Skill Formation with Siblings

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Abstract

This paper studies how skills are formed during childhood in families where children grow up with at least one sibling. I use data from the Millennium Cohort Study on the frequency of quality interactions between siblings, such as experiencing enjoyable time together, to measure the bond formed between them. This allows me to open the black box of sibling spillovers and present evidence that differences in the quality of the sibling bond are associated with persistent inequalities across households in the United Kingdom. I document a socio-economic gradient in the quality of the sibling bond and show that a stronger sibling bond at age 5 predicts better developmental, educational and health outcomes across adolescence. Building on this motivating evidence, I formalize the structural process of joint production of skills in families with siblings and estimate the contribution of the sibling bond and parental investment to the formation of the younger and older sibling's skills. The structural estimates of the skill formation technology show that a high-quality bond between siblings matters over and beyond parental investment, contributing to the younger as well as the older sibling's development.

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

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

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

I therefore study the joint production of human capital for the younger and older sibling during childhood in the United Kingdom. First, I explore the complementarity between siblings' skills in the technology of skill formation, which is assumed away when considering a *single*-child framework. Second, I use information about the frequency of parent-child interactions and sibling interactions to measure respectively parental investment and the sibling bond. Measuring the sibling bond opens the black box of sibling spillovers by capturing to what extent siblings get along with each other. In addition, measuring these two inputs enables me to consider parents as well as siblings as actors in the process of development and study their contributions to the younger and older sibling's development.

Siblings with a higher quality bond would, for example, enjoy stronger connection and co-operation, encouraging pro-social actions between each other. This in turn would make it easier for the family to function as a whole and achieve common purposes, such as the joint production of siblings' skills. To highlight the importance of considering the sibling bond in the joint technology of skill formation, I initially present two motivating facts. These empirical facts suggest that differences in the quality of the sibling bond are associated with persistent inequalities across

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

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

households. First, there is a socio-economic gradient in the quality of the sibling bond. Second, a strong bond between siblings at age 5 is predictive of better developmental, educational and health outcomes for the younger sibling across adolescence. Crucially, the richness of the MCS data allows me to document that the quality of the sibling bond is intrinsically related to the relationship and social capital between siblings rather than capturing their home environment and skills.

Building on this motivating evidence, I present and address the main challenges of structurally estimating the joint production of human capital in families with siblings. I allow for the possibility that siblings can build a bond by interacting with each other and that in turn this bond can contribute to their joint development. The main finding of the structural estimation is that a high-quality bond between siblings matters over and beyond parent-child interactions at age 5 and can contribute to the development of the younger as well as the older sibling. In addition, I show that a high-quality sibling bond at age 5 has persistent effects, predicting cognitive and socio-emotional development outcomes for the younger sibling over the life cycle.

Jointly formalizing the younger and older sibling's technology of skill formation is useful to understand the contributions of the sibling bond and parental investment to the formation of skills. In particular, I consider carefully their multi-dimensionality and study the formation of cognitive (ability to complete tasks and learn), internalizing (ability to focus to pursue long-term goals) and externalizing (ability to collaborate with others) skills (Achenbach, 1966; Achenbach et al., 2016). Estimating the technology of joint skill formation in the presence of siblings is inherently complicated and presents two main methodological challenges: (i) measurement error in the skills and inputs of the joint skill formation technology and (ii) input endogeneity. After having addressed these challenges, the technology of skill formation identifies two structural parameters of interest: the productivity of the sibling bond and of the parental investment.

To address the measurement error, I use the Millennium Cohort Study (MCS) data, which follow the life of a representative sample of children born in years 2000-02 in the United Kingdom. The MCS has administered a set of questionnaires to collect information on the cohort member and the older sibling's development as well as the quality of their interactions.[3] I map the information recorded in the MCS questionnaires into latent inputs and outputs of the skill formation technology through a dynamic factor model (Cunha, Heckman, and Schennach, 2010). This provides an effective way to summarize the information from the MCS questionnaires and obtain an efficient measure of the latent inputs and outputs, while allowing to set a metric for measurement and making the latent factors comparable over time and across siblings (Agostinelli and Wiswall, 2020; Freyberger, 2021). I additionally test the scaling assumptions needed in the factor model for the comparability between the younger and older sibling's technology of skill formation through a

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

measurement invariance test (Vandenberg and Lance, 2000; Putnick and Bornstein, 2016; Wu and Estabrook, 2016). This provides support for setting the same scale for the younger and older sibling's technology of skill formation, building confidence in the comparison between the structural estimates of their joint technologies of skill formation.

The second challenge is the endogeneity of parental investment and sibling bond. Parents who observe a positive shock to child development, which is unobserved by the econometrician, may decide to reinforce or compensate it by changing investment. A similar reasoning applies for a high-quality bond between siblings: children experiencing a positive shock to skills, unobserved by the econometrician, may have positive interactions and fewer conflicts with their siblings. Ignoring the endogeneity of the inputs would likely yield biased estimates of their productivity due to such responses to the unobserved shocks. To address this challenge, I use an instrumental variable strategy. I instrument parental investment with local labour market shocks and the sibling bond with adjustment costs to housing (Carneiro, Meghir, and Parey, 2013; Altonji, Cattan, and Ware, 2017). The two instruments I propose are consistent with a model of parental investment, where the instruments affect the siblings' human capital only through parental investment and sibling bond respectively. In addition, the richness of the MCS data allows me to condition on a large set of household characteristics, ranging from household's social skills and wealth to housing characteristics, reinforcing the assumption that any residual variation is quasi-random.

This paper contributes to six strands of the literature on the determinants of skill formation and inequalities related to human capital. Understanding the technology of skill formation during childhood is central in labor economics as a growing evidence highlights the role of childhood conditions in determining adult human capital and earnings in developed and developing countries (Currie and Almond, 2011; Almond, Currie, and Duque, 2018; Attanasio, Cattan, and Meghir, 2021).

First, it contributes to the literature estimating the technology of skill formation (Cunha and Heckman, 2008; Cunha, Heckman, and Schennach, 2010; Attanasio, Cattan, Fitzsimons, Meghir, and Rubio-Codina, 2020; Attanasio, Meghir, and Nix, 2020; Agostinelli and Wiswall, 2020). This literature presumes a *single* child.[4] However, families usually have more than one child and siblings interact, as noted by Francesconi and Heckman (2016) and McHale, Updegraff, and Whiteman (2012).[5] I move away from a single-child framework and consider the joint technology of skill formation for the younger and older sibling. This allows me to study how parental investment and a quality bond between siblings affect the development of each sibling. Considering parents and

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

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

siblings as actors in the development process highlights the importance of thinking carefully about social capital and relationships within the family. Siblings can be important team players, who can help each other achieve common goals within the family, such as their joint production of human capital. The importance of teamwork to function as whole is still understudied within the family, while it has been shown to matter, for example, within the firm (Weidmann and Deming, 2021). As I am considering siblings, I also study how the older sibling's social skills affect the younger sibling's ones and viceversa.

Second, there is a growing interest in understanding the role played by siblings, which has mostly focused on quantifying spillovers among siblings, noting that their identification is complicated. For example, Altonji, Cattan, and Ware (2017) assess the extent to which the correlations in substance use between siblings are causal. Altmejd et al. (2021) provide evidence from Chile, Croatia, Sweden, and the United States that older siblings affect the college and major choice of the younger sibling.[6] However, these papers have not attempted to measure the sibling bond directly and understand how a strong bond between siblings can contribute to development in the early years and be conducive of the spillovers among siblings. My paper tries to fill this gap by measuring the strength of the sibling bond directly and quantifying to what extent their bond contributes to growth in the early years, suggesting that the quality of this bond could mediate these spillovers.

Third, my estimates complement the literature on the trade-off between the quantity and quality of children, which examines if parents decrease their investments per child when increasing the quantity of children (Becker and Lewis, 1973; Willis, 1973; Becker and Tomes, 1976). I show that a quality bond between siblings can spur development, offering another possible explanation for why there is limited evidence of such trade-off (Black, Devereux, and Salvanes, 2005, 2010; Cáceres-Delpiano, 2006; Angrist, Lavy, and Schlosser, 2010; Åslund and Grönqvist, 2010; De Haan, 2010; Briole, Le Forner, and Lepinteur, 2020). In turn, this paper also connects to the literature on intra-household inequality in human capital. I highlight the possibility that children can interact and a strong relationship could foster both siblings' skills. It is in turn plausible that parents could facilitate such interactions between siblings through investments aimed at encouraging pro-social actions between siblings. The literature has, instead, focused on parents engaging mainly in reinforcing or compensating investment for inequality among siblings (Behrman, Pollak, and Taubman, 1982; Behrman, 1988).[7]

Fourth, this paper contributes to the literature that thinks carefully about the multi-dimensionality

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

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

of skills (Heckman, Stixrud, and Urzua, 2006; Borghans, Duckworth, Heckman, and Ter Weel, 2008; Heckman, Humphries, and Veramendi, 2018; Humphries, Joensen, and Veramendi, 2019; Papageorge, Ronda, and Zheng, 2019; Attanasio, Blundell, Conti, and Mason, 2020; Attanasio, de Paula, and Toppeta, 2022). Considering cognitive, externalizing and internalizing skills highlights that the formation of skills can be quite complex and different skills can have different processes. For example, studying the contribution of one sibling's externalizing skill to the other sibling's development allows me to investigate whether one sibling is likely to have a high internalizing skill (i.e., introvert) when the other sibling has a high externalizing skill (i.e., extrovert) and vice versa (Plomin and Daniels, 1987).

Fifth, the psychology and child development literature has also studied parent-child interactions by focusing on how environmental factors contribute to development, but now the focus is shifting to explore sibling relationships and interactions (McHale, Updegraff, and Whiteman, 2012).[8] Similarly, the anthropology literature has investigated the role of interactions between siblings for child development, highlighting that the older sibling could engage in care-taking interactions with the younger sibling (see for example Weisner et al. (1977) and Lancy (2014)). Unfortunately, these studies are characterized by a small (and sometimes selected) sample and overlook the endogeneity of parental investment and sibling bond.

The psychology literature has also proposed two alternative theories on the role of sibling interactions and bond in the context of adjustment problems and risky behaviour. On the one hand, Patterson (1984) argues that siblings take up risky behaviors when their relationships are aggressive and ridden with conflicts as these promote antisocial behaviour. On the other hand, Buhrmester, Boer, and Dunn (1992) and Rodgers and Rowe (1988) argue that siblings provide opportunities to each other for substance use and this channel is more likely to be present when the siblings have a positive relationship. My paper tests these two alternative hypotheses, finding supporting evidence on the former by showing that an age-5 higher quality bond between siblings is predictive of a lower probability that the younger sibling smokes cigarettes at ages 14 and 17 and higher socio-emotional development across adolescence

Finally, this paper has implications for policy design to improve child development, offering a fertile ground for new interventions. First, it stresses the importance of including siblings in early childhood development (ECD) interventions and collecting information on them. Evans, Jakiela, and Knauer (2021) review 478 ECD interventions in low-medium income countries, finding that only 7 studies (1%) report impacts on older siblings in middle childhood or adolescence. Second, my findings on the role of the sibling bond for child development hint towards some possible new interventions. For example, Ashraf, Bau, Low, and McGinn (2020) discuss an intervention where they train adolescent girls to negotiate more effectively with their parents by teaching them interest-

[8] Some examples of studies in psychology and child development on the role of sibling interaction and direct influence on children's development outcomes are Maynard (2002), Howe, Rinaldi, Jennings, and Petrakos (2002), Stocker, Burwell, and Briggs (2002), Bank, Burraston, and Snyder (2004) and Sun, McHale, and Updegraff (2019).

based negotiation (IBN).[9] The authors provide an example of IBN where two sisters negotiate over an orange, that both desire. The two sisters are able to find a solution, that benefits both, because *one* of them has learnt the IBN skill. My paper offers a plausible ground and a theoretical framework to think about how such training designed for the family could benefit their children's development as trainees could mediate conflicts and create better sibling relationships during childhood.

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

2 The Joint Production of Skills with Siblings

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

2.1 Motivating Evidence on the Role of Siblings for Skill Formation

Siblings are an integral component of the family system. At age 5, more than 75% of children have at least one sibling in the United Kingdom, which is the context of this paper (age-5 wave in 2006 of the Millennium Cohort Study). Siblings have everyday interactions with each other during childhood, providing social support and acting as role models for one another. As children grow up, they can spend a larger amount of time with their siblings than with their parents, hinting as to why it is important to examine the role of sibling bond above and beyond the bond between children and parents. For example, a quality bond between siblings could lead them to take pro-social actions, which discourage exploitation, and allow them to work together more effectively to achieve common purposes.

[9] IBN stresses the importance of understanding the reason why (i.e., the interest) a person enters a negotiation rather than the what a person could gain from a negotiation. This should spur win-win agreement where both parties could gain from entering the negotiation and crease better relationships. Similar evidence on the effectiveness of IBN has been found in other contexts by Blattman, Hartman, and Blair (2014), Hartman, Blair, and Blattman (2021) and Christensen, Hartman, Samii, and Toppeta (2022).

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

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

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

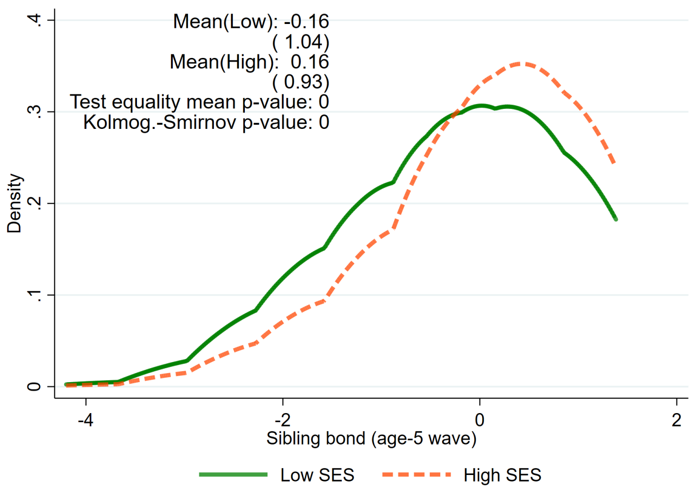
Second, the sibling bond at age 5 predicts the younger sibling's developmental, educational and health outcomes across adolescence as shown in Table 1 and Figure 2. This prediction exercise is robust to a large set of controls. These include the home environment, proxied by parental investment, siblings' social skills, mother's mental health, home atmosphere, mother's education, and how close the relationship is between the mother and child. The full list of controls is in the note of Table 1 and Figure 2.

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

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

[11] 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. It corresponds to high school diploma in the United States. Students who plan to go to university study for an A-level qualification.

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



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

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

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

The point estimates from regressing the quality of the sibling bond at age 5 on developmental outcomes across adolescence are presented in Figure 2. The dashed blue line presents the point

Table 1: Sibling bond predicts at age 5 future educational and health outcomes for the younger sibling during young adulthood

Panel A:

Outcome	Achieve A* (GCSE Math)				Achieve A* (GCSE English)			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Sibling bond (age 5)	0.048	0.079*	0.083**	0.230***	0.014	0.042	0.044	0.091
	(0.041)	(0.041)	(0.041)	(0.078)	(0.038)	(0.037)	(0.038)	(0.072)
Observations	2692	2692	2692	2692	2703	2703	2703	2703
R^2	0.001	0.129	0.129	0.240	0.000	0.134	0.134	0.259
Younger & older sib's skills (age-3 wave)		✓	✓	✓		✓	✓	✓
Parental investment (age-5 wave)			✓	✓			✓	✓
Other controls				✓				✓

Panel B:

Outcome	Study for an A-level qualification (age 17)				Aspiration to study at University (age 17)			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Sibling bond (age 5)	0.008	0.017	0.017	0.038*	-1.423	-1.266	-1.165	2.111
	(0.011)	(0.011)	(0.011)	(0.022)	(0.907)	(0.903)	(0.926)	(1.804)
Observations	2882	2882	2882	2882	2170	2170	2170	2170
R^2	0.000	0.080	0.081	0.167	0.001	0.107	0.107	0.181
Younger & older sib's skills (age-3 wave)		✓	✓	✓		✓	✓	✓
Parental investment (age-5 wave)			✓	✓			✓	✓
Other controls				✓				✓

Panel C:

Outcome	Smoke cigarettes (age 14)				Smoke cigarettes (age 17)			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Sibling bond (age 5)	-0.014**	-0.011	-0.010	-0.023	-0.008	-0.010	-0.011	-0.051**
	(0.007)	(0.007)	(0.007)	(0.014)	(0.011)	(0.011)	(0.011)	(0.022)
Observations	3500	3500	3500	3500	3122	3122	3122	3122
R^2	0.002	0.021	0.021	0.050	0.000	0.010	0.010	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 sibling bond at age 5 and the younger sibling's educational and health outcomes at ages 14 and 17 with and without controls. The index of the sibling bond is constructed by summing the values from the following 4 questions about how often [frequently, sometimes, never] the cohort member (i.e., the younger sibling): (i) Likes to be with the older sibling, (ii) Not much interested in the older sibling, (iii) Has a lot of fun with the older sibling, (iv) Teases or needles the older sibling. I recode behaviours indicating worse interactions in reverse (i.e., not much interested in older sibling and teases or needles older sibling). The index of parental investment in younger sibling is obtained by summing the values from the questions asking the parents how often [Every day, Several times a week, Once or twice a week, Once or twice a month, Less often, Not at all] they do the following activities: (i) How often do you read to the child, (ii) How often tells stories to the child, (iii) How often does musical activities with the child, (iv) How often does the child paint/draw at home, (v) How often do you play physically active games with the child?, (vi) How often play indoor games with the child? and (vii) How often play outdoor games with the child? The sibling bond index is standardized to have mean 0 and standard deviation 1. Other controls include younger sibling's gender, age gap between younger and older sibling, older sibling's gender, number of children in the house, mother's mental health, mother's education, mother's age, whether the household is dual or single headed, partner's employment status, home atmosphere, how close the bond between mother and child is, 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).

estimates of the age-5 sibling bond on future development at ages 5, 7, 11, 14, and 17 without any controls, while the solid red line includes all the controls listed in the notes of Figure 2, aiming at reducing the gap in family characteristics of siblings with different bond qualities. The sibling bond at age 5 is associated with higher externalizing, internalizing and cognitive development over the life cycle for the younger sibling. For example, an increase in one standard deviation in the quality of the sibling bond at age 5 is associated with an increase in 0.1 standard deviation in the externalizing skill at age 17 (solid red line).

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

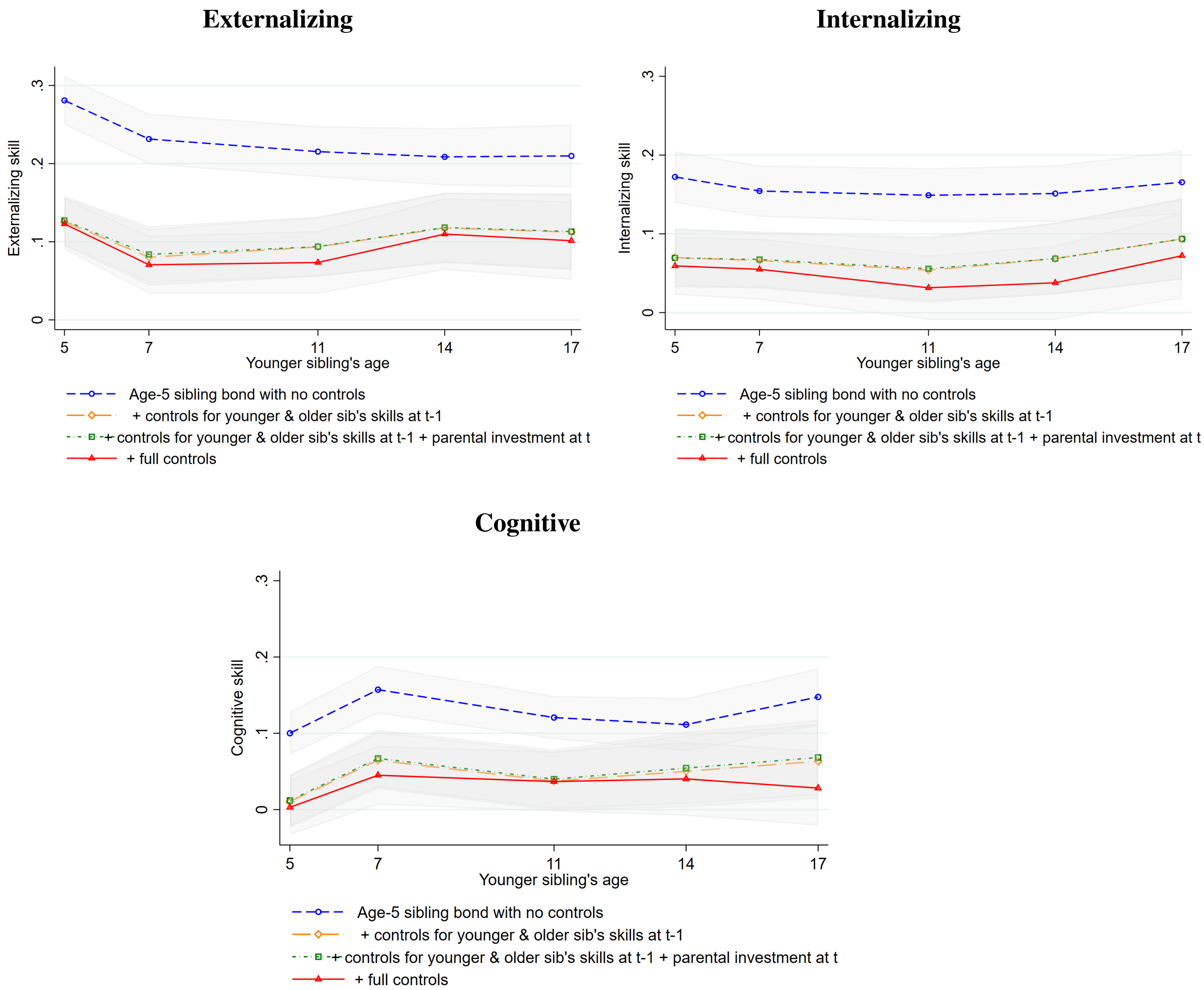
These results suggest that younger siblings who experience more positive interactions with their older siblings are more likely to develop better skills over the life cycle and achieve better educational and health outcomes.[12] A stronger connection and bond between siblings could, for example, lead siblings to talk more and in turn develop better skills. This evidence suggests why siblings with a stronger sibling bond are associated with a higher grade in the English GCSE exam and have a higher probability of pursuing an A-level qualification. Overall, this motivating evidence is suggestive that differences in the quality of the sibling bonds across household could contribute to the transmission of disadvantage. This effect may also be amplified in the future as high socio-economic status parents are more likely to have more than one child (Doepke, Hannusch, Kindermann, and Tertilt, 2022).

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

First, Appendix Table A3 presents the correlations between the sibling bond and some home environment factors, such as parental investment, mother's mental health, and the quality of mother-child bond. These correlations are low and usually below 0.20. For example, the correlation

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

Figure 2: Sibling bond at age 5 predicts development across adolescence



Note. The Figures present the relationship between the sibling bond at age 5 and development across the adolescence and young adulthood with and without controls with the respective confidence intervals at 95% level in gray. The point estimates from the prediction exercise on the y-axis are in standard deviation units as the sibling bond and developmental outcomes are then standardized to have mean 0 and standard deviation 1. 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). Internalizing and externalizing skills are measured with the Strengths and Difficulties Questionnaire (SDQ) (Goodman, 1997; Goodman, Lamping, and Ploubidis, 2010). Cognitive skills are measured with a battery of tests, such as the British Ability Scales II (BAS II). The index of the sibling bond is constructed by summing the values from the following 4 questions about how often [frequently, sometimes, never] the cohort member (i.e., the younger sibling): (i) Likes to be with the older sibling, (ii) Not much interested in the older sibling, (iii) Has a lot of fun with the older sibling, (iv) Teases or needles the older sibling. I recode behaviours indicating worse interactions in reverse (i.e., not much interested in older sibling and teases or needles older sibling). The index of parental investment in younger sibling is obtained by summing the values from the questions asking the parents how often [Every day, Several times a week, Once or twice a week, Once or twice a month, Less often, Not at all] they do the following activities: (i) How often do you read to the child, (ii) How often tells stories to the child, (iii) How often does musical activities with the child, (iv) How often does the child paint/draw at home, (v) How often do you play physically active games with the child?, (vi) How often play indoor games with the child? and (vii) How often play outdoor games with the child? Full controls include the younger and older sibling's skills at the age-3 wave, parental investment, younger sibling's gender, mother's mental health, mother's education, mother's age, whether the household is dual or single headed, partner's employment status, number of children, age gap between younger and older sibling, older sibling's gender, housing tenure, years lived in current address, home atmosphere, how close the bond between mother and child is, and region fixed effects.

between the sibling bond and the mother-child bond is 0.11, hinting that the sibling bond is not capturing the relationship that the children have with their mother. Second, I present evidence that the sibling bond is not measuring the children's social skills. Appendix Figure A7 shows that there are children with poor social skills, who still have quality interactions with their siblings, as well as siblings with good social skills, who have low quality interactions with their siblings. Third, I present additional evidence that the sibling bond and parental investment are capturing two different inputs by studying the correlations among the questions used to construct the two latent measures with an exploratory factor analysis discussed in detail in Section 3.2.1.

To conclude this section, I also exploit the data on both siblings' socio-emotional development and perform a variance decomposition of siblings' socio-emotional development to quantify to what extent the variation between siblings' skills comes from within-family variation rather than between-family variation. Appendix Figure A8 documents that most of the difference between siblings' skills come from within the family, namely up to 70%-80% of the variation remains unexplained. I then try to understand if the sibling bond can help explain the difference in the younger and older sibling's skills. Namely, I regress the difference in siblings' socio-emotional skills on the sibling bond. Appendix Table A4 presents evidence that the quality of the sibling bond is associated with a reduction in the variance of siblings' skills, providing additional evidence on the importance of such mechanism to explain the origins of disadvantage also possibly within family.

2.2 Theoretical Framework

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

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

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

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

Where θ_{cit} is a vector with the three dimensions of human capital: internalizing (INT), Externalizing (EXT), and Cognitive (COG) skill for the younger, YS, and older, OS, sibling. Cognitive skills are linked to the ability to complete tasks and learn rather than actual knowledge. On the other hand, internalizing and externalizing skills are linked respectively to intrapersonal skill, such as the ability to regulate one's behavior in pursuit of long-term goals, and interpersonal skill, such as the ability to collaborate with others (Achenbach, 1966; Achenbach et al., 2016).

I formulate this problem as static to highlight the trade-off during this developmental stage.[13] Parents' choices on how to invest in the younger sibling (YS) and older sibling (OS)'s human capital have two distinct features. First, parents invest in activities specific to one of the two siblings. Second, they can promote activities that involve both siblings and can improve their interactions and relationship.

The parents of siblings YS and OS allocate their total available time to work, L_i, as well as different types of activities that promote the development of the child: parental investment in the younger sibling $I_{YS,i}$, parental investment in the older sibling $I_{OS,i}$ and actions $SI_{YOS,i}$ aimed to foster the sibling bond $SB_{YOS,i}$ between the younger and older sibling (YOS) (equation 1). w_i and y_i in the budget constraint are respectively the wage and the non-work income (equation 2). In the current framework, I abstract from monetary investments that help children acquire skills, but the model could be easily extended to accommodate them.[14]

Parents' actions to facilitate sibling interactions, $SI_{YOS,i}$, do not have to always correspond to forming a strong sibling bond, $SB_{YOS,i}$ (equation 3). The assumption of a deterministic relationship between parents and siblings' actions would be problematic because parents could try to facilitate relations between siblings, but siblings may decide *not* to bond for reasons outside of the parents' control. I therefore try to capture this in equation (3) by defining the sibling bond $SB_{YOS,i}$ as a function of parents' actions, $SI_{YOS,i}$, and an idiosyncratic shock to siblings' actions, $e_{YOS,i}$, which is outside of the parents' control.[15]

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

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

[14]The budget constraint with monetary investment would become the following: $y_i + w_i L_i = C_i + pM_i$. The monetary investment M_i would then be an additional input in the production function and p is the price of the monetary investment. I abstract from monetary investment because the measures of parental investment in the MCS refer to parent-child interactions, with a focus on time investment in children rather than material investment.

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

$$\max_{C_i, I_{YS,i}, I_{OS,i}, SI_{YOS,i}} EU(C_i, \theta_{YS,i,1}, \theta_{OS,i,1})$$

Subject to

$$L_i = 1 - I_{YS,i} - I_{OS,i} - SI_{YOS,i} \tag{1}$$

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

$$SB_{YOS,i} = h(SI_{YOS,i}, e_{YOS,i}) \tag{3}$$

$$\theta_{YS,i,1} = f(\theta_{YS,i,0}, \theta_{OS,i,0}, I_{YS,i}, SB_{YOS,i}, \mathbf{X}_i, v_{YS,i}) \tag{4}$$

$$\theta_{OS,i,1} = g(\theta_{YS,i,0}, \theta_{OS,i,0}, I_{OS,i}, SB_{YOS,i}, \mathbf{X}_i, u_{OS,i}) \tag{5}$$

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

$$EU(C_i, \theta_{YS,i,1}, \theta_{OS,i,1}) = EU(C_i) + \alpha EU(\theta_{YS,i,1}, \theta_{OS,i,1})$$

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

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

$$I^*_{YS,i} = l_t(\theta_{YS,i,0}, \theta_{OS,i,0}, y_i, w_i, \mathbf{X}_i, \epsilon_{YS,i})$$

$$I^*_{OS,i} = m_t(\theta_{YS,i,0}, \theta_{OS,i,0}, y_i, w_i, \mathbf{X}_i, \epsilon_{OS,i})$$

$$SI^*_{YOS,i} = n_t(\theta_{YS,i,0}, \theta_{OS,i,0}, y_i, w_i, \mathbf{X}_i, \epsilon_{YOS,i})$$

The investment equations are a function of preference parameters, productivity parameters, younger and older sibling's development at the beginning of the period, income y_i, wages w_i and idiosyncratic shocks $\epsilon_{YS,i}$, $\epsilon_{OS,i}$, and $\epsilon_{YOS,i}$, which are a function of idiosyncratic shocks to each sibling's development. These shocks can be correlated within the family. The sibling bond, $SB^*_{YOS,i}$, is in turn a function of a shock $e_{YOS,i}$ and $SI^*_{YOS,i}$, which depend among other things on the younger and older sibling's skills, suggesting for example that the parents' ability to improve the quality of the interactions between siblings depends on how similar/close the two siblings are.

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

2.3 The Technology of Human Capital Formation with Siblings

This Section describes the technology of skill formation for the younger (YS) and older sibling (OS) estimated in the paper (equations 6 and 7). I assume a Cobb-Douglas functional form. Appendix D.5 experiments with different specifications, such as a translog production function to capture different degrees of substitutability between inputs. The data, however, do not reject the Cobb-Douglas specification.

$$ln(\theta^S_{YS,it}) = \sum_S \beta_{1S} ln(\theta^S_{YS,it-1}) + \sum_S \beta_{2S} ln(\theta^S_{OS,it-1}) + \beta_{3S} ln(SB_{YOS,it}) + \beta_{4S} ln I_{YS,it} + \mathbf{X}'_{it}\eta_S + \nu^S_{YS,it} \tag{6}$$

Where t represents age-5 wave and $(t-1)$ represents to age-3 wave. Skills S are internalizing (INT), Externalizing (EXT), and Cognitive (COG) skills. $I_{YS,it}$ and $SB_{YOS,it}$ represent respectively parental investment in the younger sibling and the sibling bond. As I am considering the joint process of skill formation with siblings, I include the younger and older sibling's internalizing and externalizing skills at time $t-1$ on the right hand side to consider that children with higher social skills could have more positive interactions with each other. I also control for the younger sibling's cognitive skill in the previous period, while I cannot do that for the older sibling as the MCS does not collect data on the older sibling's cognitive development.[16] Finally, X_{it} is a vector

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

of environmental factors that may affect child development. These include the younger sibling's gender, age gap between younger and older sibling, older sibling's gender, number of children in the house, mother's mental health, mother's education, mother's age, whether the household is dual or single headed, partner's employment status, home atmosphere, how close the bond between mother and child is, housing tenure, years lived in current address, region fixed effects. $\nu_{YS,it}$ is an idiosyncratic shock observed by the parents but unobserved by the econometrician. The parameters of interest are β_{3S} and β_{4S}, which capture the productivity of the sibling bond and parental investment in the younger sibling for each skill S.

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

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

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

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

2.4 Investment Functions: Endogeneity of Parental Investment and Sibling Bond

A challenge researchers encounter when estimating the technology of child development is that inputs are likely to be correlated with unobserved shocks to child development (Cunha, Heckman, and Schennach, 2010; Attanasio, Cattan, Fitzsimons, Meghir, and Rubio-Codina, 2020; Attanasio, Meghir, and Nix, 2020).[17] Parents and siblings may adjust their actions, depending on developmental shocks to human capital, making the inputs endogenous. For example, parents may adjust their investment at time t in response to unobserved shocks that affect their choices as well as the level of development, $\theta^S_{YS,it}$. Similarly, siblings experiencing a positive shock to social skills, unobserved by the econometrician, may be more likely to have positive interactions and fewer conflicts with their siblings. Ignoring this endogeneity problem would provide biased estimates of the productivity of parental investment and the sibling bond in the technology of skill formation.

Ideally, to address this problem, I would need random assignment of parental investment and the sibling bond to the child, but of course this is not ethically feasible. A feasible alternative is

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

instead resort to an instrumental variable approach motivated by the model of parental investment from Section 2.2, which derives the economic restriction consistent with the exogeneity condition.

These investment functions can in principle be computed numerically by solving the dynamic problem faced by parents, as in Del Boca, Flinn, and Wiswall (2014) and Gayle, Golan, and Soytas (2015). This approach would require stronger assumptions about parental behavior, such as requiring parents to have full knowledge of the production function. This assumption however would go against existing research, documenting that parents in both developed and developing countries have biased beliefs about the returns to investment in children (Cunha, Elo, and Culhane, 2013; Boneva and Rauh, 2018; Attanasio, Cunha, and Jervis, 2019). Instead, approximating these investment functions does not require to take a stance on whether parents know the true production function reflected in the structure of the skill formation technology (Attanasio, Meghir, and Nix, 2020; Attanasio, Cattan, Fitzsimons, Meghir, and Rubio-Codina, 2020). I therefore follow the latter approach. I derive the investment functions from the parental investment model and approximate them with the following log-linear equations:

$$ln(SB_{YOS,it}) = \sum_S \delta_{1S} ln(\theta^S_{YS,it-1}) + \sum_S \delta_{2S} ln(\theta^S_{OS,it-1}) + \delta_3 Z_{1,it} + \delta_4 Z_{2,it} + \mathbf{X}'_{it}\phi + \epsilon_{YOS,it} \quad (8)$$

$$ln(I_{YS,it}) = \sum_S \gamma_{1S} ln(\theta^S_{YS,it-1}) + \sum_S \gamma_{2S} ln(\theta^S_{OS,it-1}) + \gamma_3 Z_{1,it} + \gamma_4 Z_{2,it} + \mathbf{X}'_{it}\phi + \epsilon_{YS,it} \quad (9)$$

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

As a first step to deal with endogeneity, I exploit the richness of the MCS data and control for a large set of household characteristics and pre-determined conditions, $\mathbf{X}_{it}$, that capture the younger sibling's gender, age gap between younger and older sibling, older sibling's gender, number of children in the house, mother's mental health, mother's education, mother's age, whether the household is dual or single headed, partner's employment status, home atmosphere, how close the bond between mother and child is, housing tenure, years lived in current address, region fixed effects. For example, controlling for the younger and older sibling's lagged socio-emotional skills allows me to consider that children with higher social skills are more likely to have positive interactions and experience fewer conflicts. Similarly, controlling for mother's education, partner's employment status, housing tenure and years lived in the current address allow me to proxy the household's resources and wealth.

To deal with the endogeneity of parental investment, I use a female employment shock, $Z_{i,1t}$, proxied by the local unemployment rate at the local authority where the household lives. The richness of the MCS builds confidence that this shock is quasi-exogenous as I can condition on a large set of controls, $\mathbf{X}_{it}$, such as, for example, male employment, partner being present in the household and other variables capturing household's resources. The residual variation in the female employment shock should then not be related directly to child development, but only through parental investment (Carneiro, Meghir, and Parey, 2013). The female employment shock is a relevant instrument because a positive female employment shock could lead the mother to be more likely to work and be outside of the house, reducing the amount of time investment.[18] On the other hand, if I were to measure material investment, an instrument which could be use is local toy prices as done in Attanasio, Cattan, Fitzsimons, Meghir, and Rubio-Codina (2020).

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

Using the residual variation in the number of rooms as an instrument to capture the adjustment cost to housing could raise some concerns about violating the exclusion restriction.[19] For example, the number of rooms might affect the ability to focus their drive and determination to complete an assignment or sleep patterns. It is important to keep in mind that the MCS has very rich information on siblings' social skills, household and housing characteristics. I can control for these variables to exploit the residual variation that is plausibly exogenous and should affect development only through the sibling bond. Thinking about the aforementioned violations of the exclusion restriction, controlling for both siblings' internalizing skills would capture variables that are usually unobserved, such as the siblings' ability to focus their drive and determination, for example, to complete assignment. Also controlling for home atmosphere - i.e., how calm the house is - would capture how sleep patterns can be affected.

The idea behind the instrument for the sibling bond is similar to the one that has been employed in the studies of peer effects, that use quasi-random assignment of roommates to students in college dorms (see for example, Sacerdote (2001) and Stinebrickner and Stinebrickner (2006)). This is of course not available within the same household but the instrument tries to mimic this by quasi-randomly dividing the siblings in different rooms by building a wall. I consider similar households who live in similar homes but sometimes siblings quasi-randomly do not share the same bedroom, after having included a large set of controls, such as household's social skills, resources, and

[18]The choice of time investment as opposed to monetary investment is driven by the measures of parent-child interactions available in the MCS questionnaire, described in Section 3.1.

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

housing characteristics.

To understand the relevance of the instrument, it is important to keep in mind the questions used to measure the latent sibling bond, which contain information about teasing the sibling and spending enjoyable time with the sibling. Intuitively, the instrument is relevant because if both siblings have their own room, they could fight less and have higher quality interactions without stepping on each other toes and invading each other's privacy. If both siblings share the same bedroom, they would have harder time finding space for regaining control of emotions during a discussion, ending up exacerbating the conflicts.[20]

The literature has adopted a similar instrumental variable approach to deal with the endogeneity of parental investment when estimating the technology of child development with a single child. Some examples of instruments for parental investment are: innovations in income (Cunha, Heckman, and Schennach, 2010), variation in prices (Attanasio, Meghir, and Nix, 2020), and variation in prices and exposure to conflicts (Attanasio, Cattan, Fitzsimons, Meghir, and Rubio-Codina, 2020). In all these instances, a theoretical framework is helpful to derive the *sufficient* conditions for the excluded instruments to be valid and consistent with economic theory. However, these conditions are only sufficient as the model cannot capture every possible response to unobserved shocks by the household. Cunha, Nielsen, and Williams (2021) argue that the *necessary* conditions for the instrument to be valid depend on the nature of the unobserved shocks. For example, if the unobserved shocks capture omitted inputs, then the exclusion restriction would be difficult to satisfy as unobserved inputs could change in response, for example, to the female employment shock and the adjustment cost to housing. On the other hand, if the omitted inputs can only change at significant cost, such as moving to a different neighborhood, then the female employment shock and the adjustment cost to housing would satisfy the exclusion restriction.

3 Latent Factors and Measurement System

This section describes the available data from the Millennium Cohort Study in the United Kingdom and the measurement system adopted to map the questionnaires into the latent constructs of interest: skills, parental investment and sibling bond. The inputs and the outputs of the technology of child development are never observed directly, but I can only observe the responses to questionnaires which capture the latent constructs with some error. Cunha, Heckman, and Schennach (2010) provide a framework to allow researchers to spell out the assumptions through a measurement system on how the available observable responses to the questionnaires map into the latent constructs that researchers are interested in. The measurement system provides an effective way to summarize the available information from the questionnaire and obtain an efficient measure of the latent factors, while allowing to set a metric for measurement and making the measures comparable over time and across siblings (Agostinelli and Wiswall, 2020; Freyberger, 2021). This section also adopts advances from psychometrics to test for measurement invariance in skills across siblings. This test

[20]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.

provides support for setting the same metric for the older and younger sibling's socio-emotional skills and compare the structural estimates of the technologies of skill formation. Finally, I outline the estimation technique adopted to estimate the entire measurement system in one step.

3.1 Data: Millennium Cohort Study

The Millennium Cohort Study (MCS) follows the lives of a representative sample of children born in United Kingdom in 2000-02. Multiple measures of the cohort members' socio-emotional and cognitive development as well as detailed information on their daily life, economic circumstances, parenting, relationships and family life have been collected from birth to age 17.[21] It also contains longitudinal information on siblings' skills as well as information on the quality of the interactions between siblings and between the parent and child.

Information on the younger and older sibling's socio-emotional skills comes from the Strengths and Difficulties Questionnaire (SDQ) administered at the age-3 and age-5 waves (Goodman, 1997, 2001). The SDQ is made up of 5 scales of 5 items each: (i) Emotional symptoms, (ii) Conduct problems, (iii) Hyperactivity/inattention, (iv) Peer relationship problems and (v) Prosocial behaviour. Mothers 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' (Table 2). Since they are all behaviours indicating lower skills, I recode all of them in reverse. So higher scores correspond to higher skills. The note of Table 2 reports to which scale each questionnaire item belongs to.

Goodman (1997), Goodman (2001), and Goodman, Lamping, and Ploubidis (2010) propose adding the responses from the Conduct and Hyperactivity scales to obtain an externalizing score, and adding the responses of the Emotional and Peer problem scales to produce an internalizing score (Achenbach, 1966; Achenbach et al., 2016).[22]

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

[21]Data are publicly available through the UK data service. Interviews have taken place at birth, and ages 3, 5, 7, 11, 14 and 17. The MCS longitudinal study is still ongoing with the-age 22 wave taking place in 2022. Descriptive statistics for the estimation sample are presented in Appendix Table F22.

[22]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. Descriptive statistics for the estimation sample are presented in Appendix Tables F23, F24 and F25.

Table 2: 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, toys, pencils etc.)+
5. Has often had temper tantrums or hot tempers	6. Rather solitary, tending to play alone
7. Generally obedient, usually doing what adults requested+	8. Many worries, often seeming worried
9. Helpful if someone was hurt, upset or feeling ill+	10. Constantly fidgeting and squirming
11. Has had at least one good friend +	12. Has often had fights with other children or bullies them
13. Often unhappy, downhearted or tearful	14. Generally liked by other children+
15. Easily distracted, concentration wandered	16. Nervous or clingy in new situations, easily loses confidence
17. Kind to younger children +	18. Often lies or cheats
19. Picked on or bullied by other children	20. Often volunteer to help (parents, teachers, other children)+
21. Able to think things out before acting +	22. Stole from home, school or elsewhere
23. Getting on better with adults than with other children	24. Many fears, easily scared
25. Has seen tasks through to the end, good attention span +	

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

vocabulary, (ii) pattern construction and (iii) picture similarities from the British Ability Scales II (descriptive statistics in Appendix Table F26).

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

Finally, parental investment in the younger sibling is measured at the age-5 wave by asking the parents how often [Every day, Several times a week, Once or twice a week, Once or twice a month, Less often, Not at all] they do the following activities: (i) How often do you read to the child, (ii) How often tells stories to the child, (iii) How often does musical activities with the child, (iv) How often does the child paint/draw at home, (v) How often do you play physically active games with the child?, (vi) How often play indoor games with the child? and (vii) How often play outdoor games with the child? The descriptive statistics for the quality of interactions between siblings and parental investment questionnaires are presented respectively in Appendix Tables F27 and F28.

3.2 Measurement System

3.2.1 Exploratory Factor Analysis

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

I investigate this division in internalizing and externalizing skills and confirm it in my dataset with an exploratory factor analysis. I estimate the factor loadings from the exploratory factor analysis, based on decomposing the polychoric correlation matrix of the items and using weighted least squares (Olsson, 1979). The polychoric correlation is an estimate for the correlation between two standard normal latent factors underlying ordinal responses. The solution of the exploratory factor analysis is finally rescaled using oblique factor rotation (Hendrickson and White, 1964).

Appendix Table C5 presents the exploratory factor analysis of the SDQ, where the factor loadings show a clear separation between items and support the division in internalizing and externalizing skills proposed by theory. The factor loadings have also a similar magnitudes across siblings, highlighting the similar association between the items and the factors across the younger and older sibling.

I also perform an exploratory factor analysis to verify if parental investment and the sibling bond are capturing only one latent structure, namely the "home environment", as discussed in Section 2.1. The exploratory factor analysis in Appendix Table C6 supports the existence of two distinct latent factors and shows a clear separation between items. The question items related to parental investment are highly correlated with the first latent factor (parental investment) and the items related to the sibling bond are highly correlated with the second latent factor (sibling bond).

Finally, Appendix Table C7 reports Cronbach's alpha which measures how closely related a set of items are for each latent factor (Cronbach, 1951). Cronbach's alpha is a measure of internal consistency for scale reliability and can take values between 0 and 1, where values closer to 1 correspond to higher reliability. Values above 0.50 are considered acceptable (Taber, 2018). Appendix Table C7 documents a good reliability for each latent factor.

3.2.2 Confirmatory Factor Analysis

I use a measurement system with categorical items to measure the latent factors. This allows me to look deeper into the multi-dimensionality of skills and study two dimensions of socio-emotional development. The measurement system with categorical items exploits the variation from each item of the SDQ - instead of aggregating their responses in continuous subscales to estimate a factor model with continuous items.[23]

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

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

the subscripts c in the factor model for the younger and older sibling in equations (10) and (11).[24]

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

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

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

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

Latent factors and the measurement error terms are assumed to be normally distributed: $ln\theta_{it} \sim \mathcal{N}\left(\mu_{\theta,t}, \sigma_{\theta,t}\right)$ and $\varepsilon_{ijt} \sim \mathcal{N}\left(0, \sigma_{\varepsilon,jt}\right)$. Some normalizations are needed in equations (10) and (11) for the parameters to be identified. First, as the intercepts and the thresholds cannot be jointly identified in a factor model with categorical items, intercepts are assumed zero, $\alpha_{jt} = 0, \forall j, t$. Second, following Agostinelli and Wiswall (2020), I normalize $\lambda_{jt} = 1$ and $\tau_{1,jt} = 0$ $\forall t = \{age - 3, age - 5\}$ wave for the younger and older sibling on the SDQ item: (i) *"Often complaining of headaches, stomach-aches or sickness"* to measure the internalizing skill, and (ii) *"Has often had temper tantrums or hot tempers"* to measure the externalizing skill. These questions are chosen as their mapping from m^{*}_{ijt} to m_{ijt} can reasonably be assumed to be time-invariant. This time invariance ensures the factors are measured on the same scale over time.

The normalization of the factors is a critical step to be able to compare the objective parameters of the production function over time and across siblings. Other normalizations are conceivable too as described in Appendix C.2, however they are not recommended as they do not allows me to compare the evolution of the factors over time and compare the estimates of the joint technology of skill formation with siblings.

To measure cognitive skills, I use a factor model with continuous items (more details on this model can be found in the Appendix C.3). I set the constant α_{jt} to 0 and the loading to λ_{jt} to 1 for the "naming vocabulary test", which has been administered at age-3 and 5 waves for the younger sibling, and let the mean and the variance of the latent factor be estimated (Agostinelli and Wiswall, 2020).

To measure the latent factors capturing parental investment and the sibling bond, I use the factor model outlined in this section and set the mean to 0 and the standard deviation to 1 for the identification of each latent factor. This normalization allows me to specify the underlying assumptions for the comparison of the productivity of the inputs. If I were to have a common question in the parental investment and sibling bond questionnaire (e.g. "how frequently parent

[24] I test for the invariance of the model between younger and older sibling in the next Section 3.3 and find support for such invariance.

and child play indoor activity" in the parent's questionnaire and "how frequently siblings play indoor activity together" in the sibling's questionnaire), then I could do the normalization on that questionnaire item by setting its constant to 0 and factor loading to 1. This would be slightly preferred because the normalization done on a common question would set the metric on that question to compare the productivity of the two inputs. Nevertheless, it could still be difficult to justify this normalization because, for example, an indoor activity with siblings may be completely different from an indoor activity with parents.

3.3 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 sibling's skills, I would like to set the same metric to compare the structural estimates of the joint technologies of skill formation for the younger and older sibling. I also need to assure that I can control for comparable measures of the younger and older sibling's socio-emotional skills. This requires the socio-emotional questionnaire items to have the same relationship with the latent constructs across the younger and older sibling. In other words, socio-emotional questionnaire items in the factor model must be invariant to the group, in this instance across the younger and older sibling. Specifically, the older and younger sibling's 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.[25] Following the assumptions introduced by Wu and Estabrook (2016), the test compares the baseline model, namely the maximal identifiable model, with a series of models with stronger restrictions on the item- and sibling-specific intercepts and loadings, requiring them to be the same across groups. Their fit is then compared to see if the models with stronger restrictions have a worse fit. If the fit is not worse, then measurement invariance is not rejected.

I estimate three models with additional restrictions to compare their relative fit with respect to the baseline model. First, a threshold invariant model is estimated where the threshold are restricted to be the same across younger and older sibling ($\tau_{1,YSjt} = \tau_{1,OSjt}$, $\tau_{2,YSjt} = \tau_{2,OSjt}$, $\mu_{\theta,YSt} = \mu_{\theta,OSt} = 0$, $\sigma_{\theta,YSt} = \sigma_{\theta,OSt} = 1 \; \forall j,t$). 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

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

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

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

The recommendation is to present a range of fit indices for a more comprehensive assessment. Therefore, I first present the χ^2 statistic, but also other alternative goodness-of-fit indices commonly used, such as the root mean squared error of approximation (RMSEA), standardised root mean square residual (RMSR), the comparative fit index (CFI), and the Tucker-Lewis index (TLI).[26]

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

[26]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 3: Comparison of models' fit for measurement invariance

			Absolute fit			
	N of Parameters	χ^2	RMSEA	RMSR	CFI	TLI
Baseline model/ Threshold Invariance	98	2557.8760	0.0612	0.0841	0.9481	0.9396
Threshold and loading invariance	84	2915.3940	0.0634	0.0889	0.9405	0.9351
Threshold, loading, and intercept invariance	70	3567.5550	0.0684	0.0918	0.9265	0.9246

	Relative Fit to the Baseline model/Threshold Invariance				
	P-value	Δ RMSEA	Δ RMSR	Δ CFI	Δ TLI
Threshold and loading invariance	0.0000	0.0022	0.0048	-0.0076	-0.0044
Threshold, loading, and intercept invariance	0.0000	0.0072	0.0078	-0.0217	-0.0150

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

3.4 Estimation

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

I use the one-step estimation strategy developed in the psychometrics literature by Muthén (1984) and Muthén (1983). This estimation method is well suited to estimate factor models with *categorical* items in one step (more details on the estimation strategy can be found in Appendix C.4. Attanasio, de Paula, and Toppeta (2022) also use this estimation strategy to estimate intergenerational mobility in socio-emotional skills).

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

4 Results

This section presents the estimates for the investment and production functions for externalizing (ability to engage in interpersonality activities), internalizing (ability to focus their drive and determination to achieve long-term goal) and cognitive skills for the younger sibling and older sibling during childhood. The younger sibling's development is measured at age 5 for every child, while the older sibling's development is measured at different ages for different children. The older sibling's technology is conditional on the older sibling's age. The factor model, the production

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

function and the investment function are estimated in one step. Standard errors and p-values reported in the Tables are bootstrapped with 100 repetitions. The coefficients in the tables are elasticities as all the variables are in logs, except for the dummies and the categorical variables.

4.1 Investment Function Estimates

The estimates of the investment functions are presented in Table 4, where Column 1 focuses on the sibling bond and Column 2 on parental investment. Studying the determinants of these two inputs is relevant for understanding the origin of disadvantage and in turn understand how to intervene to break its intergenerational transmission. They depend on the younger and older sibling's skills at t-1, parental background, household resources and the excluded instruments. The key justification for the two excluded instruments, discussed below, lies in the fact that the production function includes sufficient background characteristics, such as, for example, parents and siblings' social skills, housing characteristics and family composition. This allows me to control for the household's personality and resources, that determine permanent wealth, and view the residual variation in the instruments as quasi-random.

First, the number of rooms conditional on a large set of controls is positively associated with the sibling bond, as shown by the bootstrapped F-statistic and p-values (Column 1 of Table 4). Intuitively, if siblings share the same bedroom, it would be harder for them to find space to regain control of their emotions during a heated debate, ending up exacerbating the conflicts. On the other hand, having their own bedroom would allow them to have their privacy and interact with each other when they desire to do so.

Thinking about possible violations of the exclusion restriction, it is important to keep in mind that the MCS has very rich information on background characteristics for which I can condition on. This allows me to consider similar households with similar family compositions who live in homes that are approximately the same size where quasi-randomly siblings share their bedroom in some instances, while they do not in others. Then the instrument should exploit the residual variation that is plausibly exogenous and should affect child development only through the sibling bond. Table 4 shows indeed that the adjustment cost to housing appears to affect the child's human capital only through the sibling bond (Column 1), but not through parental investment (Column 2).[28]

Second, the estimates of the investment function for parental investment are presented in Column 2 of Table 4. I use the mother's employment status as a proxy for the female local unemployment rate conditional on a large set of controls, such as, for example, the partner being present in the household, the partner's employment status, and household's resources (Carneiro,

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

Meghir, and Parey, 2013).[29] The key justification for this excluded instrument is that the residual variation should capture the plausibly exogenous variation that affects the child's human capital only through parental investment. Indeed, the residual variation in the mother's employment appears to affect child development only through parental investment (Column 2), but not through the sibling bond (Column 1).

The mother's employment status is a relevant instrument as reported by the bootstrapped F-statistics and p-values in Table 4. Intuitively, the negative relationship between the female employment shock and parental investment suggests that the mother is working and has less time available to interact with the child, after controlling for household's resources. This is consistent with the measures of parental investment in the MCS, which primarily focus on parent-child interactions, such as the frequency of reading and telling stories to the younger child, rather than material investment (Section 3.1).

Table 4: Investment function estimates (age 5)

Outcome	**Sibling Bond** (1)	**Parental Investment** (2)
Number of rooms (t-1)	0.040***	0.004
	(0.014)	(0.017)
Mother's employed (t)	0.011	-0.151***
	(0.039)	(0.031)
EXT skill (t-1)	0.245***	0.060
	(0.069)	(0.057)
INT skill (t-1)	-0.028	0.212
	(0.139)	(0.134)
COG skill (t-1)	-0.013	0.011
	(0.072)	(0.052)
Older sibling's EXT skill (t-1)	0.321***	0.100*
	(0.047)	(0.056)
Older sibling's INT skill (t-1)	0.153	-0.052
	(0.125)	(0.093)
Test of joint significance: Bootstrapped F-statistic (*p*-value)		
Number of rooms, Mother's employed	7.762 (0.021)	23.804 (0.000)
Number of rooms	7.756 (0.005)	0.084 (0.771)
Mother's employed	0.063 (0.802)	23.336 (0.000)
Observations	3044	3044
Other controls	Yes	Yes

Note. The Table presents the structural estimates of the investment functions. The measurement system and the outcome equation are estimated jointly. Other controls include younger sibling's gender, age gap between younger and older sibling, older sibling's gender, number of children in the house, mother's mental health, mother's education, mother's age, whether the household is dual or single headed, partner's employment status, home atmosphere, how close the bond between mother and child is, housing tenure, years lived in current address, region fixed effects. Standard errors in parentheses are obtained using 100 bootstrap repetitions (*** p<0.01, ** p<0.05, * p<0.1).

[29] I am currently waiting to receive access to the restricted geo-coded data from the UK dataservice. This would allow me to link household to the female local unemployment level in the local authority where the family lives. Once I gain access to the geo-coded data, I can reproduce the results with the geo-coded female local unemployment rate. All the children in the sample are attending reception school at age 5, so the mother's employment status is not simply capturing the childcare status of the child.

4.2 Production Function Estimates

This Section discusses the estimates of the joint technology of skill formation for the younger and older sibling. Outputs are externalizing (ability to engage in interpersonality activities), internalizing (ability to focus their drive and determination to achieve long-term goal) and cognitive skill (ability to learn and solve tasks). Studying these different dimensions of human capital allows me to appreciate the complexity of the development process and understand how each skill dimension is formed and interact with each other. Table 5 presents the estimates for the younger sibling's production function (equation 6). Columns 1 and 2 of Table 5 present the estimates for the externalizing skill, Columns 3 and 4 for the internalizing skill, and Columns 5 and 6 for the cognitive skill. Odd Columns present the estimates of the skill formation technology, which ignore the endogeneity of the sibling bond and parental investment and consider them as exogenous, while Even Columns present the estimates, which address the endogeneity of the inputs.

There are two general considerations to highlight before turning to the productivity of the sibling bond and parental investment. First, skills are self-productive (Cunha, Heckman, and Schennach, 2010). This holds true for each skill dimension. For example, a 10% increase in the externalizing skill at time t-1 translates into a 6.5% increase in the externalizing skill at time t (Column 1). 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% increase in the internalizing skill at time t. It would be interesting to consider additional lags of development as done in Attanasio, Bernal, Giannola, and Nores (2020) and Attanasio, De Paula, and Toppeta (2020) to study how persistent the development process is and whether it follows a first-order Markov chain processes. Unfortunately, this is not possible in my setting due to data limitation as the t-2 wave is at birth.

Second, the older 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 (2020) do not consider this as they focus on a single child. I show that an increase in the older sibling's externalizing skill at t-1 is negatively associated with the younger sibling development. The psychology literature has theorized that if one sibling has a high externalizing skill (i.e., extrovert), then the other one is likely to have a high internalizing skill (i.e., introvert) and viceversa (Plomin and Daniels, 1987). This could, for example, be because a sibling with a strong externalizing skill, which corresponds to a high ability to engage in interpersonal activity, might overshadow the other sibling and push the other sibling to develop another dimension of skill where she could have a comparative advantage.

My estimates suggest that a 10% increase in the older sibling's externalizing skill at time t-1 translates into a 1.4% decrease in the younger sibling's externalizing skill at time t (Column 2). This effect would correspond to a spillover from the older sibling's externalizing skill to the younger sibling under the assumption of unidirectional influence from the older to the younger sibling and a timing restriction. Unfortunately, I cannot control for the endogeneity of such spillovers as finding another instrument for the siblings' socio-emotional development within the family is quite demanding. The influence from the older to younger sibling is however supported by several studies in the psychology as a first approximation (Buhrmester, Boer, and Dunn, 1992; Rodgers and Rowe, 1988). This result calls for additional investigation as a negative spillover could have implications for policies aimed at improving only one sibling's interpersonal skills.

Turning to the sibling bond and parental investment, the sibling bond is productive and increases child development with a significant coefficient for each of three skill dimensions.[30] In Column 1, where the endogeneity problem is not addressed, a 10% increase in the sibling bond increases the younger sibling's externalizing skill by 0.9%. On the other hand, in Column 2, when I correct for the endogeneity problem, the productivity is four times larger, with the sibling bond increasing the younger sibling's externalizing skill by 4.4% points.

The estimates of the productivity of parental investment in the younger sibling are insignificant and sometimes have a negative coefficient when parental investment and sibling bond are treated as exogenous (Columns 1, 3 and 5). This finding is consistent with the literature when parental time investment is treated as exogenous because the endogeneity of parental time investment drives the structural estimates close to zero (Attanasio, Cattan, Fitzsimons, Meghir, and Rubio-Codina, 2020). For example, parents may observe a developmental shock to skills, which is unobserved by the econometrician, and adjust their level of investment to equalize the shock.

On the other hand, when I treat parental investment as endogenous, parental investment is productive for child development. Namely, a 10% increase in parental investment increase the younger sibling's cognitive skill by 3.2% (Column 6). Similar estimates of the productivity of parental investment for cognitive skills are found in Cunha, Heckman, and Schennach (2010). The structural estimates on parental investment are however not statistically significant. This could be due to lack of power or the inclusion of a large set of controls aimed at reinforcing the assumption, that the instruments are quasi-exogenous. Appendix Table reproduces Table 5 by restricting the productivity of the sibling bond to be zero. Estimating this restricted model entails assuming away the productivity of the sibling bond as previously done in the literature. Parental investment becomes significant, and the size of the coefficient increases when I restrict the productivity of the sibling bond to be zero (Appendix Table D11). Comparing the estimates in Column 6 from Table 5 and Appendix Table D11 hints that part of the effect of parental investment is mediated by the sibling bond in family with siblings.

Interestingly, parental investment does not seem to contribute to the younger sibling's internalizing skill. It is important to recall what activities, such as reading or playing games with the younger siblings, are captured in the parental investment questionnaire (Section 3.1). These

[30]Table 5 uses the data on the sibling bond between the cohort member (i.e., younger sibling) and the randomly-selected older sibling from whom data on social skills have been collected. This allows to condition on the younger and older sibling's social skills and captures the productivity of the sibling bond conditional, for example, on their ability to engage in interpersonal activities and focus drive their determination. Appendices D.1 and D.2 present evidence that the estimates of the sibling bond productivity in Table 5 are robust to the sibling bond from different sibling combinations in families with multiple older siblings and to the birth of new younger siblings between the age-3 and 5 waves. First, Appendix Table D9 reproduces Table 5 by using the average of the sibling bond from different younger and older sibling combinations for the younger siblings with 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 D10 reproduces the estimates for Table 5 for columns 1, 3 and 5 by controlling for the number of new births in the family, and provides suggestive evidence that the birth of another sibling does not affect the productivity of the sibling bond between the cohort member (i.e., younger sibling) and older sibling (10% of children with siblings witness the birth of another sibling between the age-3 and 5 waves).

activities are not directly aimed at improving the internalizing skill (i.e., focus their drive and determination to achieve a long-term goal).

When siblings are considered in the process of development - instead of focusing on a single child - it becomes important to study the process of development for the older sibling too (Appendix Tables D12-D13). When looking at the estimates in Appendix Tables D12-D13, three caveats need to be kept in mind due to data limitations. First, only two dimensions of socio-emotional development can be considered as the older sibling was not the target child of the MCS. Second, data are collected from the older siblings at different ages, so it is not possible to define a production function of child development at a specific age. The technology of child development controls for the older sibling's age. Third, the MCS does not collect data on parental investment in the older sibling - the parental investment in the younger sibling is included instead.

The older sibling's production function estimates present similar patterns to the younger sibling's one (Appendix Tables D12-D13). First, skills are self-productive. Second, the younger sibling's skills affect the development of the older sibling, which confirms the theory in the psychology literature stating 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) (Plomin and Daniels, 1987). Third, the productivity of sibling bond in the older sibling's skill formation technology has a similar productivity to the younger sibling's one. This evidence reiterates that strengthening the sibling bond fosters the joint production of skills, showing that a higher quality sibling bond benefits both siblings.

The estimates presented in Table 5 and Appendix Table D12 assume a Cobb-Douglas specification. Appendix D.5 experiments with different functional form assumptions for the production function, such as a translog production function, where the elasticity of substitution between inputs can be different from 1. The translog specification allows me to investigate if the sibling bond interacted by lag of the siblings' skills has an effect on their development. The estimates for the translog production function are presented in Appendix Table D14. The restrictions implied by the Cobb-Douglas specification do not seem to be rejected, suggesting that the Cobb-Dougas constitutes a good approximation in my dataset. This is consistent with Attanasio, Cattan, Fitzsimons, Meghir, and Rubio-Codina (2020) and Attanasio, Meghir, and Nix (2020).

Appendix D.6 exploits the data on the younger sibling's socio-emotional development reported by the teachers - instead of the parents - to address any concerns about misreporting bias regarding the estimates of the production of externalizing and internalizing skills.[31] Del Bono, Kinsler, and Pavan (2020) show that socio-emotional skill measures can suffer from misreporting bias when parents answer these questions. They use the responses to two different questionnaires, administered respectively to the parents and the teachers, in a factor model with continuous items to address the concerns of misreporting bias of socio-emotional skills. However, comparing responses given to different questionnaires could confound if the differences in socio-emotional skill measures are due to different respondents or different questionnaires.

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

Table 5: Technology of skill formation with siblings: younger sibling (age 5)

Outcome	Externalizing (EXT)		Internalizing (INT)		Cognitive (COG)	
	(1) Exogenous	(2) Endogenous	(3) Exogenous	(4) Endogenous	(5) Exogenous	(6) Endogenous
EXT skill (t-1)	0.654***	0.547***	-0.002	-0.126*	0.098**	-0.159
	(0.061)	(0.111)	(0.025)	(0.069)	(0.038)	(0.138)
INT skill (t-1)	-0.093	-0.113	0.771***	0.775***	0.027	-0.014
	(0.070)	(0.084)	(0.188)	(0.178)	(0.084)	(0.163)
COG skill (t-1)	0.077	0.077	-0.014	-0.013	0.574***	0.567***
	(0.068)	(0.129)	(0.028)	(0.056)	(0.035)	(0.068)
Older sibling's EXT skill (t-1)	-0.016	-0.144*	-0.053**	-0.219***	0.016	-0.330**
	(0.021)	(0.075)	(0.023)	(0.082)	(0.026)	(0.133)
Older sibling's INT skill (t-1)	-0.003	-0.041	0.025	-0.048	-0.044	-0.180
	(0.044)	(0.081)	(0.043)	(0.075)	(0.061)	(0.149)
Sibling bond (t)	0.089***	0.443**	0.043***	0.546**	-0.017	0.969**
	(0.018)	(0.211)	(0.017)	(0.220)	(0.026)	(0.399)
Parental investment (t)	0.009	0.149	-0.028*	-0.003	0.020	0.319
	(0.015)	(0.169)	(0.015)	(0.177)	(0.024)	(0.255)
Observations	3044	3044	3044	3044	3044	3044
Other controls	Yes	Yes	Yes	Yes	Yes	Yes

Note. The Table presents the structural estimates of technology of skill formation for the younger sibling at age 5. $t-1$ corresponds to age 3. The Odd columns consider the sibling bond and parental investment as exogenous, while the Even columns allow the sibling bond and parental investment to be endogenous. 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 5-6 for cognitive skill (ability to learn and solve tasks). The measurement system and the outcome equation are estimated jointly. Other controls include younger sibling's gender, age gap between younger and older sibling, older sibling's gender, number of children in the house, mother's mental health, mother's education, mother's age, whether the household is dual or single headed, partner's employment status, home atmosphere, how close the bond between mother and child is, housing tenure, years lived in current address, region fixed effects. Standard errors in parentheses are obtained using 100 bootstrap repetitions (*** p<0.01, ** p<0.05, * p<0.1).

I therefore use the individual items from the teacher's socio-emotional questionnaire that are similarly worded to the ones in the parent's questionnaire (i.e., Strengths and Difficulties Questionnaire). I then use these items to estimate a factor model with categorical items and measure externalizing skill as reported by the teachers and the parents respectively. This provides a measure of the latent externalizing skill at age 5 that differs only by the nature of the respondent as similar survey questions are used across parents and teachers.[32] Appendix Table D15 reports the structural estimates from estimating the production function with the externalizing skill reported by the teacher - instead of the parents - and finds similar structural estimates for the self-productivity of skills and the productivity of the inputs to the ones obtained when using the information about the socio-emotional skills reported by the parents (Table 5).

Finally, Appendix D.7 explores two possible source of heterogeneity in the structural estimates of younger sibling's skill formation technology: the siblings' gender and the age. Unfortunately,

[32] Appendix D.6 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.

the structural estimates become unreliable when the sample is split and investments are allowed to be endogenous as the instruments become weak. The estimates are reported in Appendix Tables D16-D21. Appendix Table D18 provides some suggestive evidence that the sibling bond could be more productive for same-sex than mixed-sex siblings.

5 Using the Structural Estimates

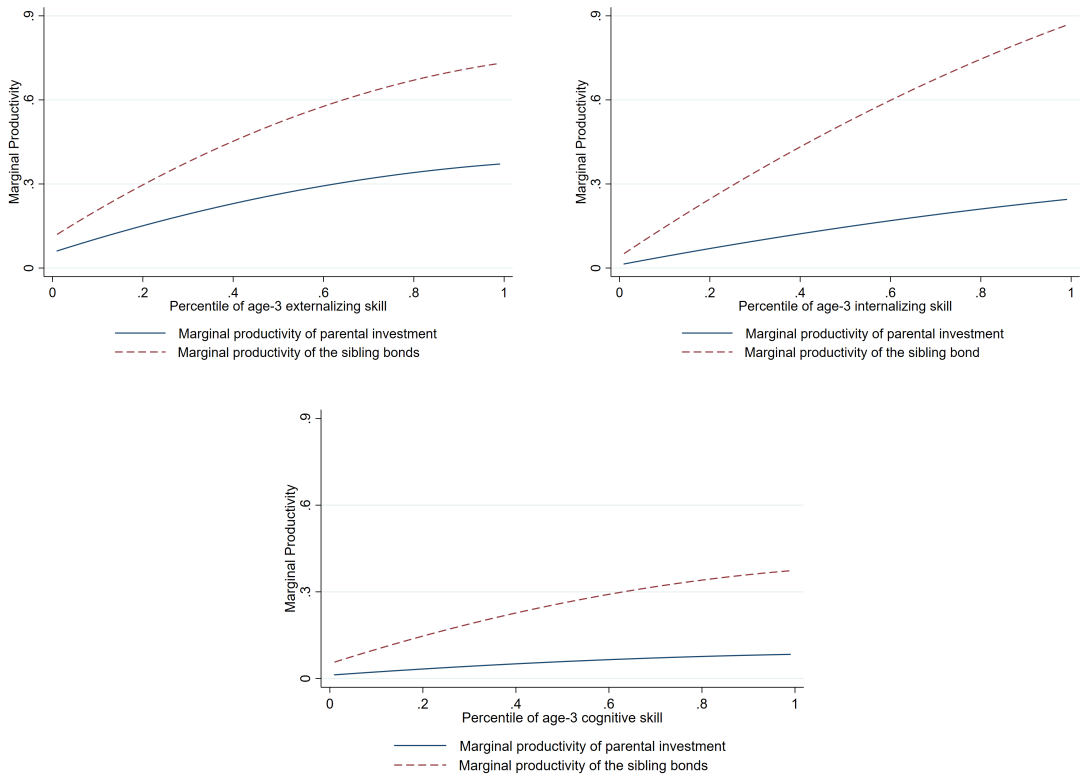
This section uses the structural model to provide some insights on the joint technology of skill formation with siblings. I focus on two aspects that are relevant for policy. First, I use the structural estimates of the younger sibling's technology to trace the marginal productivity of the sibling bond and parental investment. Second, I perform some counterfactual simulations to understand the effects of some hypothetical interventions on skills.

5.1 Marginal Productivity of Parental Investment and Sibling Bond

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

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

Figure 3: Marginal productivity of investment and sibling bond



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

5.2 Counterfactual Simulations

The structural model is useful to perform some counterfactual simulations of hypothetical interventions aimed at stimulating parental investment and the sibling bond and in turn understand how these policies would affect skill formation. So far policies have mostly focused on stimulating parent-child interactions, while not considering siblings (see for example Evans, Jakiela, and Knauer (2021)). In this section, I do not focus on practical aspects of the policy implementation, but refer to Leijten, Melendez-Torres, and Oliver (2021) who review randomized control trials to improve sibling interactions and identify only 8 studies that test these interventions with promising results. Some examples are Siddiqui and Ross (2004), Kramer (2004) and Kennedy and Kramer (2008). The design of such interventions draw from behavior management and mediation, such as directing children's behavior using reinforcement practices or maintaining impartiality and facilitating communication between siblings.

Unfortunately, these interventions have looked only at the sibling relationship as an outcome without trying to understand the effect of such interventions on child development. In addition, they have a small sample with an average of less than 55 households. Therefore, my counterfactual simulations offer some novel insights on how a hypothetical intervention aimed at stimulating the bond between siblings and/or parental investment would affect skills.

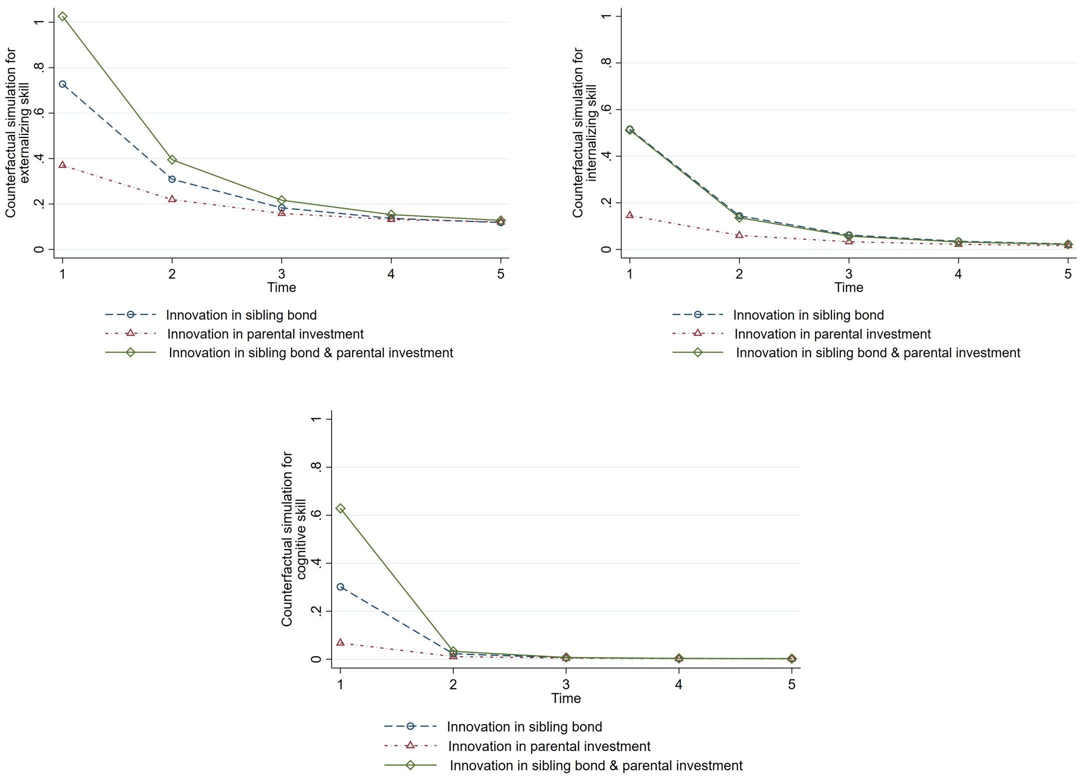
Before proceeding with the counterfactual simulations, I perform a validation exercise to check how well the model does in terms of out-of-sample prediction. I use the structural estimates of younger sibling's skill formation technology at age 5 to predict their skills over the life-cycle at ages 5, 7, 11, 14 and 17, iterating the model for each younger sibling i, based on the baseline inputs and skills.[33] Then I reproduce Figure 2, which shows that the age-5 sibling bond predicts skills across adolescence, with the predicted data from the structural model and check if I observe similar patterns to the true data collected by the MCS at ages 5, 7, 11, 14 and 17. The results are presented in Appendix Figure E9 and show that the model performs well for socio-emotional development with respect to the out-of-sample data, while it seems to slightly overpredict cognitive development. This validation builds some confidence in the counterfactual exercises presented below.

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

The second thought experiment considers children at the bottom 20% of the skill distribution and assigns them the level of the top 20% parental investment and the sibling bond at time 1. I compare this counterfactual simulation to a scenario where the children in the bottom 20% of the skill distribution receive the bottom 20% level of parental investment and the sibling bond at time 1. For the remaining 4 periods (times 2-5), parental investment and the sibling bond are set equal to their mean 0. Again, to trace the evolution of skills, the production function is assumed to have the same parameters at each time t. The counterfactual simulations are presented in Figure 5, showing that if children at the bottom of the distribution would have the opportunity to receive the parental investment and engage in higher quality relations with their siblings as the top of the distribution, then their skills would be twice as large.

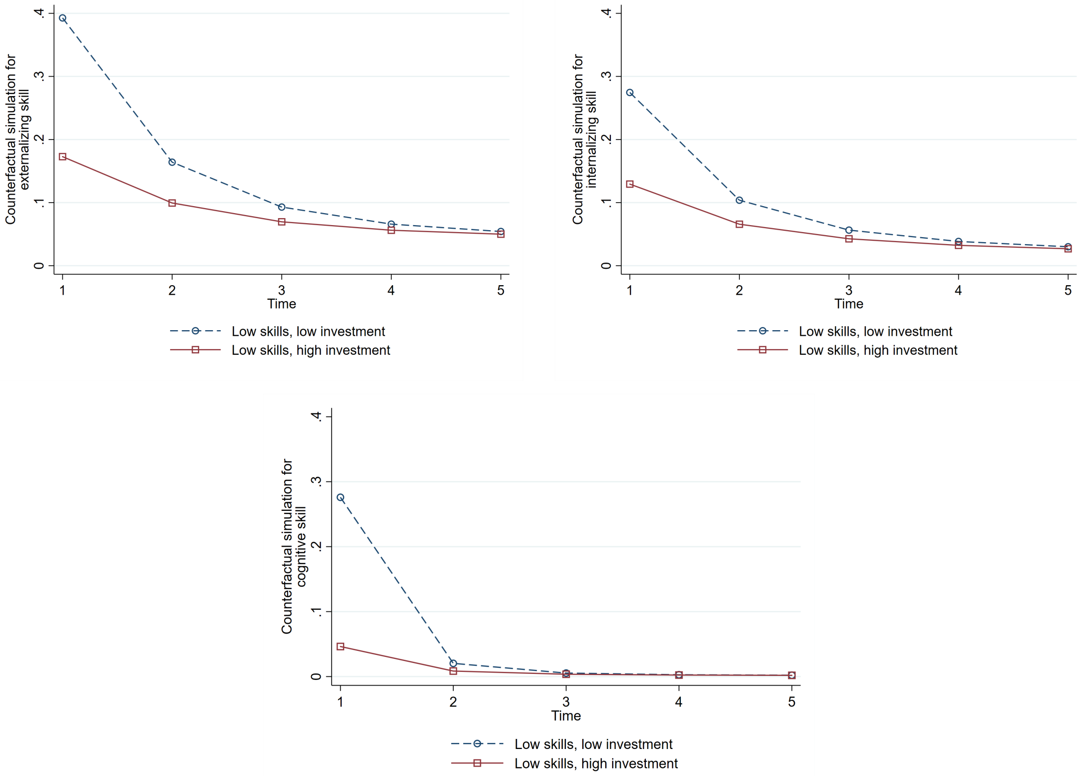
[33]While holding the parameters of younger sibling's the production function at the age-5 structural estimates, I predict the level of skills at age 5 based on the baseline inputs for each younger sibling i. I then repeat the same exercise by predicting the level of skills at age 7 based on the baseline inputs for each younger sibling i and the predicted level of skills at age 5. I keep on iterating the model up to age 17.

Figure 4: Counterfactual simulation: impact of an intervention to improve parental investment and sibling bond



Note. The Figures present the counterfactual simulation of an intervention to improve parental investment and the sibling bond on skills by 1 standard deviation only at time 1, as implied by the estimated production functions. Parental investment and sibling bond are set equal to their mean 0 from time 2 to 5. The production function is assumed to have the same parameters in each time t. While holding all inputs at their median values at baseline, the solid line draws an innovation of 1 standard deviation only at time 1 in parental investment and the sibling bond. The dash and dot-dash lines reproduces a similar exercises drawing an innovation 1 standard deviation only at time 1 respectively only in the sibling bond and parental investment.

Figure 5: Counterfactual simulation: increasing investment at the bottom of the skill distribution



Note. The Figures present the counterfactual simulation of assigning the level of the top 20% of parental investment and the sibling bond distributions to the children with skills at the bottom 20% of the distribution at time 1, as implied by the estimated production functions. Parental investment and sibling bond are set equal to their mean 0 from time 2 to 5. The production function is assumed to have the same parameters in each time t. Low correspond to the bottom 20% of the distribution, while high correspond to the top 20% of the distribution.

6 Conclusion

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

The literature has established that parent-child interactions and parents' skills are central in the human capital formation process in the early year by estimating the technology of skill formation with a *single* child. On the other hand, the role of siblings and their interactions for human capital formation have been understudied so far, even if the majority of children in most countries have at least one sibling. For example, in the United Kingdom, which is the context of this study, 75% of children have at least one sibling by the age of 5. As siblings grow up, they spend a considerable amount of time together, building a bond that is likely to last longer than any other ones. In turn, this bond can allow them to work together effectively to achieve a common purpose in the joint production of skills, while serving as sources of social support and role models for one another.

This paper formalizes and structurally estimates the joint technology of skill formation for the younger and older siblings, allowing both parental investment and the sibling bond to be productive. I use the data from the Millennium Cohort Study to open the black box of sibling spillovers by using information on the frequency of the quality of the interactions between siblings, such as experiencing enjoyable time together. This allows me to use a factor model to measure the latent factor capturing the sibling bond and explore the role of siblings and parents in the joint formation of skills within the family.

Two sets of results are presented when siblings are incorporated in the study of skill formation. First, I present suggestive 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 technology of joint skill formation for the younger and older sibling and present evidence that a quality bond between siblings matters over and beyond parental investment and benefits both siblings' development.

This paper provides a fertile ground to think about novel interventions and policies where the focus is not only on the parents of the target child but also on their siblings. For example, Evans, Jakiela, and Knauer (2021) review early childhood development interventions (ECD) in low-medium income countries and find only 7 studies out of 478 ECD reporting impacts on older siblings. Leijten, Melendez-Torres, and Oliver (2021) review randomized control trials to improve sibling relations and find only 8 studies with some limitations, such as no measures on children's outcomes. My counterfactual simulations highlight the importance of thinking about the child as part of a family system and focusing both on parent-child interactions as well as sibling interactions.

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Appendices to "Skill Formation with Siblings"

A Motivating evidence: additional results

A.1 Sibling bond and future outcomes

Table A1: Sibling bond at age 5 predicts the younger sibling's relational outcomes at age 14

Panel A:	without controls				
Outcome	Time on social network websites	Wellbeing	Argue with parents	Talk to sibling if worried	Talk to parents if worried
	(1)	(2)	(3)	(4)	(5)
Sibling bond (age 5)	-0.124***	0.047***	-0.080**	0.026***	-0.001
	(0.035)	(0.015)	(0.033)	(0.008)	(0.009)
Observations	4622	4439	4232	4542	4542
R^2	0.004	0.003	0.002	0.003	0.000
Younger & older sib's skills (age-3 wave)	No	No	No	No	No
Parental investment (age-5 wave)	No	No	No	No	No
Other controls	No	No	No	No	No

Panel B:	with controls				
Outcome	Time on social network websites	Wellbeing	Argue with parents	Talk to sibling if worried	Talk to parents if worried
	(1)	(2)	(3)	(4)	(5)
Sibling bond (age 5)	-0.067*	0.016	-0.123***	0.018**	-0.008
	(0.039)	(0.016)	(0.036)	(0.009)	(0.010)
Observations	4124	3974	3791	4057	4057
R^2	0.109	0.115	0.047	0.027	0.015
Younger & older sib's skills (age-3 wave)	Yes	Yes	Yes	Yes	Yes
Parental investment (age-5 wave)	Yes	Yes	Yes	Yes	Yes
Other controls	Yes	Yes	Yes	Yes	Yes

Note. The table presents the relationship between the sibling bond at age 5 and the younger sibling's relational outcomes at age 14 with and without controls. The index of the sibling bond is constructed by summing the values from the following 4 questions about how often [frequently, sometimes, never] the cohort member (i.e., the younger sibling): (i) Likes to be with the older sibling, (ii) Not much interested in the older sibling, (iii) Has a lot of fun with the older sibling, (iv) Teases or needles the older sibling. I recode behaviours indicating worse interactions in reverse (i.e., not much interested in older sibling and teases or needles older sibling). The index of parental investment in younger sibling is obtained by summing the values from the questions asking the parents how often [Every day, Several times a week, Once or twice a week, Once or twice a month, Less often, Not at all] they do the following activities: (i) How often do you read to the child, (ii) How often tells stories to the child, (iii) How often does musical activities with the child, (iv) How often does the child paint/draw at home, (v) How often do you play physically active games with the child?, (vi) How often play indoor games with the child? and (vii) How often play outdoor games with the child? The sibling bond index is standardized to have mean 0 and standard deviation 1. Other controls include younger sibling's gender, age gap between younger and older sibling, older sibling's gender, number of children in the house, mother's mental health, mother's education, mother's age, whether the household is dual or single headed, partner's employment status, home atmosphere, how close the bond between mother and child is, housing tenure, years lived in current address, region fixed effects. Internalizing skill captures the ability to focus their drive and determination to pursue a long-term goal. Externalizing skill captures the ability to engage in interpersonal activities. Robust standard errors in parentheses (*** p<0.01, ** p<0.05, * p<0.1).

Table A2: Sibling bond at age 5 predicts future educational and health outcomes for the younger sibling during young adulthood (full sample - i.e., children with and without siblings)

Panel A:

Outcome	Achieve A* (GCSE Math)				Achieve A* (GCSE English)			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Sibling bond (age 5)	1.019***	0.491***	0.535***	0.275*	0.912***	0.421***	0.442***	0.319**
	(0.124)	(0.159)	(0.159)	(0.155)	(0.112)	(0.148)	(0.149)	(0.143)
Dummy for single child	2.187***	1.163***	1.150***	-0.094	2.018***	1.464***	1.443***	0.872**
	(0.278)	(0.409)	(0.414)	(0.473)	(0.252)	(0.379)	(0.385)	(0.434)
Observations	4597	2833	2791	2692	4621	2843	2797	2703
R^2	0.019	0.131	0.131	0.240	0.018	0.134	0.133	0.260
Younger & older sib's skills (age-3 wave)		✓	✓	✓		✓	✓	✓
Parental investment (age-5 wave)			✓	✓			✓	✓
Other controls				✓				✓

Panel B:

Outcome	Study for A-level qualification (age 17)				Aspiration to study at University (age 17)			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Sibling bond (age 5)	0.210***	0.126***	0.134***	0.097**	17.764***	10.966***	11.562***	7.874**
	(0.032)	(0.042)	(0.043)	(0.044)	(2.735)	(3.573)	(3.602)	(3.540)
Dummy for single child	0.435***	0.310***	0.324***	0.217*	42.293***	24.307**	23.494**	8.137
	(0.073)	(0.112)	(0.114)	(0.132)	(6.173)	(9.898)	(10.045)	(11.343)
Observations	4975	3051	3002	2882	3729	2284	2252	2170
R^2	0.012	0.087	0.085	0.168	0.018	0.109	0.108	0.183
Younger & older sib's skills (age-3 wave)		✓	✓	✓		✓	✓	✓
Parental investment (age-5 wave)			✓	✓			✓	✓
Other controls				✓				✓

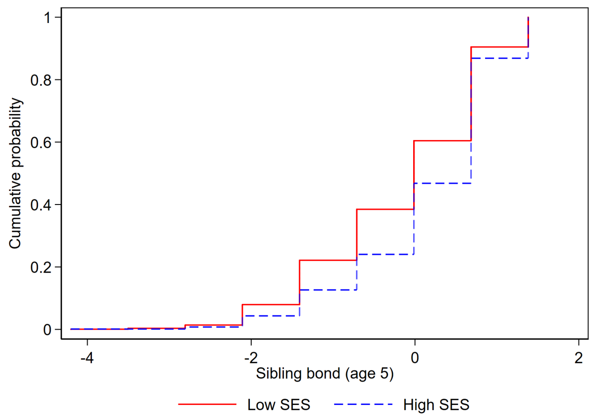
Panel C:

Outcome	Smoke cigarettes (age 14)				Smoke cigarettes (age 17)			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Sibling bond (age 5)	-0.120***	-0.075**	-0.073**	-0.057*	-0.103***	-0.119***	-0.125***	-0.095**
	(0.022)	(0.030)	(0.030)	(0.031)	(0.031)	(0.042)	(0.042)	(0.044)
Dummy for single child	-0.261***	-0.308***	-0.301***	-0.190**	-0.239***	-0.266**	-0.264**	-0.118
	(0.050)	(0.080)	(0.079)	(0.090)	(0.069)	(0.110)	(0.111)	(0.135)
Observations	6207	3706	3648	3500	5470	3306	3252	3122
R^2	0.008	0.027	0.026	0.051	0.003	0.014	0.014	0.026
Younger & older sib's skills (age-3 wave)		✓	✓	✓		✓	✓	✓
Parental investment (age-5 wave)			✓	✓			✓	✓
Other controls				✓				✓

Note. The table presents the relationship between the sibling bond at age 5 and educational and health outcomes at ages 14 and 17 for the younger siblings for the full sample (children with and without siblings) with and without controls. Observations for the sibling bond and the older sibling's social skills are replaced with their minimum level when the child is a single child. Then in the regression, I control for the number of siblings and a dummy variable equal to 1 if the child is a single child. The index of the sibling bond is constructed by summing the values from the following 4 questions about how often [frequently, sometimes, never] the cohort member (i.e., the younger sibling): (i) Likes to be with the older sibling, (ii) Not much interested in the older sibling, (iii) Has a lot of fun with the older sibling, (iv) Teases or needles the older sibling. I recode behaviours indicating worse interactions in reverse (i.e., not much interested in older sibling and teases or needles older sibling). The index of parental investment in younger sibling is obtained by summing the values from the questions asking the parents how often [Every day, Several times a week, Once or twice a week, Once or twice a month, Less often, Not at all] they do the following activities: (i) How often do you read to the child, (ii) How often tells stories to the child, (iii) How often does musical activities with the child, (iv) How often does the child paint/draw at home, (v) How often do you play physically active games with the child?, (vi) How often play indoor games with the child? and (vii) How often play outdoor games with the child? Th sibling bond index is standardized to have mean 0 and standard deviation 1. Other controls include younger sibling's gender, age gap between younger and older sibling, older sibling's gender, number of children in the house, mother's mental health, mother's education, mother's age, whether the household is dual or single headed, partner's employment status, home atmosphere, how close the bond between mother and child is, housing tenure, years lived in current address, region fixed effects. Internalizing skill captures the ability to focus their drive and determination to pursue a long-term goal. Externalizing skill captures the ability to engage in interpersonal activities. Robust standard errors in parentheses (*** p<0.01, ** p<0.05, * p<0.1).

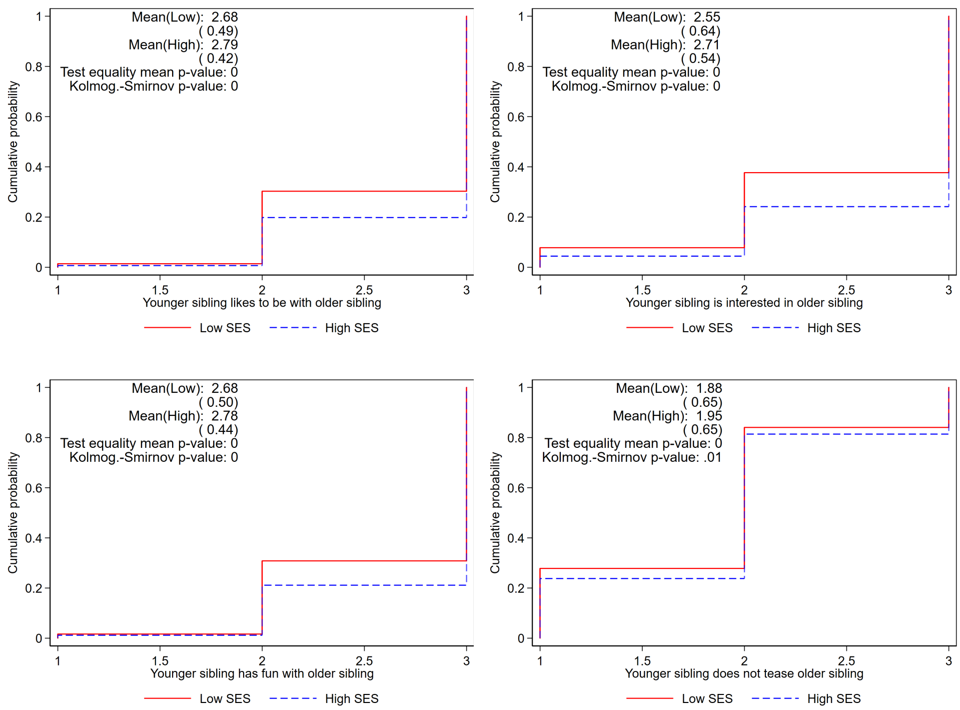
A.2 Determinants of the Sibling Bond and parental investment

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



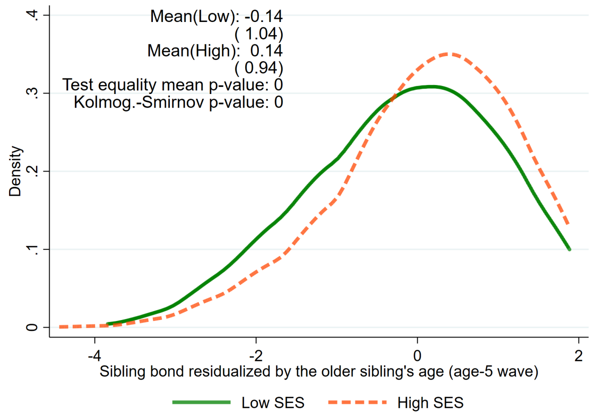
Note. The Figure presents the socioeconomic gradient in the quality of sibling bond at the age-5 wave. The socioeconomic status is the mother's education at the age-5 wave (dummy for whether the mother continued schooling past the minimum leaving age, based on her date of birth). The index of the sibling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

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



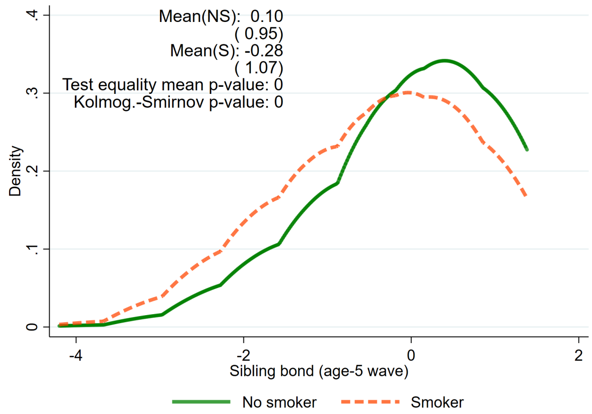
Note. The Figure presents the socioeconomic gradient in each item used to measure the quality of sibling interactions at the age-5 wave. The socioeconomic status is the mother's education at the age-5 wave (dummy for whether the mother continued schooling past the minimum leaving age, based on her date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

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



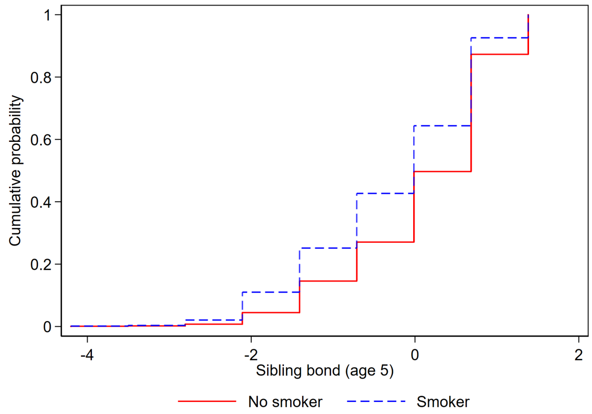
Note. The Figure presents the socioeconomic gradient in the quality of the sibling bond residualized by the older sibling's age at the age-5 wave. The socioeconomic status is the mother's education at the age-5 wave (dummy for whether the mother continued schooling past the minimum leaving age, based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

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



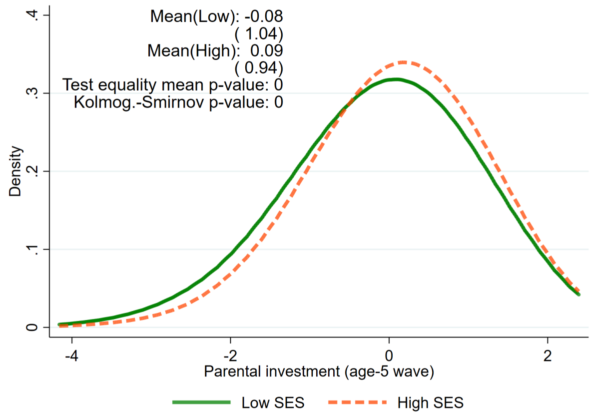
Note. The Figure presents the socioeconomic gradient in the quality of the sibling bond at the age-5 wave. The socioeconomic status is a dummy equal to 1 if the mother was smoking during pregnancy. The index of the sibling bond is constructed by summing the values from the following 4 questions about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

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



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

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



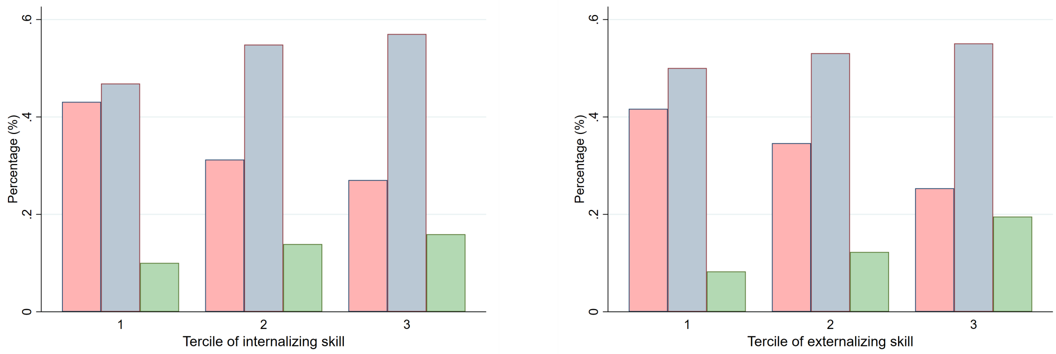
Note. The Figure presents the socioeconomic gradient in the quality of the sibling bond at the age-5 wave. The socioeconomic status is the mother's education at the age-5 wave (dummy for whether the mother continued schooling past the minimum leaving age, based on her date of birth). The index of parental investment in younger sibling is obtained by summing the values from the questions asking the parents how often [Every day, Several times a week, Once or twice a week, Once or twice a month, Less often, Not at all] they do the following activities: (i) How often do you read to the child, (ii) How often tells stories to the child, (iii) How often does musical activities with the child, (iv) How often does the child paint/draw at home, (v) How often do you play physically active games with the child?, (vi) How often play indoor games with the child? and (vii) How often play outdoor games with the child? Higher scores correspond to higher parental investment. I report the means of the quality of interactions by socioeconomic gradient and their standard errors between parentheses. The distribution is estimated nonparametrically, using an Epanechnikov kernel. I report the p-value of a t tests on the equality of means between the two groups assuming unequal variances. I report the p-value from Kolmogorov-Smirnov tests on the equality between the distributions by socioeconomic gradient.

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

	Sibling bond	Parental investment	Calm home atmosphere	How close the bond between mother and child	Mother's health	Household dual single headed
Sibling bond	1.000					
Parental investment	0.054***	1.000				
Calm home atmosphere	0.136***	0.081***	1.000			
How close the bond between mother and child	0.112***	0.132***	0.054***	1.000		
Mother's mental health	-0.210***	-0.076***	-0.188***	-0.091***	1.000	
Household dual or single headed	-0.120***	0.012	-0.018	-0.005	0.137***	1.000

Note. Table shows the correlation between the sibling bond and parental investment, how calm the home atmosphere is, close relationship between mother and child, whether the household is dual or single head. The index of the sibling bond is constructed by summing the values from the following 4 questions about how often [frequently, sometimes, never] the cohort member (i.e., the younger sibling): (i) Likes to be with the older sibling, (ii) Not much interested in the older sibling, (iii) Has a lot of fun with the older sibling, (iv) Teases or needles the older sibling. I recode behaviours indicating worse interactions in reverse (i.e., not much interested in older sibling and teases or needles older sibling). The index of parental investment in younger sibling is obtained by summing the values from the questions asking the parents how often [Every day, Several times a week, Once or twice a week, Once or twice a month, Less often, Not at all] they do the following activities: (i) How often do you read to the child, (ii) How often tells stories to the child, (iii) How often does musical activities with the child, (iv) How often does the child paint/draw at home, (v) How often do you play physically active games with the child?, (vi) How often play indoor games with the child? and (vii) How often play outdoor games with the child? Both indexes of the sibling bond and parental investment are then standardized to have mean 0 and standard deviation 1. *** p<0.01, ** p<0.05, * p<0.1.

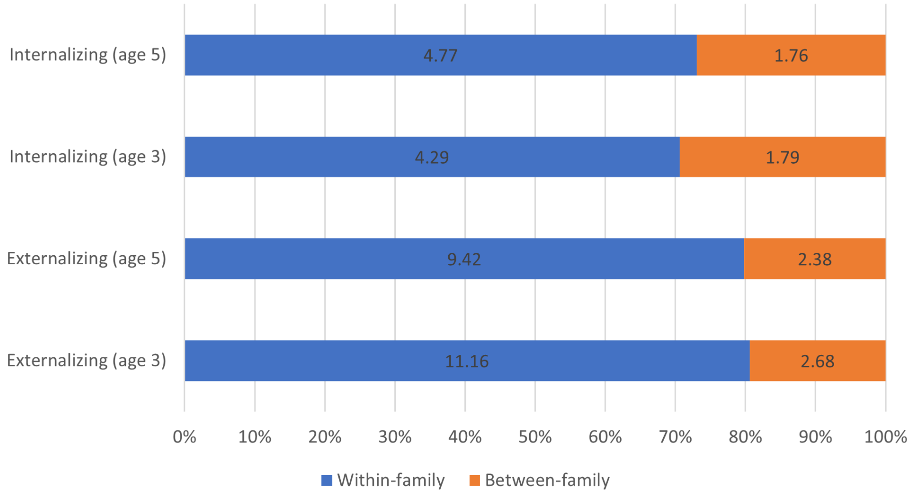
Figure A7: Sibling bond by each skill tercile



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

A.3 Inequality in Siblings' Skills

Figure A8: Variance decomposition



Note. The Figure presents the variance decomposition from estimating the following regression $skill_{ijf} = \delta_f + \epsilon_{ijf}$ where the siblings' skills are regressed on family fixed effects to quantify the role played by families. Data on siblings were collected in the age-3 and age-5 waves of the Millennium Cohort Study.

Table A4: Determinants of inequality in siblings' skills

Outcome	Difference between younger and older siblings' skills	
	Externalizing	Internalizing
	(1)	(2)
Externalizing (age-3 wave)	0.669***	0.112**
	(0.063)	(0.044)
Internalizing (age-3 wave)	-0.034	0.273***
	(0.065)	(0.048)
Cognitive (age-3 wave)	0.023	0.015
	(0.062)	(0.040)
Older sib's externalizing (age-3 wave)	-2.336***	-0.035
	(0.070)	(0.048)
Older sib's internalizing (age-3 wave)	-0.126*	-1.036***
	(0.068)	(0.052)
Sibling bond (age 5)	-0.217***	-0.230***
	(0.065)	(0.043)
Parental investment (age 5)	-0.017	-0.053
	(0.060)	(0.041)
Observations	3361	3223
R^2	0.507	0.292
Other controls	Yes	Yes

Note. The table presents the relationship between inequality in siblings' socio-emotional skills and the sibling bond. Two dimensions of socio-emotional skills are considered: 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 index of the sibling bond is constructed by summing the values from the following 4 questions about how often [frequently, sometimes, never] the cohort member (i.e., the younger sibling): (i) Likes to be with the older sibling, (ii) Not much interested in the older sibling, (iii) Has a lot of fun with the older sibling, (iv) Teases or needles the older sibling. I recode behaviours indicating worse interactions in reverse (i.e., not much interested in older sibling and teases or needles older sibling). The index of parental investment in younger sibling is obtained by summing the values from the questions asking the parents how often [Every day, Several times a week, Once or twice a week, Once or twice a month, Less often, Not at all] they do the following activities: (i) How often do you read to the child, (ii) How often tells stories to the child, (iii) How often does musical activities with the child, (iv) How often does the child paint/draw at home, (v) How often do you play physically active games with the child?, (vi) How often play indoor games with the child? and (vii) How often play outdoor games with the child? Both indexes of the sibling bond and parental investment are then standardized to have mean 0 and standard deviation 1. Other controls include younger sibling's gender, age gap between younger and older sibling, older sibling's gender, number of children in the house, mother's mental health, mother's education, mother's age, whether the household is dual or single headed, partner's employment status, home atmosphere, how close the bond between mother and child is, housing tenure, years lived in current address, region fixed effects. Robust standard errors in parentheses (*** p<0.01, ** p<0.05, * p<0.1).

B Extension to the Theoretical Framework

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

$$U^{YS}(a_{YS}, a_{OS}, \xi_{YS}) = (SB_{YOS,i} - c_{YS}) * (a_{YS} + \xi_{YS}) \tag{12}$$

$$U^{OS}(a_{YS}, a_{OS}, \xi_{OS}) = (SB_{YOS,i} - c_{OS}) * (a_{OS} + \xi_{OS}) \tag{13}$$

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

C Measurement

C.1 Exploratory Factor Analysis

Table C5: Exploratory factor analysis of the siblings' socio-emotional skill questions

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

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

Table C6: Exploratory factor analysis of the sibling bond and parental investment questions

Item	Parental investment	Sibling bond
Younger sib likes to be with older sibling	-0.016	**0.692**
Younger sib not much interested in older sibling	-0.016	**0.468**
Younger sib has a lot of fun with older sibling	0.017	**0.666**
Younger sib teases or needles older sibling	0.023	**0.172**
How often do you read to younger child	**0.387**	0.032
How often tells stories to younger child	**0.468**	-0.001
How often does musical activities with younger child	**0.453**	-0.005
How often does younger child paint/draw at home	**0.597**	-0.035
How often do you play physically active games	**0.544**	0.050
Frequency play indoor games with child	**0.606**	-0.003
Frequency take child to park or playground	**0.417**	-0.031

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 $k = 3$). O I recode behaviours indicating worse interactions in reverse (i.e., not much interested in older sibling and teases or needles older sibling).

Table C7: Scale reliability: Cronbach's alpha

Latent factor	**Cronbach's alpha**
Younger sib's internalizing (age 3)	0.517
Younger sib's internalizing (age 5)	0.556
Older sibling's internalizing (age-3 wave)	0.625
Younger sib's externalizing (age 3)	0.773
Younger sib's externalizing (age 5)	0.788
Older sibling's externalizing (age-3 wave)	0.831
Parental investment	0.702
Sibling bond	0.581

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

C.2 Identification of a Factor Model with Categorical Items

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

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

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

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

Table C8: Normalization for identification

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

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

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

Second, a choice must be made on how to scale the common factor. Two frequently used scaling conventions are either to choose a reference indicator or to standardize the common factor. In the former approach, it is usually assumed $\lambda_{1t} = 1$ and $\tau_{1t} = 0$ to allows me to estimate the mean and the variance of the factor $ln(\theta_{it})$. In the latter approach, λ_{jt} and τ_{jt} are freely estimated by fixing $E(ln(\theta_{it})) = 0$ and $V(ln(\theta_{it})) = 1$.[3] By the combinations of the two types of scaling choices, four possible parametrizations are possible, as shown in Table C8. Other parametrizations are conceivable as well, these seem to be the most commonly used.

C.3 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.

$$m^*_{ijt} = \alpha_{jt} + \lambda^{\top}_{jt} ln\theta_{it} + \varepsilon_{ijt} \tag{16}$$

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

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

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

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

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

(iii) Categorical items: $m_{ijt} \in \{1, 2, ..., L\}$: $Prob\{m_{ijt} = l\} = Pr\{\tau_{l-1,jt} \leq m_{ijt} \leq \tau_{l,jt}\}$, where $\tau_{0,jt} = -\infty$;

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

C.4 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 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}.

$$m^*_{ijt} = \alpha_{jt} + \lambda^\top_{jt} ln\theta_{it} + \varepsilon_{ijt} \tag{17}$$

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

$$m_{ijt} = \begin{cases} 0 & \text{if } m^*_{ijt} < \tau_{1,jt} \\ 1 & \text{if } m^*_{ijt} \in \left[\tau_{1,jt}, \tau_{2,jt}\right] \\ 2 & \text{if } m^*_{ijt} > \tau_{2,jt} \end{cases} \tag{18}$$

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

After setting the scale and the location as illustrated in Section 3.2, it is possible to estimate the parameters of interest by MLE. However, this problem is computationally intensive to solve. Another possibility is to adopt the method developed by Muthén (1983) and Muthén (1984) in the psychometrics literature to estimate structural equation models (SEM) with categorical items in one step. This strategy estimates the parameters of the measurement system (e.g., factor loadings and latent regression coefficients) by using a GMM strategy where the moments are built based on the (polychoric) correlations ρ between the items m^{j}_{it}. The moment conditions are constructed by first estimating each threshold for each item from the data, yielding $\hat{\tau}$.[4] Then the correlations between any two items can computed by maximum likelihood, treating $\hat{\tau}$ as fixed, obtaining the matrix of estimated polychoric correlations, $\hat{\rho}$. The remaining parameters can be estimated by minimizing a weighted least squares (WLS) function of the polychoric correlation moments and the other moments obtained from the outcome equations. Formally, let the q free parameters

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

be collected in the vector B, and let $\rho(B)$ represent the model-implied correlations. Then, the estimator $\hat{B}$ is obtained by minimizing

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

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

D Additional Results

D.1 Robustness: younger sibling's development

Table D9: Joint technology of skill formation with siblings: younger sibling - average of sibling bonds with different siblings

Outcome	Externalizing (EXT)		Internalizing (INT)		Cognitive (COG)	
	(1)	(2)	(3)	(4)	(5)	(6)
	Exogenous	Endogenous	Exogenous	Endogenous	Exogenous	Endogenous
EXT skill (t-1)	0.655***	0.565***	0.002	-0.089	0.104***	-0.106
	(0.046)	(0.087)	(0.023)	(0.070)	(0.031)	(0.107)
INT skill (t-1)	-0.096	-0.140	0.753***	0.718***	0.015	-0.090
	(0.068)	(0.090)	(0.160)	(0.169)	(0.077)	(0.185)
COG skill (t-1)	0.077***	0.050	-0.014	-0.043	0.576***	0.514***
	(0.023)	(0.056)	(0.116)	(0.052)	(0.051)	(0.070)
Older sibling's EXT skill (t-1)	-0.010	-0.114	-0.052**	-0.160***	0.015	-0.265**
	(0.023)	(0.073)	(0.024)	(0.062)	(0.033)	(0.133)
Older sibling's INT skill (t-1)	0.001	-0.021	0.023	-0.021	-0.040	-0.131
	(0.046)	(0.070)	(0.042)	(0.076)	(0.068)	(0.145)
Average sibling bond (t)	0.089***	0.439*	0.044***	0.488*	-0.018	0.973**
	(0.019)	(0.240)	(0.014)	(0.250)	(0.068)	(0.409)
Parental investment (t)	0.007	0.142	-0.028*	-0.036	0.020	0.278
	(0.017)	(0.149)	(0.013)	(0.169)	(0.023)	(0.285)
Observations	3044	3044	3044	3044	3044	3044
Other controls	Yes	Yes	Yes	Yes	Yes	Yes

Note. The Table presents the structural estimates of technology of skill formation for the younger sibling at age 5. $t-1$ corresponds to age 3. The average sibling bond is the average of the siblings bonds in families with more than two siblings. The Odd columns consider the sibling bond and parental investment as exogenous, while the Even columns allow the sibling bond and parental investment to be endogenous. 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 5-6 for cognitive skill (ability to learn and solve tasks). The measurement system and the outcome equation are estimated jointly. Other controls include younger sibling's gender, age gap between younger and older sibling, older sibling's gender, number of children in the house, mother's mental health, mother's education, mother's age, whether the household is dual or single headed, partner's employment status, home atmosphere, how close the bond between mother and child is, housing tenure, years lived in current address, region fixed effects. Standard errors in parentheses are obtained using 100 bootstrap repetitions (*** p<0.01, ** p<0.05, * p<0.1).

D.2 Robustness: younger sibling's development and the birth of another sibling

Table D10: Joint technology of skill formation with siblings: younger sibling - birth of another sibling between the age-3 and 5 waves

Outcome	**Externalizing (EXT)**	**Internalizing (INT)**	**Cognitive (COG)**
EXT skill (t-1)	0.651***	-0.002	0.100***
	(0.060)	(0.023)	(0.038)
INT skill (t-1)	-0.089	0.771***	0.021
	(0.070)	(0.170)	(0.085)
COG skill (t-1)	0.078	-0.013	0.575***
	(0.114)	(0.024)	(0.036)
Older sibling's EXT skill (t-1)	-0.016	-0.054**	0.016
	(0.021)	(0.024)	(0.027)
Older sibling's INT skill (t-1)	-0.003	0.026	-0.043
	(0.044)	(0.041)	(0.058)
Sibling bond (t)	0.090***	0.044***	-0.017
	(0.019)	(0.016)	(0.025)
Parental investment (t)	0.007	-0.026*	0.020
	(0.015)	(0.014)	(0.024)
Number of new births in the family	-0.128***	-0.008	0.022
	(0.043)	(0.035)	(0.053)
Observations	3044	3044	3044
Other controls	Yes	Yes	Yes

Note. The Table presents the structural estimates of technology of skill formation for the younger sibling at age 5, controlling for the number of new births in the family between age-3 and 5 waves. $t-1$ corresponds to age 3. The measurement system and the outcome equation are estimated jointly. Column 1 presents the structural estimates for externalizing skill (ability to engage in interpersonal activities), Column 2 for internalizing skill (ability to focus their drive and determination to achieve long-term goals), and Column 3 for cognitive skill (ability to learn and solve tasks). The measurement system and the outcome equation are estimated jointly. Other controls include the number of new births in the family between age-3 and 5 waves, younger sibling's gender, mother's mental health, mother's education, mother's age, whether the household is dual or single headed, partner's employment status, number of children, age gap between younger and older sibling, older sibling's gender, housing tenure, years lived in current address, home atmosphere, how warm the relationship between mother and child is, region fixed effects. Standard errors in parentheses are obtained using 100 bootstrap repetitions (*** p<0.01, ** p<0.05, * p<0.1).

D.3 Technology of skill formation without the sibling bond

Table D11: Technology of skill formation with siblings: younger sibling (age 5)

Outcome	Externalizing (EXT)		Internalizing (INT)		Cognitive (COG)	
	(1) Exogenous	(2) Endogenous	(3) Exogenous	(4) Endogenous	(5) Exogenous	(6) Endogenous
EXT skill (t-1)	0.669***	0.656***	0.008	0.009	0.095***	0.073*
	(0.058)	(0.062)	(0.024)	(0.027)	(0.037)	(0.043)
INT skill (t-1)	-0.098	-0.132	0.789***	0.786***	0.022	-0.062
	(0.072)	(0.086)	(0.187)	(0.193)	(0.083)	(0.080)
COG skill (t-1)	0.078***	0.076**	-0.013	-0.015	0.573***	0.565***
	(0.026)	(0.033)	(0.025)	(0.034)	(0.036)	(0.031)
Older sibling's EXT skill (t-1)	0.010	-0.007	-0.040	-0.041	0.011	-0.029
	(0.023)	(0.042)	(0.026)	(0.035)	(0.027)	(0.039)
Older sibling's INT skill (t-1)	0.009	0.021	0.031	0.032	-0.045	-0.027
	(0.044)	(0.049)	(0.041)	(0.049)	(0.056)	(0.063)
Parental investment (t)	0.011	0.167	-0.025*	-0.042	0.019	0.413*
	(0.015)	(0.248)	(0.014)	(0.201)	(0.023)	(0.227)
Observations	3044	3044	3044	3044	3044	3044
Other controls	Yes	Yes	Yes	Yes	Yes	Yes

Note. The Table presents the structural estimates of technology of skill formation for the younger sibling at age 5 when restricting the productivity of the sibling bond to be zero. $t-1$ corresponds to age 3. The Odd columns consider the sibling bond and parental investment as exogenous, while the Even columns allow the sibling bond and parental investment to be endogenous. 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 5-6 for cognitive skill (ability to learn and solve tasks). The measurement system and the outcome equation are estimated jointly. Other controls include younger sibling's gender, age gap between younger and older sibling, older sibling's gender, number of children in the house, mother's mental health, mother's education, mother's age, whether the household is dual or single headed, partner's employment status, home atmosphere, how close the bond between mother and child is, housing tenure, years lived in current address, region fixed effects. Standard errors in parentheses are obtained using 100 bootstrap repetitions (*** p<0.01, ** p<0.05, * p<0.1).

D.4 Older sibling's development

The technology of skill formation for the older sibling can then be represented with a production function, mapping initial conditions, parental time investment, sibling bond and other contextual factors onto three different dimensions of development for the younger sibling.

$$\theta^S_{OS,it} = g_t(\theta^{EXT}_{YS,it-1}, \theta^{INT}_{YS,it-1}, \theta^{INT}_{OS,it-1}, \theta^{EXT}_{OS,it-1}, SB_{YOS,it}, I_{YS,it}, \mathbf{X}_{it}, u_{OS,it}) \quad (28)$$

Where t represents the older sibling's age at the MCS age-5 wave and $t-1$ is the observation at age-3 wave. The two dimensions of skills are internalizing (INT) and Externalizing (EXT). I cannot study the older sibling's cognitive development as the MCS does not collect data on the older sibling's cognitive development. $I_{YS,it}$ and SI^{YOS}_{it} represent parental time investment in the younger sibling and quality interactions between the younger and older sibling. X_{it} is a vector of environmental factors that may affect child development; namely, younger sibling's gender, age gap between younger and older sibling, older sibling's gender, number of children in the house, mother's mental health, mother's education, mother's age, whether the household is dual or single headed, partner's employment status, home atmosphere, how close the bond between mother and child is, housing tenure, years lived in current address, region fixed effects. e_{it} is an idiosyncratic shock observed by the parents but unobserved by the econometrician.

To estimate 28, I assume a Cobb-Douglas Production function (equation 29) :

$$ln(\theta^S_{OS,it}) = \sum_S \omega_{1S} ln(\theta^S_{YS,it-1}) + \sum_S \omega_{2S} ln(\theta^S_{OS,it-1}) + \omega_{3S} ln(SB_{YOS,it}) + \omega_{4S} ln I_{YS,it} + \mathbf{X}'_{it}\varphi_S + u^S_{OS,it} \quad (29)$$

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

The estimates of the technology of child development for the older sibling based on equation (7) are presented in Table D12 when treating investments as exogenous and in Table D13 when treating investment as endogenous.

Table D12: Joint technology of skill formation of older sibling: Exogenous investments

Outcome	**Externalizing (EXT)**	**Internalizing (INT)**
EXT skill (t-1)	0.793***	-0.107***
	(0.131)	(0.027)
INT skill (t-1)	0.015	0.913***
	(0.054)	(0.101)
Younger sibling's EXT skill (t-1)	-0.086***	-0.061**
	(0.030)	(0.026)
Younger sibling's INT skill (t-1)	-0.063	-0.092
	(0.072)	(0.068)
Younger sibling's COG skill (t-1)	0.030	0.040
	(0.259)	(0.027)
Sibling bond (t)	0.076***	0.090***
	(0.022)	(0.023)
Parental investment in younger sib (t)	-0.001	0.014
	(0.019)	(0.015)
Observations	2930	2930
Other controls	Yes	Yes

Note. The measurement system and the outcome equation are estimated jointly. Other controls include younger sibling's gender, age gap between younger and older sibling, older sibling's gender, number of children in the house, mother's mental health, mother's education, mother's age, whether the household is dual or single headed, partner's employment status, home atmosphere, how close the bond between mother and child is, housing tenure, years lived in current address, region fixed effects. Standard errors in parentheses are obtained using 100 bootstrap repetitions (*** p<0.01, ** p<0.05, * p<0.1).

Table D13: Joint technology of skill formation of older sibling: Endogenous investments

Outcome	**Externalizing (EXT)**	**Internalizing (INT)**
EXT skill (t-1)	0.631***	-0.128
	(0.091)	(0.115)
INT skill (t-1)	-0.042	0.877***
	(0.092)	(0.126)
Younger sibling's EXT skill (t-1)	-0.215**	-0.080
	(0.125)	(0.077)
Younger sibling's INT skill (t-1)	-0.080	-0.053
	(0.121)	(0.100)
Younger sibling's COG skill (t-1)	0.029	0.040
	(0.211)	(0.039)
Sibling bond (t)	0.527*	0.200
	(0.316)	(0.293)
Parental investment in younger sib (t)	0.154	-0.161
	(0.224)	(0.176)
Observations	2930	2930
Other controls	Yes	Yes

Note. The measurement system and the outcome equation are estimated jointly. Other controls include younger sibling's gender, age gap between younger and older sibling, older sibling's gender, number of children in the house, mother's mental health, mother's education, mother's age, whether the household is dual or single headed, partner's employment status, home atmosphere, how close the bond between mother and child is, housing tenure, years lived in current address, region fixed effects. Standard errors in parentheses are obtained using 100 bootstrap repetitions (*** p<0.01, ** p<0.05, * p<0.1).

D.5 Translog production function

Table D14: Translog technology of skill formation estimates: younger sibling

	Externalizing (EXT)		Internalizing (INT)		Cognitive (COG)	
	(1)	(2)	(3)	(4)	(5)	(6)
	Exogenous	Endogenous	Exogenous	Endogenous	Exogenous	Endogenous
EXT skill (t-1)	0.491***	0.459***	0.074***	-0.034	0.064***	-0.103
	(0.018)	(0.108)	(0.019)	(0.103)	(0.016)	(0.095)
INT skill (t-1)	0.007	0.038	0.377***	0.373***	0.015	0.027
	(0.021)	(0.045)	(0.021)	(0.045)	(0.018)	(0.044)
COG skill (t-1)	0.084***	0.061	0.008	0.001	0.325***	0.318***
	(0.019)	(0.039)	(0.020)	(0.037)	(0.019)	(0.035)
Older sibling's EXT skill (t-1)	0.006	-0.019	-0.002	-0.112	0.004	-0.154
	(0.016)	(0.107)	(0.016)	(0.105)	(0.015)	(0.097)
Older sibling's INT skill (t-1)	-0.012	0.015	0.104***	0.072*	0.002	-0.015
	(0.021)	(0.044)	(0.021)	(0.043)	(0.018)	(0.043)
Sibling bond (t)	0.076	0.734	0.063	0.923	0.064	0.968
	(0.052)	(0.687)	(0.052)	(0.683)	(0.050)	(0.622)
Parental investment (t)	0.018	0.187	-0.006	0.194	0.010	0.216
	(0.013)	(0.171)	(0.013)	(0.170)	(0.011)	(0.157)
Sibling bond (t)*EXT skill (t-1)	0.007	0.192	-0.039	0.267	0.008	0.662
	(0.027)	(0.471)	(0.027)	(0.454)	(0.022)	(0.404)
Sibling bond (t)*INT skill (t-1)	0.011	-0.265	0.012	0.012	-0.053*	-0.042
	(0.033)	(0.361)	(0.032)	(0.364)	(0.028)	(0.382)
Sibling bond (t)*COG skill (t-1)	-0.083***	0.115	-0.072**	-0.286	-0.002	-0.225
	(0.029)	(0.624)	(0.029)	(0.563)	(0.028)	(0.548)
Sibling bond (t)*Older sib's EXT skill (t-1)	0.034	-0.024	0.023	-0.042	0.011	0.119
	(0.024)	(0.311)	(0.025)	(0.295)	(0.024)	(0.286)
Sibling bond (t)*Older sib's INT skill (t-1)	-0.006	-0.282	-0.018	-0.219	-0.004	-0.291
	(0.032)	(0.541)	(0.031)	(0.554)	(0.027)	(0.477)
Observations	3044	3044	3044	3044	3044	3044
Other controls	Yes	Yes	Yes	Yes	Yes	Yes

Note. The table presents the estimates for the translog production function. The Odd columns consider the sibling bond and parental investment as exogenous, while the Even columns allow the sibling bond and parental investment to be endogenous. A control function approach is adopted to deal with the endogeneity of parental investment and sibling bond. Other controls include younger sibling's gender, age gap between younger and older sibling, older sibling's gender, number of children in the house, mother's mental health, mother's education, mother's age, whether the household is dual or single headed, partner's employment status, home atmosphere, how close the bond between mother and child is, housing tenure, years lived in current address, region fixed effects. Robust standard errors in parentheses (*** p<0.01, ** p<0.05, * p<0.1).

D.6 Misreporting Bias

This Section 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) Understands what is right and what is wrong, and why, (iv) Considers the consequences of words and actions. There are two caveats to keep in mind. First, the responses to the teachers' questionnaire are not available in disaggregated form for England. Second, similarly-worded items are available to measure only the externalizing skill. Namely, an exploratory factor analysis on the items from the teachers' questionnaire points out to the existence of just one latent skill being captured by the teacher's questionnaire.

I therefore estimate jointly the factor model with categorical items for externalizing skill, where

I use the responses reported by the teachers - instead of the parents - to measure the externalizing skill at age 5, and its production function. This provides a measure of the latent externalizing skill at age 5 that differs only by the nature of the respondent as similar survey questions are used across parents and teachers. Appendix Table D15 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 5). Unfortunately, the bootstrapped standard errors are quite large as only data from Northern Ireland, Wales and Scotland are available.

Table D15: Joint technology of externalizing skill with siblings: using socio-emotional skills reported by teacher

Outcome	**Externalizing (EXT)**
	(1)
EXT skill (t-1)	0.605
	(0.527)
INT skill (t-1)	0.096
	(2.212)
COG skill (t-1)	0.401
	(1.558)
Older sibling's EXT skill (t-1)	-0.137
	(0.175)
Older sibling's INT skill (t-1)	-0.197
	(1.292)
Sibling bond (t)	0.163
	(0.393)
Parental investment (t)	0.010
	(0.215)
Observations	692
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. The teacher's questionnaire was administered in Northern Ireland, Wales and Scotland. The measurement system and the outcome equation are estimated jointly. Other controls include younger sibling's gender, age gap between younger and older sibling, older sibling's gender, number of children in the house, mother's mental health, mother's education, mother's age, whether the household is dual or single headed, partner's employment status, home atmosphere, how close the bond between mother and child is, housing tenure, years lived in current address, region fixed effects. Standard errors in parentheses are obtained using 100 bootstrap repetitions (*** p<0.01, ** p<0.05, * p<0.1).

D.7 Heterogeneity: the Technology of Skill Formation with Siblings

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

Appendix Tables D16 and D17 present the estimates for the younger sibling's skill formation technology by the older sibling's gender respectively when investments are exogenous and endogenous. I do not detect any big differences in the estimates. Appendix Tables D18 and D19 present the estimates for the younger sibling's skill formation technology by the siblings' gender combination respectively when investments are exogenous and endogenous. Appendix Table D18 provides some suggestive evidence that the sibling bond is more productive for same-sex than mixed-sex siblings. This hint that same-sex siblings may have more possibilities to interact while sharing similar interests and toys.

Finally, Appendix Tables D20 and D21 present the estimates for the younger sibling's skill formation technology by the siblings' age gap respectively when investments are exogenous and endogenous. The sample is split at the median age gap which corresponds to 3 years. Appendix Tables D20 and D21 test two possible hypothesis: (i) if the age gap is below the median, then the younger and older sibling could be more likely to share similar interests and interact more and (ii) if the age gap is above the median, then the younger sibling could see the older sibling as a role model. Appendix Table D20 shows that there is not heterogeneity on this margin. The lack of heterogeneity on this margin could be attributed to several reasons, such as a lack of power due to the split of the sample or the heterogeneity on the age gap being non-linear.

D.7.1 Heterogeneity by Siblings' Gender

Table D16: Technology of skill formation with siblings: Exogenous investment. Younger sibling's development by older sibling's gender.

Outcome	**Externalizing**		**Internalizing**		**Cognitive**	
Older sib's gender	Female	Male	Female	Male	Female	Male
EXT skill (t-1)	0.702***	0.601***	-0.017	0.004	0.131**	0.069
	(0.079)	(0.097)	(0.054)	(0.034)	(0.052)	(0.055)
INT skill (t-1)	-0.205	-0.007	0.956***	0.664**	0.039	0.076
	(0.156)	(0.079)	(0.253)	(0.276)	(0.129)	(0.104)
COG skill (t-1)	0.073	0.077	0.014	-0.040	0.559***	0.571***
	(0.056)	(0.100)	(0.053)	(0.552)	(0.055)	(0.060)
Older sibling's EXT skill (t-1)	-0.023	-0.015	-0.067	-0.051	0.036	0.012
	(0.042)	(0.034)	(0.042)	(0.065)	(0.047)	(0.066)
Older sibling's INT skill (t-1)	0.029	-0.033	-0.047	0.050	-0.155	0.012
	(0.075)	(0.071)	(0.088)	(0.082)	(0.106)	(0.102)
Sibling bond (t)	0.089***	0.095***	0.046	0.041	-0.021	-0.013
	(0.028)	(0.027)	(0.033)	(0.047)	(0.040)	(0.043)
Parental investment (t)	0.008	0.009	-0.032	-0.018	0.019	0.012
	(0.024)	(0.022)	(0.023)	(0.044)	(0.029)	(0.027)
Observations	1446	1598	1446	1598	1446	1598
Other controls	Yes	Yes	Yes	Yes	Yes	Yes

Note. The measurement system and the outcome equation are estimated jointly. Other controls include younger sibling's gender, mother's mental health, mother's education, mother's age, whether the household is dual or single headed, partner's employment status, number of children, age gap between younger and older sibling, housing tenure, years lived in current address, home atmosphere, how close the bond between mother and child is, region fixed effects. Standard errors in parentheses are obtained using 100 bootstrap repetitions (*** p<0.01, ** p<0.05, * p<0.1).

Table D17: Technology of skill formation with siblings: Endogenous investment. Younger sibling's development by older sibling's gender.

Outcome	**Externalizing**		**Internalizing**		**Cognitive**	
Older sib's gender	Female	Male	Female	Male	Female	Male
EXT skill (t-1)	0.565***	0.564***	-0.119	-0.106	-0.056	-0.233
	(0.129)	(0.105)	(0.118)	(0.114)	(0.136)	(0.206)
INT skill (t-1)	-0.344	0.001	0.901***	0.691**	-0.202	0.164
	(0.275)	(0.099)	(0.261)	(0.270)	(0.247)	(0.280)
COG skill (t-1)	0.110	0.061	0.037	-0.101	0.608***	0.414***
	(0.074)	(0.080)	(0.072)	(0.095)	(0.103)	(0.140)
Older sibling's EXT skill (t-1)	-0.195	-0.061	-0.194	-0.237**	-0.224	-0.487***
	(0.172)	(0.083)	(0.135)	(0.101)	(0.174)	(0.187)
Older sibling's INT skill (t-1)	0.064	-0.078	-0.042	-0.158	-0.080	-0.562**
	(0.128)	(0.146)	(0.131)	(0.265)	(0.160)	(0.275)
Sibling bond (t)	0.347	0.263	0.331	0.761	0.459	1.849***
	(0.338)	(0.306)	(0.247)	(0.533)	(0.366)	(0.567)
Parental investment (t)	0.069	0.022	0.091	-0.084	0.574*	0.124
	(0.241)	(0.187)	(0.223)	(0.228)	(0.324)	(0.307)
Observations	1446	1598	1446	1598	1446	1598
Other controls	Yes	Yes	Yes	Yes	Yes	Yes

Note. The measurement system and the outcome equation are estimated jointly. Other controls include younger sibling's gender, mother's mental health, mother's education, mother's age, whether the household is dual or single headed, partner's employment status, number of children, age gap between younger and older sibling, housing tenure, years lived in current address, home atmosphere, how close the bond between mother and child is, region fixed effects. Standard errors in parentheses are obtained using 100 bootstrap repetitions (*** p<0.01, ** p<0.05, * p<0.1).

Table D18: Technology of skill formation with siblings: Exogenous investment. Younger sibling's development by sibling's gender composition.

Outcome	**Externalizing**		**Internalizing**		**Cognitive**	
sib's gender composition	Mixed	Same	Mixed	Same	Mixed	Same
EXT skill (t-1)	0.579***	0.724***	-0.020	0.030	0.113**	0.097
	(0.075)	(0.088)	(0.033)	(0.045)	(0.047)	(0.062)
INT skill (t-1)	-0.124	-0.090	0.657***	0.930***	0.091	-0.045
	(0.105)	(0.108)	(0.186)	(0.305)	(0.142)	(0.137)
COG skill (t-1)	0.066*	0.098**	0.011	-0.046	0.565***	0.573***
	(0.035)	(0.048)	(0.030)	(0.083)	(0.056)	(0.087)
Older sibling's EXT skill (t-1)	-0.034	-0.004	-0.058*	-0.036	0.048	0.003
	(0.036)	(0.049)	(0.034)	(0.047)	(0.056)	(0.045)
Older sibling's INT skill (t-1)	0.040	-0.029	0.015	0.043	-0.109	-0.016
	(0.090)	(0.058)	(0.070)	(0.073)	(0.119)	(0.083)
Sibling bond (t)	0.082***	0.097***	0.034*	0.046	-0.031	0.001
	(0.027)	(0.036)	(0.017)	(0.033)	(0.044)	(0.036)
Parental investment (t)	-0.011	0.030	-0.041*	-0.001	0.014	0.022
	(0.028)	(0.022)	(0.020)	(0.046)	(0.027)	(0.026)
Observations	1516	1528	1516	1528	1516	1528
Other controls	Yes	Yes	Yes	Yes	Yes	Yes

Note. The measurement system and the outcome equation are estimated jointly. Other controls include younger sibling's gender, mother's mental health, mother's education, mother's age, whether the household is dual or single headed, partner's employment status, number of children, age gap between younger and older sibling, housing tenure, years lived in current address, home atmosphere, how close the bond between mother and child is, region fixed effects. Standard errors in parentheses are obtained using 100 bootstrap repetitions (*** p<0.01, ** p<0.05, * p<0.1).

Table D19: Technology of skill formation with siblings: Endogenous investment. Younger sibling's development by sibling's gender composition.

Outcome	**Externalizing**		**Internalizing**		**Cognitive**	
sib's gender composition	Mixed	Same	Mixed	Same	Mixed	Same
EXT skill (t-1)	0.427***	0.664***	-0.127	-0.116	-0.170	-0.148
	(0.111)	(0.132)	(0.083)	(0.150)	(0.184)	(0.174)
INT skill (t-1)	-0.012	-0.139	0.804***	0.816**	0.417	-0.220
	(0.223)	(0.164)	(0.210)	(0.350)	(0.448)	(0.412)
COG skill (t-1)	0.012	0.096*	-0.047	-0.019	0.428***	0.578***
	(0.083)	(0.057)	(0.105)	(0.280)	(0.165)	(0.159)
Older sibling's EXT skill (t-1)	-0.173	-0.083	-0.180*	-0.257	-0.281	-0.356*
	(0.109)	(0.147)	(0.097)	(0.211)	(0.182)	(0.192)
Older sibling's INT skill (t-1)	-0.178	-0.004	-0.198	0.037	-0.663*	0.028
	(0.190)	(0.089)	(0.153)	(0.099)	(0.387)	(0.183)
Sibling bond (t)	0.719*	0.216	0.631*	0.524	1.508**	0.669*
	(0.407)	(0.277)	(0.334)	(0.420)	(0.677)	(0.390)
Parental investment (t)	0.054	0.269	-0.086	0.170	-0.003	0.701*
	(0.207)	(0.303)	(0.179)	(0.310)	(0.421)	(0.369)
Observations	1516	1528	1516	1528	1516	1528
Other controls	Yes	Yes	Yes	Yes	Yes	Yes

Note. The measurement system and the outcome equation are estimated jointly. Other controls include younger sibling's gender, mother's mental health, mother's education, mother's age, whether the household is dual or single headed, partner's employment status, number of children, age gap between younger and older sibling, housing tenure, years lived in current address, home atmosphere, how close the bond between mother and child is, region fixed effects. Standard errors in parentheses are obtained using 100 bootstrap repetitions (*** p<0.01, ** p<0.05, * p<0.1).

D.7.2 Heterogeneity by the Age Gap between Siblings

Table D20: Technology of skill formation with siblings: Exogenous investment. Younger sibling's development by the age gap between the younger and older sibling.

Outcome	Externalizing		Internalizing		Cognitive	
Age gap	<= p50	> p50	<= p50	> p50	<= p50	> p50
EXT skill (t-1)	0.607***	0.728***	0.010	-0.002	0.109	0.083
	(0.125)	(0.094)	(0.049)	(0.064)	(0.052)	(0.036)
INT skill (t-1)	-0.060	-0.066	0.949***	0.920***	-0.033	0.108
	(0.077)	(0.078)	(0.189)	(0.175)	(0.077)	(0.064)
COG skill (t-1)	0.121	0.043	-0.015	-0.014	0.556***	0.599***
	(0.184)	(0.041)	(0.102)	(0.078)	(0.056)	(0.033)
Older sibling's EXT skill (t-1)	-0.043	0.025	-0.040	-0.142**	0.051	-0.052
	(0.040)	(0.042)	(0.045)	(0.059)	(0.043)	(0.059)
Older sibling's INT skill (t-1)	-0.013	-0.043	-0.046	0.093	-0.023	-0.047
	(0.060)	(0.055)	(0.109)	(0.085)	(0.096)	(0.082)
Sibling bond (t)	0.088**	0.101***	0.095***	0.072*	-0.000	-0.014
	(0.037)	(0.034)	(0.042)	(0.040)	(0.062)	(0.181)
Parental investment (t)	0.015	-0.001	-0.039	-0.068*	0.036	-0.011
	(0.020)	(0.026)	(0.042)	(0.039)	(0.025)	(0.105)
Observations	1882	1162	1882	1162	1882	1162
Other controls	Yes	Yes	Yes	Yes	Yes	Yes

Note. The measurement system and the outcome equation are estimated jointly. The median age gap between younger and older sibling is 3 years old. Other controls include younger sibling's gender, mother's mental health, mother's education, mother's age, whether the household is dual or single headed, partner's employment status, number of children, age gap between younger and older sibling, housing tenure, years lived in current address, home atmosphere, how close the bond between mother and child is, region fixed effects. Standard errors in parentheses are obtained using 100 bootstrap repetitions (*** p<0.01, ** p<0.05, * p<0.1).

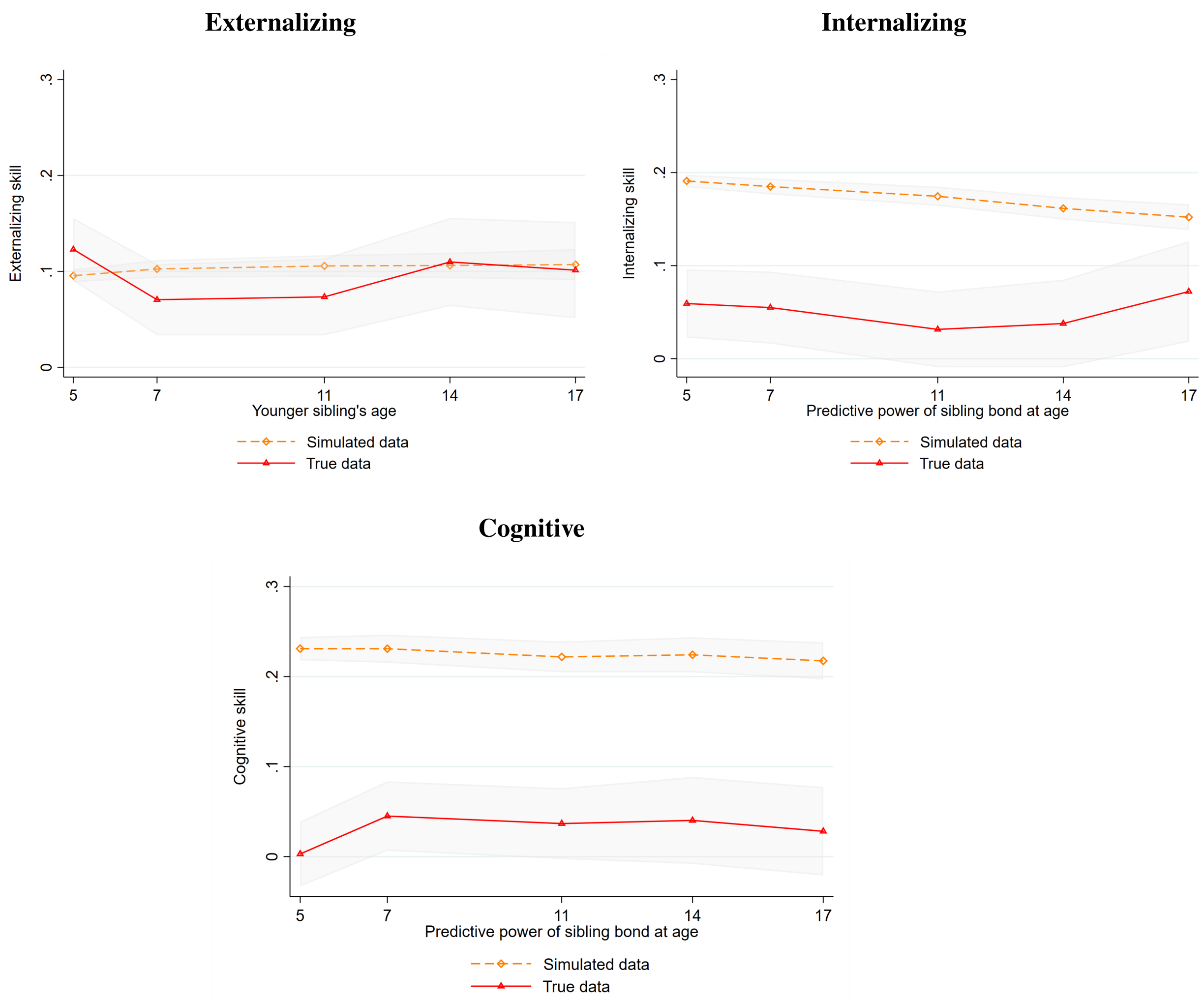
Table D21: Technology of skill formation with siblings: Endogenous investment. Younger sibling's development by the age gap between the younger and older sibling.

Outcome	Externalizing		Internalizing		Cognitive	
Age gap	Below p50	Above p50	Below p50	Above p50	Below p50	Above p50
EXT skill (t-1)	0.460***	0.653***	-0.267	-0.189	-0.303	-0.022
	(0.126)	(0.171)	(2.107)	(0.143)	(0.192)	(0.182)
INT skill (t-1)	0.002	-0.161	1.107***	0.715**	0.158	-0.007
	(0.144)	(0.198)	(0.331)	(0.276)	(0.164)	(0.261)
COG skill (t-1)	0.186**	0.022	0.137	-0.084	0.672***	0.562***
	(0.087)	(0.092)	(32.466)	(0.112)	(0.135)	(0.106)
Older sibling's EXT skill (t-1)	-0.229	-0.069	-0.418	-0.399**	-0.518***	-0.196
	(0.095)	(0.137)	(2.923)	(0.189)	(0.196)	(0.204)
Older sibling's INT skill (t-1)	-0.079	-0.059	-0.247	0.034	-0.275	-0.096
	(0.099)	(0.102)	(0.692)	(0.148)	(0.174)	(0.157)
Sibling bond (t)	0.517*	0.364	1.036*	0.856*	1.342**	0.457
	(0.266)	(0.381)	(0.607)	(0.455)	(0.561)	(0.576)
Parental investment (t)	0.031	0.284	-0.362	0.493	0.054	0.295
	(0.234)	(0.379)	(0.434)	(0.434)	(0.327)	(0.505)
Observations	1882	1162	1882	1162	1882	1162
Other controls	Yes	Yes	Yes	Yes	Yes	Yes

Note. The measurement system and the outcome equation are estimated jointly. The median age gap between younger and older sibling is 3 years old. Other controls include younger sibling's gender, mother's mental health, mother's education, mother's age, whether the household is dual or single headed, partner's employment status, number of children, age gap between younger and older sibling, housing tenure, years lived in current address, home atmosphere, how close the bond between mother and child is, region fixed effects. Standard errors in parentheses are obtained using 100 bootstrap repetitions (*** p<0.01, ** p<0.05, * p<0.1).

E Validation exercise of the structural estimates

Figure E9: Validation exercise: sibling bond and future *predicted* development, as implied by the structural estimates of the joint skill formation technology.



Note. The Figures present a validation exercise where the age-5 sibling bond predicts the younger sibling's predicted socio-emotional development, as implied by the structural estimates of the technology of skill formation (dashed line). This is compared to the solid line which shows the relationship between the sibling bond at age 5 and younger sibling's development estimated using the true data collected by the MCS 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). Both prediction exercises include controls for siblings' skill at age 5, parental investment, younger sibling's gender, mother's mental health, mother's education, mother's age, whether the household is dual or single headed, partner's employment status, number of children, age gap between younger and older sibling, older sibling's gender, housing tenure, years lived in current address, home atmosphere, how close the bond between mother and child is, region fixed effects. Confidence intervals at 95% level are reported in gray.

F Descriptive Statistics

Table F22: Descriptive statistics on sample characteristics.

	Mean (%)	St.Dev.	N
Female cohort member	0.512	0.500	3044
Female older sibling	0.473	0.499	3044
Siblings' age gap	3.386	2.114	3044
Number of siblings	1.576	0.737	3044
Mother's age at birth	31.021	4.874	3044
Mother education past compulsory (age-5 wave)	0.600	0.490	3044
Mother's mental health (Kessler 6)	2.672	3.269	3044
Years in current address	6.805	4.537	3044
Number of rooms in house	6.389	1.744	3044
Mother's employed	0.688	0.463	3044
Single mother	0.124	0.329	3044
Unemployed partner	0.116	0.320	3044

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.

Table F23: Descriptive statistics on SDQ (age 3).

	Mean (%)	St.Dev.	N
2. Restless			
Always	0.144	0.351	3044
Sometimes	0.315	0.464	3044
Never	0.542	0.498	3044
3. Complain aches			
Always	0.014	0.116	3044
Sometimes	0.063	0.242	3044
Never	0.924	0.265	3044
5. Temper tantrum			
Always	0.186	0.389	3044
Sometimes	0.442	0.497	3044
Never	0.372	0.483	3044
6. Solitary			
Always	0.031	0.174	3044
Sometimes	0.234	0.423	3044
Never	0.735	0.441	3044
7. Obedient			
Never	0.055	0.228	3044
Sometimes	0.573	0.495	3044
Always	0.372	0.484	3044
8. Worried			
Always	0.004	0.060	3044
Sometimes	0.039	0.194	3044
Never	0.957	0.203	3044
10. Fidgeting/squirming			
Always	0.079	0.270	3044
Sometimes	0.253	0.435	3044
Never	0.667	0.471	3044
11. At least one good friend			
Never	0.062	0.242	3044
Sometimes	0.210	0.407	3044
Always	0.728	0.445	3044
12. Fights			
Always	0.017	0.129	3044
Sometimes	0.117	0.322	3044
Never	0.866	0.341	3044
13. Unhappy			
Always	0.004	0.062	3044
Sometimes	0.032	0.176	3044
Never	0.964	0.186	3044
14. Liked by other children			
Never	0.003	0.055	3044
Sometimes	0.162	0.368	3044
Always	0.835	0.371	3044
15. Easily distracted			
Always	0.084	0.277	3044
Sometimes	0.433	0.496	3044
Never	0.483	0.500	3044
16. Nervous			
Always	0.109	0.312	3044
Sometimes	0.407	0.491	3044
Never	0.484	0.500	3044
18. Lies			
Always	0.083	0.276	3044
Sometimes	0.381	0.486	3044
Never	0.536	0.499	3044
19. Bullied			
Always	0.003	0.058	3044
Sometimes	0.036	0.186	3044
Never	0.961	0.194	3044
21. Think before acting			
Never	0.140	0.347	3044
Sometimes	0.676	0.468	3044
Always	0.184	0.388	3044
22. Steal			
Always	0.023	0.150	3044
Sometimes	0.243	0.429	3044
Never	0.734	0.442	3044
23. Gets on better with adults			
Always	0.027	0.164	3044
Sometimes	0.194	0.395	3044
Never	0.779	0.415	3044
24. Many fears			
Always	0.028	0.165	3044
Sometimes	0.223	0.416	3044
Never	0.749	0.433	3044
25. Sees task through end			
Never	0.112	0.316	3044
Sometimes	0.617	0.486	3044
Always	0.271	0.444	3044

Note. The table presents the descriptive statistics of the younger sibling's SDQ at age 3 (Goodman, 1997, 2001). The mean (%) is reported in column 1, standard deviation is reported in column 2, and number of observations in column 3.

Table F24: Descriptive statistics on SDQ (age 5).

	Mean (%)	St.Dev.	N
2. Restless			
Always	0.084	0.278	3044
Sometimes	0.242	0.429	3044
Never	0.673	0.469	3044
3. Complain aches			
Always	0.019	0.137	3044
Sometimes	0.121	0.326	3044
Never	0.860	0.347	3044
5. Temper tantrum			
Always	0.112	0.315	3044
Sometimes	0.356	0.479	3044
Never	0.532	0.499	3044
6. Solitary			
Always	0.029	0.168	3044
Sometimes	0.189	0.391	3044
Never	0.782	0.413	3044
7. Obedient			
Never	0.026	0.159	3044
Sometimes	0.391	0.488	3044
Always	0.583	0.493	3044
8. Worried			
Always	0.008	0.091	3044
Sometimes	0.077	0.267	3044
Never	0.915	0.279	3044
10. Fidgeting/squirming			
Always	0.063	0.243	3044
Sometimes	0.253	0.435	3044
Never	0.684	0.465	3044
11. At least one good friend			
Never	0.013	0.114	3044
Sometimes	0.073	0.261	3044
Always	0.913	0.281	3044
12. Fights			
Always	0.007	0.082	3044
Sometimes	0.053	0.224	3044
Never	0.940	0.237	3044
13. Unhappy			
Always	0.010	0.097	3044
Sometimes	0.054	0.226	3044
Never	0.937	0.244	3044
14. Liked by other children			
Never	0.005	0.070	3044
Sometimes	0.076	0.265	3044
Always	0.919	0.273	3044
15. Easily distracted			
Always	0.073	0.260	3044
Sometimes	0.360	0.480	3044
Never	0.568	0.495	3044
16. Nervous			
Always	0.070	0.255	3044
Sometimes	0.344	0.475	3044
Never	0.586	0.493	3044
18. Lies			
Always	0.015	0.120	3044
Sometimes	0.177	0.381	3044
Never	0.809	0.393	3044
19. Bullied			
Always	0.010	0.100	3044
Sometimes	0.073	0.260	3044
Never	0.917	0.276	3044
21. Think before acting			
Never	0.094	0.291	3044
Sometimes	0.682	0.466	3044
Always	0.224	0.417	3044
22. Steal			
Always	0.005	0.067	3044
Sometimes	0.021	0.143	3044
Never	0.975	0.157	3044
23. Gets on better with adults			
Always	0.020	0.141	3044
Sometimes	0.177	0.381	3044
Never	0.803	0.398	3044
24. Many fears			
Always	0.026	0.160	3044
Sometimes	0.202	0.402	3044
Never	0.771	0.420	3044
25. Sees task through end			
Never	0.068	0.251	3044
Sometimes	0.493	0.500	3044
Always	0.439	0.496	3044

Note. The table presents the descriptive statistics of the younger sibling's SDQ at age 5 (Goodman, 1997, 2001). The mean (%) is reported in column 1, standard deviation is reported in column 2, and number of observations in column 3.

Table F25: Descriptive statistics on SDQ (older sibling: age-3 wave).

	Mean (%)	St.Dev.	N		Mean (%)	St.Dev.	N
2. Restless				**14. Liked by other children**			
Always	0.129	0.335	3044	Never	0.007	0.085	3044
Sometimes	0.259	0.438	3044	Sometimes	0.115	0.319	3044
Never	0.612	0.487	3044	Always	0.878	0.327	3044
3. Complain aches				**15. Easily distracted**			
Always	0.049	0.216	3044	Always	0.139	0.346	3044
Sometimes	0.159	0.365	3044	Sometimes	0.314	0.464	3044
Never	0.792	0.406	3044	Never	0.547	0.498	3044
5. Temper tantrum				**16. Nervous**			
Always	0.117	0.322	3044	Always	0.081	0.274	3044
Sometimes	0.348	0.477	3044	Sometimes	0.305	0.461	3044
Never	0.534	0.499	3044	Never	0.613	0.487	3044
6. Solitary				**18. Lies**			
Always	0.051	0.220	3044	Always	0.021	0.143	3044
Sometimes	0.198	0.398	3044	Sometimes	0.191	0.393	3044
Never	0.751	0.432	3044	Never	0.788	0.409	3044
7. Obedient				**19. Bullied**			
Never	0.038	0.191	3044	Always	0.018	0.131	3044
Sometimes	0.371	0.483	3044	Sometimes	0.122	0.327	3044
Always	0.591	0.492	3044	Never	0.860	0.347	3044
8. Worried				**21. Think before acting**			
Always	0.046	0.209	3044	Never	0.104	0.305	3044
Sometimes	0.245	0.430	3044	Sometimes	0.520	0.500	3044
Never	0.709	0.454	3044	Always	0.377	0.485	3044
10. Fidgeting/squirming				**22. Steal**			
Always	0.093	0.291	3044	Always	0.003	0.057	3044
Sometimes	0.222	0.416	3044	Sometimes	0.018	0.133	3044
Never	0.684	0.465	3044	Never	0.979	0.144	3044
11. At least one good friend				**23. Gets on better with adults**			
Never	0.018	0.133	3044	Always	0.049	0.217	3044
Sometimes	0.082	0.274	3044	Sometimes	0.229	0.420	3044
Always	0.900	0.300	3044	Never	0.722	0.448	3044
12. Fights				**24. Many fears**			
Always	0.015	0.123	3044	Always	0.049	0.217	3044
Sometimes	0.072	0.259	3044	Sometimes	0.257	0.437	3044
Never	0.912	0.283	3044	Never	0.694	0.461	3044
13. Unhappy				**25. Sees task through end**			
Always	0.019	0.136	3044	Never	0.102	0.303	3044
Sometimes	0.126	0.332	3044	Sometimes	0.390	0.488	3044
Never	0.855	0.352	3044	Always	0.508	0.500	3044

Note. The table presents the descriptive statistics of the older sibling's SDQ at age-3 wave (Goodman, 1997, 2001). The mean (%) is reported in column 1, standard deviation is reported in column 2, and number of observations in column 3.

Table F26: Descriptive statistics on cognitive skill test.

	Mean	St.Dev.	Min	Median	Max	N
Cognitive tests (age 3)						
Colours Raw Score	7.520	3.671	0	9	11	3044
Letters Raw Score	1.612	2.243	0	1	16	3044
Numbers Raw Score	3.002	3.510	0	2	19	3044
Sizes Raw Score	4.795	2.674	0	4	12	3044
Comparisons Raw Score	2.783	2.265	0	2	10	3044
Shapes Raw Score	6.768	3.887	0	7	20	3044
Naming Vocabulary Raw Score	17.484	4.066	0	18	29	3044
Cognitive tests (age 5)						
Picture Similarity Raw Score	16.001	3.389	0	16	23	3044
Pattern Construction Raw Score	19.781	7.750	0	20	72	3044
Naming Vocabulary Raw Score	14.968	3.131	0	15	25	3044

Note. The table presents the descriptive statistics on the raw scores from the cognitive skill tests for cohort member (i.e., younger sibling) at age-3 and -5 waves. Mean (%) is reported in column 1, standard deviation in column 2, Min in column 3, median in column 4, max in column 5 and number of observations in column 6.

Table F27: Descriptive statistics on sibling interactions.

	Mean (%)	St.Dev.	N
Likes being with older sibling			
Never	0.009	0.094	3044
Sometimes	0.202	0.401	3044
Frequently	0.789	0.408	3044
Interested in being with older sibling			
Never	0.040	0.196	3044
Sometimes	0.202	0.402	3044
Frequently	0.758	0.429	3044
Has fun with older sibling			
Never	0.013	0.113	3044
Sometimes	0.199	0.399	3044
Frequently	0.788	0.409	3044
Does not tease older sibling			
Never	0.224	0.417	3044
Sometimes	0.595	0.491	3044
Frequently	0.181	0.385	3044

Note. The table presents the descriptive statistics of the quality interactions between siblings questionnaire. The mean (%) is reported in column 1, standard deviation is reported in column 2, and number of observations in column 3.

Table F28: Descriptive statistics on parental investment in cohort member child.

	Mean (%)	St.Dev.	N
Frequency you read to cohort member (CM)			
Not at all	0.006	0.077	3044
Less often	0.010	0.100	3044
Once or twice a month	0.030	0.170	3044
Once or twice a week	0.152	0.359	3044
Several times a week	0.323	0.468	3044
Every day	0.479	0.500	3044
Frequency tells stories to CM			
Not at all	0.107	0.310	3044
Less often	0.175	0.380	3044
Once or twice a month	0.206	0.405	3044
Once or twice a week	0.255	0.436	3044
Several times a week	0.157	0.364	3044
Every day	0.100	0.300	3044
Frequency musical activities with CM			
Not at all	0.017	0.130	3044
Less often	0.033	0.178	3044
Once or twice a month	0.087	0.282	3044
Once or twice a week	0.240	0.427	3044
Several times a week	0.294	0.456	3044
Every day	0.329	0.470	3044
Frequency CM paint/draw at home			
Not at all	0.029	0.167	3044
Less often	0.079	0.270	3044
Once or twice a month	0.271	0.445	3044
Once or twice a week	0.374	0.484	3044
Several times a week	0.183	0.387	3044
Every day	0.064	0.245	3044
Frequency play physically active games with CM			
Not at all	0.062	0.241	3044
Less often	0.131	0.338	3044
Once or twice a month	0.198	0.398	3044
Once or twice a week	0.381	0.486	3044
Several times a week	0.175	0.380	3044
Every day	0.052	0.223	3044
Frequency play indoor activity			
Not at all	0.014	0.119	3044
Less often	0.038	0.191	3044
Once or twice a month	0.101	0.302	3044
Once or twice a week	0.365	0.481	3044
Several times a week	0.321	0.467	3044
Every day	0.161	0.367	3044
Frequency take child to the park			
Not at all	0.026	0.160	3044
Less often	0.085	0.279	3044
Once or twice a month	0.341	0.474	3044
Once or twice a week	0.399	0.490	3044
Several times a week	0.124	0.330	3044
Every day	0.025	0.155	3044

Note. The table presents the descriptive statistics on the frequency of parent-child interactions. The interactions refer to the cohort member (CM), namely the younger silbing who is the target child of the Millennium Cohort Study. Mean (%) is reported in column 1, standard deviation is reported in column 2, and number of observations in column 3. Frequency of activity with cohort member child: 6 - every day, 5 - several times a week, 4- one or twice a week, 3 - one or twice a month, 2 - less often, 1 - not at all.