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, introducing a novel variable, the "sibling bond", which captures how well siblings get along. This measure is constructed using the Millennium Cohort Study data in the United Kingdom on the frequency and quality of interactions between siblings, such as enjoying playtime together and teasing each other. Descriptive evidence shows that a stronger sibling bond is associated with improved child outcomes during adolescence. Structural estimates further reveal that sibling bonds play a significant role in shaping both younger and older siblings' skills, even after accounting for parent-child interactions.

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

Keywords: Human Capital; Skills; Education and Inequality; Siblings; Family.

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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 et al. (2018), Attanasio et al. (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. The literature has estimated the technology of skill formation with a *single* child, showing that parental skill and investment play an important role for child development (Cunha and Heckman, 2008; Cunha, Heckman, and Schennach, 2010; Attanasio, Cattan, Fitzsimons, Meghir, and Rubio-Codina, 2020; Attanasio, Meghir, and Nix, 2020; Caucutt, Lochner, Mullins, and Park, 2020; Agostinelli and Wiswall, 2025).[2] On the other hand, the joint production of siblings' skills within the family and its policy implications have been understudied.

The Millennium Cohort Study (MCS) data in the United Kingdom enables me to introduce a novel variable, "sibling bond," which captures the quality of the relationship between siblings – namely, how well they get along. This measure combines information on sibling behaviors, such as enjoying playtime together and teasing each other. By directly measuring the quality of sibling interactions, this variable allows for an examination of how the social capital siblings share through their bond affects child development. For example, a strong sibling bond can promote cooperation, empathy, and collaborative behavior, while a weaker bond may lead to rivalry or conflict, potentially hindering child development. Additionally, siblings spend nearly two additional hours per week with each other in unstructured play – which can foster cognitive, physical, and socio-emotional development (Dankiw et al., 2020; Lee et al., 2020) – while structured and educational activities are more often shared with parents (Dunifon et al., 2017).

I initially present some descriptive evidence, which documents 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

[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 et al. (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 et al. (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 et al., 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.

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 descriptive 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 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 the early 2000s in the United Kingdom. The MCS has administered a set of questionnaires to collect information on the development of the cohort member and their older sibling, as well as the quality of their interactions at the age-5 wave. I map the information recorded in the MCS questionnaires into the latent inputs and outputs of the skill formation technology through factor models (Cunha et al., 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, 2025; Freyberger, 2021).

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 bias the estimates of their productivities due to such responses to the unobserved shocks. To address this challenge, I use two exogenous shifters - local labor market shocks and adjustment costs to housing - that should affect the siblings' skills only through parental investment and the sibling bond respectively (Carneiro et al., 2013; Altonji et al., 2017; Cunha et al., 2021). 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 exogenous.

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 et al., 2018; Attanasio et al., 2022).

First, it contributes to the literature estimating the technology of skill formation, which presumes 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, 2025).[3] However, families usually have more than one child and siblings interact, as noted by Francesconi and Heckman (2016) and McHale et al. (2012).[4] I extend the single-child framework and consider the younger and older siblings' joint technology of skill formation. This allows me to study how parental investment and a quality bond between siblings affect the development of each sibling. Considering parents and siblings in the development process highlights the importance of thinking carefully about the social capital and relationships within the family.[5] Siblings can indeed be important team players, who can help each other achieve common goals within the family, such as their joint production of skills.[6]

Moreover, this paper thinks carefully about the multi-dimensionality of skills and identifies two dimensions of socio-emotional skills (Heckman et al., 2006; Borghans et al., 2008; Heckman et al., 2018; Humphries et al., 2019; Papageorge et al., 2019; Attanasio et al., 2020, 2025). I present novel evidence on whether one sibling tends to specialize in high internalizing skills, when the other has high externalizing skills, and vice versa. In particular, considering cognitive, externalizing and internalizing skills highlights that the formation of skills can be quite complex and different skills can have different processes.

Second, there is a growing interest in understanding the role played by siblings, which has mostly focused on quantifying sibling spillovers, noting that their identification is complicated. This paper contributes to this literature by measuring directly the strength of the sibling bond and quantifying to what extent their bond contributes to child development. Previous papers have not made direct attempts to measure the strength of the sibling bond, even though a strong sibling bond could promote sibling spillovers. For example, Altonji et al. (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

[3]Other examples of estimates for the production function with a *single* child are Fiorini and Keane (2014), Attanasio et al. (2017), Moroni et al. (2019), Agostinelli et al. (2019), Attanasio et al. (2020), Gensowski et al. (2020), Houmark et al. (2020), Caucutt and Lochner (2020), Aucejo and James (2021), and Carneiro et al. (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.

[4]Del Boca et al. (2014) and Gayle et al. (2015) estimate structural model with more than one child, where they allow parents to spend time with both children at the same time, but do not allow for sibling interactions and assume that parents know the structure of the production function. Also, Cunha et al. (2013), Boneva and Rauh (2018) and Attanasio et al. (2019) have shown that parents have biased beliefs about the returns to investment.

[5]Dunifon et al. (2017) show that children with siblings spend more time in *unstructured play* with their 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)).

[6]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).

affect the college and major choice of the younger sibling.[7]

Third, estimating the joint production of human capital complements 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 et al., 2005, 2010; Cáceres-Delpiano, 2006; Angrist et al., 2010; Åslund and Grönqvist, 2010; De Haan, 2010; Briole et al., 2020). Additionally, my estimates complement the literature on the birth order effects, which have 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, emphasizing sibling interactions as another mechanism.

In turn, this paper connects to the literature on intra-household inequality in human capital. This literature has mostly focused on parents engaging in reinforcing or compensating investment for inequality among siblings (Behrman et al., 1982; Behrman, 1988).[8] I highlight the potential for interaction between siblings, where a strong bond can foster skill development in both children. As discussed in the counterfactual simulations, this has important policy implications for interventions aimed at facilitating sibling interactions. For example, investing in activities that encourage teamwork and pro-social behavior could foster the sibling bond and in turn boost skill formation (Leijten et al., 2021).

Finally, 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 et al., 2012).[9] Similarly, the anthropology literature has investigated the role of sibling interactions 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

[7]Other examples are Gurantz et al. (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), the sibling's gender (Butcher and Case, 1994; Cools and Patacchini, 2019; Brenøe, 2021; Dudek et al., 2022; Jakiela et al., 2020), and 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).

[8]Evidence is mixed on whether parents engage in compensating or reinforcing investments, with some studies finding evidence for reinforcing behavior (Behrman et al., 1994; Aizer and Cunha, 2012; Frijters et al., 2013; Adhvaryu and Nyshadham, 2016; Grätz and Torche, 2016), others for compensating behavior (Frijters et al., 2009; Del Bono et al., 2012; Bharadwaj et al., 2018), and some showing mixed or no effects (Ayalew, 2005; Almond and Currie, 2011; Yi et al., 2015).

[9]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). 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 et al. (2002), Stocker et al. (2002), Bank et al. (2004) and Sun et al. (2019).

parental investment and sibling bond.

This paper is organized as follows. Section 2 presents the data, the descriptive evidence on the role of the sibling bond in the study of child development, and the joint production of skills in the presence of siblings. Section 3 presents the structural estimates of the technology of skill formation for the younger and older siblings as well as the counterfactual simulations. Section 4 summarizes the results and concludes.

2 The joint production of skills with siblings

This section discusses the role of the sibling bond to understand their joint production of human capital. First, I introduce the Millennium Cohort Study data. Second, I present the descriptive evidence on the role of the sibling bond, and explore 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 potentially be amplified in the future as high socio-economic status parents are more likely to have more than one child (Doepke et al., 2023). Third, 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 measurement of the latent inputs and outputs as well as the endogeneity of the inputs.

2.1 Data: Millennium Cohort Study

The Millennium Cohort Study (MCS) follows the lives of a representative sample of children born in the United Kingdom from the early 2000s to age 17. This paper uses data from the age-3 and age-5 waves, as younger and older siblings' skills have been collected only for these two waves, while the sibling bond has been collected only for the age-5 wave.[10] I present the descriptive statistics for the estimation sample in Appendix Table A1 and describe each measure below in detail.

Information on the younger and older siblings' socio-emotional skills comes from the Strengths and Difficulties Questionnaire (SDQ) administered at the age-3 and age-5 waves (Goodman, 1997, 2001). The SDQ is made up of 5 scales of 5 items each: (i) Emotional symptoms, (ii) Conduct problems, (iii) Hyperactivity/inattention, (iv) Peer relationship problems and (v) Prosocial behavior. 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 A2). Since they are all behaviors indicating lower skills, I recode all of them in reverse for higher scores to correspond to higher skills. Goodman (1997), Goodman (2001), and Goodman et al. (2010) propose adding the responses of 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.,

[10] The cohort member of the MCS is the younger sibling in each sibling pair.

2016).[11]

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) Colors (represent both primary colors and basic color terms), (ii) Letters (measure knowledge of both upper- and lower-case letters), (iii) Numbers/Counting (measure recognition of single- and double-digit numbers and assign a number value to a set of objects), (iv) Sizes (describe concepts of one, two, and three dimensions), (v) Comparisons (measure ability to match and/or differentiate objects based on one or more of their salient characteristics), and (vi) Shapes (include 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 has been collected only 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, (ix) How often child sees grandparents, (x) How often child sees other relatives, (xi) How often child spends time with friends outside school, (xii) How often ignores child when naughty, (xiii) How often smacks child when naughty, (xiv) How often shouts at child when naughty, (xv) How often sends child to bedroom/naughty chair, (xvi) How often takes away treats from child when naughty, (xvii) How often tells child off when naughty, (xviii) How often bribes child when naughty, (xix) How often tries to reason with child when naughty, (xx) How often makes sure child obeys instruction/request, (xxi) How close the bond between mother and child is.

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 in the local authority where the household resides.[12] Data on the local employment at the age-5 wave are unfortunately not available for Northern Ireland.

[11]The note of Appendix Table A2 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.

[12]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.

2.2 Descriptive evidence on the sibling bond

Siblings play a vital role within the family and often spend more time with each other than with their parents while growing up (Dunifon et al., 2017). For example, Dunifon et al. (2017) documents that siblings spend nearly two additional hours per week with each other in unstructured play, which can foster cognitive, physical, and socio-emotional development (Dankiw et al., 2020; Lee et al., 2020), while structured and educational activities are more often shared with parents.

I present evidence on two motivating facts that justify the importance of the sibling bond in the study of skill formation, beyond parent-child interactions. To measure the strength of the sibling bond, I use a unique set of questions on the quality of sibling interactions, available in the age-5 wave of the MCS and described in the previous section. 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.

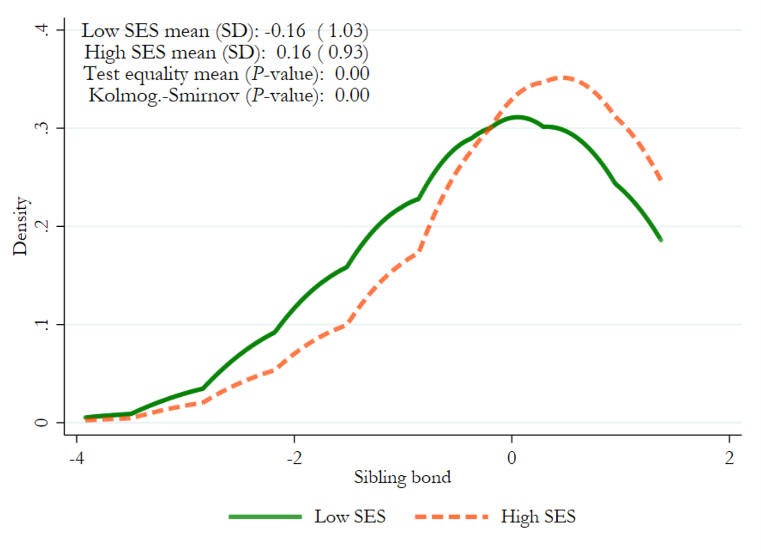
First, Figure 1 documents a socio-economic gradient in the quality of the sibling bond, with both the means and the distributions of the sibling bond being statistically different by mother's education. Similar results are also found if the socio-economic status is defined as a dummy equal to 1 if the mother was smoking during pregnancy (Appendix Figure A1) and when the quality of the sibling bond is residualized by the siblings' age gap (Appendix Figure A2). Finally, Appendix Figure A3 shows that there is a SES gradient in each item used to construct the sibling bond.

Second, Figure 2 documents that the sibling bond at age 5 predicts the younger sibling's developmental outcomes across adolescence. In this analysis, I pay particular attention to the multi-dimensionality of skills and consider three dimensions of development: *externalizing* (ability to engage in interpersonal activities), *internalizing* (ability to focus determination in pursuit of long-term goals) and *cognitive* (ability to learn and solve tasks) skills (Achenbach, 1966; Achenbach et al., 2016). I use the 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 et al., 2010).

The MCS dataset helps me to show in Figure 2 that the sibling bond matters over and beyond the home environment and both siblings' inter-personal and intra-personal skills.[13] This dataset includes information on demographic characteristics, such as the mother's education, age, employment, household structure, and housing arrangements, as well as information on the mother's mental health and the closeness of the mother-child relationship. 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, and information on the socio-emotional skills of both siblings involved in the relationship.

[13]The full list of controls is in the note of Figure 2. This includes younger and older siblings' skills, mother's education, mother's age, mother's mental health, 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.

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 behaviors 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 deviations (SD) 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.

Nevertheless, it is important to consider a plausible concern – both in relation to this evidence and to the broader study of sibling bonds in child development – namely, whether the sibling bond is capturing a stimulating home environment rather than sibling interactions. Appendix A.3 utilizes the richness of the MCS data and provides three pieces of evidence, summarized below, suggesting that the sibling bond is intrinsically related to the interactions and social capital siblings share through their relationship, rather than to a stimulating home environment, other relationships, or their personalities. First, Appendix Table A3 presents the correlations between the sibling bond and some home environment factors, such as parental investment, mother's mental health, and the quality of mother-child bond. These correlations are low and usually around 0.10. 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, Appendix Figure A4 presents evidence that the sibling bond is not measuring the children's social skills: 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, Section 2.4.1 presents additional evidence from an exploratory factor analysis that the items from the sibling bond and parental investment questionnaires are capturing two different inputs.

Turning to Figure 2, a stronger sibling bond at age 5 predicts better developmental outcomes across the younger sibling's adolescence at ages 5, 7, 11, 14, and 17, conditional on the large set of controls discussed above. 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. The comparison of the blue dots (without controls) with red triangles (with full controls) suggests that the decline in the coefficient of the age-5 sibling bond is primarily driven by 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 during adolescence. While some individual coefficients are statistically insignificant at certain ages, the pooled estimates presented in Appendix Table A4 indicate a robust and significant overall association between early sibling bonds and later pooled developmental outcomes.

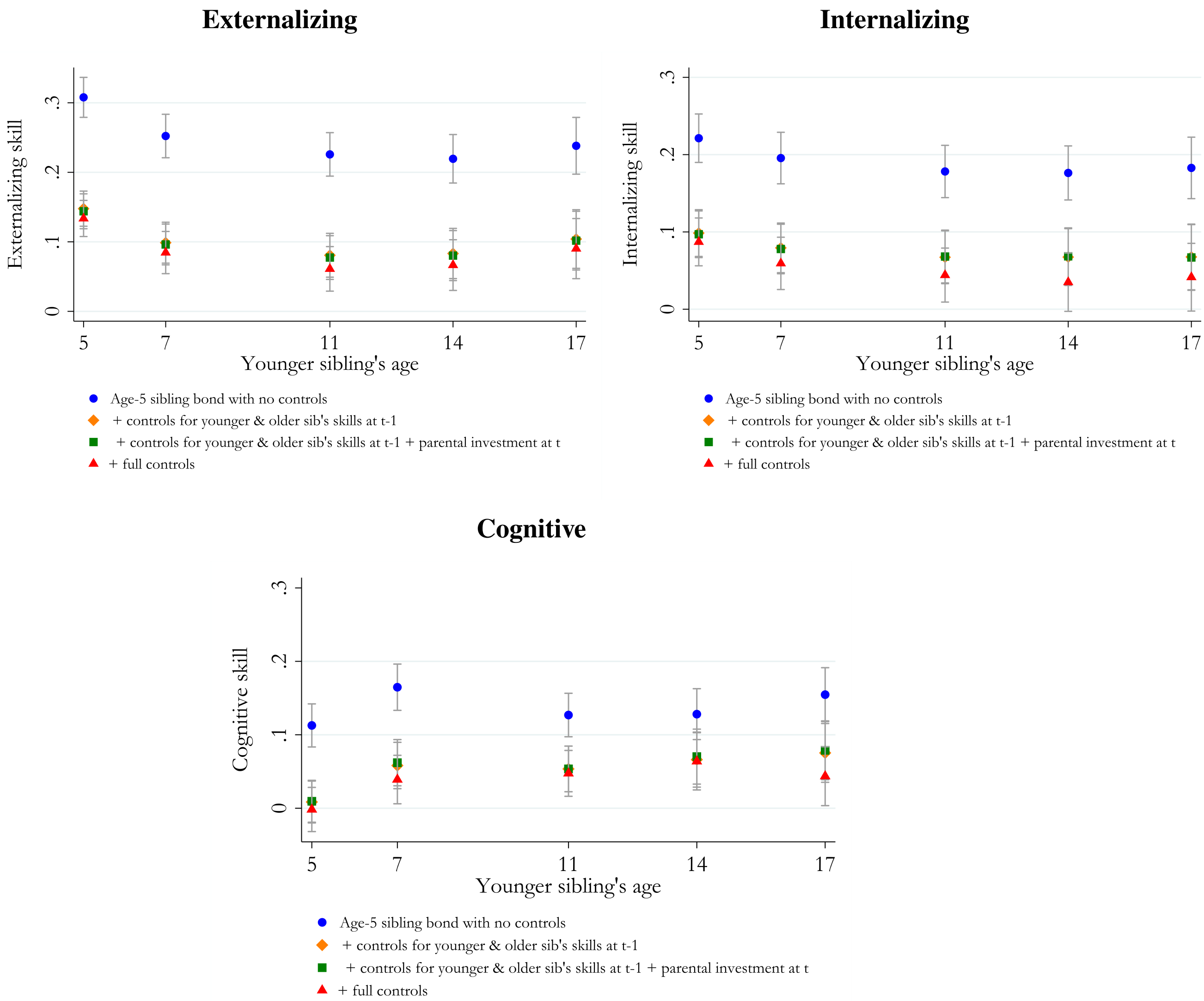
Appendix Table A5 provides additional evidence that a stronger sibling bond is predictive of better educational and health outcomes at age 17, conditional on the environmental factors discussed above. A strong sibling bond is associated with a higher grade in the English GCSE exam, a key academic milestone in the UK, and with a greater likelihood of progressing to A-levels, which are required for university entry. It is also linked to a lower probability of smoking cigarettes at age 17, which is consistent with the psychology theory by Patterson (1984), arguing that siblings take up risky behaviors, such as smoking, when the sibling relationship is ridden with conflicts. I also assess whether these results are driven by restricting the sample to children with siblings: Appendix Table A6 reproduces Appendix Table A5 using the full sample, including children without siblings. For children without siblings, the sibling bond and older sibling's social skills variables are imputed with the minimum and maximum observed values, respectively. I then control for the number of siblings and include a dummy variable equal to 1 if the child is an only child. The estimates in Appendix Table A6 are robust and closely resemble those in Appendix Table A5, likely because the majority of the sample (75%) has at least one sibling.

Finally, Appendix Table A7 speaks to a limitation of the MCS dataset, which measures the sibling bond only at the age-5 wave.[14] I document that a strong sibling bond at age 5 lays the foundation for long-term positive interactions between siblings. Columns 1-4 of Appendix Table A7 document that a strong sibling bond at age 5 predicts that siblings are more likely to talk to each other rather than to their parents at age 14 when worried about something. This suggests that the sibling bond is shaped through repeated interactions, with its benefits including increased communication and cooperation, and its costs involving the potential for long-lasting conflict with someone they may not always get along with. The age-5 sibling bond also seems to affect other relationships later in life, such as having fewer arguments with parents at age 14 (Columns 5-6 of Appendix Table A7).

To further explore 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

[14]Measures of the sibling bond are not typically collected in large-scale cohort studies.

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 et al., 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 behaviors 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, (vii) How often play outdoor games with the child, (viii) How often family does indoor activities together, (ix) How often child sees grandparents, (x) How often child sees other relatives, (xi) How often child spends time with friends outside school, (xii) How often ignores child when naughty, (xiii) How often smacks child when naughty, (xiv) How often shouts at child when naughty, (xv) How often sends child to bedroom/naughty chair, (xvi) How often takes away treats from child when naughty, (xvii) How often tells child off when naughty, (xviii) How often bribes child when naughty, (xix) How often tries to reason with child when naughty, (xx) How often makes sure child obeys instruction/request, (xxi) 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.

Child Development Supplement (CDS) of the Panel Study of Income Dynamics (PSID) in the United States (US) can provide some interesting insights on this as it collects time-use diaries. Dunifon et al. (2017) present two descriptive patterns in the time use of 6- to 12-year-old children with and without siblings in the U.S., using CDS time-use data.[15] First, 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. Second, siblings spend time in *unstructured play* with each other (almost 2 hours more per week than single children), while they are more likely to do *structured and educational* activities with their 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, physical and socio-emotional development (e.g., Dankiw et al. (2020) and Lee et al. (2020)).

2.3 The joint technology of skill formation with siblings

Building on the descriptive evidence presented above, I extend standard models of human capital investment, which typically assume that parents care about their own consumption, C_i, and the development of a *single* child, θ_i (e.g., Attanasio, 2015). I develop a model that accounts for parents with *two* children, incorporating sibling interactions alongside parent-child interactions, as outlined in the stylized model in Appendix A.4.

To capture the complexity of skill formation, I define the joint technology for both the younger (Y) and older (O) siblings in family i at time t, taking into account the multi-dimensional nature of skills: internalizing (INT), externalizing (EXT), and cognitive (COG) skills. I explore several specifications, including a translog production function to allow for different degrees of substitutability between inputs in Appendix A.17. However, the data do not reject the Cobb-Douglas specification, which I therefore adopt for the analysis and present below.

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

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

Where t represents the age-5 wave and $(t-1)$ represents the age-3 wave. Skills θ^S_{it} are internalizing (INT), Externalizing (EXT), and Cognitive (COG) skills. PI_{it} and SB_{it} represent

[15] Dunifon et al. (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.

respectively parental investment and the sibling bond.[16] As I am considering the joint process of skill formation with siblings, I incorporate the younger and older siblings' internalizing and 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.[17] X_{it} is a vector of environmental factors that may affect child development. These include siblings' gender, age gap between younger and older sibling, number of children in the household, household structure (dual- or single-headed), mother's education, mother's age, mother's mental health, housing tenure, years lived in current address, local employment at the local authority where the family lives, region fixed effects. $v_{Y,it}$ is an idiosyncratic shock observed by the parents, but unobserved by the econometrician.

The analysis focuses on four key parameters: β_{3S}, ω_{3S}, β_{4S}, and ω_{4S}. The coefficients β_{3S} and ω_{3S} capture the productivity of the sibling bond for the younger and older siblings, respectively, for each skill S. While β_{4S} and ω_{4S} capture the productivity of parental investment for the younger and older siblings, respectively, for each skill S. In addition, β_{1S} and ω_{2S} capture the self-productivity and cross-productivity of skills, respectively, whereas β_{2S} and ω_{1S} capture how the younger sibling's skills affect the older sibling's skills, and vice versa.

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 were not collected on cognitive skills. Second, since the older sibling is not the target child of the cohort study, data on them are collected at varying ages. As a result, the older sibling's production function is adjusted for age, given that it is defined across different stages of development.

The structural estimation of equations (1) and (2) presents two key methodological challenges discussed in Sections 2.4 and 2.5 respectively.

2.4 Measurement system

This section describes the measurement system used to map questionnaire responses into the latent constructs of interest – skills, parental investment, and sibling bond. Following the framework of Cunha et al. (2010), the measurement system efficiently links observed responses to latent factors and sets a measurement scale that ensures comparability of the structural estimates across siblings (Agostinelli and Wiswall, 2025; Freyberger, 2021). I first present an Explanatory Factor Analysis (EFA) to identify latent structures and reduce data complexity, followed by a Confirmatory Factor Analysis (CFA) to validate the proposed factor structure.

[16] 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 shifters, as discussed in Section 2.5, which would be necessary to identify several dimensions of investment separately.

[17] 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.

2.4.1 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 et al., 2016; Goodman, 1997, 2001; Goodman et al., 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 et al., 2010).[18] Similarly, parental investment and the sibling bond can represent two different dimensions of interactions: parent-child and sibling interactions (McHale et al., 2012; Francesconi and Heckman, 2016). I investigate empirically these divisions in my dataset via an exploratory factor analysis. This enables me 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. Then, using this evidence, I proceed to the estimation of the measurement system I use in the estimation of the joint technology of skill formation.

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).[19] 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 A8). The factor loadings also have similar magnitudes across siblings, highlighting the similar association between the items and the factors across the 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" (see also Section 2.2). The exploratory factor analysis in Table 1 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 A9 reproduces Table 1 using the questionnaire items residualized by the set of controls previously described. The results are even more pronounced: the correlation between the two latent factors decreases from 0.15 to 0.06 after residualization.

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 robustness check investigates if the questionnaires are capturing four different latent constructs. Reassuringly, Appendix Table A10 shows that questionnaire items meant to measure a certain latent factor load on that specific latent factor, while being uncorrelated with the other factors.

[18] Goodman et al. (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.

[19] The polychoric correlation estimates 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).

Table 1: 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/request	**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 behaviors indicating worse interactions in reverse (i.e., not much interested in older sibling and teases or needles older sibling).

Finally, Appendix Table A11 reports Cronbach's alphas, which are usually above 0.53 for all the latent factors considered. Cronbach's alpha is a measure of internal consistency used to assess scale reliability, indicating how closely related a set of items are within each latent factor (Cronbach, 1951). It ranges from 0 to 1, with values closer to 1 indicating higher reliability; values above 0.50 are generally considered acceptable (Taber, 2018).

2.4.2 Confirmatory factor analysis

I use a measurement system with categorical items to measure the latent factors. Rather than aggregating the SDQ items into continuous subscales, this system leverages the variation in each categorical item to estimate a factor model. This enables me to pay particular attention to the multi-dimensionality of skills and study two dimensions of socio-emotional development. On the other hand, Cunha, Heckman, and Schennach (2010), Attanasio, Cattan, Fitzsimons, Meghir, and Rubio-Codina (2020), Attanasio, Meghir, and Nix (2020), and Agostinelli and Wiswall (2025) use a measurement system with continuous items and explore fewer dimensions of human capital.

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 (3) and (4).

$$m^*_{ijt} = \alpha_{jt} + \lambda^{\top}_{jt} ln\theta_{it} + \varepsilon_{ijt} \tag{3}$$

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

$$m_{ijt} = \begin{cases} 0 & \text{if } m^*_{ijt} < \tau_{1,jt} \\ 1 & \text{if } m^*_{ijt} \in [\tau_{1,jt}, \tau_{2,jt}] \\ 2 & \text{if } m^*_{ijt} > \tau_{2,jt} \end{cases} \tag{4}$$

Where τ_{jt} is the threshold, for example, for showing a certain behavior 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 2.4.1 (Heckman et al., 2013). Latent factors and the measurement error terms are normally distributed: $ln\theta_{it} \sim \mathcal{N}(\mu_{\theta,t}, \sigma_{\theta,t})$ and $\varepsilon_{ijt} \sim \mathcal{N}(0, \sigma_{\varepsilon,jt})$. Some normalizations are also needed in equations (3) and (4) for the parameters to be identified. First, 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, to let the mean and the variance of the latent factor be estimated, I normalize $\lambda_{jt} = 1$ and $\tau_{1,jt} = 0$ at the age-3 and 5 waves for the younger and older siblings, respectively, on the following SDQ items: (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.

Additionally, Appendix A.6 draws on advances in psychometrics to present a test for measurement invariance (Vandenberg and Lance, 2000; Putnick and Bornstein, 2016; Wu and Estabrook, 2016). This test allows me to assess whether assuming a common metric for the latent socio-emotional skills of younger and older siblings is appropriate. Establishing measurement invariance strengthens the validity of comparing the structural estimates of the skill formation technology between younger and older siblings.

To measure cognitive skills, I use a factor model with continuous items (Appendix A.7). I set the constant α_{jt} to 0 and the loading λ_{jt} to 1 for the "naming vocabulary test", which has been administered at the age-3 and 5 waves for the younger sibling, and let the mean and the variance of the latent factor be estimated (Agostinelli and Wiswall, 2025).

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 specifies the underlying assumptions for the comparison of the productivity of these inputs.

2.5 Investment functions

The second 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).[20] 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. 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 would provide biased estimates of the productivity of parental investment and the sibling bond.

Ideally, to address this problem, I would need random assignment of parental investment and the sibling bond to the child, but of course this is not always feasible. A feasible alternative is, instead, to resort to using some exogenous shifters for parental investment and the sibling bond, motivated by the theoretical model in Appendix A.4, which derives the economic restriction consistent with the exogeneity condition. 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 exogenous shifters to be valid and consistent with economic theory. However, these conditions are only sufficient as the model cannot capture every possible response to unobserved shocks by the household. Cunha et al. (2021) argue that the *necessary* conditions for the exogenous shifters 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. On the other hand, if the omitted inputs can only change at significant cost, such as moving to a different neighborhood, then the exogenous shifters would satisfy the exclusion restriction. In Section 3.1, I discuss this further and present evidence on the validity of the shifters by showing that they are uncorrelated with pre-determined observables.

The investment functions can in principle be computed numerically by solving the dynamic problem faced by parents, as in Del Boca et al. (2014) and Gayle et al. (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 et al., 2013; Boneva and Rauh, 2018; Attanasio et al., 2019). Instead, approximating these investment functions does not require taking a stance on whether parents know the true production function (Attanasio, Meghir, and Nix, 2020; Attanasio, Cattan, Fitzsimons, Meghir, and Rubio-Codina, 2020). I therefore follow the latter approach and use the log-linear investment functions from a parental investment model (Appendix A.4).

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

$$ln(SB_{it}) = \sum_S \delta_{1S} ln(\theta^S_{Y,it-1}) + \sum_S \delta_{2S} ln(\theta^S_{O,it-1}) + \delta_3 Z_{1,it} + \delta_4 Z_{2,it-1} + \mathbf{X}'_{it}\phi_S + \epsilon^{SB}_{it} \quad (5)$$

$$ln(PI_{it}) = \sum_S \gamma_{1S} ln(\theta^S_{Y,it-1}) + \sum_S \gamma_{2S} ln(\theta^S_{O,it-1}) + \gamma_3 Z_{1,it} + \gamma_4 Z_{2,it-1} + \mathbf{X}'_{it}\phi_I + \epsilon^{PI}_{it} \quad (6)$$

The investment functions in equations (5) and (6) depend on the younger and older siblings' skills at time $t-1$, parental background, and a set of household characteristics captured by $\mathbf{X}_{it}$. To address the potential endogeneity and simultaneity between parental investment and sibling bond, the two inputs are modeled as jointly determined endogenous variables within a structural system of simultaneous equations. This approach allows for the identification of their respective impacts through the use of exclusion restrictions and appropriate instruments, $Z_{i,1t}$ and $Z_{2,it-1}$, mitigating bias in the estimation of the skill production functions. These instruments are assumed to affect children's skill development only indirectly – through their influence on one of the endogenous variables – without entering the human capital production function directly. I discuss the identification strategy, the choice of instruments, and their limitations in detail in the following 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 lends support to the assumption that this shock is 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 variation in the female employment shock should not be directly related to child development, but only affect it indirectly through changes in parental investment (Carneiro et al., 2013). The female employment shock is a relevant shifter because a female employment shock could affect the household's labor supply, in turn 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, $Z_{2,it-1}$, proxied by the number of rooms in the house at the age-3 wave.[21] To strengthen the credibility of the exogenous shifter and make sure that its variation is exogenous, I condition on the same large set of controls, $\mathbf{X}_{it}$. Although the MCS has very rich information to condition on, it is important to discuss plausible concerns about violating the exclusion restriction. For example, the number of rooms in a household might directly affect children's ability to focus or regulate behavior, beyond its effect on sibling bond. For example, to address this, I incorporate

[21] The idea behind using an adjustment cost to housing 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 exogenous shifter tries to mimic this by considering similar households, who live in similar homes, where sometimes siblings exogenously do not share the same bedroom.

controls for both siblings' socio-emotional skills, which proxy for otherwise unobserved traits such as attentional control and social aptitude, accounting for alternative channels. In Section 3.1, I discuss this further and present a validity check.

To understand the relevance of this exogenous shifter, it is important to consider the questions used to measure the 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's toes and invading each other's privacy (Appendix Table A13). On the other hand, if both siblings share the same bedroom, they would have a harder time finding space for regaining control of emotions during a discussion, ending up exacerbating the conflicts (Leventhal and Newman, 2010; Solari and Mare, 2012). 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. I further discuss the relevance as well as the monotonicity of the exogenous shifters in Section 3.1 by re-estimating the investment functions for different sub-samples.

2.6 Estimation

The factor model, the production function and the investment functions 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 et al., 2021).

The one-step estimation strategy was developed in the psychometric literature by Muthén (1983, 1984) and has also been adopted by Attanasio, de Paula, and Toppeta (2025). This approach relies on the generalized method of moments (GMM), which makes it more computationally tractable to estimate measurement systems with *categorical* items.[22]

I briefly outline here the estimation methodology and refer to Appendix A.9 for additional detail. This strategy estimates the parameters of the measurement system, such as factor loadings and latent regression coefficients using a Generalized Method of Moments (GMM) approach. The moments of the factor model are constructed from the (polychoric) correlations among the items m_{ijt}, while the remaining moments are derived from the outcome equations. Following the language in Muthén (1984), the "reduced form" parameters comprise thresholds, slope and covariance parameters that are functions of the "structural" parameters in the factor model and regression of interest. Letting ρ denote the reduced form parameters (as in Muthén (1984)) and β denote the structural parameters, we thus have that $\rho = g(\beta)$ for a known function $g(\cdot)$.

Consider, for simplicity, the case where $I \in \mathbb{R}$ denotes the sibling bond and parental investment and $\mathbf{X} \in \mathbb{R}$. Omitting i subscripts, we can represent the skill formation technology and investment function as:

[22] Other estimation methods used in the literature include a non-linear filtering method (Cunha et al., 2010), a three-step simulation algorithm (Attanasio et al., 2020), the generalized method of moments (Agostinelli and Wiswall, 2025), and a bias-correction method for two-step estimation (Croon, 2002; Heckman et al., 2013).

$$
\underbrace{\begin{bmatrix} \theta \\ I \end{bmatrix}}_{:=\eta} = \underbrace{\begin{bmatrix} \phi \\ \pi_0 \end{bmatrix}}_{:=\alpha} + \underbrace{\begin{bmatrix} 0 & \gamma \\ 0 & 0 \end{bmatrix}}_{:=B} \begin{bmatrix} \theta \\ I \end{bmatrix} + \underbrace{\begin{bmatrix} \omega & 0 \\ \pi_X & \pi_Z \end{bmatrix}}_{:=\Gamma} \begin{bmatrix} \mathbf{X} \\ \mathbf{Z} \end{bmatrix} + \underbrace{\begin{bmatrix} \epsilon \\ \nu \end{bmatrix}}_{:=\xi},
$$

where the first row expresses the production function and the second row expresses the investment function. This corresponds to equation (3) in Muthén (1984). Following his notation for comparison, one then obtains that:

$$
\eta = (I - B)^{-1}\alpha + (I - B)^{-1}\Gamma\mathbf{X} + (I - B)^{-1}\xi.
$$

Using our equation (3) we then get that:

$$
m_j^* = \nu_j + \lambda_j^\top \eta + u_j
$$

Consequently, one can write:

$$
m_j^* = \nu_j + \lambda_j^\top (I - B)^{-1}\alpha + \lambda_j^\top (I - B)^{-1}\Gamma\mathbf{X} + \lambda_j^\top (I - B)^{-1}\xi + u_j
$$

Given the above, and under the assumption that the composite error term $\lambda_j^\top (I - B)^{-1}\xi + u_j$ is normally distributed, the latent variables m_j^* follow a multivariate normal distribution conditional on the covariates $\mathbf{X}$. In this context, $\hat{\rho}$ contains the estimated item thresholds, polychoric correlations of the questionnaire items, and any coefficients from the regression of m_{jc}^* on $\mathbf{X}$. These in turn will be functions of the parameters β in the measurement system, skill formation technology and investment function as highlighted above.

Once the estimates $\hat{\rho}$ are obtained, the procedure fits the structural parameters using a minimum distance estimator based on the following objective function:

$$
F_W(\beta) = (g(\beta) - \hat{\rho})^\top \mathbf{W}^{-1}(g(\beta) - \hat{\rho}), \tag{7}
$$

where $\mathbf{W}$ is a weight matrix and the minimization is performed with respect to β. Muthén (1978) recommends using a consistent estimator of the asymptotic covariance matrix of $\hat{\rho}$ as the weight matrix $\mathbf{W}$. The resulting estimator for β is known in the psychometrics literature as the Weighted Least Squares (WLS) estimator. This analysis employs the Diagonally Weighted Least Squares (DWLS) estimator, which uses only the diagonal elements of $\mathbf{W}$, offering computational advantages and improved performance in small samples (Muthén, 1997).

3 Structural estimates

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 as well as counterfactual simulations of hypothetical interventions. The younger sibling's development (i.e., cohort member) 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.

3.1 Investment function estimates

The estimates of the investment functions are presented in Table 2, 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, understanding how to intervene to break its intergenerational transmission.

Table 2: 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 1. 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 based on the GMM asymptotic variance formula in parentheses (*** p<0.01, ** p<0.05, * p<0.1).

First, Column 1 presents the estimates of the determinants of the sibling bond. The younger and older siblings' externalizing skills, not surprisingly, are important determinants of the sibling bond. Children with a higher ability to engage in interpersonal activities at time $(t-1)$ are more likely to enjoy a stronger bond at time t. Turning attention to the exogenous shifter, the number of rooms at $(t-1)$ is positively and significantly associated with the sibling bond, as shown by the F-statistic and p-values (Column 1 of Table 2). 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 their 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 (Leventhal and Newman, 2010; Solari and Mare, 2012).

I acknowledge the limitations of using the number of rooms as an exogenous shifter for sibling bond. While this approach follows previous literature (Cunha, Heckman, and Schennach, 2010; Attanasio, Cattan, Fitzsimons, Meghir, and Rubio-Codina, 2020; Attanasio, Meghir, and Nix, 2020), I attempt to support its validity through three pieces of evidence, leveraging the rich background information available in the MCS to condition on detailed family and household characteristics. First, the MCS data enables me to consider similar households with similar family compositions, who live in similar homes, where siblings sometimes may share a bedroom due to external circumstances, and other times may not. Second, the exogenous shifter should then affect child development only through the sibling bond. Table 2 supports this: the adjustment cost to housing affects the child's human capital only through the sibling bond (Column 1), but not through parental investment (Column 2).[23] Third, Appendix Table A14 presents a validity check of the exclusion restriction, suggesting that the shifter is uncorrelated with pre-determined characteristics when controlling for the rich set of variables discussed above. However, it is important to note that convincingly testing the exogeneity condition remains challenging.

Second, Column 2 presents the estimates of the determinants of parental investment. The exogenous shifter is the female local employment rate in the local authority where the household lives (Carneiro et al., 2013). The female local employment is a relevant shifter as reported by the F-statistics and p-values in Table 2. The positive association between the local female employment rate and parental investment suggests that, despite potential time constraints due to work commitments, the increased resources from employment allow for a higher level of parental investment in terms of quality interactions with the children (Leibowitz, 1974; Guryan et al., 2008).

The justification for using the female local employment rate in the local authority as an exogenous shifter lies in its variation affecting the child's human capital only through parental investment. First, in support of this, the female local employment appears to affect child development only through parental investment (Column 2 of Table 2), but not through the sibling bond (Column 1). Second, the extensive set of controls includes factors, such as local employment in the local authority where the family lives, which can account for additional influences on the outcomes of interest. By incorporating them, I can more accurately examine the specific effects of the variables under investigation, while mitigating the potential confounding effects of other factors. Third, Appendix Table A14 shows balance across pre-determined characteristics for the exogenous shifters when the rich set of controls is included.

Before turning to the production function estimates, it is important to discuss the monotonicity of the exogenous shifters. Appendix Tables A15-A18 reproduce Table 2 for different sub-samples defined by: younger sibling's gender, older sibling's gender, siblings' gender composition and siblings' age gap. Appendix Tables A15-A18 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

[23] Another exogenous shifter 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 3.2, I present a robustness check, where I instrument family size with the siblings' gender composition and provide suggestive evidence that the estimates are robust.

similar magnitude across subgroups, providing support for their monotonicity.

3.2 Production function estimates

This section discusses the estimates of the joint technology of skill formation for the younger and older siblings when treating investments as endogenous (Table 3). Outputs are externalizing, internalizing and cognitive skills. Studying these different dimensions of human capital provides insights into the complexity of the development process and the interplay between each skill dimension. Columns 1-4 of Table 3 present the estimates for the externalizing skill, Columns 5-8 for the internalizing skill, and Columns 9-10 for the cognitive skill. Even Columns present the estimates, when considering siblings and allowing the sibling bond to be productive, while 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, 2025). Appendix Table A19 reports the estimates of the joint technology when investments are treated as exogenous.

Table 3: 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 1. 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 based on the GMM asymptotic variance formula in parentheses (*** p<0.01, ** p<0.05, * p<0.1).

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 et al., 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).[24]

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 (2025) 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.[25] For example, 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 (Altonji et al., 2017). Unfortunately, I cannot control for the endogeneity of such spillover (Manski, 1993). Finding another exogenous shifter 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 psychology as a first approximation (Buhrmester et al., 1992; Rodgers and Rowe, 1988). This finding 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, a comparison between the Odd and Even Columns in Table 3 yields three key takeaways.[26] First, the sibling bond contributes to the formation of skills, even after considering parent-child interactions. Second, the comparison of the estimates in the Even and Odd Columns suggests that some parent-child interactions are mediated through sibling interactions, which are more likely to occur when siblings are more connected - that is, when they share a strong sibling bond (Dunifon et al., 2017). Third, a strong sibling bond benefits both the younger and older siblings' development. For example, a 10% increase in the sibling bond at time t translates into a 4.06% and 3.97% increase respectively in the younger and older siblings' externalizing skill at time t (Columns 2 and 4). This result complements the literature on the trade-off between the quantity and quality of children (Becker and Lewis, 1973; Willis, 1973; Becker and Tomes, 1976), suggesting that actions aimed at encouraging pro-social behavior and mediating siblings' conflicts fruitfully (rather than only reinforcing or compensating siblings' inequality) could foster both siblings' skills.

Finally, Appendix Figure A5 illustrates graphically the quantitative importance of the sibling

[24]It would be interesting to consider additional lags of development as done in Attanasio et al. (2020) and Attanasio et al. (2020) who 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.

[25]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 vice versa (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. This is also found in Appendix Table A20, which reproduces the odd Columns in Table 3, when restricting only the sibling bond to have zero productivity, and in Appendix Table A19 when treating investment as exogenous.

[26]Similar evidence is also found in the estimates of the joint technology when investments are treated as exogenous (Appendix Table A19).

bond and parental investment, presenting their marginal productivity by age-3 skill levels.[27] This figure is useful to reiterate two points. First, there is a complementarity between the age-5 input and the age-3 skill for each skill dimension, reiterating 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 2.2) and would benefit from a higher productivity of the sibling bond (Appendix Figure A5). 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.

Robustness checks: Table 3 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 by MCS. 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 their determination. Appendices A.15 and A.16 present evidence that the estimates of the sibling bond productivity in Table 3 are robust to using the average sibling bond in families with at least two older siblings and to family size. First, Appendix Table A21 reproduces Table 3 by using the average of the sibling bonds from each sibling combination 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 A22 reproduces the estimates for Table 3, instrumenting family size with the siblings' gender composition, and provides suggestive evidence that the estimates are robust. It is important to highlight that the exogenous shifter for family size (i.e., siblings' gender composition) is weak; estimates must therefore be taken with caution.

The estimates presented in Table 3 assumes a Cobb-Douglas specification. Appendix A.17 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 A23. 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).

Finally, Appendix A.18 exploits the data on the younger sibling's socio-emotional development reported by the teachers – instead of the parents – to address any concerns about

[27]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.

misreporting bias regarding the estimates of the socio-emotional skill production functions.[28] In Appendix Table A24, I estimate the production function – using the items from the teacher's socio-emotional questionnaire – and find similar structural estimates. This analysis enables me to measure the latent externalizing skill at age 5, which differs only by the nature of the respondent as similar survey questions are used across parents and teachers.[29]

Heterogeneity: Appendix A.19 explores two possible sources of heterogeneity in the structural estimates of the siblings' skill formation technology: the siblings' gender and age (Appendix Tables A25-A28). Appendix Table A27 provides some suggestive evidence that the sibling bond could be more productive for same-sex than mixed-sex siblings. On the other hand, Appendix Table A28 suggests that the effect of sibling bond varies by the siblings' age gap. Closer age gaps could encourage shared activities and mutual learning, enhancing cognitive development; while larger age gaps could allow the older sibling to act as a role model, promoting socio-emotional development. Unfortunately, the structural estimates become imprecise as the exogenous shifters become weak when the sample is split and investments are allowed to be endogenous (Appendix Tables A15-A18).

Validating the structural estimates: 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 the younger sibling's skill formation technology at age 5 in Table 3 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 A6 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 next.

Using the structural estimates: Counterfactual simulations of hypothetical interventions are useful to understand how policies, aimed at stimulating parental investment and the sibling bond, would affect skill formation. So far, policies have mostly focused on stimulating parent-child interactions while not considering siblings (e.g., Evans et al. (2021)). Interventions to foster the sibling bond could draw from behavior management and mediation by directing siblings' pro-social behavior using reinforcement practices, mediating conflicts and facilitating

[28] The estimates of the technology of cognitive skill do not present this concern as the MCS interviewers collect the responses to the cognitive tests. Del Bono et al. (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.

[29] Appendix A.18 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.

communication (Leijten et al., 2021).[30] Alternative interventions could also consider housing policies. For example, crowded housing - linked to room sharing - may hinder positive sibling interactions by reducing privacy, increasing conflict, and limiting the quality of the sibling bond. Improving access to family-sized housing via housing vouchers or subsidized accommodation could potentially affect child development via stronger sibling bonds. As highlighted in the theoretical model in Appendix A.4, such interventions should aim to target the family as a whole, targeting parents as well as siblings.

Appendix Figure A7 presents some counterfactual simulations which offer some insights on how such interventions, aimed at stimulating either the sibling bond or parental investment, would affect skills. I explore the effect of a persistent shock to only the sibling bond and, separately, to only parental investment over simulated periods 1 to 5 (ages 5, 7, 11, 14 and 17). For each simulation, the increase is by one standard deviation, while fixing all the other inputs at their median values in the sample and assuming that the production function has the same parameters in each simulated period. Holding the parameters of the production function fixed at different developmental stages is a strong assumption, but is reasonably supported in this instance by the validation exercise presented above (see also Appendix Figure A6). The counterfactual simulations indicate that the most substantial effects are observed in socio-emotional skills, with interventions targeting either input – sibling bond or parental investment – producing comparable impacts.

4 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. Families can use their knowledge of the technology of skill formation to break the intergenerational transmission of disadvantage by engaging in actions to foster children's human capital. Similarly, policy makers can use this knowledge to design effective interventions to boost human capital formation.

The literature has estimated the technology of skill formation assuming a *single* child and has established that parent-child interactions and parental skills are key determinants in the human capital formation process during childhood. On the other hand, the role of siblings and their policy implications 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

[30] Leijten et al. (2021) review randomized control trials to improve sibling interactions and identify only 8 studies that test such interventions. These studies have estimated the impact of the interventions only on the sibling bond with a small sample, without trying to understand their effect on child development (Leijten et al., 2021). Some examples are Siddiqui and Ross (2004), Kramer (2004) and Kennedy and Kramer (2008).

productive. The data from the Millennium Cohort Study in the United Kingdom enables me to introduce a novel variable, "sibling bond", which captures how well siblings get along by measuring the frequency of the quality of sibling interactions, such as experiencing enjoyable time together.

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. These interventions could, for example, draw from behavior management and mediation to foster the sibling bond and in turn boost children's human capital. Housing policies could also be considered, as crowded living conditions – such as room sharing – may negatively affect sibling relationships by limiting privacy, increasing conflict, and weakening the quality of their bond. My counterfactual simulations highlight the potential benefits of such interventions, emphasizing the importance of focusing on both parent-child and sibling interactions.

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A Appendices to "Skill Formation with Siblings"

A.1 Descriptive statistics

Table A1: 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
Indicator variable for step sibling	0.004	0.07	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.

A.2 Strengths and Difficulties Questionnaire (SDQ)

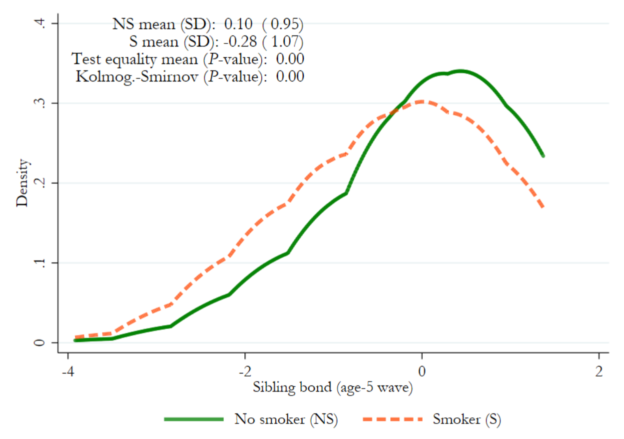
Table A2: Strengths and Difficulties Questionnaire (SDQ)

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 behaviors 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 behavior are 1, 4, 9, 17 and 20.

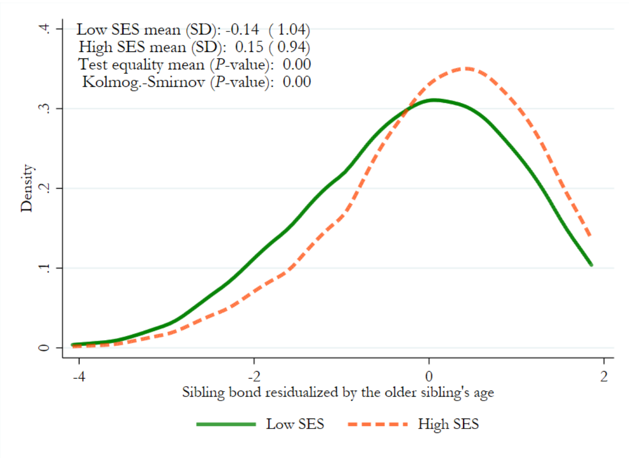
A.3 Motivating evidence: additional results

Figure A1: Socio-economic gradient (mother was smoking during pregnancy) in the sibling bond



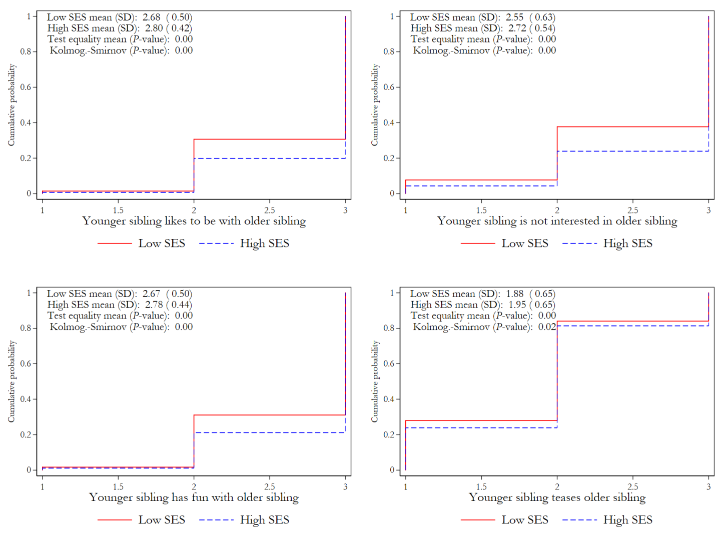
Note. The Figure presents the socioeconomic gradient in the quality of the sibling bond at the age-5 wave. The socioeconomic status is a dummy equal to 1 if the mother was smoking during pregnancy. The sibling bond index is constructed by summing the values from the following 4 questions about how often [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 behaviors 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 deviations (SD) 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 A2: Socio-economic gradient (mother's education) in the sibling bond residualized by the siblings' age gap



Note. The Figure presents the socioeconomic gradient in the quality of the sibling bond residualized by the siblings' age gap 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 behaviors 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 deviations (SD) 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 A3: Cumulative distribution function: socio-economic gradient (mother's education) for each item used to measure sibling bond



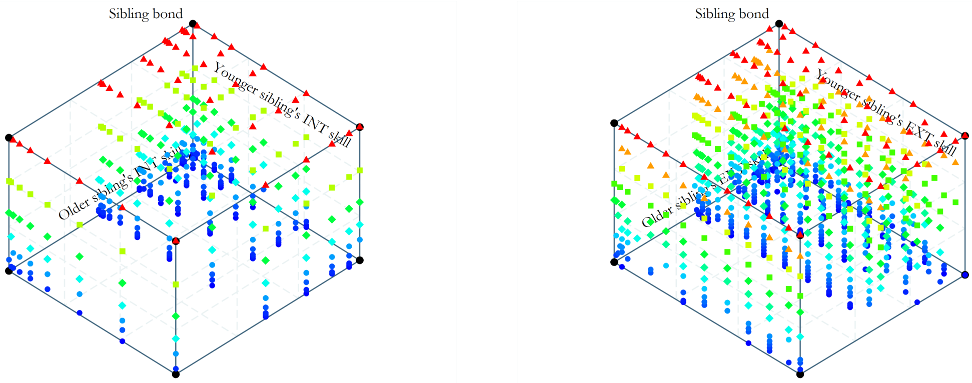
Note. The Figure presents the socioeconomic gradient in each item used to measure the quality of sibling interactions at the age-5 wave. The socioeconomic status is the mother's education at the age-5 wave (dummy for whether the mother continued schooling past the minimum leaving age, based on her date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

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

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

Note. Table shows the correlation between the sibling bond and parental investment, how calm the home atmosphere is, close relationship between mother and child, whether the household is dual or single head. The 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 behaviors 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, (vii) How often play outdoor games with the child, (viii) How often family does indoor activities together, (ix) How often child sees grandparents, (x) How often child sees other relatives, (xi) How often child spends time with friends outside school, (xii) How often ignores child when naughty, (xiii) How often smacks child when naughty, (xiv) How often shouts at child when naughty, (xv) How often sends child to bedroom/naughty chair, (xvi) How often takes away treats from child when naughty, (xvii) How often tells child off when naughty, (xviii) How often bribes child when naughty, (xix) How often tries to reason with child when naughty, (xx) How often makes sure child obeys instruction/request, (xxi) 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.

Figure A4: Sibling bond and siblings' socio-emotional skills



Note. The figures show the 3D-plot of the sibling bonds and siblings' skills. It presents descriptive evidence 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. 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 behaviors indicating worse interactions in reverse (i.e., not much interested in older sibling and teases or needles older sibling).

Table A4: Age-5 sibling bond and younger sibling's pooled development during young adulthood (age 5-17)

Outcome	Externalizing		Internalizing		Cognitive	
	(1)	(2)	(3)	(4)	(5)	(6)
Sibling bond (age 5)	0.310***	0.109***	0.259***	0.076***	0.175***	0.046*
	(0.024)	(0.021)	(0.025)	(0.023)	(0.028)	(0.026)
Observations	2505	2505	2505	2505	2191	2191
R^2	0.093	0.434	0.067	0.319	0.030	0.299
Younger & older sib's skills (age-3 wave)	No	Yes	No	Yes	No	Yes
Parental investment (age-5 wave)	No	Yes	No	Yes	No	Yes
Other controls	No	Yes	No	Yes	No	Yes

Note. The table presents the relationship between the age-5 sibling bond and the younger sibling's pooled development during young adulthood (age 5-17). Variables are standaridized to have mean 0 and standard deviation 1. 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 behaviors 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, (vii) How often play outdoor games with the child, (viii) How often family does indoor activities together, (ix) How often child sees grandparents, (x) How often child sees other relatives, (xi) How often child spends time with friends outside school, (xii) How often ignores child when naughty, (xiii) How often smacks child when naughty, (xiv) How often shouts at child when naughty, (xv) How often sends child to bedroom/naughty chair, (xvi) How often takes away treats from child when naughty, (xvii) How often tells child off when naughty, (xviii) How often bribes child when naughty, (xix) How often tries to reason with child when naughty, (xx) How often makes sure child obeys instruction/request, (xxi) How close the bond between mother and child is. 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 A5: 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)	0.322***	0.138***	0.142***	0.059	0.308***	0.142***	0.143***	0.094***
	(0.040)	(0.040)	(0.040)	(0.039)	(0.036)	(0.037)	(0.037)	(0.036)
Observations	3031	3031	3031	3031	3041	3041	3041	3041
R^2	0.027	0.137	0.138	0.259	0.029	0.141	0.141	0.271
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)				Smoke cigarettes (age 17)			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Sibling bond (age 5)	0.069***	0.032***	0.034***	0.021**	-0.029***	-0.028**	-0.030***	-0.023**
	(0.011)	(0.011)	(0.011)	(0.011)	(0.010)	(0.011)	(0.011)	(0.011)
Observations	3250	3250	3250	3250	3569	3569	3569	3569
R^2	0.017	0.092	0.095	0.176	0.003	0.009	0.012	0.025
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 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 behaviors indicating worse interactions in reverse (i.e., not much interested in older sibling and teases or needles older sibling). The sibling bond index is standardized to have mean 0 and standard deviation 1. 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, (vii) How often play outdoor games with the child, (viii) How often family does indoor activities together, (ix) How often child sees grandparents, (x) How often child sees other relatives, (xi) How often child spends time with friends outside school, (xii) How often ignores child when naughty, (xiii) How often smacks child when naughty, (xiv) How often shouts at child when naughty, (xv) How often sends child to bedroom/naughty chair, (xvi) How often takes away treats from child when naughty, (xvii) How often tells child off when naughty, (xviii) How often bribes child when naughty, (xix) How often tries to reason with child when naughty, (xx) How often makes sure child obeys instruction/request, (xxi) How close the bond between mother and child is. 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. 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. Robust standard errors in parentheses (*** p<0.01, ** p<0.05, * p<0.1).

Table A6: Age-5 sibling bond and younger sibling's age-17 outcomes (full sample)

Panel A:

	Grade GCSE Math		Grade GCSE English	
	(1)	(2)	(3)	(4)
Sibling bond (worst interaction for single child)	0.202***		0.113**	
	(0.054)		(0.049)	
Sibling bond (best interaction for single child)		0.057		0.106***
		(0.040)		(0.037)
Observations	3980	3980	3994	3994
R^2	0.244	0.241	0.260	0.261
Younger & older sib's skills (age-3 wave)	✓	✓	✓	✓
Parental investment (age-5 wave)	✓	✓	✓	✓
Other controls	✓	✓	✓	✓

Panel B:

	Study for A-level qualification (age 17)		Smoke cigarettes (age 17)	
	(1)	(2)	(3)	(4)
Sibling bond (worst interaction for single child)	0.034**		-0.033**	
	(0.015)		(0.015)	
Sibling bond (best interaction for single child)		0.022**		-0.023**
		(0.011)		(0.011)
Observations	4281	4281	4699	4699
R^2	0.172	0.172	0.022	0.022
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 behaviors indicating worse interactions in reverse (i.e., not much interested in older sibling and teases or needles older sibling). The sibling bond index is standardized to have mean 0 and standard deviation 1. 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, (vii) How often play outdoor games with the child, (viii) How often family does indoor activities together, (ix) How often child sees grandparents, (x) How often child sees other relatives, (xi) How often child spends time with friends outside school, (xii) How often ignores child when naughty, (xiii) How often smacks child when naughty, (xiv) How often shouts at child when naughty, (xv) How often sends child to bedroom/naughty chair, (xvi) How often takes away treats from child when naughty, (xvii) How often tells child off when naughty, (xviii) How often bribes child when naughty, (xix) How often tries to reason with child when naughty, (xx) How often makes sure child obeys instruction/request, (xxi) How close the bond between mother and child is. 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. 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 A7: Age-5 sibling bond and younger sibling's age-14 actions

Outcome	Talk to sibling if worried		Talk to parents if worried		Argue with parents	
	(1)	(2)	(3)	(4)	(5)	
Sibling bond (age 5)	0.025***	0.019**	-0.003	-0.006	-0.107***	-0.132***
	(0.008)	(0.009)	(0.010)	(0.010)	(0.035)	(0.037)
Observations	4006	4006	4006	4006	3733	3733
R^2	0.003	0.023	0.000	0.009	0.004	0.041
Younger & older sib's skills (age-3 wave)	No	Yes	No	Yes	No	Yes
Parental investment (age-5 wave)	No	Yes	No	Yes	No	Yes
Other controls	No	Yes	No	Yes	No	Yes

Note. The table presents the relationship between the age-5 sibling bond and the younger sibling's actions 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 behaviors indicating worse interactions in reverse (i.e., not much interested in older sibling and teases or needles older sibling). The sibling bond index is standardized to have mean 0 and standard deviation 1. 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, (vii) How often play outdoor games with the child, (viii) How often family does indoor activities together, (ix) How often child sees grandparents, (x) How often child sees other relatives, (xi) How often child spends time with friends outside school, (xii) How often ignores child when naughty, (xiii) How often smacks child when naughty, (xiv) How often shouts at child when naughty, (xv) How often sends child to bedroom/naughty chair, (xvi) How often takes away treats from child when naughty, (xvii) How often tells child off when naughty, (xviii) How often bribes child when naughty, (xix) How often tries to reason with child when naughty, (xx) How often makes sure child obeys instruction/request, (xxi) How close the bond between mother and child is. 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).

A.4 Theoretical framework

This appendix 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 2.5.

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 allow for sibling interactions (i.e., building a bond) as well as parent-child interactions. 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 both the younger (Y) and older (O) siblings (c) in family i at time t. I formulate this problem as static and omit t from the model below to highlight the trade-off during this developmental stage. The model can be easily extended 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.

Parents optimize the expected utility function of consumption and siblings' human capital, while facing a resource constraint (equations 8 and 9), the sibling bond (equation 10) and joint technology of skill formation (equations 11 and 12). 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 in the joint technology of skill formation.

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

Subject to

$$L_i = 1 - PI_i \tag{8}$$

$$y_i + w_i L_i = C_i \tag{9}$$

$$SB_i = h(A_Y, A_O, e_i) \tag{10}$$

$$\theta_{Y,i,1} = f(\theta_{Y,i,0}, \theta_{O,i,0}, PI_i, SB_i, \mathbf{X}_i, v_{Y,i}) \tag{11}$$

$$\theta_{O,i,1} = g(\theta_{Y,i,0}, \theta_{O,i,0}, PI_i, SB_i, \mathbf{X}_i, u_{O,i}) \tag{12}$$

The parents of siblings Y and O can allocate their available time to work, L_i, as well as parental investment, PI_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 as well as joint activities. The model can be extended with sibling-specific investment to consider the productivity-equity trade-off within the family (e.g., Behrman et al. (1982) and Behrman (1988)). In the current framework, I focus on a composite measure of parental investment for ease of exposition and data availability, but the framework could easily accommodate these different dimensions of investment. w_i and y_i in the budget constraint are respectively the price and the non-work income (equation 9)

The sibling bond SB_i is a function of siblings' actions, A_Y and A_O, and an idiosyncratic shock to their actions, e_i. The siblings' actions, A_Y and A_O, over the proposed unstructured activity aim to maximize the siblings' pay-off, $EU^c(A_Y, A_O, \xi_Y) = U(PI_i, A_Y, A_O, \xi_c)$, in a non-cooperative game, where they best respond to each other. These interactions can for example be modeled as a repeated dynamic game, where a sibling takes the first action, acting as a leader, and then the other sibling follows, as this would allow for role modeling (see for example Bell et al. (2019)).[2] Finally, e_i implies a non-deterministic link from parents' actions to the sibling bond 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:

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

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

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, $\epsilon_{PI,i}$ and $\epsilon_{SB,i}$. Importantly, because both parental investment and sibling bond are jointly determined within the family's decision-making process, their policy functions are inherently interdependent. This potential simultaneity implies that observed measures of PI_i^* and SB_i^* are endogenous. To account for this, I model them as jointly determined endogenous variables within a structural system of equations and discuss in detail the identification of their respective impacts through the use of exclusion restrictions and appropriate instruments.

This stylized model of parental investment guides the choice of exogenous shifters that could satisfy the exogeneity condition, providing the *sufficient* conditions for the exogenous shifters to be valid and consistent with economic theory. It is possible to infer from the model that the exogenous shifters 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 correspond to variables related to wages and non-labor income. These conditions are only sufficient as the model cannot capture every possible response to unobserved shocks. Section 2.5 discusses in detail the *necessary* conditions for the exogenous shifters to be valid and affect the child's human capital only through parental investment and the sibling bond respectively.

[2] A similar extension to a dynamic Stackelberg game is considered in Del Boca et al. (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.

A.5 Exploratory factor analysis

Table A8: 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 behaviors indicating lower skills, we recode all of them in reverse, i.e. 'Certainly applies' = 0, 'Somewhat applies' = 1, 'Does not apply' = 2.

Table A9: 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/request	**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 behaviors indicating worse interactions in reverse (i.e., not much interested in older sibling and teases or needles older sibling).

Table A10: 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/request	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 behaviors indicating worse interactions in reverse (i.e., not much interested in older sibling and teases or needles older sibling).

Table A11: 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).

A.6 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 their joint skill formation technology.

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.[3] 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.

[3]Versions of this test have now been used in economics by Attanasio et al. (2020), Attanasio et al. (2025), and Heckman and Zhou (2022).

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 the 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). 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 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 et al., 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).[4]

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 A12 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 worsens when I also restrict the intercepts to be the same, but still provides a 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

[4]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 A12: Comparison of models' fit for measurement invariance

		Absolute fit				
	N of Parameters	χ^2	RMSEA	RMSR	CFI	TLI
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	0.002	0.005	-0.008	-0.005
Threshold, loading, and intercept invariance	0.000	0.007	0.009	-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.

younger and older siblings' the joint technology of skills.

A.7 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.

$$m^*_{ijt} = \alpha_{jt} + \lambda^{\top}_{jt} ln\theta_{it} + \varepsilon_{ijt} \tag{13}$$

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 et al. (2010), Attanasio et al. (2020) and Attanasio et al. (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.

A.8 Correlational evidence

Table A13: Relationship between number of rooms (t-1) and teasing sibling

Outcome	Not teasing sibling	
Number of rooms (t-1)	0.068***	0.042*
	(0.022)	(0.025)
Local female employment rate		-0.054
		(0.062)
Observations	2558	2558
Other controls	No	Yes

Note. The Table presents the relationship between the exogenous shifters and teasing siblings (the item capturing siblings conflict in the sibling bond variable). 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 based on the GMM asymptotic variance formula in parentheses (*** p<0.01, ** p<0.05, * p<0.1).

A.9 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}.

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

Given that m^*_{ijt} is unobserved, a threshold model is added to equation 14 to accommodate the categorical nature of the observed response, m_{ijt} such that:

$$m_{ijt} = \begin{cases} 0 & \text{if } m^*_{ijt} < \tau_{1,jt} \\ 1 & \text{if } m^*_{ijt} \in \left[\tau_{1,jt}, \tau_{2,jt}\right] \\ 2 & \text{if } m^*_{ijt} > \tau_{2,jt} \end{cases} \tag{15}$$

Where τ_j is the threshold for showing a certain behavior 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:

$$
\begin{aligned}
Pr\left[m_{ijt}=0|ln\theta_{it}\right] =& Pr\left[m^*_{ijt}<\tau_{1,jt}|ln\theta_{it}\right]\\
=& Pr\left[\varepsilon_{ijt}<\tau_{1,jt}-\alpha_{jt}-\lambda_{jt}ln\theta_{it}|ln\theta_{it}\right]\\
=& \Phi\left(\frac{\tau_{1,jt}-\alpha_{jt}-\lambda_{jt}ln\theta_{it}}{\sigma_{\varepsilon,jt}}|ln\theta_{it}\right) \qquad (16)\\
Pr\left[m_{ijt}=1|ln\theta_{it}\right] =& \Phi\left(\frac{\tau_{2,jt}-\alpha_{jt}-\lambda_{jt}ln\theta_{it}}{\sigma_{\varepsilon,jt}}|ln\theta_{it}\right)\\
&-\Phi\left(\frac{\tau_{1,jt}-\alpha_{jt}-\lambda_{jt}ln\theta_{it}}{\sigma_{\varepsilon,jt}}|ln\theta_{it}\right) \qquad (17)\\
Pr\left[m_{ijt}=2|ln\theta_{it}\right] =& Pr\left[m^*_{ijt}>\tau_{2,jt}|ln\theta_{it}\right]\\
=& Pr\left[\varepsilon_{ijt}>\tau_{2,jt}-\alpha_{jt}-\lambda_{jt}ln\theta_{it}|ln\theta_{it}\right]\\
=& 1-\Phi\left(\frac{\tau_{2,jt}-\alpha_{jt}-\lambda_{jt}ln\theta_{it}}{\sigma_{\varepsilon,jt}}|ln\theta_{it}\right) \qquad (18)
\end{aligned}
$$

$\sigma_{\varepsilon,jt}$ is set to one and all intercepts are set to zero because the intercepts and thresholds (joinly) cannot be identified as evident from 16, 17, and 18.

$$
\begin{aligned}
Pr\left[m_{ijt}=0|ln\theta_{it}\right] =& \Phi\left(\tau_{1,jt}-\lambda_{jt}ln\theta_{it}|ln\theta_{it}\right) \qquad (19)\\
Pr\left[m_{ijt}=1|ln\theta_{it}\right] =& \Phi\left(\tau_{2,jt}-\lambda_{jt}ln\theta_{it}|ln\theta_{it}\right)-\Phi\left(\tau_{1,jt}-\lambda_{jt}ln\theta_{it}|ln\theta_{it}\right) \qquad (20)\\
Pr\left[m_{ijt}=2|ln\theta_{it}\right] =& 1-\Phi\left(\tau_{2,jt}-\lambda_{jt}ln\theta_{it}|ln\theta_{it}\right) \qquad (21)
\end{aligned}
$$

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:

$$
\begin{aligned}
\mathcal{L}_{i,t} &= E_{ln\theta_{it}}\left[\prod_{j=1}^{J}\left\{f\left(m_{ijt}|ln\theta_{it}\right)\right\}\right] \\
&= E_{ln\theta_{it}}\left[\prod_{j=1}^{J}\left\{Pr\left[m_{ijt}=0|ln\theta_{it}\right]^{1[m_{ijt}=0]}\times Pr\left[m_{ijt}=1|ln\theta_{it}\right]^{1[m_{ijt}=1]}\right.\right. \\
&\qquad\qquad \left.\left.\times Pr\left[m_{ijt}=2|ln\theta_{it}\right]^{1[m_{ijt}=2]}\right\}\right] \\
&= E_{ln\theta_{it}}\left[\prod_{j=1}^{J}\left\{\Phi\left(\tau_{1,jt}-\lambda_{jt}ln\theta_{it}|ln\theta_{it}\right)^{1[m_{ijt}=0]}\right.\right. \\
&\qquad \times\left(\Phi\left(\tau_{2,jt}-\lambda_{jt}ln\theta_{it}|ln\theta_{it}\right)-\Phi\left(\tau_{1,jt}-\lambda_{jt}ln\theta_{it}|ln\theta_{it}\right)\right)^{1[m_{ijt}=1]} \\
&\qquad \left.\left.\times\left(1-\Phi\left(\tau_{2,jt}-\lambda_{jt}ln\theta_{it}|ln\theta_{it}\right)\right)^{1[m_{ijt}=2]}\right\}\right]
\end{aligned}
\tag{22}
$$

If we assume that $ln\theta_{it} \sim \mathcal{N}\left(\mu_{\theta,t},\sigma_{\theta,t}\right)$, then 22 can be written as:

$$
\begin{aligned}
\mathcal{L}_{i,t} &= \int_{\infty}^{\infty}\left[\prod_{j=1}^{J}\left\{\Phi\left(\tau_{1,jt}-\lambda_{jt}ln\theta_{it}|ln\theta_{it}\right)^{1[m_{ijt}=0]}\right.\right. \\
&\qquad \times\left(\Phi\left(\tau_{2,jt}-\lambda_{jt}ln\theta_{it}|ln\theta_{it}\right)-\Phi\left(\tau_{1,jt}-\lambda_{jt}ln\theta_{it}|ln\theta_{it}\right)\right)^{1[m_{ijt}=1]} \\
&\times\left(1-\Phi\left(\tau_{2,jt}-\lambda_{jt}ln\theta_{it}|ln\theta_{it}\right)\right)^{1[m^{j}_{,t}=2]}\left.\left.\right\}\times\frac{exp\left(\frac{1}{2\sigma^2_{\theta,t}}(ln\theta_t-\mu_{\theta,t})^2\right)}{\sigma_{\theta,t}\sqrt{2\pi}}\right]dln\theta
\end{aligned}
\tag{23}
$$

After setting the scale and the location as illustrated in Section 2.4, 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 of the factor model are built based on the (polychoric) correlations between the items m_{ijt} and the other moments are obtained from the outcome equations. Following the language in Muthén (1984), the "reduced form" parameters comprise thresholds, slope and covariance parameters that are functions of the "structural" parameters in the factor model and regression of interest. Letting ρ denote the reduced form parameters (as in Muthén (1984)) and β denote the structural parameters, we thus have that $\rho = g(\beta)$ for a known function $g(\cdot)$.

Consider, for simplicity, the case where $I \in \mathbb{R}$ denotes the sibling bond and parental investment denoted and $\mathbf{X} \in \mathbb{R}$. Omitting i subscripts, we can represent the skill formation technology and investment function as:

$$\underbrace{\begin{bmatrix} \theta \\ I \end{bmatrix}}_{:=\eta} = \underbrace{\begin{bmatrix} \phi \\ \pi_0 \end{bmatrix}}_{:=\alpha} + \underbrace{\begin{bmatrix} 0 & \gamma \\ 0 & 0 \end{bmatrix}}_{:=B} \begin{bmatrix} \theta \\ I \end{bmatrix} + \underbrace{\begin{bmatrix} \omega & 0 \\ \pi_X & \pi_Z \end{bmatrix}}_{:=\Gamma} \begin{bmatrix} \mathbf{X} \\ \mathbf{Z} \end{bmatrix} + \underbrace{\begin{bmatrix} \epsilon \\ \nu \end{bmatrix}}_{:=\xi},$$

where the first row expresses the production function and the second row expresses the investment function. This corresponds to equation (3) in Muthén (1984). Following his notation for comparison, one then obtains that:

$$\eta = (I - B)^{-1}\alpha + (I - B)^{-1}\Gamma\mathbf{X} + (I - B)^{-1}\xi.$$

Using our equation (3) we then get that:

$$m_j^* = \nu_j + \lambda_j^\top \eta + u_j$$

Consequently, one can write:

$$m_j^* = \nu_j + \lambda_j^\top (I - B)^{-1}\alpha + \lambda_j^\top (I - B)^{-1}\Gamma\mathbf{X} + \lambda_j^\top (I - B)^{-1}\xi + u_j$$

Given the above, and under the assumption that the composite error term $\lambda_j^\top (I - B)^{-1}\xi + u_j$ is normally distributed, the latent variables m_j^* follow a multivariate normal distribution conditional on the covariates $\mathbf{X}$. In this context, $\hat{\rho}$ contains the estimated item thresholds, polychoric correlations of the questionnaire items, and any reduced-form coefficients from the regression of m_{jc}^* on $\mathbf{X}$. These in turn will be functions of the parameters β in the measurement system, skill formation technology and investment function as highlighted above.

Let $\hat{\rho}$ denote the estimates obtained in this initial stage. Once the estimates $\hat{\rho}$ are obtained, the procedure fits the structural parameters using a minimum distance estimator based on the following objective function:

$$F_W(\beta) = (g(\beta) - \hat{\rho})^\top \mathbf{W}^{-1} (g(\beta) - \hat{\rho}), \tag{24}$$

for a weight matrix $\mathbf{W}$, to be minimized with respect to B. Muthén (1978) suggests using a consistent estimator for the 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 (2) the identity matrix (Unweighted Least Squares, ULS). I adopt the DWLS weight matrix in the estimation.

A.10 Balance check

Table A14: Balance table: cohort member's pre-determined characteristics at birth

Outcome	Number of siblings		Mother's mental health		Mother employed before pregnancy		Public transport in area		Months lived in current address	
Number of rooms (t-1)	0.023***	0.004	-0.099***	-0.013	0.015**	-0.013	-0.045***	-0.020	-0.990	-0.690
	(0.008)	(0.007)	(0.024)	(0.024)	(0.007)	(0.008)	(0.016)	(0.018)	(0.731)	(0.587)
Local female employment rate	-0.006**	-0.004	-0.004	0.004	0.003	0.002	-0.010**	0.032**	-0.483**	-0.420
	(0.003)	(0.005)	(0.008)	(0.020)	(0.002)	(0.006)	(0.005)	(0.013)	(0.224)	(0.491)
Observations	2220	2220	2220	2220	2220	2220	2220	2220	2220	2220
Other controls	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes

Note. The Table presents the balance checks for the exogenous shifters on the cohort member's pre-determined characteristics at birth (age-0 wave). Odd columns do *not* include any controls, while even columns include other controls. 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 based on the GMM asymptotic variance formula in parentheses (*** p<0.01, ** p<0.05, * p<0.1).

A.11 Heterogeneity: investment functions

Table A15: 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. 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 based on the GMM asymptotic variance formula in parentheses (*** p<0.01, ** p<0.05, * p<0.1).

Table A16: 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. 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 based on the GMM asymptotic variance formula in parentheses (*** p<0.01, ** p<0.05, * p<0.1).

Table A17: 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. 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 based on the GMM asymptotic variance formula in parentheses (*** p<0.01, ** p<0.05, * p<0.1).

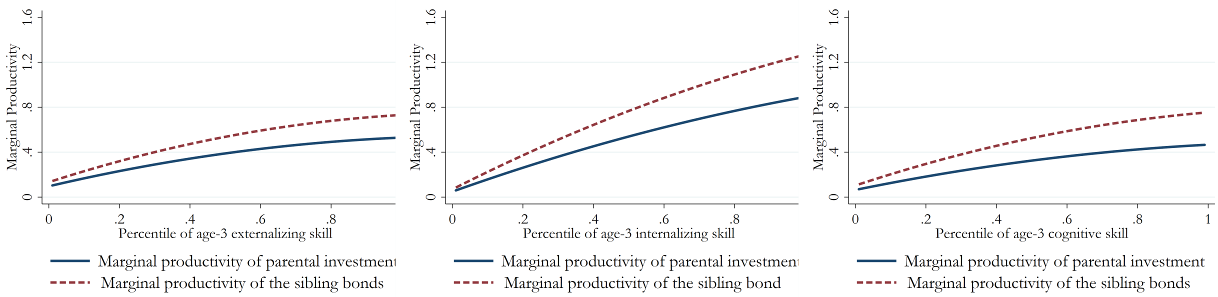
Table A18: Investment functions: Sibling bond & parental investment by the siblings' age gap

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. 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 based on the GMM asymptotic variance formula in parentheses (*** p<0.01, ** p<0.05, * p<0.1).

A.12 Marginal productivity

Figure A5: 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.

A.13 Joint technology of skill formation: exogenous investments

Table A19: Joint technology of skill formation: younger & older siblings - exogenous investments

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. This table presents the estimates of the joint technology when parental investment and sibling bond are treated as exogenous (i.e., their respective investment functions with the exogenous shifters are not estimates). 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 based on the GMM asymptotic variance formula in parentheses (*** p<0.01, ** p<0.05, * p<0.1).

A.14 Additional estimates of joint technology

Table A20: 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 1. 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 based on the GMM asymptotic variance formula in parentheses (*** p<0.01, ** p<0.05, * p<0.1).

A.15 Robustness: families with more than two siblings

Table A21: Joint technology of skill formation: average sibling bond 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 based on the GMM asymptotic variance formula in parentheses (*** p<0.01, ** p<0.05, * p<0.1).

A.16 Robustness: family size & fertility

Table A22: 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 based on the GMM asymptotic variance formula in parentheses (*** p<0.01, ** p<0.05, * p<0.1).

A.17 Translog production function

Table A23: 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).

A.18 Misreporting Bias

This appendix exploits the data about socio-emotional development 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 unfortunately 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 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 A24: 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 based on the GMM asymptotic variance formula 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 A24 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 reported by the parents (Table 3). Unfortunately, the standard errors are quite large as only data from Northern Ireland, Wales and Scotland are available.

A.19 Heterogeneity: joint technology of skill formation

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

Appendix Tables A25, A26 and A27 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 A27 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 A28 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 A25: 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 based on the GMM asymptotic variance formula in parentheses (*** p<0.01, ** p<0.05, * p<0.1).

Table A26: 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 based on the GMM asymptotic variance formula in parentheses (*** p<0.01, ** p<0.05, * p<0.1).

Table A27: 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 based on the GMM asymptotic variance formula in parentheses (*** p<0.01, ** p<0.05, * p<0.1).

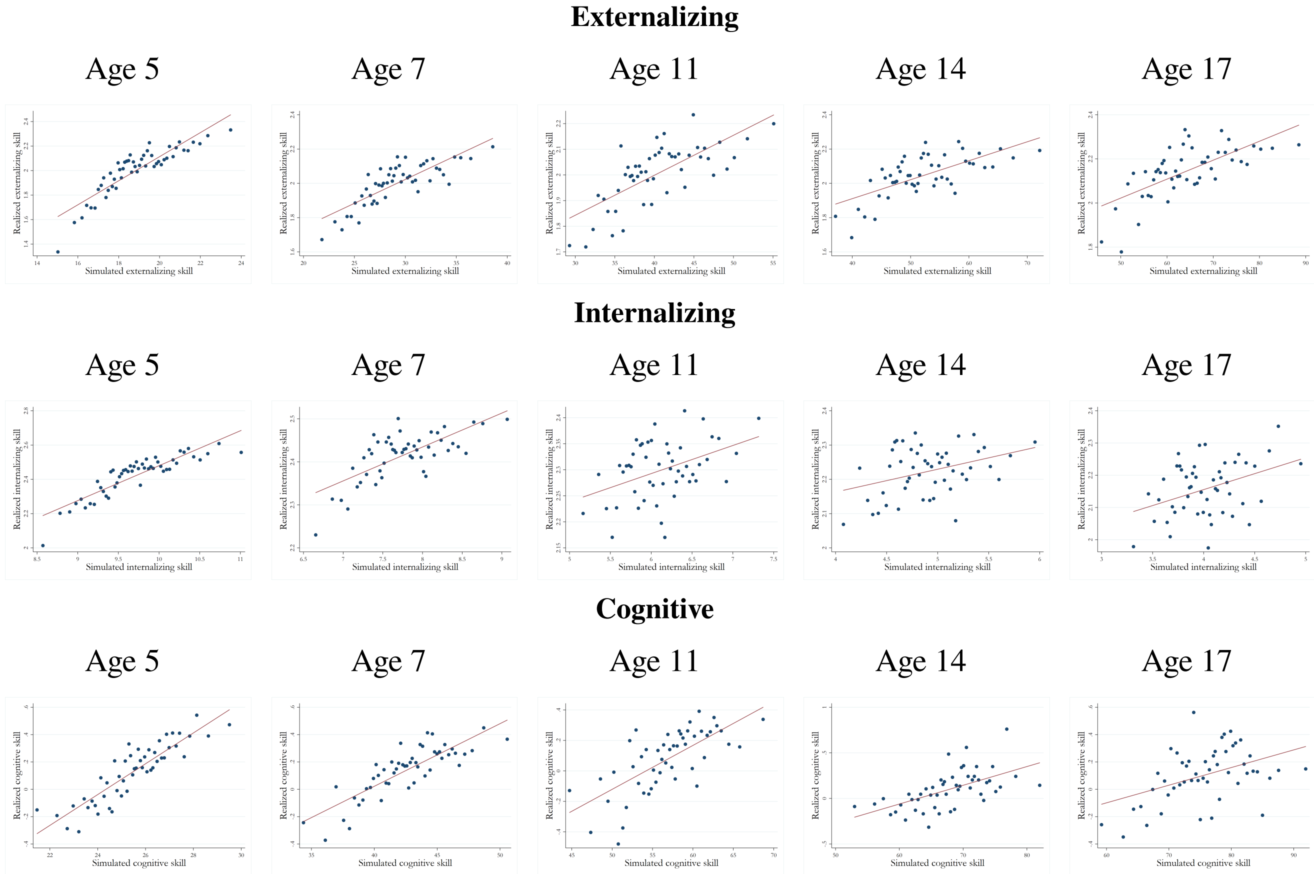
Table A28: Joint technology of skill formation by siblings' age gap

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 based on the GMM asymptotic variance formula in parentheses (*** p<0.01, ** p<0.05, * p<0.1).

A.20 Validating the structural estimates

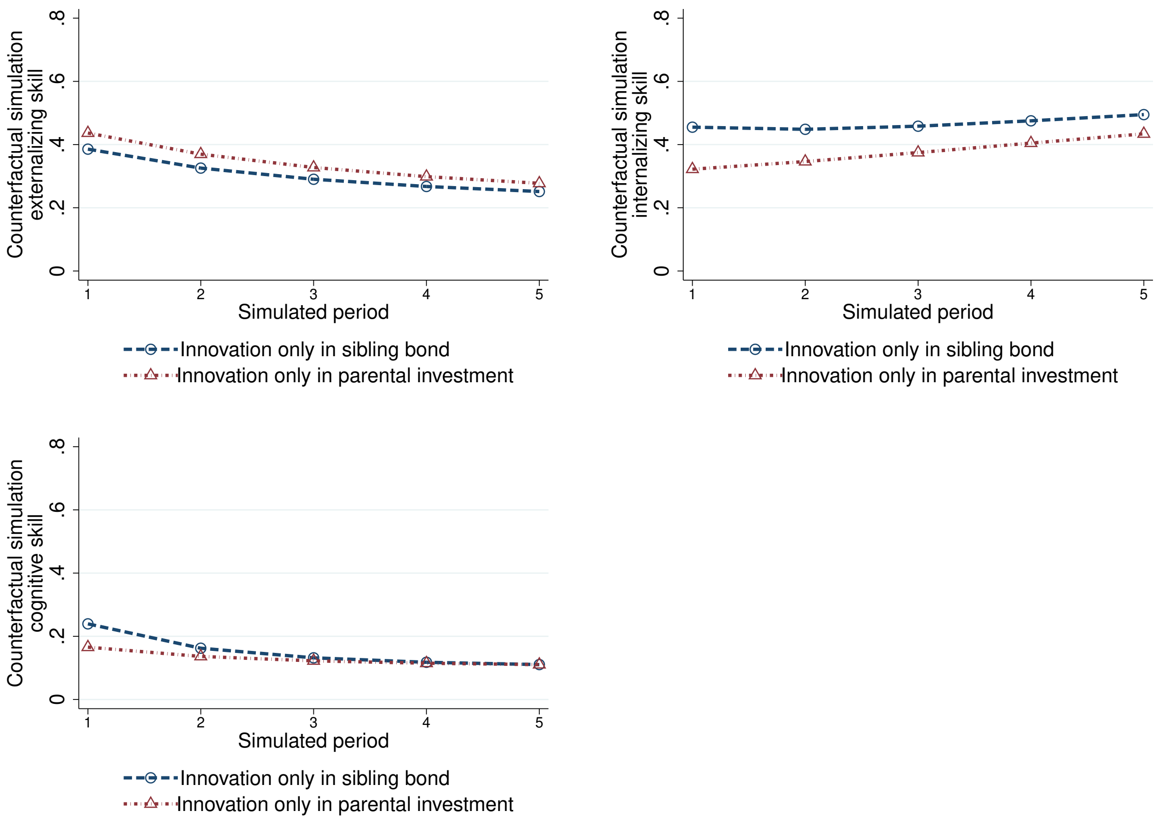
Figure A6: Validation exercise: future realized development and *simulated* development, as implied by the structural estimates of the joint skill formation technology.



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).

A.21 Counterfactual simulations

Figure A7: Counterfactual simulations of hypothetical interventions



Note. The figures present counterfactual simulations of a hypothetical intervention aimed at fostering skills by increasing either the sibling bond or parental investment by 1 standard deviation over simulated periods 1-5 (ages 5, 7, 11, 14, and 17), as implied by the estimated production functions. The production function parameters are assumed to remain constant across all simulated periods.