0.022**	-0.021**	-0.017*	-0.030***	-0.035***	-0.036***	-0.026*
	(0.007)	(0.010)	(0.010)	(0.010)	(0.010)	(0.013)	(0.014)	(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 sibling bond index 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 parental investment index 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 (iix) How often child sees grandparents (ix) 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 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, 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).

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. The reason behind the robustness of the estimates is that the majority of the sample (i.e., 75% of the sample) has at least one sibling.

Figure 2 provides additional evidence, showing that a stronger sibling bond at age 5 predicts better developmental outcomes across the younger sibling's adolescence, conditional on the same large set of controls discussed above.[15] The blue dots are the point estimates from regressing the developmental outcomes across the younger sibling's adolescence on the age-5 sibling bond without any controls. On the other hand, the red triangles are the point estimates after conditioning on all the controls, aiming at reducing the gap in family characteristics of siblings with different bond qualities. Interestingly, by comparing the blue dots (without controls) and red triangles (with full controls), it is worth noting that the decline in the coefficient of the age-5 sibling bond is primarily driven by the the younger and older siblings' skills in the previous wave. On the other hand, the additional controls, such as the home environment, parental resources and the mother-child bond, do no longer have a substantial effect on mediating the association between the age-5 sibling bond and the younger sibling's higher development at ages 5, 7, 11, 14, and 17.

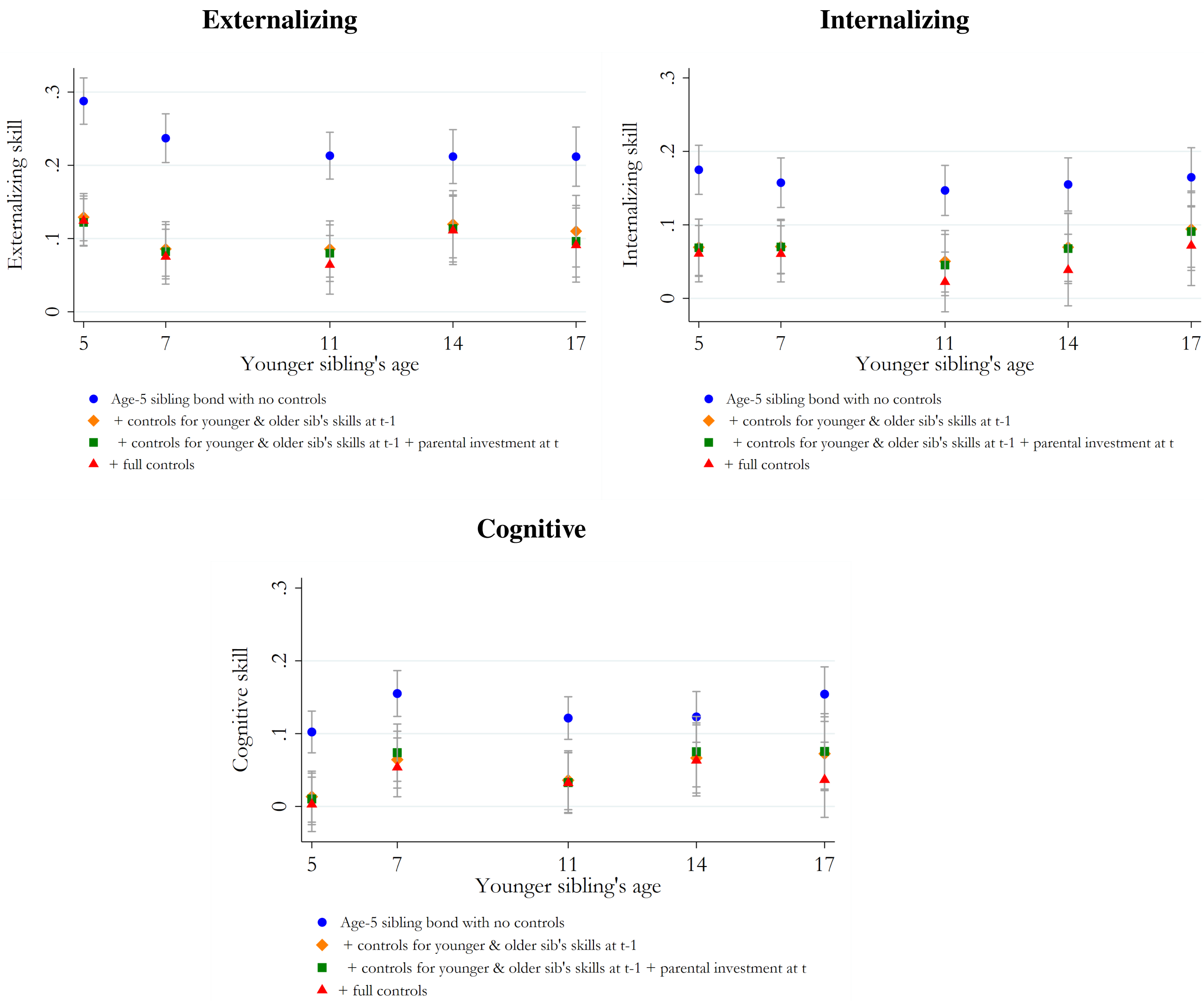
Finally, Appendix Table A3 attempts to open the black box of the sibling bond and investigates how the age-5 sibling bond relates to siblings' actions and relational outcomes during adolescence. Columns 1 and 2 of Appendix Table A3 document that when children are worried about something during adolescence, they are more likely to talk to their sibling rather than to their parents.[16] The evidence in Column 1 of Appendix Table A3 speaks to a limitation of the MCS dataset, which does not contain longitudinal data on the sibling bond, by suggesting that a strong sibling bond at age 5 is the base for a long-term positive relationship between siblings. 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 A3). No effects are found on time on social media and well-being (Columns 4 and 5).

To further open the sibling bond, time use data can be helpful to understand how siblings spend their time. Unfortunately, the MCS does not contain such data. On the other hand, the Child Development Supplement (CDS) of the Panel Study of Income Dynamics (PSID) in the United States (US) can provide some interesting insights on how siblings spend their time as it

[15]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, Lamping, and Ploubidis, 2010).

[16]It is plausible to think about the sibling bond as the social capital sibling share, which originates from repeated interactions that are likely to last for long. The benefit of a positive relationship is that siblings are more likely to talk to each other and cooperate, while the cost involves getting stuck and fighting with somebody they don't get along.

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, Lamping, and Ploubidis, 2010). Cognitive skills are measured with a battery of tests, such as the British Ability Scales II (BAS II). The sibling bond index 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 parental investment index 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 (iix) How often child sees grandparents (ix) 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. Full controls include the younger and older siblings' skills at the age-3 wave, parental investment, 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, region fixed effects.

collects time use diaries. Dunifon, Fomby, and Musick (2017) present a descriptive analysis of how 6-12-year-old children with and without siblings spend their time in the US, using the CDS time use data.[17]

Children with siblings spend about 50% of their time outside of school engaged with siblings, and another 20% with siblings present, meaning that the vast majority of children's discretionary time is spent with their siblings. Children with and without siblings look similar in the amount of time they spend in various activities, with *one exception*: children with siblings spend more time in *unstructured play* with the siblings (almost 2 hours more per week), while are more likely to do *structured and educational* activities with parents. This is important as unstructured play allows children the freedom to explore, create and discover without predetermined rules or guidelines, and has been shown to foster cognitive development, while boosting physical and socio-emotional development (e.g., Dankiw et al. (2020) and Lee et al. (2020)).

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 restrictions discussed in detail in Section 2.4.

In standard models of human capital investment, it is assumed that parents care about their own consumption C_i and the development of a *single* child θ_i (e.g., Attanasio (2015)). I augment this standard framework by considering parents with *two* children and allowing for the possibility that siblings can interact with each other, building a bond, as well as parents can take actions to foster this bond. In turn, this theoretical framework speaks to the literature on intra-household allocation by highlighting that parents can invest in fostering the sibling bond to increase their children's human capital - instead of only compensating or reinforcing differences in siblings' skills to trade off between equity and efficiency (e.g., Behrman et al. (1982) and Behrman (1988)).

I begin by defining human capital and pay particular attention to its multi-dimensionality by specifying three skill dimensions: internalizing (INT), Externalizing (EXT), and Cognitive (COG) skills for each sibling c (younger, Y, and older, O) in family i at time t, $\theta_{cit} = H_t(\theta_{cit}^{EXT}, \theta_{cit}^{INT}, \theta_{cit}^{COG})$. I formulate this problem as static and omit t from the model below to highlight the trade-off during this developmental stage.[18]

Parents optimize the expected utility function of consumption and siblings' human capital, while facing a resource constraint (equations 1 and 2), the sibling bond (equation 3) and joint technology of skill formation (equations 4 and 5). Parents take the level of skills at beginning of the period ($\theta_{i,0}$), generated by their past investments, and the developmental shocks as given

[17] Dunifon, Fomby, and Musick (2017) focus on children's discretionary time, defined as time children are not at school, sleeping, or engaged in personal care such as bathing or dressing (~7 hours per weekday and ~12 hours per weekend day). They note that 82% of children below age 18 lived with at least one sibling in the United States.

[18] It is possible to extend the model to multiple periods, where parents enjoy utility at different point in 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.

in the joint technology of skill formation.

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

Subject to

$$L_i = 1 - I_i \tag{1}$$

$$y_i + w_i L_i = C_i \tag{2}$$

$$SB_i = h(I_i, A_Y, A_O, e_i) \tag{3}$$

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

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

The parents of siblings Y and O can allocate their available time to work, L_i, as well as invest in the home environment, I_i, to improve their children's human capital and sibling bond. Parental investment in the home environment is defined to encompass different types of activities, that promote the development of the child, such as material, time and parenting-style investment in each sibling individually as well as joint activities. In the current framework, I focus on such composite measure of parental investment for ease of exposition and data availability, but the model could easily be extended to accommodate the different dimensions. w_i and y_i in the budget constraint are respectively the price and the non-work income (equation 2)

The sibling bond originates from parent-child as well as sibling interactions. This is captured in equation (3) by defining the sibling bond SB_i as a function of parental investment, I_i, siblings' actions, A_Y and A_O, and an idiosyncratic shock to their actions, e_i. Parental actions can involve investment directly aimed at fostering the sibling bond as well as proposing unstructured activities over which siblings can interact. When parents propose unstructured activities to siblings, sibling interactions over such activity can also foster the sibling bond.

The siblings' actions, A_Y and A_O, over the proposed activity aim to maximize the siblings' pay-off, $EU^c(A_Y, A_O, \xi_Y) = U(I_i, A_Y, A_O, \xi_c)$, in a non-cooperative game, where they best respond to each other. The timing of this game could be simultaneous, dynamic or repeated. It could be more reasonable to think about these interactions as a repeated dynamic game, where the older sibling takes the first action, acting as a leader, and then the younger sibling follows, as this would allow for role modelling (see for example Bell et al. (2019)).[19] Finally, e_i implies a non-deterministic link from parents' and siblings' actions to the sibling bond. A deterministic link would be problematic because parents, for example, could try to foster the sibling bond, but siblings may decide *not* to bond for reasons outside of the parents' control.

From this problem, it is possible to derive the following investment policy functions:

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

[19]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.

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

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 the idiosyncratic shocks, $\epsilon_{I,i}$ and $\epsilon_{SB,i}$, which are a function of idiosyncratic shocks to each sibling's development. These shocks can be correlated within the family.

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 joint technology of skill formation for the younger (Y) and older (O) siblings estimated in the paper (equations 6 and 7). Appendix C.6 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 therefore present the Cobb-Douglas functional forms below:

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

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

Where t represents the 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.[20] As I am considering the joint process of skill formation with siblings, I include the younger and older siblings' internalizing and

[20]Various measures of parental investments can be constructed, each capturing different dimensions such as investment in individual children and joint activities. For the purpose of the 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.

externalizing skills at time $(t-1)$. 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.[21]

Finally, X_{it} is a vector of environmental factors that may affect child development. These include siblings' gender, age gap between younger and older sibling, mother's mental health, mother's education, mother's age, whether the household is dual or single headed, number of children, housing tenure, years lived in current address, local employment at the local authority where family lives, region fixed effects. $\nu_{Y,it}$ is an idiosyncratic shock observed by the parents, but unobserved by the econometrician.

The parameters of interest are β_{3S}, ω_{3S}, β_{4S} and ω_{4S}. β_{3S} and ω_{3S} capture the productivity of the sibling bond respectively for the younger and older siblings for each skill S, while β_{4S} and ω_{4S} capture the productivity of parental investment respectively for the younger and older siblings for each skill S.

There are two caveats to keep in mind due to data limitations, when considering the older sibling's production function. First, only two dimensions of socio-emotional development can be considered as the older sibling was not the target child of the MCS and data are not collected on cognitive skills. 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).[22] 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, $\theta^S_{Y,it}$. 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

[21] Data on cognitive skills are only available 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.

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

is, instead, to resort to finding some exogenous shifters for parental investment and the sibling bond, motivated by the theoretical model in 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, 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.

$$ln(SB_{it}) = \sum_{S} \delta_{1S} ln(\theta^S_{Y,it-1}) + \sum_{S} \delta_{2S} ln(\theta^S_{O,it-1}) + \delta_3 Z_{1,it} + \delta_4 Z_{2,it} + \mathbf{X}'_{it}\phi_S + \epsilon^{SB}_{it} \tag{8}$$

$$ln(I_{it}) = \sum_{S} \gamma_{1S} ln(\theta^S_{Y,it-1}) + \sum_{S} \gamma_{2S} ln(\theta^S_{O,it-1}) + \gamma_3 Z_{1,it} + \gamma_4 Z_{2,it} + \mathbf{X}'_{it}\phi_I + \epsilon^{I}_{it} \tag{9}$$

The investment functions in equations (8) and (9) depend on the younger and older siblings' skills at $t-1$, parental background and several household characteristics contained in $\mathbf{X}_{it}$. The variables $Z_{i,1t}$ and $Z_{2,it}$ are respectively the exogenous shifters 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 many 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.

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 exogenous shifter to capture the adjustment cost to housing could raise some concerns about violating the exclusion restriction.[23] For example, the number of rooms might affect the ability of children to focus 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 determination, for example, to complete an assignment.

The idea behind using an adjustment cost to housing, proxied by the number of rooms in the house in the previous period, is inspired by studies on 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 considering 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, 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.[24] I further discuss the relevance as well as the monotonicity of the exogenous shifters in Section 4.1 by re-estimating the investment functions for different sub-samples.

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.

[23]Alternative exogenous shifters, that could be used to measure the adjustment cost to housing, are geographic variations in renovation costs, local house prices, or 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.

[24]For 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.

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

3 Measurement System and Latent Factors

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 (Vandenberg and Lance, 2000; Putnick and Bornstein, 2016; Wu and Estabrook, 2016). 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.[25] It also contains longitudinal information on siblings' skills as well as information on the quality of the interactions between siblings and between the parents and children.

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

[25]Data 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 B4.

(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 B5). 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 and Peer problem scales to produce an internalizing score (Achenbach, 1966; Achenbach et al., 2016).[26]

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 [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 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, (iix) How often child sees grandparents, (ix) 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.

[26]The note of Table B5 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.

Finally, the UK dataservice has kindly 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.[27] Unfortunately, data on the local employment at the age-5 wave are not available for Northen Ireland.

3.2 Measurement System

In this Section, I first use exploratory factor analysis to identify which measures are relevant for which factor and test the hypothesis that a dedicated system, where a single factor loads on each of the available measures, represents the data well. Namely, the exploratory factor analysis provides a test that the division of the available measures in latent factors - as outlined by the economic and psychology theories - is confirmed in the available data. Second, using this evidence, I proceed to the estimation of the measurement system I use in the estimation of the joint technology of skill formation.

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).[28] Similarly, parental investment and the sibling bond can be thought as capturing two different dimensions of interactions, respectively parent-child and sibling interactions (McHale, Updegraff, and Whiteman, 2012; Francesconi and Heckman, 2016).

First, I investigate the 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 maximum likelihood estimation (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 supports the division in internalizing and externalizing skills proposed by theory (Appendix Table B6). The factor loadings have also a similar magnitudes across siblings, highlighting the similar association between the items and the factors across the

[27]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.

[28]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.

younger and older siblings.

Second, I 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 questionnaire 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 B7 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.

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).

As a robustness check, I also perform an exploratory factor analysis of the questions meant to measure (i) parental investment, (ii) sibling bond, (iii) younger sibling's internalizing and (iv) externalizing skills at age 5. This is meant to investigate if the questionnaires are capturing four different latent constructs. Reassuringly, Appendix Table B7 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 B9 reports Cronbach's alpha, which are usually above 0.53 for all the latent factors considered. Cronbach's alpha measures how closely related a set of items are for each latent factor (Cronbach, 1951). It 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).

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.[29] 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).[30]

$$m^*_{ijt} = \alpha_{jt} + \lambda^{\top}_{jt} ln\theta_{it} + \varepsilon_{ijt} \tag{10}$$

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

$$m_{ijt} = \begin{cases} 0 & \text{if } m^*_{ijt} < \tau_{1,jt} \\ 1 & \text{if } m^*_{ijt} \in \left[\tau_{1,jt}, \tau_{2,jt}\right] \\ 2 & \text{if } m^*_{ijt} > \tau_{2,jt} \end{cases} \tag{11}$$

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 (Heckman, Pinto, and Savelyev, 2013).

Latent factors and the measurement error terms are usually assumed to be normally distributed: $ln\theta_{it} \sim \mathcal{N}\left(\mu_{\theta,t}, \sigma_{\theta,t}\right)$ and $\varepsilon_{ijt} \sim \mathcal{N}\left(0, \sigma_{\varepsilon,jt}\right)$. 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 $\tau_{1,jt} = 0$ at age-3 and 5 waves 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

[29]Cunha, 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).

[30]I test for the invariance of the model between younger and older sibling in Appendix B.5 and find support for such invariance.

parameters of the production function across siblings and over time. Other normalizations are conceivable too as described in Appendix B.4, however they are not recommended as they do not allow to compare factors across siblings and over time. Appendix B.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 B.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 differ 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 psychometric literature by Muthén (1983, 1984).[31] This estimation method is well-suited to estimate factor models with *categorical* items in one step. On the other hand, other estimation methods commonly used in the literature are well-suited to estimate factor models with *continuous* items: a non-linear filtering method (Cunha, Heckman, and Schennach, 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,

[31] This estimation strategy is also used to estimate intergenerational mobility in socio-emotional skills in Attanasio, de Paula, and Toppeta (2022).

and Savelyev (2013).[32]

I briefly outline here the estimation methodology and refer to Appendix B.7 for additional detail. In principle, the measurement system with categorical items can be estimated by maximum likelihood estimation (MLE). However, the problem is computationally intensive. Therefore, the psychometric literature suggests an estimation strategy based on generalized method of moments (GMM), which is more computationally tractable (Muthén, 1983, 1984).

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} and the other moments obtained from the outcome equations. The parameters can then be estimated by minimizing a weighted least squares (WLS) function of the polychoric correlation moments and the other moments obtained from the outcome equations.

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.

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.

[32] The 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 functions: Sibling bond and parental investment

Outcome	Sibling bond	Parental investment
Number of rooms (t-1)	0.066***	0.011
	(0.017)	(0.012)
Local female employment rate	-0.019	0.046***
	(0.013)	(0.009)
Younger sib's EXT skill (t-1)	0.180***	0.190***
	(0.032)	(0.024)
Younger sib's INT skill (t-1)	0.039	0.304***
	(0.089)	(0.070)
Younger sib's COG skill (t-1)	0.061**	-0.032
	(0.058)	(0.021)
Older sib's EXT skill (t-1)	0.304***	0.119***
	(0.028)	(0.019)
Older sib's INT skill (t-1)	0.136**	-0.048
	(0.058)	(0.043)
Test of joint significance: F-statistic (p-value)		
Number of rooms	14.867 (0.000)	
Mother's employed		25.211 (0.000)
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 siblings' gender, age gap between younger and older sibling, mother's mental health, mother's education, mother's age, whether the household is dual or single headed, number of children, housing tenure, years lived in current address, local employment at the local authority where family lives, region fixed effects. The questionnaire items used to measure the latent sibling bond and parental investment are presented in Table 2. 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).

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 in the excluded instrument can be then considered plausibly 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).[33]

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 where the family lives. 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

[33]Another 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)). In Section 4.2, I present a robustness check, where I instrument family size with the siblings' gender composition and provide suggestive evidence that the estimates are robust.

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 has 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.

Before turning to the production function estimates, it is important to discuss the monotonicity of the instruments. Appendix Tables C12-C15 reproduce Table 3 for difference sub-samples defined by: younger sibling's gender, older sibling's gender, siblings' gender composition and siblings' age gap. Appendix Tables C12-C15 show that the coefficients on the number of rooms at time $t-1$ and the female local employment do not change sign and have a similar magnitude across subgroups, providing support for the monotonicity.

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 considering siblings and 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 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.

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

Outcome	**Externalizing (EXT)**				**Internalizing (INT)**				**Cognitive (COG)**	
	Younger		**Older**		**Younger**		**Older**		**Younger**	
	Restricted	Unrestricted	Restricted	Unrestricted	Restricted	Unrestricted	Restricted	Unrestricted	Restricted	Unrestricted
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Younger sib's EXT skill (t-1)	0.569***	0.500***		-0.277***	-0.050*	-0.107**		-0.099*	0.005	-0.068
	(0.060)	(0.076)		(0.071)	(0.028)	(0.047)		(0.053)	(0.047)	(0.068)
Younger sib's INT skill (t-1)	-0.338***	-0.282***		-0.260**	0.769***	0.750***		-0.313***	-0.204*	-0.127
	(0.094)	(0.091)		(0.109)	(0.108)	(0.108)		(0.093)	(0.106)	(0.109)
Younger sib's COG skill (t-1)	0.113***	0.089***		0.038	-0.015	-0.038*		0.046*	0.598***	0.568***
	(0.022)	(0.027)		(0.029)	(0.015)	(0.022)		(0.026)	(0.030)	(0.035)
Older sib's EXT skill (t-1)		-0.176**	0.680***	0.595***		-0.166***	-0.142***	-0.219***		-0.172**
		(0.065)	(0.043)	(0.078)		(0.051)	(0.027)	(0.060)		(0.075)
Older sib's INT skill (t-1)		0.000	-0.077*	-0.007		-0.015	0.868***	0.943***		-0.093
		(0.047)	(0.041)	(0.055)		(0.039)	(0.078)	(0.088)		(0.059)
Parental investment (t)	0.559***	0.460**	0.662***	0.624***	0.212*	0.194	0.167	0.225	0.432**	0.331
	(0.184)	(0.196)	(0.195)	(0.281)	(0.115)	(0.150)	(0.128)	(0.159)	(0.211)	(0.242)
Sibling bond (t)		0.406**		0.397**		0.344**		0.242*		0.491**
		(0.172)		(0.195)		(0.133)		(0.145)		(0.200)
Observations	2558	2558	2475	2475	2558	2558	2475	2475	2558	2558
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 siblings' gender, age gap between younger and older sibling, mother's mental health, mother's education, mother's age, whether the household is dual or single headed, number of children, housing tenure, years lived in current address, local employment at the local authority where family lives, region fixed effects. The questionnaire items used to measure the latent sibling bond and parental investment are presented in Table 2. 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).

Second, the siblings' socio-emotional development matters too. Cunha, Heckman, and Schennach (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 presume 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.[34] 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 (Manski, 1993). 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

[34] This is also shown in Appendix Table C16, which reproduces the odd Columns in Table 4, when restricting only the sibling bond to have productivity zero.

each of three skill dimensions.[35] A comparison between the Odd and Even Columns in Table 4 sheds light on the importance of the sibling bond.[36] Disregarding the sibling bond would overlook a crucial factor in children's development and lead to overestimate the effect of parental investment. As siblings grow up together, they tend to spend more time interacting with each other 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.

Another noteworthy takeaway from Table 4 is that a strong sibling bond benefits both the younger and older siblings' development. This finding complements the literature on the trade-off between the quantity and quality of children (Becker and Lewis, 1973; Willis, 1973; Becker and Tomes, 1976). The literature has focused on parents engaging mainly in reinforcing or compensating investment for inequality among siblings, finding mixed evidence (Behrman, Pollak, and Taubman, 1982; Behrman, 1988). My estimates suggest 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. For example, parents can engage in actions aimed at encouraging pro-social actions between siblings and mediating siblings' conflicts fruitfully, rather than only reinforcing or compensating siblings' inequality.

The estimates presented in Table 4 assumes a Cobb-Douglas specification. Appendix C.6 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 investigates if the sibling bond interacted either by lag of the siblings' skills or parental investment has an effect on their development. The estimates for the translog production function are presented in Appendix Table C20. 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 C.7 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.[37] Del Bono,

[35]Table 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 C.3 and C.4 present evidence that the estimates of the sibling bond productivity in Table 4 are robust to using the average sibling bond in families with at least two older siblings and to family size. First, Appendix Table C17 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 C18 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 C19 presents the estimates for Table 4 when treating investment as exogenous.

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

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

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 to address the concerns of misreporting bias of socio-emotional skills. However, comparing such responses does not allow to disentangle if such bias is 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 estimate a factor model with the similarly-worded 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.[38] Appendix Table C21 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 C.8 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 (Appendix Tables C12-C15). The estimates are reported in Appendix Tables C22-C25. Appendix Table C24 provides some suggestive evidence that the sibling bond could be more productive for same-sex than mixed-sex siblings.

Before proceeding to 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 in Table 4 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 C8 presents the binscatter plot of the realized skills against the simulated skills from the structural model, showing that the model performs well in terms of the out-of-sample prediction across adolescence. This analysis builds confidence in the counterfactual exercises presented in the next Section.

[38]Appendix C.7 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.

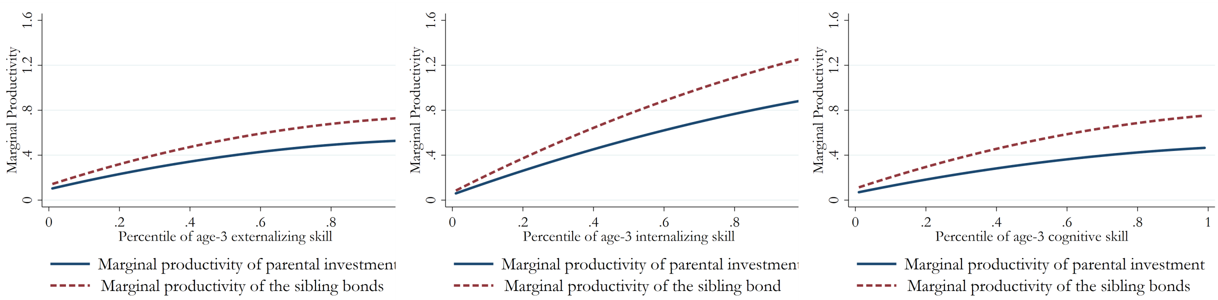
5 Using the Structural Estimates

5.1 Marginal Productivity of Parental Investment and Sibling Bond

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 the age-3 skill percentile-specific 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 differences in the sibling bond are associated with persistent inequalities across households. Indeed, a stronger sibling bond would amplify inequality even more as high-SES children are more likely to have higher skills and a stronger sibling bond (Section 2.1) and at the same time they would benefit from a higher productivity of the sibling bond (Figure 3). Second, the marginal productivity of the inputs describes the differences in productivity between parental investment and the sibling bond. 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 the age-3 skill percentile-specific 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.

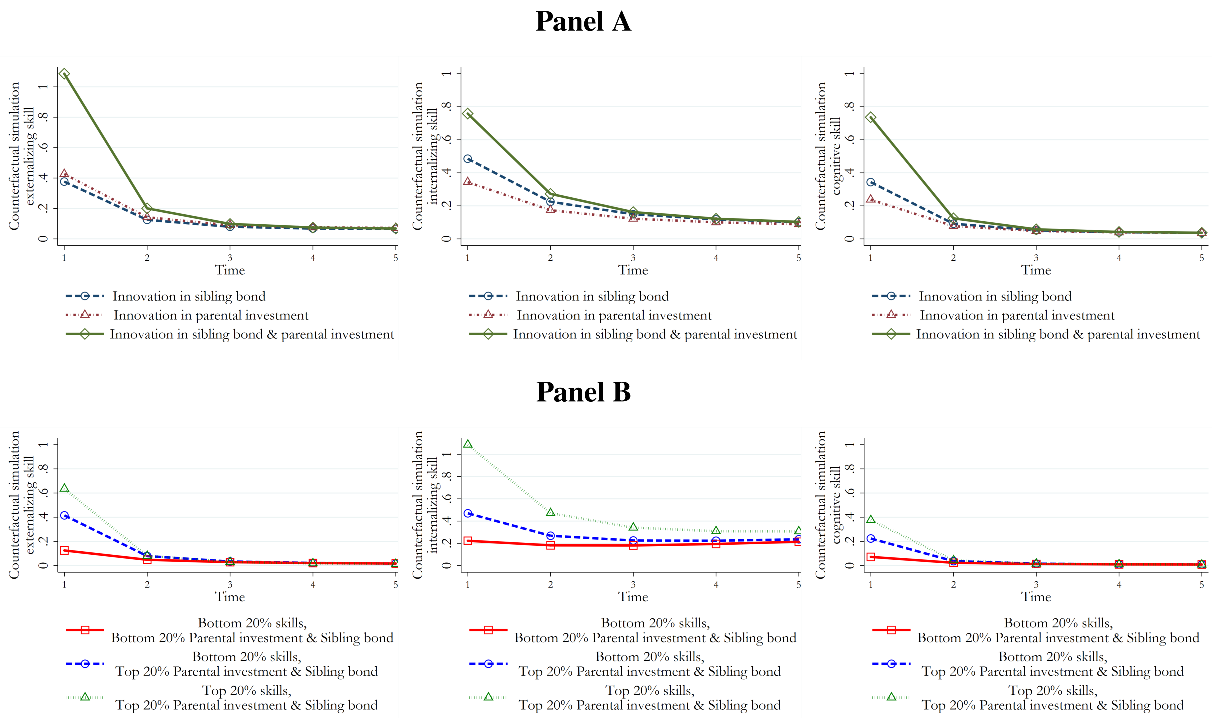
5.2 Counterfactual Simulations

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, Jakiela, and Knauer (2021)).

I do not focus on the 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.[39] The design of such interventions draws from behavior management and mediation, such as directing children's pro-social behavior using reinforcement practices, maintaining impartiality during siblings' conflicts and facilitating communication between siblings. As highlighted in the theoretical model in Section 2.2, such interventions should aim to target the family as whole, targeting parents as well as siblings.

Unfortunately, the interventions, reviewed in Leijten, Melendez-Torres, and Oliver (2021), 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 in Figure 4 offer some novel insights on how a hypothetical intervention, aimed at stimulating the sibling bond and/or parental investment, would affect skills.

Figure 4: Counterfactual simulations



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 first thought experiment increases only parental investment, then only the sibling bond and finally both parental investment and the sibling bond at time 1 (Panel A of Figure 4). 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 plot

[39]Some examples are Siddiqui and Ross (2004), Kramer (2004) and Kennedy and Kramer (2008).

the effect of this one-time increase on skills in each time period (1-5), 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 in Appendix Figure C8 (discussed in Section 4.2). The solid line shows that a hypothetical intervention, aimed at stimulating parental investment as well as the sibling bond, would have a larger effect on skill formation.

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 (Panel B of Figure 4). 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 plot the effect of this one-time shock on skills in each time period (1-5), the production function is assumed to have the same parameters at each time t. The counterfactual simulations show that if children at the bottom of the distribution 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 enable them to work together effectively to achieve common goals, while also serving as sources of social support and acting as role models for each other.

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 the whole family - i.e., parents as well as siblings - is targeted. For example, Evans, Jakiela, 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, finding only 8 studies with some limitations, such as no measures on children's outcomes. These novel interventions could draw from behavior management and mediation, for example, by directing children's prosocial behavior using reinforcement practices, maintaining impartiality during siblings' conflics and facilitating communication between siblings. My counterfactual simulations highlight the importance of thinking about the child as part of the family system and focusing both on parent-child as well as sibling interactions.

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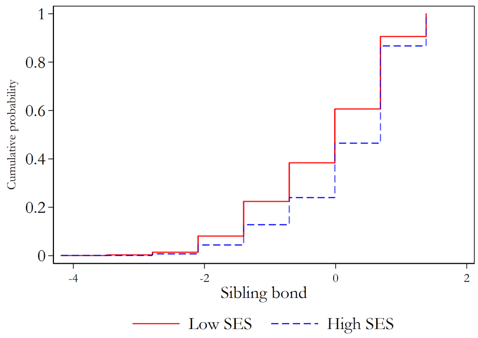
Appendices to "Skill Formation with Siblings"

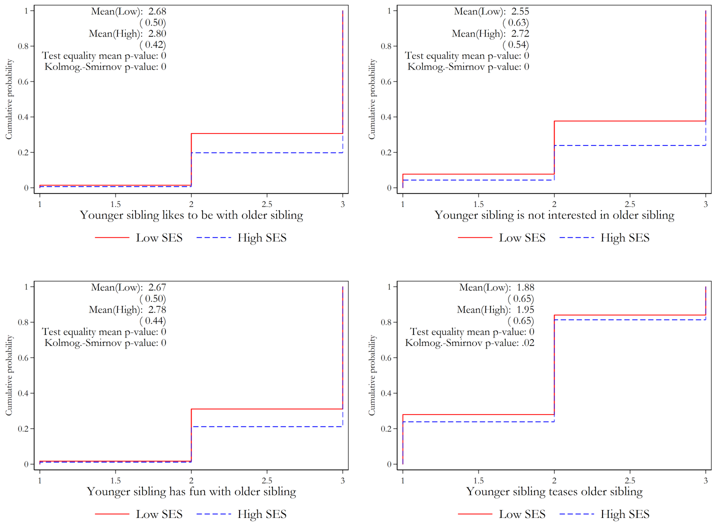
A Motivating evidence: additional results

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



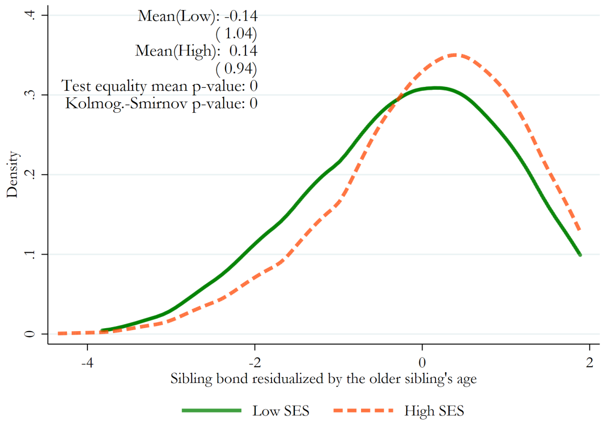
Note. The Figure presents the socioeconomic gradient in the quality of sibling bond at the age-5 wave. The socioeconomic status is the mother's education at the age-5 wave (dummy for whether the mother continued schooling past the minimum leaving age, based on her date of birth). The sibling bond index 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



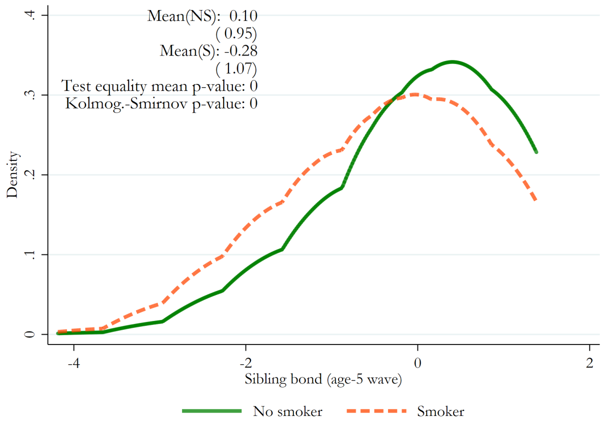
Note. The Figure presents the socioeconomic gradient in each item used to measure the quality of sibling interactions at the age-5 wave. The socioeconomic status is the mother's education at the age-5 wave (dummy for whether the mother continued schooling past the minimum leaving age, based on her date 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



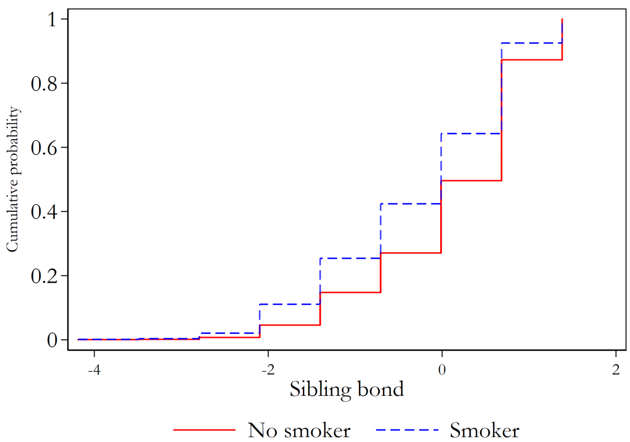
Note. The Figure presents the socioeconomic gradient in the quality of the sibling bond residualized by the older sibling's age at the age-5 wave. The socioeconomic status is the mother's education at the age-5 wave (dummy for whether the mother continued schooling past the minimum leaving age, based on her date of birth). The sibling bond index 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



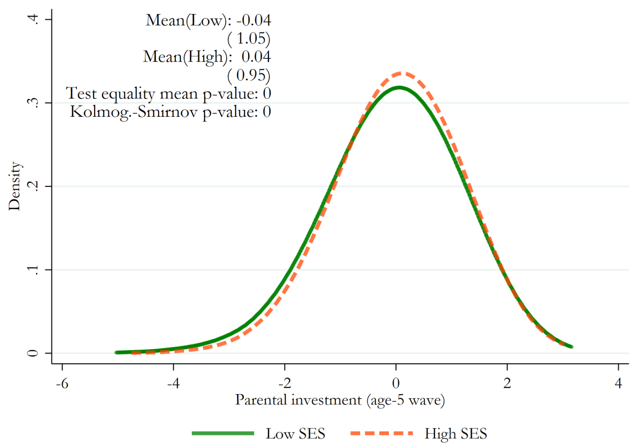
Note. The Figure presents the socioeconomic gradient in the quality of the sibling bond at the age-5 wave. The socioeconomic status is a dummy equal to 1 if the mother was smoking during pregnancy. The sibling bond index is constructed by summing the values from the following 4 questions about how often [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



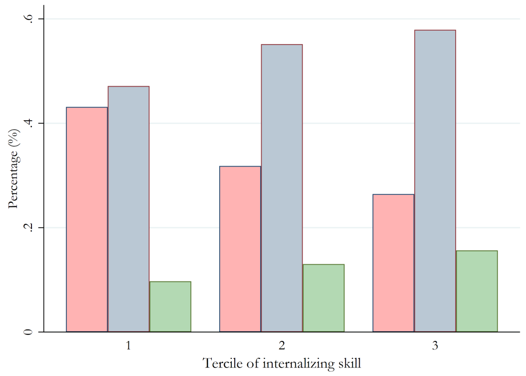
Note. The Figure presents the socioeconomic gradient in the quality of sibling interactions at the age-5 wave. The sibling bond index is constructed by summing the values from the following 4 questions about how often [frequently, sometimes, never] the cohort member (i.e., the younger sibling): (i) Likes 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.

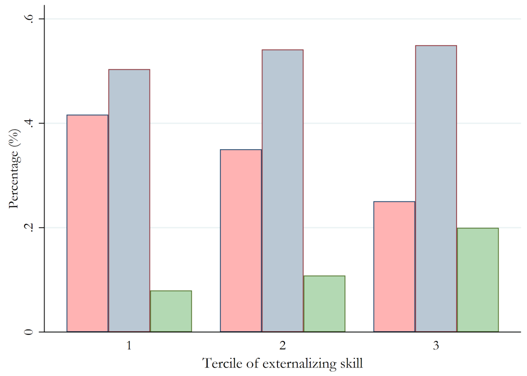
Figure A6: Socio-economic gradient (mother's education) in parental investment



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 parental investment index 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 (iix) How often child sees grandparents (ix) 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. 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 have low-quality bond with the older sibling and viceversa. The Figure presents the proportion of the quality of interactions between siblings in each younger sibling's skill (internalizing and externalizing) tercile. The sibling bond is divided in tercile that are plotted in the figure against the tercile of the skill distribution. The sibling bond index 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 A1: 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 sibling bond index 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 parental investment index 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 (iix) How often child sees grandparents (ix) 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. 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.

Table A2: Age-5 sibling bond and younger sibling's future outcomes (full sample)

Panel A:

	Grade GCSE Math		Grade GCSE English	
	(1)	(2)	(3)	(4)
Sibling bond (worst interaction for single child)	0.207***		0.104	
	(0.071)		(0.064)	
Sibling bond (best interaction for single child)		0.076		0.109**
		(0.051)		(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*		2.480	
	(0.019)		(1.591)	
Sibling bond (best interaction for single child)		0.022		2.433**
		(0.014)		(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*		-0.056***	
	(0.013)		(0.020)	
Sibling bond (best interaction for single child)		-0.018*		-0.023
		(0.010)		(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 sibling bond index 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 parental investment index 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 (iix) How often child sees grandparents (ix) 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 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, 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 A3: Age-5 sibling bond and younger sibling's age-14 relational outcomes

Panel A:			without controls		
Outcome	Talk to sibling if worried	Talk to parents if worried	Argue with parents	Time on social network websites	Well-being
	(1)	(2)	(3)	(4)	(5)
Sibling bond (age 5)	0.026***	-0.003	-0.091***	-0.119***	0.048***
	(0.008)	(0.009)	(0.033)	(0.036)	(0.015)
Observations	4301	4301	4003	4377	4208
R^2	0.003	0.000	0.003	0.003	0.003
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

Panel B:			with controls		
Outcome	Talk to sibling if worried	Talk to parents if worried	Argue with parents	Time on social network websites	Well-being
	(1)	(2)	(3)	(4)	(5)
Sibling bond (age 5)	0.019**	-0.008	-0.128***	-0.059	0.018
	(0.009)	(0.011)	(0.038)	(0.040)	(0.017)
Observations	3721	3721	3477	3780	3645
R^2	0.026	0.009	0.043	0.103	0.103
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 sibling bond index 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 parental investment index 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 (iix) How often child sees grandparents (ix) 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 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, 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).

B Measurement

B.1 Descriptive Statistics

Table B4: Descriptive statistics on sample characteristics.

	Mean	St.Dev.	N
Female younger sib	0.51	0.50	2558
Female older sib	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.

B.2 Strengths and Difficulties Questionnaire (SDQ)

Table B5: 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.

B.3 Exploratory Factor Analysis

Table B6: 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 oulined 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 B7: Exploratory factor analysis: residualized sibling bond and parental investment

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/reques	**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 B8: 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 B9: 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).

B.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 (15) and (16).

$$m^*_{ijt} = \alpha_{jt} + \lambda^\top_{jt} ln\theta_{it} + \varepsilon_{ijt} \tag{12}$$

Given that m^*_{ijt} is unobserved, a threshold model is added to equation 15 to accommodate the categorical nature of the observed response, m_{ijt} such that:

$$m^j_{it} = \begin{cases} 0 & \text{if } m^*_{ijt} < \tau_{1,jt} \\ 1 & \text{if } m^*_{ijt} \in \left[\tau_{1,jt}, \tau_{2,jt}\right] \\ 2 & \text{if } m^*_{ijt} > \tau_{2,jt} \end{cases} \tag{13}$$

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 $ln\theta_{it} \sim \mathcal{N}\left(\mu_{\theta,t}, \sigma_{\theta,t}\right)$ and $\varepsilon_{ijt} \sim \mathcal{N}\left(0, \sigma_{\varepsilon,jt}\right)$. 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 $V(\varepsilon_{ijt}) = 1 - \lambda^2_{jt} V(ln(\theta_{it}))$ as the remainder. Another possibility is to constrain the residuals $V(\varepsilon_{ijt})$ to be 1 and obtain $y^*_{jt} = \lambda^2_{jt} V(ln(\theta_{it})) + 1$.[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 B10. Other parametrizations are conceivable as well, these seem to be the most commonly used.

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

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

Table B10: Normalization for identification

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

B.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 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 minimal 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 and compare their relative fit 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 ($\tau_{1,YSjt} = \tau_{1,OSjt}$, $\tau_{2,YSjt} = \tau_{2,OSjt}$, $\mu_{\theta,YSt} = \mu_{\theta,OSt} = 0$, $\sigma_{\theta,YSt} = \sigma_{\theta,OSt} = 1\ \forall j,t$). This is observationally equivalent to the baseline model when each item is a categorical variable with three categories (Wu and Estabrook, 2016).

[4] Versions 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).

Second, the loading- and threshold-invariant model is estimated, imposing stronger restrictions on the factor loadings and the thresholds of the items, which must be the same across siblings ($\tau_{1,YSjt} = \tau_{1,OSjt}$, $\tau_{2,YSjt} = \tau_{2,OSjt}$, $\lambda_{YSjt} = \lambda_{OSjt}$, $\mu_{\theta,YSt} = \mu_{\theta,OSt} = 0$, $\sigma_{\theta,YSt} = 1 \; \forall j, t$). 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 ($\tau_{1,YSjt} = \tau_{1,OSjt}$, $\tau_{2,YSjt} = \tau_{2,OSjt}$, $\lambda_{YSjt} = \lambda_{OSjt}$, $\alpha_{YSjt} = \alpha_{OSjt} = 0$, $\mu_{\theta,YSt} = 0$, $\sigma_{\theta,YSt} = 1 \; \forall j, t$).

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: ΔRMSEA>0.015, ΔCFI<-0.010, and ΔRMSR>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 B11 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.

[5]The 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 B11: Comparison of models' fit for measurement invariance

	N of Parameters	χ^2	RMSEA	RMSR	CFI	TLI
			Absolute fit			
Baseline model/ Threshold Invariance	98	2339.833	0.064	0.084	0.949	0.940
Threshold and loading invariance	84	2693.985	0.066	0.089	0.941	0.935
Threshold, loading, and intercept invariance	70	3276.389	0.071	0.093	0.927	0.925

		Relative Fit to the Baseline model/Threshold Invariance				
		P-value	Δ RMSEA	Δ RMSR	Δ CFI	Δ TLI
Threshold and loading invariance		0.000	0.003	0.005	-0.008	-0.005
Threshold, loading, and intercept invariance		0.000	0.008	0.008	-0.022	-0.015

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.

B.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.

$$m^*_{ijt} = \alpha_{jt} + \lambda^{\top}_{jt} ln\theta_{it} + \varepsilon_{ijt} \tag{14}$$

Depending on the nature of the item, m^*_{ijt}, we can specify the following models:

(i) Continuous items: $m_{ijt} = m^*_{ijt}$;

(ii) Binary items: $m_{ijt} \in \{0, 1\}$: $Prob\{m_{ijt} = 1\} = Pr\{m^*_{ijt} \geq 0\}$;

(iii) Categorical items: $m_{ijt} \in \{1, 2, ..., L\}$: $Prob\{m_{ijt} = l\} = Pr\{\tau_{l-1,jt} \leq m_{ijt} \leq \tau_{l,jt}\}$, 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.

B.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}.

$$m^*_{ijt} = \alpha_{jt} + \lambda^\top_{jt} ln\theta_{it} + \varepsilon_{ijt} \tag{15}$$

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:

$$m_{ijt} = \begin{cases} 0 & \text{if } m^*_{ijt} < \tau_{1,jt} \\ 1 & \text{if } m^*_{ijt} \in \left[\tau_{1,jt}, \tau_{2,jt}\right] \\ 2 & \text{if } m^*_{ijt} > \tau_{2,jt} \end{cases} \tag{16}$$

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

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

$$\begin{aligned} Pr\left[m_{ijt} = 0 | ln\theta_{it}\right] =& Pr\left[m^*_{ijt} < \tau_{1,jt} | ln\theta_{it}\right] \\ =& Pr\left[\varepsilon_{ijt} < \tau_{1,jt} - \alpha_{jt} - \lambda_{jt} ln\theta_{it} | ln\theta_{it}\right] \\ =& \Phi\left(\frac{\tau_{1,jt} - \alpha_{jt} - \lambda_{jt} ln\theta_{it}}{\sigma_{\varepsilon,jt}} | ln\theta_{it}\right) \end{aligned} \tag{17}$$

$$\begin{aligned} Pr\left[m_{ijt} = 1 | ln\theta_{it}\right] =& \Phi\left(\frac{\tau_{2,jt} - \alpha_{jt} - \lambda_{jt} ln\theta_{it}}{\sigma_{\varepsilon,jt}} | ln\theta_{it}\right) \\ & - \Phi\left(\frac{\tau_{1,jt} - \alpha_{jt} - \lambda_{jt} ln\theta_{it}}{\sigma_{\varepsilon,jt}} | ln\theta_{it}\right) \end{aligned} \tag{18}$$

$$\begin{aligned} Pr\left[m_{ijt} = 2 | ln\theta_{it}\right] =& Pr\left[m^*_{ijt} > \tau_{2,jt} | ln\theta_{it}\right] \\ =& Pr\left[\varepsilon_{ijt} > \tau_{2,jt} - \alpha_{jt} - \lambda_{jt} ln\theta_{it} | ln\theta_{it}\right] \\ =& 1 - \Phi\left(\frac{\tau_{2,jt} - \alpha_{jt} - \lambda_{jt} ln\theta_{it}}{\sigma_{\varepsilon,jt}} | ln\theta_{it}\right) \end{aligned} \tag{19}$$

$\sigma_{\varepsilon,jt}$ is set to one and all intercepts are set to zero because the intercepts and thresholds (joinly) cannot be identified as evident from 17, 18, and 19.

$$Pr\left[m_{ijt} = 0 | ln\theta_{it}\right] = \Phi\left(\tau_{1,jt} - \lambda_{jt} ln\theta_{it} | ln\theta_{it}\right) \tag{20}$$

$$Pr\left[m_{ijt} = 1 | ln\theta_{it}\right] = \Phi\left(\tau_{2,jt} - \lambda_{jt} ln\theta_{it} | ln\theta_{it}\right) - \Phi\left(\tau_{1,jt} - \lambda_{jt} ln\theta_{it} | ln\theta_{it}\right) \tag{21}$$

$$Pr\left[m_{ijt} = 2 | ln\theta_{it}\right] = 1 - \Phi\left(\tau_{2,jt} - \lambda_{jt} ln\theta_{it} | ln\theta_{it}\right) \tag{22}$$

Define $m_{it} = \begin{bmatrix} m_{i1t} & m_{i2t} & \dots & m_{iJt} \end{bmatrix}$ 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:

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

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

$$\begin{aligned}\mathcal{L}_{i,t} &= E_{ln\theta_{it}}\left[\prod_{j=1}^{J}\left\{f\left(m_{ijt}|ln\theta_{it}\right)\right\}\right] \\ &= E_{ln\theta_{it}}\left[\prod_{j=1}^{J}\left\{Pr\left[m_{ijt}=0|ln\theta_{it}\right]^{1[m_{ijt}=0]} \times Pr\left[m_{ijt}=1|ln\theta_{it}\right]^{1[m_{ijt}=1]}\right.\right. \\ &\qquad \left.\left. \times Pr\left[m_{ijt}=2|ln\theta_{it}\right]^{1[m_{ijt}=2]}\right\}\right] \\ &= E_{ln\theta_{it}}\left[\prod_{j=1}^{J}\left\{\Phi\left(\tau_{1,jt}-\lambda_{jt}ln\theta_{it}|ln\theta_{it}\right)^{1[m_{ijt}=0]}\right.\right. \\ &\qquad \times\left(\Phi\left(\tau_{2,jt}-\lambda_{jt}ln\theta_{it}|ln\theta_{it}\right)-\Phi\left(\tau_{1,jt}-\lambda_{jt}ln\theta_{it}|ln\theta_{it}\right)\right)^{1[m_{ijt}=1]} \\ &\qquad \left.\left. \times\left(1-\Phi\left(\tau_{2,jt}-\lambda_{jt}ln\theta_{it}|ln\theta_{it}\right)\right)^{1[m_{ijt}=2]}\right\}\right]\end{aligned} \tag{23}$$

If we assume that $ln\theta_{it} \sim \mathcal{N}\left(\mu_{\theta,t},\sigma_{\theta,t}\right)$, then 23 can be written as:

$$\begin{aligned}\mathcal{L}_{i,t} &= \int_{\infty}^{\infty}\left[\prod_{j=1}^{J}\left\{\Phi\left(\tau_{1,jt}-\lambda_{jt}ln\theta_{it}|ln\theta_{it}\right)^{1[m_{ijt}=0]}\right.\right. \\ &\qquad \times\left(\Phi\left(\tau_{2,jt}-\lambda_{jt}ln\theta_{it}|ln\theta_{it}\right)-\Phi\left(\tau_{1,jt}-\lambda_{jt}ln\theta_{it}|ln\theta_{it}\right)\right)^{1[m_{ijt}=1]} \\ &\qquad \left.\left.\times\left(1-\Phi\left(\tau_{2,jt}-\lambda_{jt}ln\theta_{it}|ln\theta_{it}\right)\right)^{1[m^{j}_{,t}=2]}\right\} \times \frac{exp\left(\frac{1}{2\sigma^2_{\theta,t}}(ln\theta_t-\mu_{\theta,t})^2\right)}{\sigma_{\theta,t}\sqrt{2\pi}}\right] dln\theta\end{aligned} \tag{24}$$

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 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

$$F_W(B) = (\rho(B) - \hat{\rho})^\top \mathbf{W}^{-1}(\rho(B) - \hat{\rho}), \tag{25}$$

for a weight matrix $\mathbf{W}$, to be minimised with respect to B. Muthén (1978) suggests using a consistent estimator for asymptotic covariance matrix of $\hat{\rho}$ as $\mathbf{W}$. 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 $\mathbf{W}$ (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.

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

C Additional Estimates of Joint Technology of Skill Formation

C.1 Heterogeneity: investment functions

Table C12: Investment functions: Sibling bond & parental investment by the older sibling's gender

Older sibling's gender	**Female**		**Male**	
Outcome	**Sibling bond**	**Parental investment**	**Sibling bond**	**Parental investment**
Number of rooms (t-1)	0.059**	0.000	0.076***	0.015
	(0.024)	(0.019)	(0.025)	(0.017)
Local female employment rate	-0.017	0.051***	-0.021	0.032***
	(0.019)	(0.015)	(0.018)	(0.012)
Test of joint significance: F-statistic				
Number of rooms	5.842		9.159	
Mother's employed		11.251		6.879
Observations	1216	1216	1342	1342
Controls for siblings' skills	Yes	Yes	Yes	Yes
Other controls	Yes	Yes	Yes	Yes

Note. The Table presents the structural estimates of the investment functions by the older sibling's gender. Measurement system and equations are estimated jointly (Muthén, 1984). Other controls include younger sibling's externalizing, internalizing and cognitive skill at $t-1$, older sibling's externalizing and internalizing, siblings' gender, age gap between younger and older sibling, mother's mental health, mother's education, mother's age, whether the household is dual or single headed, number of children, housing tenure, years lived in current address, local employment at the local authority where family lives, region fixed effects. The questionnaire items used to measure the latent sibling bond and parental investment are presented in Table 2. 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 C13: Investment functions: Sibling bond & parental investment by the younger sibling's gender

Younger sibling's gender	**Female**		**Male**	
Outcome	**Sibling bond**	**Parental investment**	**Sibling bond**	**Parental investment**
Number of rooms (t-1)	0.110***	0.012	0.064**	-0.003
	(0.030)	(0.019)	(0.031)	(0.017)
Local female employment rate	-0.037	0.032**	-0.019	0.059***
	(0.023)	(0.012)	(0.024)	(0.017)
Test of joint significance: F-statistic				
Number of rooms	13.031		4.190	
Mother's employed		6.493		12.558
Observations	1312	1312	1245	1245
Controls for siblings' skills	Yes	Yes	Yes	Yes
Other controls	Yes	Yes	Yes	Yes

Note. The Table presents the structural estimates of the investment functions by the younger sibling's gender. Measurement system and equations are estimated jointly (Muthén, 1984). Other controls include younger sibling's externalizing, internalizing and cognitive skill at $t-1$, older sibling's externalizing and internalizing, siblings' gender, age gap between younger and older sibling, mother's mental health, mother's education, mother's age, whether the household is dual or single headed, number of children, housing tenure, years lived in current address, local employment at the local authority where family lives, region fixed effects. The questionnaire items used to measure the latent sibling bond and parental investment are presented in Table 2. 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 C14: Investment functions: Sibling bond & parental investment by the siblings' gender composition

Siblings' gender composition	**Mixed**		**Same**	
Outcome	**Sibling bond**	**Parental investment**	**Sibling bond**	**Parental investment**
Number of rooms (t-1)	0.074***	0.043**	0.066**	-0.026
	(0.022)	(0.017)	(0.028)	(0.018)
Local female employment rate	-0.002	0.024*	-0.035*	0.067***
	(0.017)	(0.013)	(0.020)	(0.013)
Test of joint significance: F-statistic				
Number of rooms	11.116		5.580	
Mother's employed		3.339		24.931
Observations	1266	1266	1292	1292
Controls for siblings' skills	Yes	Yes	Yes	Yes
Other controls	Yes	Yes	Yes	Yes

Note. The Table presents the structural estimates of the investment functions by the siblings' gender composition. Measurement system and equations are estimated jointly (Muthén, 1984). Other controls include younger sibling's externalizing, internalizing and cognitive skill at $t-1$, older sibling's externalizing and internalizing, siblings' gender, age gap between younger and older sibling, mother's mental health, mother's education, mother's age, whether the household is dual or single headed, number of children, housing tenure, years lived in current address, local employment at the local authority where family lives, region fixed effects. The questionnaire items used to measure the latent sibling bond and parental investment are presented in Table 2. 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 C15: Investment functions: Sibling bond & parental investment by the siblings' age gap

Siblings' age gap	**Small**		**Large**	
Outcome	**Sibling bond**	**Parental investment**	**Sibling bond**	**Parental investment**
Number of rooms (t-1)	0.072***	0.019	0.072***	0.000
	(0.023)	(0.016)	(0.026)	(0.021)
Local female employment rate	-0.035*	0.038***	0.006	0.053***
	(0.018)	(0.012)	(0.019)	(0.015)
Test of joint significance: F-statistic				
Number of rooms	9.717		7.689	
Mother's employed		9.107		12.420
Observations	1573	1573	985	985
Controls for siblings' skills	Yes	Yes	Yes	Yes
Other controls	Yes	Yes	Yes	Yes

Note. The Table presents the structural estimates of the investment functions by the siblings' age gap. 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 o Measurement system and equations are estimated jointly (Muthén, 1984). Other controls include younger sibling's externalizing, internalizing and cognitive skill at $t-1$, older sibling's externalizing and internalizing, siblings' gender, age gap between younger and older sibling, mother's mental health, mother's education, mother's age, whether the household is dual or single headed, number of children, housing tenure, years lived in current address, local employment at the local authority where family lives, region fixed effects. The questionnaire items used to measure the latent sibling bond and parental investment are presented in Table 2. 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).

C.2 Additional estimates of joint technology

Table C16: Joint technology of skill formation: younger and older siblings

Outcome	Externalizing (EXT)				Internalizing (INT)				Cognitive (COG)	
	Younger		Older		Younger		Older		Younger	
	Restricted	Unrestricted	Restricted	Unrestricted	Restricted	Unrestricted	Restricted	Unrestricted	Restricted	Unrestricted
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Younger sib's EXT skill (t-1)	0.572***	0.500***	-0.203***	-0.277***	-0.050*	-0.107**	-0.041	-0.099*	0.004	-0.068
	(0.064)	(0.076)	(0.044)	(0.071)	(0.029)	(0.047)	(0.033)	(0.053)	(0.046)	(0.068)
Younger sib's INT skill (t-1)	-0.324***	-0.282***	-0.259***	-0.260**	0.775***	0.750***	-0.285**	-0.313***	-0.139	-0.127
	(0.083)	(0.091)	(0.098)	(0.109)	(0.103)	(0.108)	(0.084)	(0.093)	(0.095)	(0.109)
Younger sib's COG skill (t-1)	0.121***	0.089***	0.061*	0.038	-0.013	-0.038*	0.057**	0.046*	0.599***	0.568***
	(0.024)	(0.027)	(0.025)	(0.029)	(0.017)	(0.022)	(0.024)	(0.026)	(0.031)	(0.035)
Older sib's EXT skill (t-1)	-0.064**	-0.176**	0.706***	0.595***	-0.067***	-0.166***	-0.137***	-0.219***	-0.035	-0.172**
	(0.031)	(0.065)	(0.041)	(0.078)	(0.021)	(0.051)	(0.026)	(0.060)	(0.032)	(0.075)
Older sib's INT skill (t-1)	0.062	0.000	0.048	-0.007	0.032	-0.015	0.973***	0.943***	-0.022	-0.093
	(0.041)	(0.047)	(0.044)	(0.055)	(0.030)	(0.039)	(0.088)	(0.088)	(0.046)	(0.059)
Parental investment (t)	0.564***	0.460**	0.647***	0.624***	0.232*	0.194	0.170	0.225	0.426**	0.331
	(0.186)	(0.196)	(0.191)	(0.281)	(0.122)	(0.150)	(0.134)	(0.159)	(0.208)	(0.242)
Sibling bond (t)		0.406**		0.397**		0.344**		0.242*		0.491**
		(0.172)		(0.195)		(0.133)		(0.145)		(0.200)
Observations	2558	2558	2475	2475	2558	2558	2475	2475	2558	2558
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 siblings' gender, age gap between younger and older sibling, mother's mental health, mother's education, mother's age, whether the household is dual or single headed, number of children, housing tenure, years lived in current address, local employment at the local authority where family lives, region fixed effects. The questionnaire items used to measure the latent sibling bond and parental investment are presented in Table 2. 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).

C.3 Robustness: families with more than two siblings

Table C17: Joint technology of skill formation: average sibling bond in families with more than two siblings

Outcome	Externalizing (EXT)		Internalizing (INT)		Cognitive (COG)
	(1)	(2)	(3)	(4)	(5)
	Younger	Older	Younger	Older	Younger
Younger sibling's EXT skill (t-1)	0.499***	-0.013	-0.111**	-0.100*	-0.096
	(0.091)	(0.057)	(0.053)	(0.054)	(0.085)
Younger sibling's INT skill (t-1)	-0.325***	-0.268**	0.751***	-0.318***	-0.205
	(0.105)	(0.112)	(0.115)	(0.094)	(0.134)
Younger sibling's COG skill (t-1)	0.083***	0.039	-0.033	0.048*	0.589***
	(0.029)	(0.029)	(0.021)	(0.026)	(0.037)
Older sibling's EXT skill (t-1)	-0.188**	0.592***	-0.164***	-0.221***	-0.225**
	(0.078)	(0.081)	(0.058)	(0.062)	(0.094)
Older sibling's INT skill (t-1)	-0.010	-0.013	-0.020	0.940***	-0.076
	(0.052)	(0.057)	(0.041)	(0.089)	(0.068)
Average sibling bond (t)	0.461**	0.461**	0.397**	0.284	0.657**
	(0.212)	(0.233)	(0.167)	(0.173)	(0.283)
Parental investment (t)	0.480**	0.627***	0.200	0.227	0.415
	(0.220)	(0.222)	(0.162)	(0.162)	(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 siblings' gender, age gap between younger and older sibling, mother's mental health, mother's education, mother's age, whether the household is dual or single headed, number of children, housing tenure, years lived in current address, local employment at the local authority where family lives, 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).

C.4 Robustness: family size & fertility

Table C18: Joint technology of skill formation: family size & fertility

Outcome	Externalizing (EXT)		Internalizing (INT)		Cognitive (COG)
	(1)	(2)	(3)	(4)	(5)
	Younger	Older	Younger	Older	Younger
Younger sibling's EXT skill (t-1)	0.551***	-0.350***	-0.029	-0.042	-0.050
	(0.066)	(0.071)	(0.036)	(0.041)	(0.059)
Younger sibling's INT skill (t-1)	-0.324***	-0.398**	0.839***	-0.240**	-0.172
	(0.105)	(0.168)	(0.122)	(0.095)	(0.128)
Younger sibling's COG skill (t-1)	0.088**	-0.098	0.046	0.108***	0.593***
	(0.043)	(0.072)	(0.032)	(0.037)	(0.050)
Older sibling's EXT skill (t-1)	-0.177***	0.360***	0.051	-0.067	-0.160**
	(0.062)	(0.118)	(0.049)	(0.055)	(0.081)
Older sibling's INT skill (t-1)	-0.010	-0.090	0.011	0.961***	-0.074
	(0.050)	(0.097)	(0.040)	(0.091)	(0.061)
Sibling bond (t)	0.418***	1.139***	-0.135	-0.121	0.454**
	(0.140)	(0.286)	(0.106)	(0.115)	(0.178)
Parental investment (t)	0.408**	0.510***	0.107	0.166	0.290
	(0.177)	(0.177)	(0.117)	(0.136)	(0.214)
Number of siblings (t)	0.098	-0.671*	0.491***	0.416**	0.079
	(0.238)	(0.343)	(0.169)	(0.188)	(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 siblings' gender, age gap between younger and older sibling, mother's mental health, mother's education, mother's age, whether the household is dual or single headed, number of children, housing tenure, years lived in current address, local employment at the local authority where family lives, 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).

C.5 Joint technology of skill formation with siblings: Exogenous investments

Table C19: Joint technology of skill formation: younger and older siblings - exogenous investment

Outcome	Externalizing (EXT)				Internalizing (INT)				Cognitive (COG)	
	Younger		Older		Younger		Older		Younger	
	Restricted	Unrestricted	Restricted	Unrestricted	Restricted	Unrestricted	Restricted	Unrestricted	Restricted	Unrestricted
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Younger sib's EXT skill (t-1)	0.696***	0.681***	-0.092***	-0.096***	0.005	-0.004	-0.020	-0.036*	0.082***	0.085***
	(0.037)	(0.037)	(0.018)	(0.019)	(0.015)	(0.015)	(0.021)	(0.021)	(0.022)	(0.022)
Younger sib's INT skill (t-1)	-0.134***	-0.134***	-0.057	-0.052	0.831***	0.806***	-0.233***	-0.233***	-0.005	-0.005
	(0.051)	(0.051)	(0.054)	(0.053)	(0.100)	(0.097)	(0.068)	(0.067)	(0.063)	(0.062)
Younger sib's COG skill (t-1)	0.089***	0.084***	0.029	0.031*	-0.019	-0.022	0.055**	0.051**	0.590***	0.594***
	(0.018)	(0.018)	(0.018)	(0.019)	(0.016)	(0.016)	(0.022)	(0.022)	(0.028)	(0.028)
Older sib's EXT skill (t-1)	0.004	-0.023	0.770***	0.766***	-0.032**	-0.044***	-0.116***	-0.138***	0.015	0.022
	(0.015)	(0.015)	(0.034)	(0.034)	(0.013)	(0.014)	(0.020)	(0.020)	(0.018)	(0.019)
Older sib's INT skill (t-1)	0.008	-0.003	0.012	0.011	0.020	0.015	0.987***	0.969***	-0.044	-0.040
	(0.031)	(0.032)	(0.034)	(0.034)	(0.028)	(0.029)	(0.088)	(0.087)	(0.042)	(0.042)
Parental investment (t)	0.052***	0.049***	0.068***	0.013	-0.026***	-0.028***	0.020	0.017	0.013	0.014
	(0.010)	(0.014)	(0.014)	(0.010)	(0.009)	(0.009)	(0.012)	(0.012)	(0.012)	(0.012)
Sibling bond (t)		0.099***		0.067***		0.046***		0.079***		-0.025
		(0.011)		(0.014)		(0.013)		(0.018)		(0.018)
Observations	2558	2558	2475	2475	2558	2558	2475	2475	2558	2558
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 siblings' gender, age gap between younger and older sibling, mother's mental health, mother's education, mother's age, whether the household is dual or single headed, number of children, housing tenure, years lived in current address, local employment at the local authority where family lives, 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).

C.6 Translog production function

Table C20: Translog joint technology of skill formation

	Externalizing (EXT)				Internalizing (INT)				Cognitive (COG)	
	Younger	Younger	Older	Older	Younger	Younger	Older	Older	Younger	Younger
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Younger sib's EXT skill (t-1)	1.086***	1.086***	0.004	0.006	0.035	0.035	0.004	0.005	0.181	0.180
	(0.102)	(0.102)	(0.232)	(0.232)	(0.039)	(0.039)	(0.151)	(0.151)	(0.155)	(0.155)
Younger sib's INT skill (t-1)	-0.192*	-0.190*	-0.063	-0.058	0.837***	0.838***	-0.069	-0.066	-0.187	-0.189
	(0.103)	(0.103)	(0.265)	(0.265)	(0.042)	(0.042)	(0.172)	(0.173)	(0.156)	(0.157)
Younger sib's COG skill (t-1)	0.116	0.134	0.332*	0.380*	-0.057*	-0.049	0.006	0.038	0.675***	0.651***
	(0.076)	(0.091)	(0.199)	(0.224)	(0.030)	(0.037)	(0.134)	(0.154)	(0.134)	(0.133)
Older sib's EXT skill (t-1)	-0.059	-0.074	0.533***	0.496**	-0.072**	-0.078**	-0.104	-0.130	-0.082	-0.063
	(0.083)	(0.089)	(0.191)	(0.211)	(0.032)	(0.034)	(0.120)	(0.134)	(0.137)	(0.158)
Older sib's INT skill (t-1)	0.026	0.034	0.281	0.302	-0.018	-0.015	0.537***	0.550***	0.064	0.053
	(0.112)	(0.114)	(0.295)	(0.299)	(0.046)	(0.046)	(0.202)	(0.203)	(0.157)	(0.161)
Parental investment (t)	0.069***	0.068***	0.080**	0.079**	-0.025***	-0.025***	0.040*	0.039*	0.017	0.018
	(0.014)	(0.014)	(0.033)	(0.034)	(0.005)	(0.005)	(0.022)	(0.022)	(0.018)	(0.018)
Sibling bond (t)	0.078	0.043	-0.197	-0.291	0.170*	0.154	0.021	-0.042	0.356	0.403
	(0.236)	(0.261)	(0.563)	(0.607)	(0.098)	(0.108)	(0.356)	(0.394)	(0.328)	(0.343)
Parental investment (t) * Sibling bond (t)		-0.075		-0.197		-0.033		-0.133		0.099
		(0.203)		(0.478)		(0.079)		(0.336)		(0.294)
Younger sib's EXT skill (t-1) * Sibling bond (t)	0.063	0.096	-0.094	-0.005	0.028	0.043	0.062	0.123	0.166	0.121
	(0.080)	(0.116)	(0.219)	(0.310)	(0.032)	(0.048)	(0.137)	(0.209)	(0.126)	(0.174)
Younger sib's INT skill (t-1) * Sibling bond (t)	-0.152	-0.141	-0.136	-0.108	-0.043	-0.038	0.155	0.174	-0.293	-0.307
	(0.164)	(0.167)	(0.402)	(0.409)	(0.064)	(0.065)	(0.268)	(0.274)	(0.257)	(0.268)
Younger sib's COG skill (t-1) * Sibling bond (t)	0.112	0.131	0.473*	0.522*	-0.001	0.007	-0.014	0.019	0.043	0.019
	(0.105)	(0.117)	(0.272)	(0.289)	(0.042)	(0.047)	(0.182)	(0.197)	(0.181)	(0.177)
Older sib's EXT skill (t-1) * Sibling bond (t)	-0.078	-0.091	-0.386*	-0.420**	-0.000	-0.006	-0.183	-0.205	-0.080	-0.063
	(0.092)	(0.096)	(0.200)	(0.212)	(0.035)	(0.037)	(0.133)	(0.142)	(0.129)	(0.143)
Older sib's INT skill (t-1) * Sibling bond (t)	0.012	0.013	0.175	0.179	0.004	0.004	-0.034	-0.032	0.167	0.165
	(0.153)	(0.153)	(0.392)	(0.393)	(0.062)	(0.062)	(0.261)	(0.261)	(0.222)	(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. The interactions between the lag of the siblings' skills and the sibling bond are instrumented by the interaction between the lag of the siblings' skills and the exogenous shifter for the sibling bond (i.e., adjustment cost to housing with a control function approach.Other controls include siblings' gender, age gap between younger and older sibling, mother's mental health, mother's education, mother's age, whether the household is dual or single headed, number of children, housing tenure, years lived in current address, local employment at the local authority where family lives, region fixed effects. Robust standard errors in parentheses (*** p<0.01, ** p<0.05, * p<0.1).

C.7 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 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 only for the externalizing skill. Namely, an exploratory factor analysis of 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. I consider parental investment and the sibling bond to be exogenous as estimating the investment functions would require a larger

Table C21: 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 siblings' gender, age gap between younger and older sibling, mother's mental health, mother's education, mother's age, whether the household is dual or single headed, number of children, housing tenure, years lived in current address, local employment at the local authority where family lives, region fixed effects. Standard errors computed based on inverting information matrix in parentheses (*** p<0.01, ** p<0.05, * p<0.1).

sample, which unfortunately is not available as the data are not collected from the teachers in England. This analysis 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 C21 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.

C.8 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 instruments become weak when when the sample is split and investments are allowed to be endogenous, often yielding structural estimates which are unreliable.

Appendix Tables C22, C23 and C24 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 C24 provides some suggestive evidence that the sibling bond is more productive for same-sex than mixed-sex siblings. This hints that same-sex siblings may have more possibilities to interact, while sharing similar interests and toys.

Finally, Appendix Tables C25 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 C22: 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	Male	Female	Male	Female	Male	Female	Male	Female	Male
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Younger sib's EXT skill (t-1)	0.232	0.629***	-0.459**	-0.239**	-0.091	-0.082	-0.526*	-0.055	-0.080	-0.074
	(0.237)	(0.076)	(0.192)	(0.101)	(0.117)	(0.093)	(0.310)	(0.125)	(0.073)	(0.083)
Younger sib's INT skill (t-1)	-0.429**	-0.024	-0.208	-0.150*	0.579***	0.889***	-0.868***	-0.250**	-0.148	0.065
	(0.201)	(0.056)	(0.174)	(0.078)	(0.132)	(0.132)	(0.330)	(0.127)	(0.128)	(0.087)
Younger sib's COG skill (t-1)	0.327**	0.048	0.096	0.000	0.108	-0.208***	0.216	0.113	0.625***	0.513***
	(0.131)	(0.038)	(0.087)	(0.060)	(0.068)	(0.078)	(0.146)	(0.081)	(0.073)	(0.063)
Older sib's EXT skill (t-1)	-0.356*	-0.037	0.436***	0.674***	-0.259**	-0.228**	-0.810**	-0.285**	-0.172	-0.163*
	(0.185)	(0.049)	(0.190)	(0.086)	(0.110)	(0.111)	(0.331)	(0.110)	(0.115)	(0.097)
Older sib's INT skill (t-1)	0.028	-0.074	0.002	-0.056	0.101	-0.064	1.622***	1.313***	-0.119	-0.128
	(0.113)	(0.054)	(0.134)	(0.106)	(0.082)	(0.115)	(0.230)	(0.154)	(0.087)	(0.096)
Parental investment (t)	0.732*	0.292	0.637***	0.816*	0.105	0.573	0.869*	-0.207	0.297	0.352
	(0.433)	(0.271)	(0.338)	(0.481)	(0.229)	(0.524)	(0.514)	(0.609)	(0.258)	(0.490)
Sibling bond (t)	0.791*	0.137	0.724	0.221	0.384	0.424	1.191	0.185	0.453	0.456*
	(0.433)	(0.154)	(0.475)	(0.229)	(0.268)	(0.287)	(0.795)	(0.291)	(0.258)	(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 siblings' gender, age gap between younger and older sibling, mother's mental health, mother's education, mother's age, whether the household is dual or single headed, number of children, housing tenure, years lived in current address, local employment at the local authority where family lives, 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).

Table C23: 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	Male	Female	Male	Female	Male	Female	Male	Female	Male
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Younger sib's EXT skill (t-1)	0.557***	0.226	-0.259***	-0.333**	-0.108*	-0.123	-0.177	-0.201	-0.029	-0.133
	(0.105)	(0.252)	(0.091)	(0.150)	(0.061)	(0.090)	(0.121)	(0.213)	(0.089)	(0.146)
Younger sib's INT skill (t-1)	-0.218*	-0.172	-0.176	-0.067	0.603***	0.900***	-0.779***	-0.215	0.027	-0.043
	(0.128)	(0.141)	(0.132)	(0.120)	(0.123)	(0.184)	(0.240)	(0.182)	(0.124)	(0.207)
Younger sib's COG skill (t-1)	0.091**	0.134***	0.062	-0.012	-0.045*	0.022	0.122	0.014	0.570***	0.526***
	(0.038)	(0.047)	(0.044)	(0.073)	(0.027)	(0.035)	(0.075)	(0.107)	(0.042)	(0.056)
Older sib's EXT skill (t-1)	-0.122	-0.218	0.636***	0.646***	-0.161***	-0.150*	-0.462**	-0.462**	-0.032	-0.267*
	(0.077)	(0.141)	(0.095)	(0.120)	(0.054)	(0.0.88)	(0.137)	(0.178)	(0.074)	(0.142)
Older sib's INT skill (t-1)	0.020	0.017	-0.110	-0.122	0.050	-0.003	1.451***	1.279***	-0.070	-0.132
	(0.067)	(0.087)	(0.096)	(0.186)	(0.049)	(0.073)	(0.174)	(0.221)	(0.069)	(0.121)
Parental investment (t)	0.227	0.646**	0.746**	0.400	0.186	0.189	0.696	0.228	0.107	0.400
	(0.337)	(0.307)	(0.345)	(0.306)	(0.222)	(0.196)	(0.456)	(0.414)	(0.346)	(0.327)
Sibling bond (t)	0.299**	0.398	0.282	0.632	0.188**	0.296	0.352	0.590	0.137	0.573*
	(0.124)	(0.339)	(0.205)	(0.431)	(0.085)	(0.206)	(0.291)	(0.624)	(0.118)	(0.335)
Observations	1312	1246	1272	1203	1312	1246	1272	1203	1312	1246
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 siblings' gender, age gap between younger and older sibling, mother's mental health, mother's education, mother's age, whether the household is dual or single headed, number of children, housing tenure, years lived in current address, local employment at the local authority where family lives, 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).

Table C24: Joint technology of skill formation by siblings' gender composition

Outcome	Externalizing (EXT)				Internalizing (INT)				Cognitive (COG)	
	Younger		Older		Younger		Older		Younger	
Gender composition	Mixed	Same	Mixed	Same	Mixed	Same	Mixed	Same	Mixed	Same
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Younger sib's EXT skill (t-1)	0.539***	0.497***	-0.186***	-0.719	-0.045	-0.276	-0.131	-0.363	-0.046	-0.002
	(0.078)	(0.180)	(0.051)	(0.651)	(0.063)	(0.283)	(0.102)	(0.440)	(0.063)	(0.157)
Younger sib's INT skill (t-1)	-0.251	-0.141	0.031	-0.032	0.663***	0.872***	-0.755**	-0.449*	-0.043	0.051
	(0.204)	(0.087)	(0.128)	(0.127)	(0.199)	(0.190)	(0.309)	(0.265)	(0.210)	(0.097)
Younger sib's COG skill (t-1)	0.097	0.149**	0.131**	0.042	0.011	-0.071	0.176	0.096	0.548***	0.588***
	(0.098)	(0.041)	(0.065)	(0.115)	(0.106)	(0.072)	(0.132)	(0.095)	(0.100)	(0.046)
Older sib's EXT skill (t-1)	-0.159***	-0.154	0.683***	0.198	-0.257***	-0.412	-0.460***	-0.664	-0.143*	-0.103
	(0.053)	(0.166)	(0.060)	(0.673)	(0.079)	(0.287)	(0.113)	(0.477)	(0.075)	(0.158)
Older sib's INT skill (t-1)	-0.018	-0.012	0.031	-0.032	-0.056	0.053	1.648***	1.302***	-0.209	-0.044
	(0.156)	(0.044)	(0.128)	(0.127)	(0.171)	(0.090)	(0.257)	(0.145)	(0.173)	(0.049)
Parental investment (t)	0.625	0.363	0.464	1.238	-0.052	0.556	0.907	0.543	0.467	0.108
	(0.502)	(0.273)	(0.391)	(1.251)	(0.549)	(0.519)	(0.693)	(0.843)	(0.576)	(0.298)
Sibling bond (t)	0.298	0.342	0.106	1.293	0.531	0.815	0.039	0.825	0.449	0.243
	(0.358)	(0.318)	(0.272)	(1.325)	(0.399)	(0.592)	(0.544)	(0.900)	(0.411)	(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 siblings' gender, age gap between younger and older sibling, mother's mental health, mother's education, mother's age, whether the household is dual or single headed, number of children, housing tenure, years lived in current address, local employment at the local authority where family lives, 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).

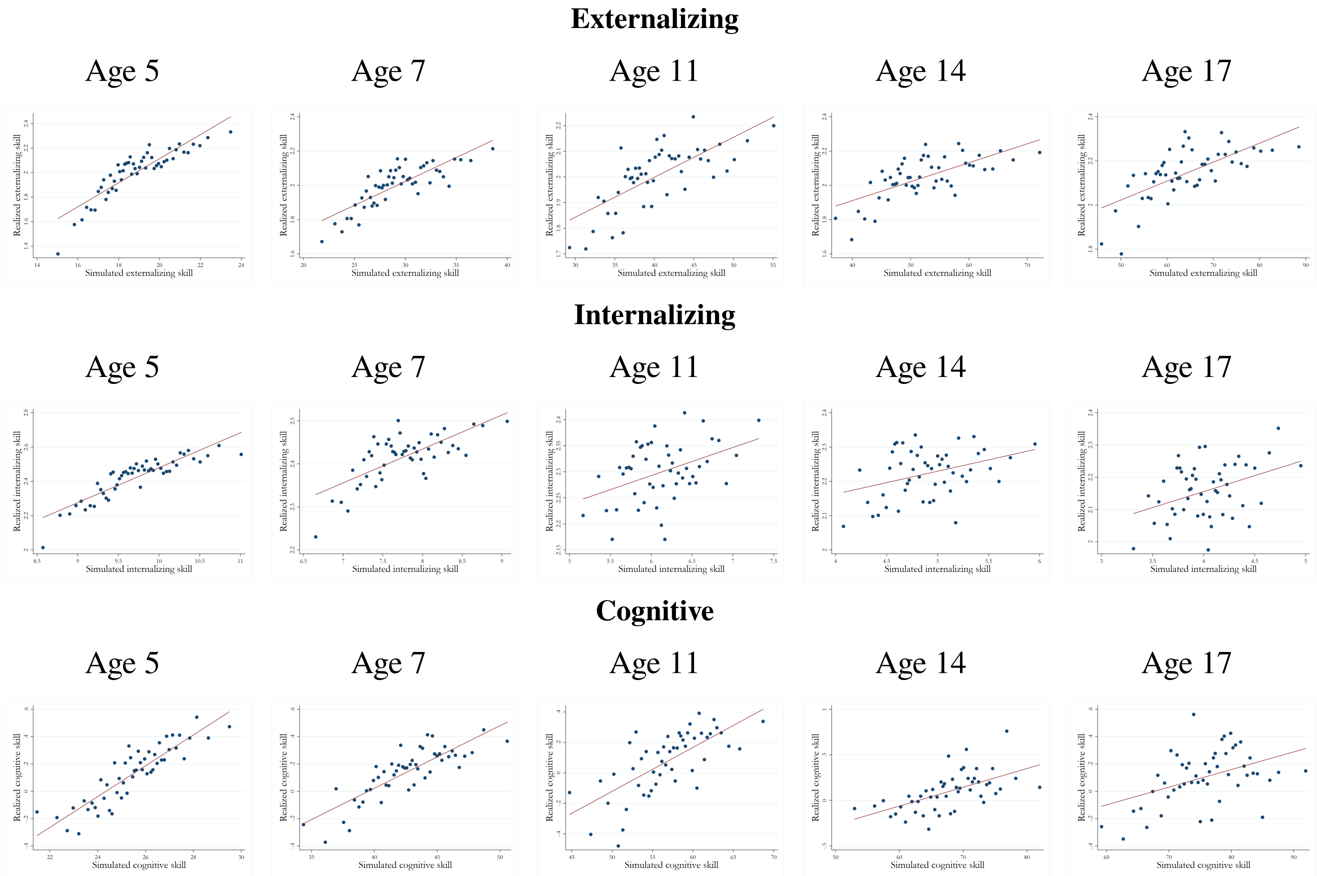
Table C25: Joint technology of skill formation by siblings' age gap

Outcome	Externalizing (EXT)				Internalizing (INT)				Cognitive (COG)	
	Younger		Older		Younger		Older		Younger	
Age gap	Small	Large	Small	Large	Small	Large	Small	Large	Small	Large
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Younger sib's EXT skill (t-1)	0.476***	0.605***	-0.240***	-0.281**	-0.110	-0.146	-0.230**	-0.072	-0.125	-0.017
	(0.101)	(0.103)	(0.068)	(0.108)	(0.077)	(0.137)	(0.112)	(0.121)	(0.102)	(0.085)
Younger sib's INT skill (t-1)	-0.145*	-0.217*	-0.149**	-0.177	0.824***	0.902***	-0.505***	-0.240	-0.067	-0.046
	(0.086)	(0.116)	(0.071)	(0.134)	(0.114)	(0.183)	(0.150)	(0.172)	(0.101)	(0.129)
Younger sib's COG skill (t-1)	0.160***	0.054	0.040	0.056	-0.039	-0.064	0.124*	0.040	0.592***	0.593***
	(0.034)	(0.046)	(0.033)	(0.048)	(0.037)	(0.063)	(0.066)	(0.062)	(0.044)	(0.054)
Older sib's EXT skill (t-1)	-0.185**	-0.073	0.676***	0.573***	-0.163*	-0.289***	-0.338**	-0.379***	-0.225*	-0.123
	(0.083)	(0.067)	(0.094)	(0.081)	(0.092)	(0.098)	(0.153)	(0.099)	(0.116)	(0.080)
Older sib's INT skill (t-1)	0.029	-0.124*	0.064	-0.163*	0.019	0.010	1.410***	1.126***	-0.069	-0.100
	(0.071)	(0.067)	(0.065)	(0.099)	(0.068)	(0.112)	(0.149)	(0.146)	(0.085)	(0.074)
Parental investment (t)	0.456*	0.376	0.509**	0.608*	0.350	-0.095	0.396	0.371	0.407	0.335
	(0.264)	(0.277)	(0.235)	(0.321)	(0.265)	(0.404)	(0.383)	(0.356)	(321)	(0.331)
Sibling bond (t)	0.269*	0.473*	0.317*	0.375	0.283	0.779**	0.493	0.208	0.516**	0.184
	(0.161)	(0.278)	(0.183)	(0.296)	(0.182)	(0.390)	(0.303)	(0.338)	(0.216)	(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 siblings' gender, age gap between younger and older sibling, mother's mental health, mother's education, mother's age, whether the household is dual or single headed, number of children, housing tenure, years lived in current address, local employment at the local authority where family lives, 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).

C.9 Validating the Structural Estimates

Figure C8: 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).