JOB MARKET PAPER

Parental Investment and the Birth Order Gap in Cognitive Skill Formation: The Role of Resource Dilution

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This version: November 2nd, 2021. Click here for latest version.

Abstract

Siblings compete for limited parental time and financial resources, so that investments available to each child decline as the number of children in the family increases. This resource dilution is present for secondborns throughout their life, whereas firstborns have the natural advantage of experiencing a period alone with parents. This paper shows that resource dilution is a quantitively convincing mechanism to explain why firstborn children tend to outperform their secondborn siblings on cognitive exams. Using a framework similar to Del Boca, Flinn, and Wiswall (2014), structural estimates of the child quality production function suggest an extra (counterfactual) year alone with parents for the firstborn leads to a 0.12 standard deviation increase of the birth order gap in child quality between the ages of 6 and 12. This effect accounts for a little over 1/3 of the observed gap in cognitive ability test scores for a US representative sample of two-child families of white mothers from the (C)NLSY79. Investment spillovers between siblings add to the dynamic impacts of resource dilution and make the uplift of the firstborn's relative position persist over time.

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1 Introduction

Earlier-born children tend to outperform their younger siblings on measures of academic achievement and labor market outcomes.[1] An important determinant of birth order differences in cognitive ability test scores has been attributed to the level of parental investment received by siblings in early childhood (see Pavan, 2016; Lehmann, Nuevo-Chiquero, and Vidal-Fernandez, 2018). However, the mechanism that leads parents to invest relatively less in later-born children remains unclear. This paper proposes that the decline in per-child parental inputs as the number of children in the family increases explains a quantitively convincing share of the birth order gap in cognitive ability scores observed at ages when children attend elementary school. While both siblings are alive, they compete for limited parental time and financial resources, so the investment accrued to each child declines. This effect is present for secondborn children throughout their life, whereas firstborns experience a period without resource dilution.

Relying on information about parental investments and children's cognitive ability test scores from the Children of the National Longitudinal Survey of Youth (CNLSY79), structural estimates of a child quality production function are obtained using a framework similar to Del Boca, Flinn, and Wiswall (2014). To measure how resource dilution generates a birth order gap in cognitive ability, I simulate a counterfactual time delay between births in a two-child household choice model where parents invest in the production of children's quality. Results suggest that an extra year spent alone with parents for the firstborn leads to a 0.12 standard deviation increase of the birth order gap in child quality between the ages of 6 and 12. This resource dilution effect accounts for a little over 1/3 of the observed gap in standardized cognitive ability test scores for a US nationally representative sample of two-child families of white mothers.

Moreover, predictions from the model indicate that a longer delay between births generates an uplift of the relative position in accumulated child quality for the firstborn, while that of the secondborn remains broadly unchanged. This asymmetric birth spacing effect across siblings is in line with causal estimates of Buckles and Munnich (2012), who instrument the time between births using variation in whether a miscarriage is experienced during that period. Approximately 50% of the cognitive ability score gap implied by their causal birth spacing estimates can be explained by the dynamic impacts

[1] See, for instance, Kantarevic and Mechoulan (2006), Booth and Kee (2009), Black, Devereux, and Salvanes (2005), Black, Devereux, and Salvanes (2011), Hotz and Pantano (2015), Pavan (2016), Lehmann, Nuevo-Chiquero, and Vidal-Fernandez (2018), Bagger et al. (2020). On the noncognitive side, Black, Grönqvist, and Öckert (2018) document birth order effects on personality traits, while Breining et al. (2020) find that among boys, the secondborn is more likely to develop delinquent behavior than the firstborn.

of an extra year without having to compete for parental resources for the firstborn in the model.

The role of parental investment as determinant of birth order differences in cognitive ability scores is among several proposed mechanisms[2]. Pavan (2016) demonstrates the importance of considering the dynamic impacts of parental investment to explain the observed birth order gap in later childhood. By allowing the child development process to depend on past development stages, parental inputs in early childhood can have lasting and multiplying effects on the path of human capital accumulation.

In addition to the dynamic impacts of child-specific parental inputs, this paper considers a child quality production function with spillovers from investment directed to the other sibling. Model predictions suggest that more than 1/3 of the superior accumulated child quality retained by the firstborn from the period spent alone with parents is explained by spillovers from parental inputs dedicated to the second child. Even if parents find it more productive to invest in the secondborn when both siblings are alive, the birth order gap persists over time because the firstborn benefits from a share of investments directed to her/his younger sibling. Moreover, spillovers have a dual role in the model in that they introduce economies of scale in parental investments. As opposed to the case considering only child-specific inputs in the production function, the scale effects make it such that the per-child level of investment in the model is not restricted to fall after the second child's birth.

Following Del Boca, Flinn, and Wiswall (2014) and Caucutt et al. (2020), the structural estimation of the child quality production function accounts for measurement error in the mapping between child quality and cognitive ability test scores, the opportunity costs of time and expenditure inputs in children, and their substitutability/complementarity. Although actual time and expenditure in children are not directly observed in the CNLSY79, parental input choices in the model are tied to corresponding items of the Home Observation Measurement of the Environment (HOME), extending the approach utilized by Del Boca, Flinn, and Wiswall (2014) to measure child quality from observed cognitive ability test scores.

[2]The confluence model (Zajonc and Markus, 1975; Zajonc, 1976) proposes that child development depends on the average intelligence level of the household, detrimental to later-born siblings in families of larger sibship size. Ejrnæs and Pörtner (2006) show that birth order effects can arise from an optimal stopping fertility behavior based on the genetic endowments of children. Price (2008) observes that the overall involvement in children decreases over time, which advantages earlier-born siblings. Hotz and Pantano (2015) show that parents illustrate a more stringent disciplinary attitude towards the firstborn to deter bad behavior in later-born children. Works in evolutionary psychology (Sulloway, 1995) also explore determinants of birth order effects, while medical outcomes are attributed in specific settings (Jayachandran & Pande, 2017).

The proposition advanced by this paper ties the birth order gap in cognitive ability scores to the natural advantage of the firstborn to enjoy the early years of her/his life without having to compete for parental resources. After accounting for economies of scale in parental investments, structural estimates of the child quality production function suggest that the second child never receives an equivalent level of inputs. Counterfactual simulations of the model predict that the longer this advantage lasts for the firstborn, the more distant the relative position with her/his sibling becomes in terms of accumulated child quality at any given age. This result is a direct implication of findings by Cunha and Heckman (2008) and Cunha, Heckman, and Schennach (2010), who demonstrate that the cognitive (and non-cognitive) skill formation process is to a large extent shaped by the early childhood environment. This paper adds to the study of how fertility timing impacts disparities in parental investment and academic achievement across siblings (Price, 2008, 2010; Buckles and Munnich, 2012) and relates more generally to the family quantity-quality trade-off (Becker and Lewis, 1973; Becker and Tomes, 1976; Hanushek, 1992) and resource dilution theories (Blake, 1981; Downey, 1995, 2001).

Section 2 proceeds with a description of the data and a reduced form analysis motivating the structural environment. Section 3 presents the model, with a focus on the structural determinants of per-child investments before and after the second child's birth. Section 4 covers the details of measurement, identification and estimation of the model parameters. The interpretation of the parameter estimates governing the child quality production function is presented in section 5, joint with the sample fit and external validity of model predictions. In section 6, the resource dilution effect is measured, followed by a brief discussion on implications for family-related policies. Section 7 concludes.

2 Data

This section presents the data and describes key features that motivate the structural approach used to measure how resource dilution generates a birth order gap in cognitive ability. For two-child families of white mothers, I document that the per-child level of parental investments declines after the second child's birth. Families with longer time between births illustrate larger birth order gaps in average measures of parental investments and cognitive skills. While financial expenditures are similar across siblings, firstborns benefit from having more time spent on them over childhood.

Sample Description

This study uses mother-child matched data from the National Longitudinal Survey of Youth 1979 (NLSY79) and the Children of the NLSY79 (CNLSY79). The NLSY79 is a US nationally representative panel of 12,686 respondents aged between 14 and 21 in 1979. Respondents were surveyed periodically throughout their lives on education, labor market outcomes, family structure, and other background characteristics.

The CNLSY79 follows 11,504 children of 79% of mothers in the NLSY79, surveyed from an early age up to their early adult life. For this study, useful variables consist of the Home Observation Measurement of the Environment (HOME), household background characteristics, and a rich set of cognitive ability test scores. HOME scores consist of child-specific proxies for the level of parental investment. They are constructed by summing 0-1 recoded measures on criteria such as the time parents spend reading to a child, the number of books the child has access to, or the number of times the child is taken to an outing, among others. Items that compose the HOME scores change according to four childhood periods, defined between the ages of 0-2, 3-5, 6-9 and 10+.

Children also answer cognitive ability tests from an early age, such as the Motor and Social Development (MSD) scale for children aged 0-3 years, and the Peabody Picture Vocabulary Test (PPVT) administered after age 3. They then follow-up with the Peabody Individual Achievement Test (PIAT) when children are above age 5 until the end of their teens, divided into three subtests: math, reading comprehension, and reading recognition. To characterize the cognitive skills of children, I focus on PIAT tests administered between the ages of 6 and 11 because it is observed for most sibling pairs in the sample, and for multiple iterations over time before each child leaves elementary school. The math and reading subtests are each composed of 84 questions of increasing difficulty taken by children older than 5 at different ages[3].

One advantage of the CNLSY79, as compared to other available datasets containing parental investment measures, e.g., the Child Development Supplement (CDS) from the PSID, is the recurring frequency of HOME surveys for a given family. Every 2-3 years, an observer visits the household and surveys the environment specific to each child, while parents are asked to answer questions about their involvement in promoting child development. This survey design makes it possible to observe the per-child level of parental investment before and after the birth of a sibling, a key feature to assess

[3]Scores for the reading comprehension subtest is the same as that for the reading recognition if the child gets less than 19 right answers in the latter. Upon getting 19 right answers in the reading recognition subtest, a base score of 18 is added to the number of rights answers out of the 66 questions from the reading comprehension subtest.

whether the increase in family size is accompanied by a decline in resources allocated to each child in the data.

I restrict the sample to two-child families of white mothers. Considering families of greater size than two introduces selection on the fertility margin and augments the complexity of the modelling approach. For two-child families of black and hispanic families, I find that the birth order gap in measures of cognitive skills is fully captured by the gender composition of siblings and is only present for households where the firstborn is a girl and the secondborn is a boy. Since the child development process in the current framework does not consider the impact of siblings' gender differences, those families are left out of the study[4]. The final sample is also restricted to non-military families for which both siblings observe non-missing measures of parental investments (HOME scores) between the ages of 0 and 11 and cognitive skills (PIAT scores: math, reading recognition or comprehension) between the ages of 6 and 11[5]. Oversampled low-income families of white mothers are omitted since they were last surveyed in 1990 for budget considerations. Families with twins are also discarded from the sample.

The final sample comprises 518 households for which summary statistics are reported in table 1. Comparing the first- and secondborn, the household environment siblings grow up in is similar with respect to the presence of fathers or the years of schooling of mothers, as well as with participation in regular child care between the ages of 0 and 3. The per-parent average income from labor during the childhood of the secondborn is above that observed for the firstborn. While hours of work remain roughly constant, this difference is accounted for by increasing wages over time, as depicted in figure 7 of Appendix A1. The average time between births is 3.73 years[6]. Of note is that the second child is assessed at a younger age relative to the first, eight months younger for the assessments of HOME and over a year younger for assessments of PIAT tests. For the scores to be comparable across siblings and over different childhood periods, they are adjusted for the age at assessment up to a polynomial of degree three, and standardized. The birth order gaps, defined as the mean standardized scores of the second child minus that of the first, are -0.31 standard deviation for HOME scores evaluated between the

[4]See Appendix A2 for a complementary reduced form analysis for families with up to four children, and tables 16 and 17 of Appendix A3 for two-child families of black and hispanic mothers.

[5]See table 19 of Appendix A3 for a complementary reduced form analysis on cognitive ability test scores before the age of 6 and after 11, for which data is missing for approximately half of the sample. A similar analysis is done for non-cognitive ability test scores between the ages of 6 and 11 (see table 20 of Appendix A3).

[6]Mean birth spacing between siblings for families up to five children is 3.4 years in the NLSY79 and statistically not different than the comparable statistic in the 1988 Natality Detail File Sample (see Buckles and Munnich, 2012).

Table 1: Sample descriptive statistics

	Child 1			Child 2	
	Mean	Std		Mean	Std
Birth year	1988.29	4.68		1992.02	4.89
Age of mother at birth	26.86	4.43		30.59	4.51
Male	0.50	-		0.54	-
Share of years with father living in household	0.85	-		0.86	-
Years of schooling of mother	13.82	2.39		13.90	2.40
Share of years sent to regular child care, age: 0-3	0.60	-		0.55	-
Per-parent income from labor during childhood, age 0-11	38 788	15 219		41 585	16 329
Age at home inventory assessments	7.50	0.94		6.81	1.04
Age at cognitive ability assessments	9.11	1.92		7.67	1.71
		Mean	Std		
Birth order gap: std HOME scores (Child 2 - Child 1), age 0-11		-0.31	0.64		
Birth order gap: std PIAT scores (Child 2 - Child 1), age 6-11		-0.28	1.20		
	Mean	Std	p25	p50	p75
Birth spacing	3.73	2.27	2.33	3.17	4.42
N	518			518	

Notes: Statistics based on a sample of two-child households of white mothers from the NLSY79 and CNLSY79. The sample excludes households with twins or with missing data for one or both siblings. Time is measured as year-month units and months are divided by 12 to be scaled between 0-1. Standardized HOME and PIAT scores flexibly control for the age at assessment, up to a polynomial of degree three. The PIAT scores are averaged over the math, reading comprehension and reading recognition subtests. The 25th, 50th and 75th percentiles of the empirical birth spacing distribution are represented by p25, p50 and p75, respectively. Birth spacing is measured as the year-month distance between the age of mothers at births.

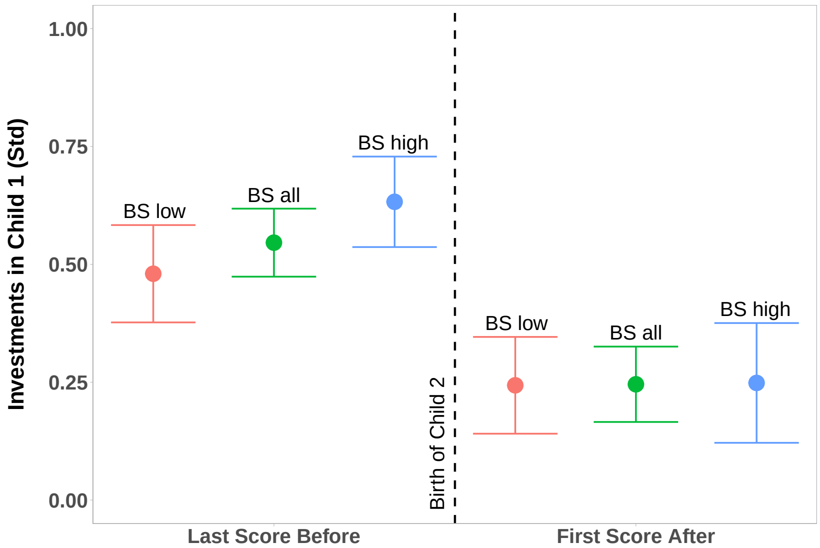
ages of 0 and 11 and -0.28 std for PIAT scores assessed between the ages of 6 and 11.

Per-Child Investments Before and After the Second Child's Birth

To evaluate whether per-child investments by parents decline after the second child's birth in the data, I compare the last and first available HOME scores specific to the firstborn before and after the birth of her/his sibling. After adjusting for differences between the timing of HOME assessments and the birth event up to a polynomial of degree three, the investment measures provide estimates of the parental inputs directed to the first child just before and after the second child's birth.

Figure 1 compares the before and after estimates for all households in the sample (green), and those with birth spacing above or below the sample average (blue and red respectively). Estimates suggest that the firstborn receives 0.3 standard deviation more investments when alone with parents just before the second child's birth[7]. Households with longer time between births illustrate a larger decline in per-child investments after the increase in family size. This is mostly driven by the relatively higher investments in the first child before the birth event. This pattern is consistent with parents increasingly investing in the firstborn over time when only one child is alive.

Figure 1: Investments in child 1 before and after the second child's birth, across birth spacing (BS)



Notes: Left (right) panel reports the sample mean of the last (first) HOME scores observed for child 1 before (after) the second child's birth. The scores are adjusted for differences between the timing of HOME assessments and the birth event up to a polynomial of degree three. *BS low* (*high*) includes households that observe birth spacing below (above) the sample average at 3.73 years, while *BS all* includes all households in the sample. Confidence intervals are reported at the 95% level.

If per-child investments decline with the increase in family size, average inputs received by the firstborn over childhood are expected to be superior to those received by the secondborn, and this difference should be increasing with the time child 1 spends alone with parents. Moreover, if parental investments shape to some extent the cognitive skill formation process of children, households with longer time between births are expected to observe larger birth order differences in measures of cognitive skills.

[7]Differences between mean investment scores before-after are significantly different from 0 at 95% for the full sample, and households with birth spacing above or below the sample average.

Birth Spacing and Gaps in Measures of Investments and Cognitive skills

I next regress birth order differences in measures of parental investments and cognitive skills on birth spacing. Since time between births is only partially exogenous, coefficient estimates of the regressions are not to be interpreted as causal. The within-family specification accounts for time invariant household specific characteristics. Each observation represents a family j, for which the dependent variable $\Delta y_j = y_{2,j} - y_{1,j}$ is either (a) the birth order gap in standardized HOME scores between the ages of 0 and 11, or (b) the birth order gap in standardized PIAT scores between the ages of 6 and 11, where $y_{i,j}$ for $i \in \{1, 2\}$ is the mean standardized score of child 1 or child 2 in household j:

$$\Delta y_j = \beta_0 + \beta_1 \cdot \text{birth spacing}_j + \beta_2 \cdot \Delta X_j + \epsilon_j. \tag{1}$$

The explanatory variables consist of a constant, the time between births and a set of controls ΔX_j, where β_2 is a parameter vector. Controls include differences between siblings with respect to their gender, the share of childhood years the father was present in the household, the years of schooling of the mother, their participation in regular child care between the ages 0 and 3, the per-parent average income from labor during childhood and whether at least one miscarriage occurred between the births.

Table 2: OLS estimates: birth spacing and gaps in measures of investments and cognitive skills

	(a) Parental investments, age 0-11		(b) Cognitive skills, age 6-11	
	Birth order gap: HOME std scores		Birth order gap: PIAT std scores	
	(1)	(2)	(1)	(2)
Birth Spacing	-0.057***	-0.055***	-0.075***	-0.064**
	(0.015)	(0.018)	(0.023)	(0.027)
Controls		✓		✓
N	518	518	518	518
R^2	0.06	0.08	0.03	0.03

Notes: OLS regressions are based on the sample described in table 1 and each column reports the estimates of a separate regression. Each household is characterized by a single observation. The dependent variable is the mean birth order gap in either age-adjusted standardized HOME (a) or PIAT (b) scores, observed between the ages of 0 and 11, and 6 and 11 respectively. A constant is included in each specification and controls include differences between child 1 and child 2 with respect to their gender, presence of the father in the household, years of schooling of the mother and per-parent average income from labor during childhood, participation in regular child care between the ages 0 and 3, and whether at least one miscarriage occurred between the births.
*** p<0.01, ** p<0.05, * p<0.1. Robust standard errors in parentheses.

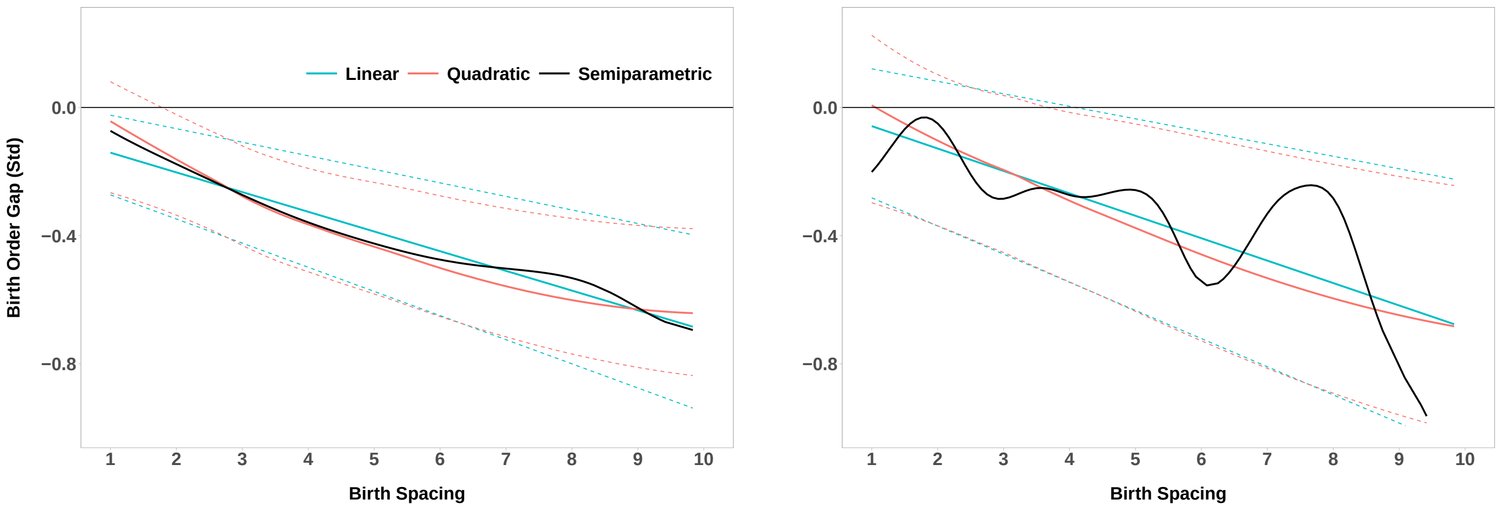
OLS estimation results are reported in table 2, excluding (1) and including controls

(2). One extra year between the births of siblings is associated with a 0.055 and 0.064 standard deviation increase of the birth order gaps in measures of investments (HOME) and cognitive skills (PIAT) respectively. Predicted gaps as function of birth spacing, from the OLS estimation results with controls, as well as from quadratic and nonparametric specifications of birth spacing, are shown in figure 2. Predicted birth order differences in both measures of investments and cognitive skills are not statistically different from zero at the 95% level for households with births close to one year apart. The predicted gaps increase with birth spacing for the three specifications and become statistically significant at the 95% level past two-year spacing for investment measures and four-year spacing for measures of cognitive skills. Specifying birth spacing linearly does not miss on critical non-linear patterns.

Figure 2: Birth spacing and predicted gaps in measures of investments and cognitive skills

(a) Parental investments, age 0-11
Birth order gap: HOME std scores

(b) Cognitive skills, age 6-11
Birth order gap: PIAT std scores



Notes: Predictions in blue are from the linear specification of birth spacing in equation (1), which estimates are reported in columns (2) of table 2, while predictions in red are from a quadratic specification of birth spacing. The black lines represent nonparametric mean predictions of partially linear regressions, following the estimation procedure in Robinson (1988), of the specification $\Delta y_j = \beta_0 + g(BS_j) + \Delta X_j \beta_2 + \epsilon_j$, where $g(\cdot)$ is an unknown nonparametric function of birth spacing. Prediction confidence intervals are reported at the 95% level.

Evaluating the impact of parental investments on birth order differences in cognitive ability is not ideal in such a reduced form setting. The dynamic impacts of investments cannot be correctly accounted for, while measurement error can affect how parental investments and cognitive ability are characterized by HOME and PIAT scores. The structural framework considered in this paper accounts for those issues. Nonetheless, it is instructive to evaluate whether the impact of investments are larger when driven by variation in birth spacing. In other words, do birth order differences in investments arising from the firstborn spending shorter or longer time alone with parents explain more of the subsequent cognitive skill gap than overall underinvestments? To answer this, I next regress the birth order gap in measures of cognitive skills on those in parental investments in column (1) of table 3, and compare this to a regression on the birth order gap in investments predicted by birth spacing in column (2).

Table 3: OLS estimates: early investment differences and the gap in measures of cognitive skills

	Cognitive skills, age 6-11	
	Birth order gap: PIAT std scores	
Parental investments, age 0-11	(1)	(2)
Birth order gap: HOME std scores	0.43***	
	(0.079)	
Birth order $\widehat{\text{gap}}$: HOME std scores		1.24**
(Predicted by birth spacing)		(0.509)
Controls	✓	✓
N	518	518
R^2	0.08	0.03

Notes: OLS regressions are based on the sample described in table 1 and each column reports the estimates of a separate regression. Each household is characterized by a single observation. The dependent variable is the mean birth order gap in age-adjusted standardized PIAT scores, observed between the ages of 6 and 11. Column (1) reports the OLS coefficient estimate of the mean gap in age-adjusted standardized PIAT scores between the ages of 0 and 11, while column (2) reports the OLS estimate for the same gap, but predicted by birth spacing from equation (1). A constant is included in each specification and controls include differences between child 1 and child 2 with respect to their gender, presence of the father in the household, years of schooling of the mother and per-parent average income from labor during childhood, participation in regular child care between the ages 0 and 3, and whether at least one miscarriage occurred between the births.
*** p<0.01, ** p<0.05, * p<0.1. Robust standard errors in parentheses.

The estimated impact of investments is almost three times as large when driven by variation in birth spacing, or in other words, by investment differences arising from the early childhood environment. Together with estimates from table 2, an extra year alone with parents for the firstborn leads to a 0.055 standard deviation increase of the gap in measures of investments, and 124% of this increase, corresponding to 0.068 standard deviation, maps into the birth order gap in measures of cognitive skills. Thus, the estimated relationship between birth spacing and the gap in measures of cognitive skills, as reported in column (4) of table 2, can be fully explained by its intermediate effect on parental investments. The structural framework considered in this paper finds the impact of an extra (counterfactual) year alone with parents for the firstborn to be almost twice as large as that predicted by the reduced form estimates.

Parental Time Investments and Financial Expenditures in Children

To examine whether birth order differences in parental investments differ across input types, I separate items that compose the HOME scores in two categories: a first category with items related to active time invested in children, and a second with items related to financial expenditures in children[8]. By summing the respective 0-1 recoded items for each category, a HOME subscore for time inputs, and one for expenditure inputs, are generated. Figure 3 reports the sample mean estimates of the standardized birth order gap in time investments and financial expenditures in children, after adjusting the respective HOME subscores for the age at assessments.

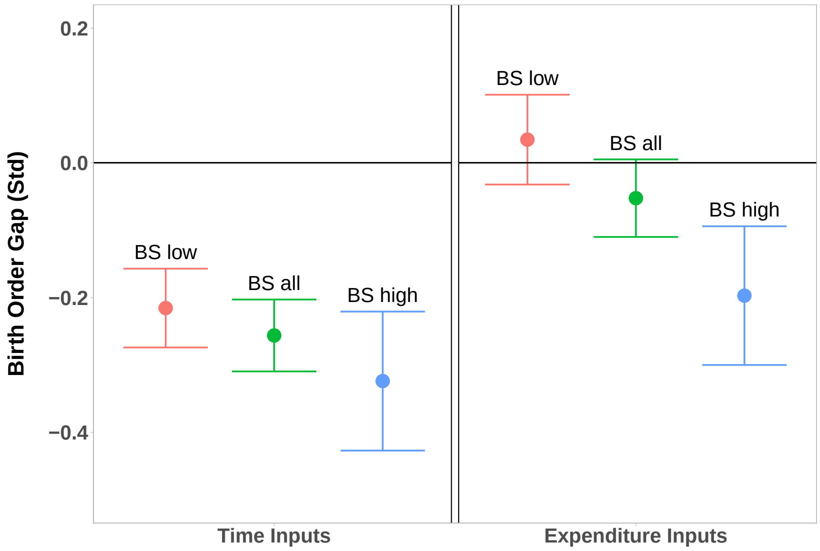
Results suggest that while financial expenditures are similar across siblings, firstborns benefit from having more time spent on them over childhood. The mean birth order gap in time inputs is estimated at -0.26 standard deviation between the ages of 0 and 9, while that for expenditure inputs is not statistically different from 0 at the 95% level. Households with birth spacing above the sample average do illustrate significant underinvestment of financial expenditures in the later-born sibling. To capture differences in time versus expenditure investments allocated to siblings by parents in the data, the structural framework next considered not only allows the two input types to differ in their respective child development productivities and substitutability/complementarity, but also with respect to their opportunity costs[9].

Based on the above empirical analysis, I find evidence supporting a decline in per-child investments following the second child's birth. When firstborns experience a longer period alone with parents, birth order differences in measures of investments and cognitive skills are larger. I interpret those results as suggestive that, as the number of children in the family increases, the dilution of parental resources impacts birth order differences in children's cognitive skills. To measure the role of resource dilution, I consider a framework in which households spend a shorter or longer (counterfactual) time alone with the first child, and where parents invest in the development process of

[8]See table 9 of Appendix A1 for the description of HOME items selected into each category.

[9]Households wages and working hours over the different age periods of siblings are depicted in figure 7 of Appendix A1. While hours of works remain constant over time, households wages tend to increase as children get older.

Figure 3: Birth order differences in time and expenditure inputs from parents, across birth spacing (BS)



Notes: Sample mean estimates of birth order differences in standardized time and expenditure HOME subscores evaluated between the ages of 0 and 9, according to the selection of items described in table 9 of Appendix A1. *BS low* (*high*) includes households that observe birth spacing below (above) the sample average at 3.73 years, while *BS all* includes all households in the sample. Confidence intervals are reported at the 95% level.

children's cognitive abilities using limited time and financial resources.

3 Model

This section presents a model of child development and household resource allocation to understand how counterfactual delays between births can impact siblings' relative cognitive skill formation through parental investments. The roles of resource dilution and investment spillovers between siblings are emphasized. A set of model assumptions is formulated to allow for tractable closed-form solutions to the households' optimization problem and facilitate the identification of the behavioral parameters using variation contained in the data.

Timing, Preferences and Wage Offers

Two-parent households (h) enter the model with the birth of child 1 in initial period t_0. Time is discrete with infinite horizon and the age of a child increases by one unit after each period. Households know that a second child will be born after S_h periods and birth spacing is random. Between the initial period t_0 and the birth of child 2 in period $t_h^s = t_0 + S_h$, parents invest in the quality of child 1 only. When both siblings are alive, parents invest in the quality of each child until the secondborn turns 16 in period $T_h^s = t_0 + S_h + 16$.

Households decide in a cooperative manner[10]. In this simplified framework, a household is left with only four choices in the periods prior to the birth of child 2: a joint decision on parental time ($\tau_{1,t}$) and expenditure ($e_{1,t}$) inputs towards investment in the quality of child 1, a total hours of work by both parents (z_t) and a total household level of consumption good (c_t). Following the birth of child 2, two additional choices are made by parents: the time ($\tau_{2,t}$) and expenditure ($e_{2,t}$) inputs towards investment in the quality of child 2.

The specification of households' preference borrows from the two-child case in Del Boca, Flinn, and Wiswall (2014), where the utility function is specified as Cobb-Douglas. The shares $\alpha_{1,h}$, $\alpha_{2,h}$, $\alpha_{3,h}$ and $\alpha_{4,h}$ are respectively assigned to joint leisure l_t, consumption c_t, quality of child 1 $k_{1,t}$ and quality of child 2 $k_{2,t}$, where $\alpha_{1,h}+\alpha_{2,h}+\alpha_{3,h}+\alpha_{4,h} = 1$, set out to be household specific and constant over time:

$$u_{t,h}(l_t, c_t, k_{1,t}, k_{2,t}) = \alpha_{1,h} ln(l_t) + \alpha_{2,h} ln(c_t) + \alpha_{3,h} ln(k_{1,t}) + \alpha_{4,h} ln(k_{2,t}),\ t = t_0, \ldots, T_h^s - 1.$$

When only child 1 is born, a household replaces $k_{2,t}$ by the second child's expected initial quality: $k_2^0 = E_{t_0}(k_{2,t_h^s})$.

To close the model, after child 2 has reached 16, the utility function for the remaining periods is restricted to depend exclusively on the child qualities accumulated by both siblings in period T_h^s:

$$u_{t,h}(k_{1,t}, k_{2,t}) = \psi_1(S_h) ln(k_{1,T_h^s}) + \psi_2 ln(k_{2,T_h^s}),\ t = T_h^s, \ldots, \infty.$$

$\psi_1(S_h)$ and ψ_2 are free parameters to be estimated, which assign a respective weight on the child qualities' utility shares that characterizes some unmodelled later development stage. The weight on the share of child 1 is allowed to vary with S_h, accounting for child 1 being older in period T_h^s for households with longer time between births.

[10]Unfortunately, investment measures specific to mothers and fathers are not available in the CNLSY79. Del Boca, Flinn, and Wiswall (2014) show distinct productivity patterns of time investment between them. The simplified joint decisions of parents are to be thought as encompassing unobserved heterogeneity between what mothers and fathers provide. If the composition of households were to change over time, this assumption would have implications on the determinants of the birth order gap in cognitive skill formation, which is the focus of this paper. But as shown in table 1, fathers' presence in households during the first 11 years of life of child 1 is similar to that of child 2.

The joint wage offer received by parents every period is characterized by a household specific intercept ($\mu_{0,h}$), time-dependant slope ($\mu_{1,h}$) and a random shock $\epsilon_{t,h}$:

$$ln(w_{t,h}) = \mu_{0,h} + \mu_{1,h} \cdot t + \epsilon_{t,h},\ t = t_0, \ldots, T_h^s - 1.$$

Overall, heterogeneity across households arises along four dimensions in the model: 1) the Cobb-Douglas preference shares, 2) the initial child qualities, 3) the time between births, and 4) the intercept and slope of the wage schedule.

Child Quality Production

The process governing the formation of child quality depends on children's past development stages, parents' investments in time and financial expenditure, and Total Factor Productivity. When both children are alive, the production of quality for one sibling also depends on parental investments directed to the other sibling. Utility of parents is not derived from current investments, such as the enjoyment of time doing activities with children, but from the future child quality generated by those inputs.

Prior to the birth of child 2, next period's quality of child 1 ($k_{1,t+1}$) is produced according to a Cobb-Douglas technology, taking as inputs the current level of child quality ($k_{1,t}$), a parental investment composite $I_{1,t}$ and age-dependant Total Factor Productivity ($A_{a(1,t)}$):

$$k_{1,t+1} = A_{a(1,t)} k_{1,t}^{\delta_{1,a(1,t)}} I_{1,t}^{\delta_{2,a(1,t)}},\ t = t_0, \ldots, t_h^s - 1, \tag{2}$$

where $a(1,t)$ denotes the age of child 1 in period t. The productivity parameter $\delta_{1,a(1,t)}$ dictates how child quality builds upon itself, and $\delta_{2,a(1,t)}$ characterizes the productivity of parental investments. Both parameters and TFP are allowed to vary with the age of the child.

While the Cobb-Douglas functional form assumption restricts interactions between the current level of child quality ($k_{1,t}$) and the parental investment composite ($I_{1,t}$), substitutability/complementarity between time ($\tau_{1,t}$) and expenditure ($e_{1,t}$) inputs is allowed for in the formation of the parental investment composite according to a constant return to scale CES aggregator:

$$I_{1,t} = [\phi_{a(1,t)}(\theta_\tau \cdot \tau_{1,t})^\rho + (1 - \phi_{a(1,t)})(\theta_e \cdot e_{1,t})^\rho]^{1/\rho}. \tag{3}$$

The substitution parameter $\rho < 1$ determines whether time and expenditure inputs are substitutes or complements in producing child quality. The time input share ($\phi_{a(1,t)}$) is allowed to vary with the age of child 1, and $\theta_{\{\tau,e\}}$ are the respective scaling parameters for the inputs.

After the birth of child 2, the production of child quality also depends on spillovers from investment directed to the other sibling. While investment measures in the CNLSY79 are specific to each sibling, the spillover technology accounts for the fact that a child can indirectly benefit from a book or musical instrument, or time spent reading with a parent, that is dedicated to a sister or brother. Because inputs dedicated to one sibling can benefit the other sibling as well, the spillovers introduce economies of scale in parents' investments.

For periods in which both siblings are alive, child qualities for the first and secondborn are produced according to:

$$\begin{aligned} k_{1,t+1} &= A_{a(1,t)} k_{1,t}^{\delta_{1,a(1,t)}} I_{1,t}^{\delta_{3,a(1,t)}} I_{2,t}^{\delta_{4,a(1,t)}} \\ k_{2,t+1} &= A_{a(2,t)} k_{2,t}^{\delta_{1,a(2,t)}} I_{2,t}^{\delta_{3,a(2,t)}} I_{1,t}^{\delta_{5,a(2,t)}} \end{aligned} \quad , \, t = t_h^s, \ldots, T_h^s - 1,$$

where $a(i,t)$ denotes the age of child $i \in \{1,2\}$ in period t. Quality is produced by investments that are specific to each child with productivity $\delta_{3,a(i,t)}$, and differs from (2) by the introduction of spillovers from investments in the other sibling. Child 1 (child 2) benefits from investments directed to child 2 (child 1) with productivities $\delta_{4,a(1,t)}$ ($\delta_{5,a(2,t)}$) that are potentially asymmetric between siblings. Because the productivity of spillovers depends on the age of children, benefits accrued to the firstborn from investment directed to the second child ($I_{2,t}^{\delta_{4,a(1,t)}}$) can vary according to the difference between the siblings' ages at any point in time. This captures that firstborns aged 6 versus 1 at the time of birth of their respective sibling potentially benefit differently from investments directed to the newborn.

The respective parental investment composites of siblings when both alive ($I_{1,t}$ and $I_{2,t}$) are specified according to the same CES technology as in (3)[11]. A limitation of specifying the spillovers as function of the investment composites is to leave out heterogeneity in how time and expenditure inputs can be shared differently between siblings. Under this restriction, the time-to-expenditure input decisions of parents depend on their relative costs, productivity and substitutability/complementarity, and omit to consider that the productivity of spillovers may differ across both investment types. This restriction is traded-off for a simplification to the household's problem that delivers tractable

[11] Since the time input share is age-dependent, the relative productivity of time-to-expenditure inputs can differ across siblings at one point in time. The investment composite for child 2 is specified as: $I_{2,t} = [\phi_{a(2,t)}(\theta_\tau \cdot \tau_{2,t})^\rho + (1-\phi_{a(2,t)})(\theta_e \cdot e_{2,t})^\rho]^{1/\rho}$.

closed form solutions by separating it into linked intra- and intertemporal subproblems following Caucutt et al. (2020).

Intratemporal Problem

In the intratemporal problem at period (t), the household's objective is to minimize the cost of time and expenditure inputs, conditional on values of parental investment composites ($I_{1,t}$ before the birth of child 2, and both $I_{1,t}$ and $I_{2,t}$ after). Fixing $I_{1,t}$ and $I_{2,t}$, there is no interaction between investments in the first and second child, such that parents minimize the cost of inputs in each child (i) separately at period (t) for $i \in \{1(t_0 \leq t \leq T_h^s - 1), 2(t_h^s \leq t \leq T_h^s - 1)\}$:

$$\underset{e_{i,t},\tau_{i,t}}{\text{Min}}\ e_{i,t} + w_t \cdot \tau_{i,t}$$
$$\text{s.t. } I_{i,t} = [\phi_{a(i,t)}(\theta_\tau \cdot \tau_{i,t})^\rho + (1 - \phi_{a(i,t)})(\theta_e \cdot e_{i,t})^\rho]^{1/\rho};\ e_{i,t} \geq 0;\ \tau_{i,t} \geq 0,$$

The price of goods for children is assumed to be the numeraire[12], and the price of time inputs is the wage offer received in period t, i.e., the income forgone from dedicating this time to children instead of work.

The FOCs yield that the optimal relative time-to-expenditure inputs from parents in each child is a function of the inputs' relative price (w_t), productivity ($\phi_{a(i,t)}$) and substitutability/complementarity (ρ)[13]:

$$\tau_{i,t}^* = e_{i,t} \cdot \left(\frac{(1 - \phi_{a(i,t)})\theta_e^\rho}{\phi_{a(i,t)}\theta_\tau^\rho} \cdot w_t\right)^{\frac{1}{\rho-1}} = e_{i,t} \cdot \Phi_{i,t},$$

where the scaling parameters $\theta_{\tau,e}$ bear no economic meaning. Information from the intratemporal problem can be summarized by the unit price of the parental investment composite for each child:

$$P_{i,t} = \frac{1 + w_t\Phi_{i,t}}{[\phi_{a(i,t)}(\theta_\tau \cdot \Phi_{i,t})^\rho + (1 - \phi_{a(i,t)})\theta_e^\rho]^{1/\rho}},$$

such that the cost of investments in periods $t_0 \leq t < t_h^s$ when child 1 is alone with

[12]The price of consumption goods is also fixed to the numeraire, such that goods for children are identically priced.

[13]The spending share on time inputs $S_{i,t}^\tau = w_t\Phi_{i,t}/(1 + w_t\Phi_{i,t})$ is a strictly increasing function of the time input share ($\partial S_{i,t}^\tau/\partial\phi_{i,t} > 0$), while the inverse holds for the spending share on expenditure inputs $S_{i,t}^\tau = 1/(1 + w_t\Phi_{i,t})$. If time and expenditure inputs are substitutes $\rho > 0$ (complements $\rho < 0$), the spending share on time inputs is a strictly decreasing (increasing) function of the wage offer w_t; the inverse can be stated for the spending share on expenditure inputs.

parents is $P_{1,t}I_{1,t}$, and in periods $t_h^s \leq t \leq T_h^s - 1$ when both siblings are alive, this cost is $P_{1,t}I_{1,t} + P_{2,t}I_{2,t}$.

Intertemporal Problem

Information from the intratemporal problem is summarized by the unit price of the investment composite ($P_{i,t}$), such that the intertemporal problem faced by households can be simplified to choosing a sequence of joint working hours, consumption goods and parental investment composite(s), from the birth of child 1 at t_0 until child 2 reaches the age of 16 after period $T_h^s - 1$. Prior to the birth of child 2, this intertemporal problem can be characterized by the Bellman equations:

$$V_t^{\text{pre}}(k_{1,t}, k_2^0) = \underset{l_t, I_{1,t}}{\text{Max}} \; u(l_t, c_t, k_{1,t}, k_2^0) \quad \begin{cases} +\beta E_t[V_{t+1}^{\text{pre}}(k_{1,t+1}, k_2^0)], \; t = t_0 \dots t_h^s - 2 \\ +\beta E_t[V_{t+1}^{\text{post}}(k_{1,t+1}, k_{2,t+1})], \; t = t_h^s - 1 \end{cases}$$

$$\text{s.t. } c_t = w_t(T - l_t) - P_{1,t}I_{1,t}; \; l_t \leq T; \; I_{1,t} \geq 0$$
$$k_{1,t+1} = A_{a(1,t)} k_{1,t}^{\delta_{1,a(1,t)}} I_{1,t}^{\delta_{2,a(1,t)}},$$

where $V_t^{\text{pre}}(\cdot)$ and $V_t^{\text{post}}(\cdot)$ are the value functions of the household pre/post birth of child 2, and T is the number of available hours for joint leisure, work and time investments in the first child within a period. Birth spacing is discrete and lasts at least one year ($S^h \geq 1$), such that no twins are allowed in the model. Once child 2 is alive, the problem becomes:

$$V_t^{\text{post}}(k_{1,t}, k_{2,t}) = \underset{l_t, I_{1,t}, I_{2,t}}{\text{Max}} \; u(l_t, c_t, k_{1,t}, k_{2,t}) \quad \begin{cases} +\beta E_t[V_{t+1}^{\text{post}}(k_{1,t+1}, k_{2,t+1})], \; t = t_h^s \dots T_h^s - 2 \\ +\beta E_t[V_{T_h^s}^{\text{end}}(k_{1,T_h^s}, k_{2,T_h^s})], \; t = T_h^s - 1 \end{cases}$$

$$\text{s.t. } c_t = w_t(T - l_t) - P_{1,t}I_{1,t} - P_{2,t}I_{2,t}; \; l_t \leq T; \; I_{1,t} \geq 0; \; I_{2,t} \geq 0$$
$$k_{1,t+1} = A_{a(1,t)} k_{1,t}^{\delta_{1,a(1,t)}} I_{1,t}^{\delta_{3,a(1,t)}} I_{2,t}^{\delta_{4,a(1,t)}}$$
$$k_{2,t+1} = A_{a(2,t)} k_{2,t}^{\delta_{1,a(2,t)}} I_{2,t}^{\delta_{3,a(2,t)}} I_{1,t}^{\delta_{5,a(2,t)}},$$

where $V_{T_h^s}^{\text{end}}(k_{1,T_h^s}, k_{2,T_h^s}) = \frac{\beta^{T_h^s - 1}}{(1-\beta)}[\psi_1(S_h)ln(k_{1,T_h^s}) + \psi_2 ln(k_{2,T_h^s})]$ is the terminal value of the household after child 2 reaches the age of 16.

The FOCs of the intertemporal problem yield the following optimal spending share in parental investments directed to child 1 in periods prior to the second child's birth:

$$\frac{P_{1,t}I_{1,t}^{*\text{pre}}}{Tw_t} = \frac{\beta\eta_{1,t+1}\delta_{2,a(1,t)}}{\beta\eta_{1,t+1}\delta_{2,a(1,t)} + \alpha_{1,h} + \alpha_{2,h}}, \; t = t_0, \dots, t_h^s - 1,$$

whereas in periods when both siblings are alive, the corresponding solutions for the first and second child are respectively:

$$\frac{P_{1,t} I_{1,t}^{*\text{post}}}{T w_t} = \frac{\beta(\eta_{1,t+1}\delta_{3,a(1,t)} + \eta_{2,t+1}\delta_{5,a(2,t)})}{\beta\eta_{1,t+1}(\delta_{3,a(1,t)} + \delta_{4,a(1,t)}) + \beta\eta_{2,t+1}(\delta_{3,a(2,t)} + \delta_{5,a(2,t)}) + \alpha_{1,h} + \alpha_{2,h}}$$

$$\frac{P_{2,t} I_{2,t}^{*\text{post}}}{T w_t} = \frac{\beta(\eta_{2,t+1}\delta_{3,a(2,t)} + \eta_{1,t+1}\delta_{4,a(1,t)})}{\beta\eta_{1,t+1}(\delta_{3,a(1,t)} + \delta_{4,a(1,t)}) + \beta\eta_{2,t+1}(\delta_{3,a(2,t)} + \delta_{5,a(2,t)}) + \alpha_{1,h} + \alpha_{2,h}}, \ t = t_h^s, \ldots, T_h^s - 1.$$

$\eta_{1,t+1} = \frac{\partial V_{t+1}(k_{1,t+1}, k_{2,t+1})}{\partial log(k_{1,t+1})}$ and $\eta_{2,t+1} = \frac{\partial V_{t+1}(k_{1,t+1}, k_{2,t+1})}{\partial log(k_{2,t+1})}$ represent the discounted future marginal utility of (log) child quality for both siblings, following the recursive structure detailed in Del Boca, Flinn, and Wiswall (2014)[14].

The interpretation of the solutions governing parental investments in the model is straightforward. If parents were to spend all their resources on child i's investment composite in period t, they could purchase $\frac{Tw_t}{P_{i,t}}$ units. Parents not only care for the quality of child 1, but also for leisure and consumption, such that they optimally only dedicate a share $\frac{\beta\eta_{1,t+1}\delta_{2,a(1,t)}}{[\beta\eta_{1,t+1}\delta_{2,a(1,t)} + \alpha_{1,h} + \alpha_{2,h}]}$ of available resources on the quality of child 1 for periods prior to the birth of child 2. This share is proportional to the returns on investments measured in discounted future utility of child quality and inversely proportional to how they currently value leisure and consumption.

When both siblings are alive, the share of available resources that parents optimally dedicate to each child is not only proportional to the returns in future discounted utility from own investment in this child, but also from the returns that arise from spillovers of investments directed to the other sibling. If investments directed to child 1 (child 2) generate large spillovers towards child 2 (child 1), parents will optimally increase the share of resources allocated to child 1 (child 2). The relative productivity of investment spillovers can vary with the age of children.

Whether resource dilution arises in the model depends on how the optimal per-child level of investment composite compares before and after the second child's birth. As illustrated next, if the child quality production function restricts investments to be specific to each child, such that the spillover technology is shut-down ($\delta_{4,a(1,t)} = 0, \ \delta_{5,a(2,t)} = 0$), the model necessarily generates a decline in the per-child level of investments following the second child's birth, as long as parents care for both siblings. In contrast, the spillover technology can fully offset this decline by the introduction of economies of scale in parental investments.

[14] $\eta_{1,t+1}$ and $\eta_{2,t+1}$ both depend on the productivity of current child quality $\delta_{1,a(i,t)}$ and the discount factor. They differ with respect to their Cobb-Douglas utility shares on child quality, $\alpha_{3,h}$ and $\alpha_{4,h}$, and the free parameters assigned to the terminal value of the household $\psi_1(S^h)$ and ψ_2.

Illustrating the Dilution of Resources: Restriction on the Spillover Technology

To illustrate how the dilution of parental resources can arise in the model, let's consider a "standard" case where no spillovers are introduced in the child quality production function ($\delta_{4,a(1,t)} = 0,\ \delta_{5,a(2,t)} = 0$) and the parental investment productivity parameter is the same before and after the second child's birth ($\delta_{2,a(i,t)} = \delta_{3,a(i,t)}$). In this restricted case, next period's child quality is always produced according to: $k_{i,t+1} = A_{a(i,t)} k_{i,t}^{\delta_{1,a(i,t)}} I_{i,t}^{\delta_{2,a(i,t)}}$. Denote by $\tilde{I}_{i,t}^{\text{post}}$ what would be the optimal level of parental investments in child i when both siblings are alive in this simplified version of the model. If parents care for both siblings ($\eta_{1,t+1} > 0$ and $\eta_{2,t+1} > 0$) and the productivity of parental investments is strictly positive ($\delta_{2,a(i,t)} > 0$), the comparison of the optimal level of investment composite directed to child 1 before the second child's birth ($I_{1,t}^{*\text{pre}}$), and that when both siblings are alive ($\tilde{I}_{1,t}^{*\text{post}}$), yields the following inequality for a given counterfactual period t:

$$I_{1,t}^{*\text{pre}} = \frac{Tw_t\beta\eta_{1,t+1}\delta_{2,a(1,t)}}{P_{1,t}[\beta\eta_{1,t+1}\delta_{2,a(1,t)} + \alpha_{1,h} + \alpha_{2,h}]} > \frac{Tw_t\beta\eta_{1,t+1}\delta_{2,a(1,t)}}{P_{1,t}[\beta\eta_{1,t+1}\delta_{2,a(1,t)} + \beta\eta_{2,t+1}\delta_{2,a(2,t)} + \alpha_{1,h} + \alpha_{2,h}]} = \tilde{I}_{1,t}^{*\text{post}}.$$

Holding $a(1,t)$ and w_t constant, this expression shows that without the spillover technology, resources dedicated to investments in children when both alive come from the same total resources as when only one child is present. Therefore, resources for each child decline when more children are present in the family.

Spillovers as Potential Dilution Mitigator

It is next instructive to introduce one parameter that characterizes spillovers received by child 2 from investments directed to child 1 ($\delta_{5,a(1,t)}$), holding the productivity of investments that are specific to each child to be the same before and after the second child's birth ($\delta_{2,a(i,t)} = \delta_{3,a(i,t)}$). In this case, next period's quality for the second child is produced according to: $k_{2,t+1} = A_{a(1,t)} k_{2,t}^{\delta_{1,a(2,t)}} I_{2,t}^{\delta_{2,a(2,t)}} I_{1,t}^{\delta_{5,a(2,t)}}$. Denote by $\hat{I}_{1,t}^{\text{post}}$ what would be the optimal level of investment composite in child 1 when both siblings are alive in this alternative model with partial spillovers. Under the same conditions as above ($\eta_{1,t+1} > 0$, $\eta_{2,t+1} > 0$, $\delta_{2,a(i,t)} > 0$) and that the productivity from spillovers is strictly positive ($\delta_{5,a(1,t)} > 0$), comparing $\hat{I}_{1,t}^{\text{post}}$ and $\tilde{I}_{1,t}^{*\text{post}}$ for a given period t yields:

$$\hat{I}_{1,t}^{\text{post}} = \frac{Tw_t\beta(\eta_{1,t+1}\delta_{2,a(1,t)} + \eta_{2,t+1}\delta_{5,a(2,t)})}{P_{1,t}[\beta\eta_{1,t+1}\delta_{2,a(1,t)} + \beta\eta_{2,t+1}(\delta_{2,a(2,t)} + \delta_{5,a(2,t)}) + \alpha_{1,h} + \alpha_{2,h}]} > \tilde{I}_{1,t}^{*\text{post}}.$$

As consequence of the economies of scale from the introduction of spillovers going to child 2 ($\delta_{5,a(1,t)}$), the decline in the per-child level of investment composite in child 1 before and after the second child's birth can be fully offset.

The child quality production function technology considered in this paper allows the productivity of investments that are specific to each child to differ before and after the second child's birth ($\delta_{2,a(i,t)} \neq \delta_{3,a(i,t)}$), in addition to incorporate spillovers received by child 1 from investments directed to child 2 ($\delta_{4,a(1,t)} \neq 0$). Put together, the change of per-child parental investment composite around the second child's birth can end up positive, negative or null in the model. Thus, if resource dilution is predicted by the model, it would not be imposed by its structural assumptions as in the case without the spillover technology.

4 Measurement, Identification and Estimation

This section describes the approach utilized to measure latent child quality and parental inputs in time and financial expenditure from observed cognitive ability test scores and investment proxies contained in the CNLSY79. Based on measures of child quality, investment inputs, and parents' working hours and wages, the variation that serves to identify the model parameters is then characterized. This section ends with a brief description of the simulated moment-based method employed to estimate the model parameters.

Measuring Child Quality and Investment Inputs

Latent measures of child quality and parental inputs in time and financial expenditure in children are obtained from a mapping that leverages the discreteness of cognitive ability test scores and investment proxies observed in the data. To test the cognitive ability of children surveyed in the CNLSY79, they answer a series of periodic PIAT tests when they are of age to attend elementary school. Scores on PIAT tests are defined as the number of correctly answered questions over the total number of questions administered (84 in the case of PIAT tests). Thus each question takes a value of 1 if correct, 0 otherwise, and the score is obtained by summing over those values. By specifying the probability that the child gets a correct answer as function of latent child quality under parametric restrictions, PIAT scores can be modelled as realizations of a

Binomial random variable[15]. This approach allows for measurement error in the mapping between child quality and cognitive ability test scores.

Proxies of parental investments contained in the CNLSY79 have a similar discrete structure. The HOME scores sum over the values of surveyed investment items, each re-coded to take a value of 1 if the investment measure is judged sufficiently high by administrators of the CNLSY79, 0 otherwise. This re-coding makes values on different investment items comparable, even if they are initially based on different scales, e.g. "the number of books the child has access to?"; or, "does the child have access to a musical instrument?". According to items selected to characterize investment proxies related to time and financial expenditure in children, as described in table 9 of Appendix A1, realized HOME subscores can also be modelled as realizations of a Binomial random variable under parametric assumptions on the probability of success.

Given the number of trials defining PIAT scores (N^k) and HOME subscores related to time ($N^{\tau}_{a(i,t)}$) and expenditure ($N^{e}_{a(i,t)}$)[16], and their respective probability of success, the realization of each score is characterized by the following Binomial random variables:

$$\begin{aligned} \text{PIAT scores: } & k^*_{i,a(i,t)} \sim B(N^k, p(k_{i,t})) \\ \text{HOME-time subscores: } & \tau^*_{i,a(i,t)} \sim B(N^{\tau}_{a(i,t)}, p(\tau_{i,t})) \\ \text{HOME-expenditure subscores: } & e^*_{i,a(i,t)} \sim B(N^{e}_{a(i,t)}, p(e_{i,t})). \end{aligned}$$

$k_{i,t}$, $\tau_{i,t}$ and $e_{i,t}$ are the latent child quality, time inputs and financial expenditure in children, and $k^*_{i,a(i,t)}$, $\tau^*_{i,a(i,t)}$ and $e^*_{i,a(i,t)}$ are the corresponding discrete score realizations. Based on the optimal decisions of households on latent investments, model equivalents to PIAT and HOME scores can be generated and matched to their actual measures in the data.

The probability of success for each score is specified as logistic, such that for $x \in \{k, \tau, e\}$:

$$p(x_{i,t}; \lambda^x) = \frac{exp(\lambda^x_0 + \lambda^x_1 ln(x_{i,t}))}{1 + exp(\lambda^x_0 + \lambda^x_1 ln(x_{i,t}))}.$$

The parameters λ^x for $x \in \{k, \tau, e\}$ must be "known" for the behavioral parameters in the

[15] Borrowed from the psychometric literature, this replicates the application by Del Boca, Flinn, and Wiswall (2014) where child quality is measured based on the 57 question Letter-Word test scores from the Child Development Supplement of the PSID.

[16] The number of trials for HOME subscores are specified to change with the age of the child, reflecting that the number of investment items change over the different childhood periods in the CNLSY79. The number of questions asked in PIAT tests is fixed at $N^k = 84$, irrespective of the age of the child.

model to be identified by the estimation procedure. This parametric constraint implies a trade-off between restricting the probability of success to be specified identically at different ages and identifying how investment productivities change with the age of the child in the model. In addition, because the measurement unit of child quality is not known, the values for λ^k must be set in somewhat an “ad hoc” way, insuring that the probability of success is strictly increasing in k. Borrowing from Del Boca, Flinn, and Wiswall (2014) the parameters are set to $\lambda_0^k = 0$ and $\lambda_0^k = 1$.

While the unit of child quality in the model is set arbitrarily, units of parental inputs in children should correspond to actual shares of households’ available time and income dedicated to children that is observed in the data. Provided that the slope of the logistic index functions is fixed ($\lambda_1^\tau = 1$ and $\lambda_1^e = 1$), λ_0^τ and λ_0^e are calibrated based on empirical moments of actual parental time inputs and financial expenditure in children for two-child families from the Child Development Supplement (CDS) of the PSID[17]. Denote by $\hat{\tau}$ and $\hat{e}$ the corresponding sample average of actual time and financial expenditure observed in the CDS, and by $\hat{p}(\tau)$ and $\hat{p}(e)$ the average share of items that constitute the HOME subscores in the CNLSY79 taking a value of one. For $x \in \{\tau, e\}$, λ_0^x can be obtained by inverting the logistic probability function evaluated at $p(x_{i,t}; \lambda^x) = \hat{p}(x)$, $x_{i,t} = \hat{x}$ and $\lambda_1^x = 1$, where it is assumed that $\hat{p}(x) \in (0, 1)$ and $\hat{x}$ is strictly positive and finite:

$$\lambda_0^x = ln[\frac{\hat{p}(x)}{(1 - \hat{p}(x)) \cdot \hat{x}}].$$

The calibration of λ_0^x makes it such that the average share of HOME items taking a value of one for two-child families in the CNLSY79 is characterized by the average time and financial expenditure in children observed for two-child families in the CDS.

Identification

Based on the above measurement approach, this section assumes that measures of child quality $k_{i,t}$, time investment $\tau_{i,t}$ and financial expenditure in children $e_{i,t}$ are available and serve to characterize the model parameters. The identification approach builds on Del Boca, Flinn, and Wiswall (2014) where the estimation of the child quality production function is augmented by moments on parents’ working hours, and time and expenditure

[17]Average active time inputs for two-child families are borrowed from Del Boca, Flinn, and Wiswall (2014) and total household child expenditure (in 2002 dollars) for one- or two-child families are borrowed from Caucutt et al. (2020), who show that similar expenditure numbers are found in the Consumer Expenditure Survey (CEX).

investments that are tied to optimal decisions of parents from the model. Estimates of productivity parameters of the child quality production function thus account for the opportunity costs of parental inputs, such that investment decisions are not only based on productivity considerations, but also cost minimization. The child quality production function considered in this paper differs to theirs in that it allows for investment spillovers between siblings and for complementarity/substitutability between time and expenditure inputs.

To determine what variation in the data is required to identify the parameters governing the child quality production function, it is instructive to show how they can be estimated separately from the augmented moments tied to parents' decisions from the model. Consider the non-linear least square estimator for the production process of next period's child (i) quality for a sample household h when the first child is alive in period $t \geq t_0$, assuming away investment spillovers between siblings:

$$\hat{\Gamma}_1 = \arg\min_{\Gamma_1} \sum_{h \in H; i \in \{1(t \geq t_0), 2(t \geq t_h^s)\}} (lnk_{i,t+1}^h - (\delta_0 + \delta_{0,a} a(i,t) + \delta_{1,a(i,t)} lnk_{i,t}^h \\ + (\delta_{2,a(i,t)}/\rho) ln[\phi_{a(i,t)}(\tau_{i,t}^h)^\rho + (1 - \phi_{a(i,t)})(\theta_e \cdot e_{i,t}^h)^\rho]))^2,$$

where δ_0 is a constant, $a(i,t)$ is the age of the child in period t, θ_τ is normalized to 1 and the second child is alive S_h periods after t_0, from $t_h^s = t_0 + S_h$. The full rank condition that ensures consistency of the estimator $\hat{\Gamma}$ requires either that input choices $\tau_{i,t}^h$ and $e_{i,t}^h$ differ across households in the sample, or across siblings within households, and that inputs must be observed at different ages of children across or within households. Both conditions, with that of observing child quality $k_{i,t}^h$ over different ages for children, are satisfied by variation contained in the CNLSY79.

Under the restriction that parameters governing the CES investment composite are identical before and after the second child's birth, estimates of the time input share $\hat{\phi}_{a(i,t)}$, the substitution parameter $\hat{\rho}$ and scaling parameter $\hat{\theta}_e$ from $\hat{\Gamma}_1$ can be used to estimate the child quality production process with investment spillovers. Consider the non-linear least square estimator for production of next period's child quality for the firstborn (the case for the secondborn follows through) at $t \geq t_h^s$, when both siblings are alive:

$$\tilde{\Gamma}_2 = \arg\min_{\Gamma_2} \sum_{h\in H} (lnk^h_{1,t+1} - (\delta_0 + \delta_{0,a}a(i,t) + \hat{\delta}_{1,a(1,t)} lnk^h_{1,t}$$
$$+ (\delta_{3,a(1,t)}/\hat{\rho}) ln[\hat{\phi}_{a(1,t)}(\tau^h_{1,t})^{\hat{\rho}} + (1-\hat{\phi}_{a(1,t)})(\hat{\theta}_e \cdot e^h_{1,t})^{\hat{\rho}}])$$
$$+ (\delta_{4,a(1,t)}/\hat{\rho}) ln[\hat{\phi}_{a(2,t)}(\tau^h_{2,t})^{\hat{\rho}} + (1-\hat{\phi}_{a(2,t)})(\hat{\theta}_e \cdot e^h_{2,t})^{\hat{\rho}}]))^2.$$

The full rank condition for consistency of $\tilde{\Gamma}_2$ requires that investments $\tau^h_{i,t}$ and $e^h_{i,t}$ differ across siblings $i \in \{1,2\}$ within a family, and that those differences are not the same across households. In addition, the age dependence of investment productivity parameters necessitates to observe those within-household investments at different ages of children, which is available in the CNLSY79 due to the periodic (2-3 years) frequency of surveys for a given household.

To deal with missing observations from the irregular frequency of household surveys in the data, a simulated moment-based method is employed to estimate the parameters governing the child quality production function[18]. Based on the identification arguments presented above, selected moments that characterize variation necessary to identify the parameters of the production function are the marginal distributions of investments in siblings and child quality at different ages (sample mean and standard deviation), the correlations of child quality for different ages, and the correlations between investments and child quality for different ages that are specific to a child and across siblings in a family.

The household wage offer and birth spacing processes are assumed exogenous in the model[19]. Following Del Boca, Flinn, and Wiswall (2014), the child quality production function is estimated jointly with the behavioral parameters in the model. Fixing Γ_1, Γ_2, the discount factor β and free parameters $\psi_1(S^h)$ and ψ_2, moments characterizing the marginal distributions (sample mean and standard deviation) of observed hours of work and investment inputs in children can identify the time invariant utility shares

[18]To simulate the path of child quality in the model, households draw an initial child quality $k^0_i = \frac{p_{i,0}}{1-p_{i,0}}$, where $p_{i,0} \sim \text{Beta}(1+\gamma_1, 1+\gamma_2)$. Estimates of γ_1 and γ_2 minimize the distance between the sequence of child quality predicted by the model and that measured in the data, given a set of parameters governing the child quality production and a sequence of households' investment decisions.

[19]The intercept $\mu_{0,h} \sim N(\mu_0, \sigma_{\mu_0})$, slope $\mu_{1,h} \sim N(\mu_1, \sigma_{\mu_1})$ and unobservables $\epsilon_{t,h} \sim N(\epsilon, \sigma_\epsilon)$, define the joint wage offer received by a household (h) in period t: $ln(w_{t,h}) = \mu_{0,h} + \mu_{1,h} \cdot t + \epsilon_{t,h}$. Estimates of the parameters governing $\mu_{0,h}$ and $\mu_{1,h}$ match sample mean and standard deviation of households' per-parent average wage conditional on AFQT scores, years of schooling and birth cohort dummies of the mother, while parameters governing $\epsilon_{t,h}$ match the unconditional wages, given $\mu_{0,h}$ and $\mu_{1,h}$. Birth spacing is discrete and drawn from a Poisson distribution with mean parameters estimated to match the empirical deciles of the time between births observed for sample households.

$\alpha_{1,h} + \alpha_{2,h} + \alpha_{3,h} + \alpha_{4,h} = 1$. Given a wage offer in period $t \geq t_0$, decisions on hours of work and inputs in children in the model are positive, such that they can be inverted to yield a household specific set of utility shares. Estimates of the static parameters governing preferences of households minimize the distance between the optimal decisions of parents in the model and corresponding hours of work and investments observed in the data at one point in time. Estimates of the discount factor β and free parameters $\psi_1(S^h)$ and ψ_2 minimize the distance between the sequence of households' decisions over time and the actual sequences of working hours and investments in the data.

Parametric Specification and Estimation

Productivity parameters on past child quality and investment composites ($\delta_{\{1,2,3,4,5\},a(i,t)}$), as well as total factor productivity ($A_{a(i,t)}$), vary with the age of the child and would ideally be estimated at each age increment. To save on parameter space, the productivity parameters are specified as exponential with respective index specified as linear in the age of the child following Del Boca, Flinn, and Wiswall (2014):

$$
\begin{aligned}
\delta_{x,a(i,t)} &= exp(\varphi_{x,0} + \varphi_{x,1} \cdot a(i,t)),\ x \in \{1,2,3,4,5\} \\
A_{a(i,t)} &= exp(\varphi_{A,0} + \varphi_{A,1} \cdot a(i,t) + \omega_{a(i,t)}),
\end{aligned}
$$

where $\varphi_{\cdot,0}$ are the intercepts and $\varphi_{\cdot,1}$ the age slopes. A general assumption on the disturbance term of total factor productivity ($A_{a(i,t)}$) is maintained: $\omega_{a(i,t)} \overset{\text{i.i.d.}}{\sim} (0, \sigma^2_\omega)$. The time input share is specified as logistic, also with an index that is linear in the age of the child:

$$
\phi_{a(i,t)} = \frac{exp(\varphi_{0,0} + \varphi_{0,1} \cdot a(i,t))}{1 + exp(\varphi_{0,0} + \varphi_{0,1} \cdot a(i,t))}.
$$

The household specific utility shares $\alpha_{1,h} + \alpha_{2,h} + \alpha_{3,h} + \alpha_{4,h} = 1$ are based on a three-by-one multivariate normal vector $\Omega_h \sim N(\mu_\Omega, \Sigma_\Omega)$, where μ_Ω is a three-by-one mean vector and Σ_Ω a three-by-three dimensional full rank covariance matrix. Each household (h) draws a vector Ω_h from which the utility shares are obtained so to add-up to one:

$$
\begin{aligned}
\alpha_{x,h} &= \frac{exp(\Omega_{h,x})}{1 + exp(\Omega_{h,1}) + exp(\Omega_{h,2}) + exp(\Omega_{h,3})},\ x \in \{1,2,3\} \\
\alpha_{4,h} &= \frac{1}{1 + exp(\Omega_{h,1}) + exp(\Omega_{h,2}) + exp(\Omega_{h,3})}.
\end{aligned}
$$

Parameters of the model are estimated by Method of Simulated Moments (MSM), which deals with missing observations from the irregular delays between surveys administered to households in the CNLSY79. Simulated moments based on decisions of households in the model can match corresponding empirical moments on different childhood periods that aggregate observations from irregularly spaced surveys in the data. In addition, the MSM allows for measurement error in the mapping between child quality and cognitive ability test scores, as well as between latent parental inputs and investment proxies observed in the data.

To simulate the model environment, a number of $\mathcal{H}$ households enter in period $t = t_0$, having drawn their respective utility shares $\alpha_{\{1,2,3,4\},h}$, a joint wage schedule intercept $\mu_{0,h}$ and slope $\mu_{1,h}$, an initial child quality for the first born k_{1,t_0} and a birth spacing S^h, after which they draw their respective child quality for the second born k_{2,t_h^s}. At every period until child 2 reaches the age of 16, each household receives a shock $\epsilon_{h,t}$ on its wage offer and $\omega_{a(i,t)}$ on the total factor productivity for each child $i \in \{1, 2\}$. Given a fixed set of model parameters Π, the optimal decisions of households can be solved by backward induction. The MSM estimator is defined as the parameter vector Π that minimizes the weighted sum of squared distances between the observed moments in the data M_H and the moments based on the simulated decisions of households in the model $\tilde{M}_{\mathcal{H}}(\Pi)$:

$$\hat{\Pi} = \arg\min_{\Pi} \, (M_H - \tilde{M}_{\mathcal{H}}(\Pi))' W_H (M_H - \tilde{M}_{\mathcal{H}}(\Pi)),$$

where the weighting matrix W_H is symmetric and positive-definite. The selected W_H is the inverse of the estimated covariance matrix of the empirical moments M_H, based on 200 bootstrap samples in the data. Given a positive-definite matrix W_H, random generation of the model environment and the identifying variation from the data, as the number of simulated households $\mathcal{H}$ grows indefinitely large, under the regularity conditions considered in Pakes and Pollard (1989), the MSM estimator $\tilde{\Pi}_{\mathcal{H}}$ is a consistent estimator of the true parameter vector Π_0: $\operatorname*{plim}_{\mathcal{H}\to\infty, H\to\infty} \tilde{\Pi}_{\mathcal{H}} \to \Pi_0$. Evaluated at the MSM estimate $\tilde{\Pi}_{\mathcal{H}}$, the simulated moments converge in probability to the population moments: $\operatorname*{plim}_{\mathcal{H}\to\infty, H\to\infty} \tilde{M}_{\mathcal{H}}(\tilde{\Pi}_{\mathcal{H}}) = M_H = M$, if and only if $\tilde{\Pi}_{\mathcal{H}} = \Pi_0$. The estimated covariance matrix of the MSM estimator is obtained by resampling the estimation procedure based on 300 simulated samples. The set of empirical moments targeted by the estimation procedure is described in table 21 of Appendix A4.

5 Estimates and Sample Fit of the Model

This section details the production function parameter estimates and how well the model fits empirical moments targeted by the estimation procedure. To assess the external validity of the results, causal parameter estimates of the birth spacing effect on siblings' respective cognitive ability test scores from Buckles and Munnich (2012) are compared to the corresponding metrics generated by the model. Model predictions are also compared to a set of untargeted empirical moments, previously documented in section 2.

Estimates of the Technology Parameters

Estimates of the parameters governing the technology of child quality production are reported in table 4. Considerable persistence of child quality over time are expressed by the estimated model. At age 1, the productivity share on the last period' child quality (δ_1) is estimated at 0.91. This share decreases with age to reach 0.83 by age 10. Together with Total Factor Productivity (A) scaling over childhood, this persistence makes early changes to the path of human capital accumulation have larger impacts over time as compared to changes occurring in later periods.

The productivity of parental investments in child 1 when alone with parents is characterized by the parameter δ_2. At age 0, this share is estimated at 0.03. Its age slope coefficient is positive, but imprecise. The magnitude of this share is difficult to interpret because it is affected by the scale of the investment composite. It is, on the other hand, larger than the productivity of child specific investments when both siblings are alive (δ_3), estimated at 0.018 when the child is of age 0. The age slope of δ_3 is relatively steep and negative, such that by age 10, the productivity of child specific investments declines to 0.002. Because child 1 is older at the arrival of the second child for households with longer time between births, parents find it relatively more productive to invest in the newborn, as depicted in panel (a) of figure 4.

The decline in the productivity of child specific investments before (δ_2) and after (δ_3) the second child's birth is accounted for by important productivities of investment spillovers between siblings. At the second child's birth, the share on spillovers going to child 1 from investments directed to child 2, represented by the parameter δ_4, is 0.013 for households with two years between births. This is comparable to the productivity of child specific investments in the firstborn at this time. The age slope of the productivity of spillovers going to child 1 (δ_4) is negative, but less steep than for child specific investments in periods when both siblings are alive (δ_3).

The productivity of spillovers received by child 2 from investments directed to child

1 (δ_5) is also considerable. The estimated share at age 0 is 0.009, half the level of the productivity of investments specific to the secondborn at this age. Panel (b) of figure 4 illustrates the spillover productivity parameters over time, starting from the moment both siblings are alive. Productivity of spillovers going to child 1 (δ_4) are lower for households with more time between births because the firstborn is older at the second child's birth. Comparing panels (a) and (b) of figure 4, past the moment child 2 reaches the age of 6, the productivities of spillovers (δ_4 and δ_5) dominate that of child specific investments (δ_3) for both siblings. In other words, the production of quality for one child becomes increasingly dependent of investments received by the other sibling over time.

Table 4: Technology parameter estimates

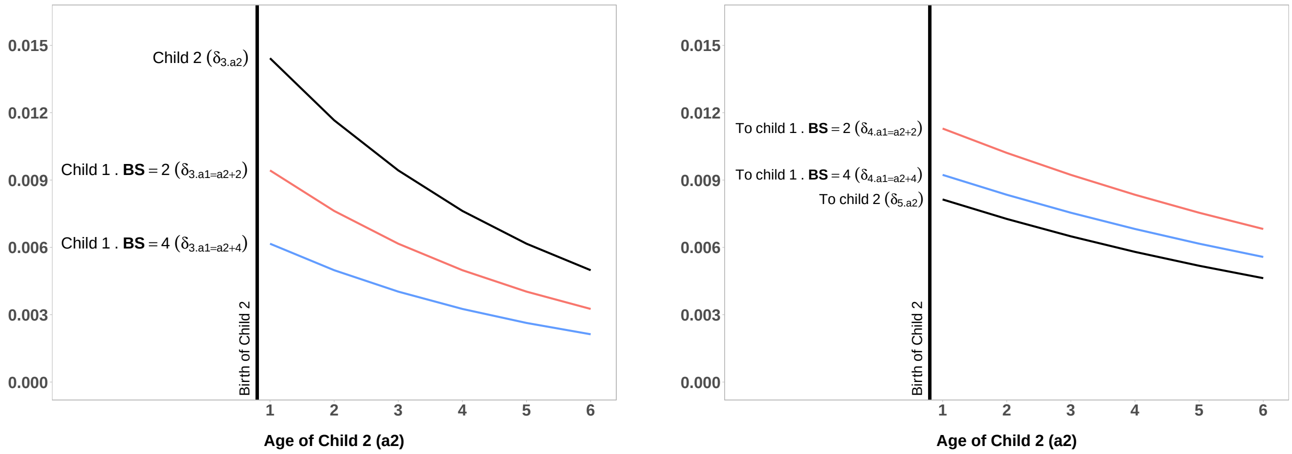
	Estimate	SE
Last period child quality δ_1 intercept	-0.09	0.012
Last period child quality δ_1 age slope	-0.01	0.003
	Before birth of child 2	
Child 1 investment δ_2 intercept	-3.41	0.170
Child 1 investment δ_2 age slope	0.04	0.035
	After birth of child 2	
Child specific investment δ_3 intercept	-4.03	0.107
Child specific investment δ_3 age slope	-0.21	0.018
Child 1 spillovers from child 2 δ_4 intercept	-4.18	0.112
Child 1 spillovers from child 2 δ_4 age slope	-0.10	0.017
Child 2 spillovers from child 1 δ_5 intercept	-4.70	0.130
Child 2 spillovers from child 1 δ_5 age slope	-0.11	0.027
Share of time investment ϕ intercept	0.50	0.017
Share of time investment ϕ age slope	0.03	0.002
Substitution parameter ρ	0.25	0.010
TFP A intercept	0.37	0.077
TFP A age slope	-0.01	0.008

Notes: Technology parameter estimates of the child quality production function based on 300 bootstrap samples of the SMS estimation procedure. Productivity parameters $\delta_{1,2,3,4,5}$ and A are specified as exponential functions with linear index in age, represented by their respective intercept and age slope parameters. The share of time investment in the investment composite CES function is specified as logistic with linear index in age, characterized by an intercept and age slope parameters.

As expected, time investments are more productive than expenditure goods in children. The time input share ϕ of the CES investment composite is estimated at 0.62 when the child is born. It increases with age to reach 0.69 when the child is 10. I estimate a

Figure 4: Productivity of child specific investments and spillovers after the birth of child 2

(a) Productivity of child specific investments (b) Productivity of spillovers



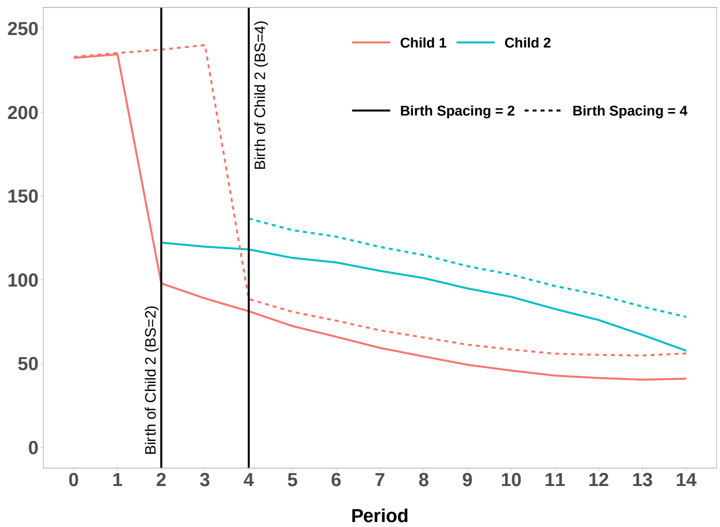
Notes: Panel (a) plots the estimate of the child specific investment productivity after the birth of child 2 ($\delta_{3,a(i,t)}$) for households with 2 and 4 years spacing between births (BS). The productivity levels for firstborns differ across birth spacing because this child is older at the second child's birth for households with more time between births, and from the fact that productivity parameters are age-dependent. Panel (b) plots the spillover productivity estimates going to child 1 from investments directed to child 2 ($\delta_{4,a(1,t)}$) for households with birth spacing at 2 (red) and 4 (blue) years, and the reverse ($\delta_{5,a(2,t)}$: productivity of spillovers going to child 2 from investments directed to child 1) in black. Similarly, the levels of spillover productivities for child 1 differ across birth spacing because they depend on the age of the firstborn at the timing of the second child's birth, which differs according to households time between births.

constant elasticity of substitution ($1/(1\text{-}\rho)$) between the two input types at 1.14, such that time investments and financial expenditure in children are to some extent substitutes in the production of child quality. Facing an upward sloping wage schedule, all else equal, this substitution effect drives parents to invest relatively less in time inputs over time from cost minimization.

Estimates of the preference parameters are relegated to table 10 of appendix A1. Because the duration of investments in child 1 is longer than that for child 2, there is a larger discount on the future marginal utility from investments in the firstborn at any given age. To compensate, the household assigns a larger utility share ($\alpha_{3,h}$) and a lower weight (ψ_1) on this child terminal value. Inversely, child 2 gets a lower utility share ($\alpha_{4,h}$), but a relatively higher weight on her/his terminal value (ψ_2). This compensating variation relieves the model of an investment break in child 1 before the terminal period, which matters for households with relatively more time between births[20], but makes the

[20]Del Boca, Flinn, and Wiswall (2014) fix birth spacing at 2 years and restrict the investment in child 1 to stop at age 16, two years before the terminal period.

Figure 5: Simulated parental investment composite over time



Notes: Predicted investment composite over time from a simulated sample of 1000 households with counterfactual time between births of 2 or 4 years, from the model evaluated at the estimated parameters.

comparison of households' relative preference on the quality of siblings impracticable.

Based on predictions from the model evaluated at the estimated parameters, figure 5 shows the evolution of the simulated mean level of investment composite received by each sibling over time for households with 2 and 4 years between births. The simulated per-child level of investments sees a sharp decline following the birth of child 2, even after accounting for spillovers. When both siblings are alive, higher productivity of investments specific to the second child and the spillovers they generate make parents invest relatively more in the younger child. The overall investments in children decrease over time from their declining productivities as siblings get older.

Model Fit of Targeted Moments

The analysis now turns to how well the model replicates empirical moments from the observed sample that are targeted by the estimation procedure. Since processes governing the wage offers and the birth spacing distribution are estimated exogenously, the analysis focuses on the "endogenous" moments targeted by the structural model, detailed in table 21 of Appendix A4. Following the discussion on identification in section 4, parameters governing the child quality production function (δ_1, δ_2, δ_3, δ_4, δ_5, ϕ, ρ) are characterized by: (1) the mean and standard deviation of time and expenditure inputs in children, measured by HOME subscores in the data, for both siblings separately over different age periods; (2) the mean and standard deviation of cognitive ability, measured by PIAT scores in the data, for both siblings jointly over different age periods; (4) the correlation of PIAT scores specific to a child over time; (5) the correlation between cognitive ability and child specific time and expenditure inputs separately (measured by HOME and PIAT scores); and (6) the cross-sibling correlation between cognitive ability of the firstborn (secondborn) and time and expenditure inputs in the secondborn (firstborn) separately (measured by HOME and PIAT scores). To identify the preference shares of households (α_1, α_2, α_3, α_4), the discount factor (β) and the free parameters (ψ_1, ψ_2) on the last period's child qualities of siblings, this set of moments is augmented by the sequence of hours of work by parents during the childhood of siblings, having already included moments on the marginal distributions of inputs in children chosen over time in (1) above. Targeted moments do not condition on the time between births, nor do they characterize the birth order gap in cognitive skills.

The fit of key empirical moments are reported in table 5, where the targeted empirical statistics are compared to the corresponding metrics obtained from a simulated sample of 1000 households in the model evaluated at the estimated parameter values. Referring to panels (1) and (2), the model fits generally well the empirical moments on relative standardized per-child investments between the ages of 0 and 5, such that child 1 receives more time and expenditure inputs relative to child 2 at this age. However, the model does not capture the persistence of birth order differences in investments past the age of 6, as observed in the data. Instead, when both siblings are born, parents find it more productive to invest in the younger child in the model. Overall, birth order differences in time inputs observed in the data are underpredicted by the model, while those for expenditure inputs are overpredicted. This miss can originate from the simplifying assumption that time and expenditure inputs are not differentiated with respect to their respective productivity of spillovers. While providing for tractable analytical solutions to the household's problem, this assumption may hide an additional reason why parents could choose to invest relatively more in expenditure inputs over time, for example, if child investment goods are more easily shareable between siblings.

Panel (3) shows that the model replicates generally well the overall child quality accumulation path when compared to observed PIAT test scores assessed when children are of age to attend elementary school. According to panel (4), the simulated hours of work during the childhood periods of siblings in the model are generally in line with observed per-parent average working hours for households in the sample.

In panel (5), correlation coefficients of child specific PIAT scores across age periods simulated by the model fit the data reasonably well. The data is however suggesting even stronger persistence of cognitive ability test scores past the age of 10 as compared to what the model predicts. Correlation coefficients between HOME and PIAT scores are shown in panels (6a) for time and (6b) for expenditure. The correlation between time inputs and child quality in the model overpredicts what is suggested by the data, while the corresponding correlation for expenditure inputs is underpredicted by the model. I interpret this to be the consequence of accounting for the relative opportunity cost of investment inputs in the model. Since input choices are tied to wages, the structural productivity estimates of time and expenditure in children correct for the part of parental investment decisions that arise from cost-minimization. Parents who tend to invest more in expenditure inputs not only do so from productivity considerations, but also because time investment is relatively more costly to them.

Panel (7) shows the cross-sibling correlation coefficients between HOME and PIAT scores, i.e., the correlation between HOME scores of child 1 (child 2) and PIAT scores of child 2 (child 1)[21]. The model achieves to generate positive cross-sibling correlation patterns between investments and cognitive skills, as observed in the data. This is the consequence of the spillover technology in the child quality production function. But an additional contributing factor to this cross-sibling correlation is the trade-off faced by parents in the model. When they invest in one sibling, they are implicitly renouncing to parental resources dedicated to the other. This trade-off offsets the cross-sibling correlation, which helps explain why the model underpredicts the coefficients from the data.

Untargeted Moments and External Validity

To validate the structural parameter estimates of the model, I next analyze the fit of empirical moments that are not targeted by the estimation procedure. Model predictions are compared to features of the data previously documented in section 2: the birth order gap in measures of parental investments and cognitive skills conditional on the time between births, and the dilution of per-child investments before and after the second child's birth. To get a sense of the external validity of the results, I then compare Buckles and Munnich (2012)'s causal estimates of the effect of birth spacing on cognitive ability test scores of the first and second child, to the corresponding metrics predicted by the model.

Panels (1) and (2) of table 6 show that the model predicts increasing birth order differences in parental investments for households with longer time between births. This

[21]Cross sibling correlation coefficients are based on observations for which the HOME score of a sibling is assessed before the timing of PIAT assessment for the other sibling, and when both children are alive.

Table 5: Model sample fit of targeted moments

(1) Mean std time HOME scores

	Child 1		Child 2	
Child age	Data	Simulated	Data	Simulated
0-9	0.13	0.05	-0.12	-0.05
0-2	0.20	0.14	-0.14	-0.14
3-5	0.07	0.06	-0.09	-0.06
6-9	0.14	-0.06	-0.14	0.06

(2) Mean std expenditure HOME scores

	Child 1		Child 2	
Child age	Data	Simulated	Data	Simulated
0-9	0.02	0.03	-0.02	-0.03
0-2	0.03	0.10	-0.02	-0.10
3-5	0.03	0.06	-0.05	-0.06
6-9	-0.01	-0.05	-0.00	0.05

(3) Mean PIAT scores (#/84)

Child age	Data	Simulated
6-15	49.5	52.0
6-7	27.0	29.5
8-9	43.2	45.1
10-11	53.3	56.3
12-13	59.9	62.7
14-15	63.9	66.0

(4) Mean per-parent weekly hours of work

	Child 1		Child 2	
Child age	Data	Simulated	Data	Simulated
0-15	36.6	36.5	36.7	36.4
0-2	36.6	37.1	36.6	36.7
3-5	36.5	36.6	36.6	36.4
6-9	36.6	36.4	36.6	36.2
10-12	36.6	36.2	36.7	36.1
13-15	36.5	36.3	36.9	36.3

(5) Correlation of child specific PIAT scores

	Data	Simulated
Child age	6-9	
10-12	0.79	0.79
13-15	0.85	0.76
	10-12	
13-15	0.77	0.56

(6) Child specific correlation between HOME and PIAT scores

(6a) Time HOME scores at age

PIAT scores at age	0-2		3-5		6-9	
	Data	Simulated	Data	Simulated	Data	Simulated
6-9	0.08	0.23	0.09	0.22	0.04	0.19
10-12	0.17	0.27	0.23	0.24	0.19	0.19
13-15	0.08	0.11	0.16	0.10	0.17	0.08

(6b) Expenditure HOME scores at age

PIAT scores at age	0-2		3-5		6-9	
	Data	Simulated	Data	Simulated	Data	Simulated
6-9	0.10	0.13	0.08	0.11	0.05	0.11
10-12	0.23	0.18	0.24	0.16	0.20	0.13
13-15	0.28	0.09	0.34	0.09	0.29	0.07

(7) Cross-sibling correlation between HOME and PIAT scores

Average HOME scores age 0-9

Sibling PIAT scores at age	Child 1 HOME scores		Child 2 HOME scores	
	Data	Simulated	Data	Simulated
6-9	0.15	0.04	0.08	0.09
10-12	0.18	0.05	0.18	0.11
13-15	0.12	0.03	0.15	0.10

Notes: Empirical moments targeted by the estimation procedure in the *Data* columns are based on the sample described in section 2 for two-child families of white mothers. The *Simulated* columns report the corresponding moments from the simulated household choices (simulated sample of size 1000) in the model.

is in most part driven by the decline in per-child investments following the second child's birth. But because parents invest relatively more in the secondborn when both siblings are alive, the model cannot generate a birth order gap in inputs past the age of 5, as is observed in the data. Panel (3) shows that the implied birth order differences in cognitive skills across birth spacing from predictions by the model are larger than that observed in the data. This can follow from the exogeneity assumption of the birth spacing process in the model.

Table 6: Model sample fit of untargeted moments

(1) Std time HOME scores birth order gap				
	Low birth spacing		High birth spacing	
Child age	Data	Simulated	Data	Simulated
0-9	-0.22	-0.01	-0.33	-0.18
0-2	-0.36	-0.27	-0.31	-0.27
3-5	-0.04	0.01	-0.35	-0.27
6-9	-0.25	0.23	-0.34	-0.00

(2) Std expenditure HOME scores birth order gap				
	Low birth spacing		High birth spacing	
Child age	Data	Simulated	Data	Simulated
0-9	0.04	-0.01	-0.17	-0.13
0-2	-0.03	-0.20	-0.08	-0.19
3-5	0.05	0.01	-0.31	-0.24
6-9	0.09	0.17	-0.13	0.05

(3) Std PIAT scores birth order gap				
	Low birth spacing		High birth spacing	
Child age	Data	Simulated	Data	Simulated
6-15	-0.19	-0.21	-0.36	-0.56
6-9	-0.13	-0.24	-0.37	-0.70
10-12	-0.18	-0.21	-0.35	-0.59
13-15	-0.22	-0.17	-0.36	-0.41

(4) Investments before and after the second child's birth			
	child 1 after - child 1 before		
	Std HOME scores		Investment composite
Birth Spacing	Data	Simulated	Simulated
All	-0.30	-0.47	-1.30
Low	-0.24	-0.45	-1.09
High	-0.38	-0.48	-1.52

Notes: Empirical moments not targeted by the estimation procedure in the *Data* columns are based on the sample described in section 2 for two-child families of white mothers. The *Simulated* columns report the moments from the simulated household choices (simulated sample of size 1000) in the model. Panel (5) compares the estimates of child 1 investments before and after the second child's birth, as documented in figure 1, to the corresponding coefficients generated by the model. *BS low* (*high*) includes observed or simulated households with birth spacing below (above) their respective sample average, while *BS all* includes all households in the sample

Panel (4) of table 6 compares the model predicted change in measures of investments before and after the second child's birth to their corresponding estimates from figure 1. The decline in per-child investment scores predicted by the model is reasonably close to its empirical counterpart. In terms of latent child inputs, this decline is more than twice as large as that for the generated error-ridden HOME scores, potentially suggesting more important resource dilution patterns underlying what is observed in the data.

To get a sense of the external validity of the results, the predicted effect of birth

Table 7: Effect of birth spacing on children's cognitive ability scores: causal estimates of Buckles and Munnich (2012) and model predictions

	Std PIAT test scores				Std child quality	
	Child 1		Child 2		Child 1	Child 2
	B.M. (2012)	Simulated	B.M. (2012)	Simulated	Simulated	Simulated
Slope estimate	0.16	0.11	-0.02	-0.00	0.15	0.01

Notes: The slope estimates from Buckles and Munnich (2012) (referred to as B.M. (2012)) average over the birth spacing effects on PIAT math and reading scores from the IV coefficients reported in table 7 in B.M. (2012). They are compared to coefficient estimates of corresponding birth spacing effects on PIAT scores and child quality predicted by the model for each sibling.

spacing on standardized cognitive ability scores of the first and second child are compared to the corresponding IV estimates from Buckles and Munnich (2012) in table 7. What makes the two metrics comparable is the assumption that birth spacing is counterfactual in the model, while the authors make the time between births "accidental" by instrumenting it using variation in miscarriage. Thus, both metrics characterize the effect of a time delay between births, which is exogenous to parents, on the cognitive ability scores of siblings. What contrasts the two is that the effect is only attributable to differences in the parental investments received by children in the model.

Buckles and Munnich (2012) estimate that an "accidental" time delay between births increases significantly the standardized scores of the firstborn, while no statistically significant effect is found for the secondborn. Predictions from the model also capture this asymmetric birth spacing effect across siblings. As illustrated in figure 8 of Appendix A1, the model predicts that as birth spacing increases, child 1 receives relatively more investments in early childhood and this translates into a superior accumulated child quality. In contrast, relative investments and accumulated child quality do not vary as much across the birth spacing distribution for child 2. According to the causal estimates from Buckles and Munnich (2012), an "accidental" year delay between births increases the birth order gap by 0.18 standard deviation, as shown in table 7. The model predicts that 78% of this effect, based on the preferred measure of child quality, can be accounted for by differentials in the parental investments received by siblings, in line with results by Pavan (2016).

6 The Role of Resource Dilution

This section quantifies the impact of resource dilution on the birth order gap in accumulated child quality between the ages of 6 and 12. The measurement strategy delays the counterfactual time between births in the model and evaluates the implied predicted change of the gap in child quality. To isolate the impact of the decline in per-child investments following the arrival of the second child, age dynamics in the productivity of investments dedicated to the first child when alone with parents are shut down. I show that investment spillovers between siblings add to the dynamic impacts of early investments and account for an important share of the persistence of the predicted gap over time. The section ends by considering the impacts of parental input price reductions on the resource dilution effect.

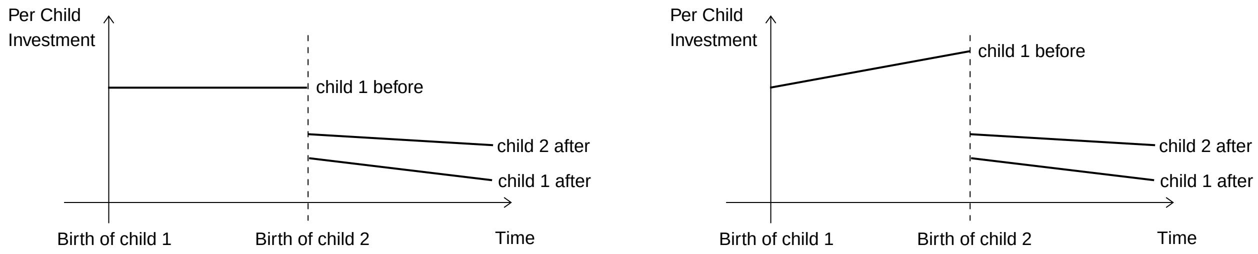
The Dynamic Impacts of an Extra Counterfactual Year Alone with Parents

To measure the dynamic impacts of the decline in per-child investments due to the arrival of the second child, I delay the counterfactual time between births in the model and evaluate the implied change in the birth order gap in child quality. This provides an estimate of the effect of spending an additional year alone with parents for the firstborn on later birth order differences in cognitive skills. To isolate this effect, I shut down the age dynamics in the productivity of investments dedicated to the firstborn before the second child's birth, as illustrated in panel (a) of figure 6 under the restricted (R) technology. This insures that variation in the time delay between births does not capture increasing investments in the firstborn when alone with parents from the positive estimated age slope of δ_2, as shown in panel (b) of figure 6 under the unrestricted (UR) technology.

The intercept and birth spacing slope coefficients from a linear regression between the counterfactual birth spacing of households in the model and their predicted birth order gap in accumulated child quality are shown in the first two columns of each panel in table 8, where an observation represents one simulated household. The third column shows the corresponding mean predicted birth order gap for the simulated sample of 1000 households. The first panel is based on model simulations under restriction (R) on the child quality production technology, such that age dynamics in the productivity of investments directed to the firstborn when alone with parents are shut down. Panel 2 imposes the same restriction (R), in addition to shutting down the investment spillover

Figure 6: Measuring the role of resource dilution - outline

(a) Resource dilution - R　　　(b) Full model - UR



Notes: Panel (a) outlines the restriction on child quality production technology imposed to shut down age dynamics of the productivity of investments directed to child 1 when alone with parretns (the slope of $\delta_{2,a(1,t)}$ is evaluated at zero). Panel (b) outlines the unrestricted child quality production technology in the full model.

technology in periods when both siblings are alive, such that $\delta_{4,a(1,t)} = \delta_{5,a(2,t)} = 0$[22]. Predictions from the full model without restriction on the child quality production technology are shown in the third panel.

Predictions under restriction (R) suggest that an extra counterfactual year alone with parents for the firstborn, holding the productivity of investments constant during that period, increases the birth order gap in accumulated child quality between the ages of 6 and 12 by 0.12 standard deviation[23]. This resource dilution effect accounts for 75% of the overall birth spacing effect in the full model with unrestricted child quality production technology (UR). If child quality is evaluated between the ages of 6 and 15 (not reported in table 8), the resource dilution effect, under restriction (R), is estimated at -0.09, accounting for roughly 50% of the causal birth spacing effect found by Buckles and Munnich (2012) for that age period[24].

To better understand the channel through which the decline of per-child investments, as the number of children in the family increases, translates into birth order differences in accumulated child quality, I shut down the investment spillover technol-

[22]The intercept of $\delta_{3,a(i,t)}$ is replaced by the intercept of $\delta_{2,a(i,t)}$ and the age slope is the average of the age slopes of $\delta_{3,a(i,t)}$, $\delta_{4,a(1,t)}$ and $\delta_{5,a(i,t)}$, such that the investment productivity is symmetric across siblings at a given age when both alive.

[23]The corresponding effect for the predicted gap in simulated PIAT scores between the ages of 6 and 12 from the model is slightly lower at -0.10 standard deviation, accounting for a little over 35% of the observed gap in the data for two-child families of white mothers (0.28 standard deviation as reported in table 1).

[24]The birth spacing slope of child quality from the model, the preferred measure of cognitive skills, is compared to that of PIAT scores in Buckles and Munnich (2012), given their instrumental variable strategy is potentially correcting for classical measurement error issues.

ogy ($\delta_{4,a(1,t)} = \delta_{5,a(2,t)} = 0$) under restriction (R) for predictions in the second panel of table 8. Without sibling spillovers, the dynamic impacts of investments alone account for 2/3 of the resource dilution effect on the child quality gap evaluated between the ages of 6 and 12. The spillover technology accounts for the remaining share, and its contribution to the persistence of the birth order gap increases over time. In fact, spillovers are necessary to generate a statistically significant (at 95%) resource dilution effect past the age of 10. By receiving spillovers from investments directed to the second child, the firstborn maintains her/his superior relative position that originates from the benefits reaped during the time spent alone with parents. Joint with the dynamic impacts of investment, this channel explains why the birth order gap in child quality persists over time, even if parents invest relatively more in the secondborn when both siblings are alive. To get a sense of the results implication for families-related polices, I next evaluate the impact of reducing prices of parental inputs on the resource dilution effect predicted by the model.

Implications for Family-Related Policies

Tax deductions, public libraries and community centres are examples of policies put in place to incentivize parental investments through direct and indirect reductions in the price of time and expenditure inputs in children. In the model environment, I evaluate the impacts of such interventions on birth order effects arising from the decline in per-child investments following the arrival of the second child. Two intervention schedules are evaluated: 1) a 20% reduction in the price of time or/and expenditure inputs starting from the moment child 1 is alive until the final period in the model; 2) the same reduction, but introduced only after the second child's birth. Reducing the price of time inputs is assumed to leave households wage offers unchanged.

Simulation results are reported in table 11 of Appendix A1. Overall, I find that reducing the price of parental investments generates limited impacts on the resource dilution effect. A 20% reduction of time and expenditure input prices introduced after the second child's birth cuts down 4% of the marginal child quality gap implied by an additional year alone with parents for the firstborn, holding the productivity of investments constant before the second child's birth. I find similar results under complementarity between time and expenditure inputs by calibrating the substitution parameter at the average coefficient estimates obtained by Caucutt et al. (2020) ($\rho = -1.86$). If the input price reductions are implemented from the moment the firstborn is alive, the resource dilution effect is instead amplified.

Table 8: Predicted birth order gap in child quality: intercept and birth spacing slope from the model

	Resource dilution - R			R without spillovers			Full model - UR		
Age	Intercept	Slope	Mean predicted gap	Intercept	Slope	Mean predicted gap	Intercept	Slope	Mean predicted gap
6-12	0.02 (0.075)	-0.12 (0.019)	-0.41	-0.02 (0.077)	-0.07 (0.019)	-0.28	0.12 (0.074)	-0.16 (0.019)	-0.48
6	0.06 (0.078)	-0.13 (0.019)	-0.43	-0.01 (0.079)	-0.09 (0.020)	-0.35	0.15 (0.077)	-0.18 (0.019)	-0.50
7	0.10 (0.081)	-0.14 (0.020)	-0.43	0.04 (0.083)	-0.10 (0.021)	-0.34	0.21 (0.081)	-0.20 (0.020)	-0.50
8	0.05 (0.087)	-0.13 (0.022)	-0.43	-0.00 (0.088)	-0.09 (0.022)	-0.31	0.18 (0.085)	-0.18 (0.021)	-0.49
9	0.02 (0.089)	-0.12 (0.022)	-0.43	-0.03 (0.091)	-0.08 (0.023)	-0.30	0.15 (0.088)	-0.18 (0.022)	-0.50
10	0.03 (0.091)	-0.13 (0.023)	-0.43	-0.00 (0.093)	-0.07 (0.023)	-0.27	0.14 (0.089)	-0.17 (0.022)	-0.49
11	-0.04 (0.095)	-0.09 (0.024)	-0.37	-0.06 (0.097)	-0.04 (0.024)	-0.21	0.05 (0.094)	-0.13 (0.023)	-0.43
12	-0.09 (0.097)	-0.08 (0.024)	-0.38	-0.09 (0.099)	-0.03 (0.025)	-0.20	-0.01 (0.096)	-0.11 (0.024)	-0.43

Notes: The birth spacing *slope* and *intercept* of the birth order gap in standardized child quality predicted by the model between the ages of 6 and 12 are reported in the first two columns of each panel (standard errors in parentheses), with the mean predicted gap in their respective third column. The resource dilution effect is measured by the *Slope* column of the first panel R, for which age dynamics of the productivity of investments in the first child when alone with parents are shut-down. The second panel considers the case without investment spillovers ($\delta_{4,a(1,t)} = \delta_{5,a(2,t)} = 0$) under restriction (R). Predictions from the full model, without restriction on the child quality production technology, is shown in panel 3.

A contributing factor to the limited impacts of reducing the costs of parental investments is the interdependence of the child development processes of siblings that is driven by the spillover technology. Even if parents find it suddenly more productive to invest in the second child when both siblings are alive, the firstborn reaps a share of those investments through spillovers. This channel generates persistence in the superior position of the firstborn, obtained from her/his time alone with parents, and holds even if more resources are dedicated to the younger child .

A caveat in the model is that parents cannot dedicate exclusive resources to younger sibling. Sufficiently long time between births could imply that while the firstborn attends elementary school or goes to a market-based child care service, the secondborn is taken care of at home. If parental investments and the care provided outside of the home are not perfect substitutes in their child development productivities, investment cost reductions, or a parental leave, could potentially attenuate the resource dilution effect. In this context, the endogeneity of the fertility timing decisions by parents should be accounted for to deliver policy relevant recommendations.

7 Conclusion

This paper shows that the additional resources accrued to the firstborn when alone with parents have lasting effects on birth order differences in cognitive skills. Because parental resources are finite, investments available to each child decline as the number of children in the family increases. This dilution of parental resources is present throughout the life of the secondborn, whereas the firstborn experiences a period without having to compete for parental time and financial expenditures. Based on structural estimates of the child quality production function, using a framework similar to Del Boca, Flinn, and Wiswall (2014), an extra (counterfactual) year alone with parents for the firstborn leads to a 0.12 standard deviation increase of the birth order gap in child quality between the ages of 6 and 12. This resource dilution effect is quantitatively important in that it accounts for a little over 1/3 of the observed gap in cognitive ability test scores for a US representative sample of two-child families of white mothers.

I find that investment spillovers received by the firstborn, from investments directed to the secondborn, drive the persistence of the resource dilution effect over time. When both siblings are alive, parents find it more productive to invest in the younger child, but catching-up to the first child's quality does not materialize. By receiving an indirect share of investments dedicated to the second child, the firstborn maintains her/his superior position that originates from the time spent alone with parents. I estimate that the spillover technology contributes to over 1/3 of the persistence of the resource dilution effect and becomes increasingly important as children get older. This channel reflects findings in Breining et al. (2020), suggesting that firstborns' early-childhood investments are extended by the arrival of the second child, and speaks to the importance of sibling spillovers in the human capital production function (see Karbownik and Özek, 2021).

Moreover, the mechanism considered in the model leads to predictions in line with causal birth spacing estimates in Buckles and Munnich (2012), according to which longer time between births increases the cognitive skills of firstborns, while no effect is found for secondborns. Approximately 50% of the birth order gap implied by their estimates can be accounted for by the dynamic impacts of resource dilution in the model.

Whether interventions aimed at incentivizing parental investments are effective at offsetting birth order effects due to resource dilution remains an open question. The exogeneity assumption of the birth spacing process and the simplistic child care arrangements available to households in the model limit the relevancy of simulated intervention outcomes for policy design. Nonetheless, in the current framework, price reductions of time and expenditure inputs in children deliver only minor attenuation of birth order differences in cognitive skills caused by the additional investments received by the firstborn when alone with parents. The small impacts of such interventions follow from the interdependence of the development processes of siblings that is driven by the spillover technology in the model. Even if investment conditions get improved after the arrival of the second child, the firstborn retains a superior position in accumulated child quality by reaping a share of the intervention benefits through spillovers. In other words, parents can't isolate investments in the secondborn from contributing indirectly to the development of the first child. However, it may be the case that parents invest exclusive resources in the second child during her/his first years of life. For example, parents perhaps decide to send the older sibling to a market-based child care service, or school if birth spacing is sufficiently long, while the seconborn is taken care of at home. For that reason, a reliable evaluation of the effectiveness of interventions aimed at incentivizing parental investments should account for the endogeneity of the birth spacing decision (see Rosenzweig, 1986) in an environment where parents can choose to use market-based child care services, as in Caucutt et al. (2020), to unload the competition for parental resources in the first years of second child's life.

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Appendix

A1. Supplemental Material

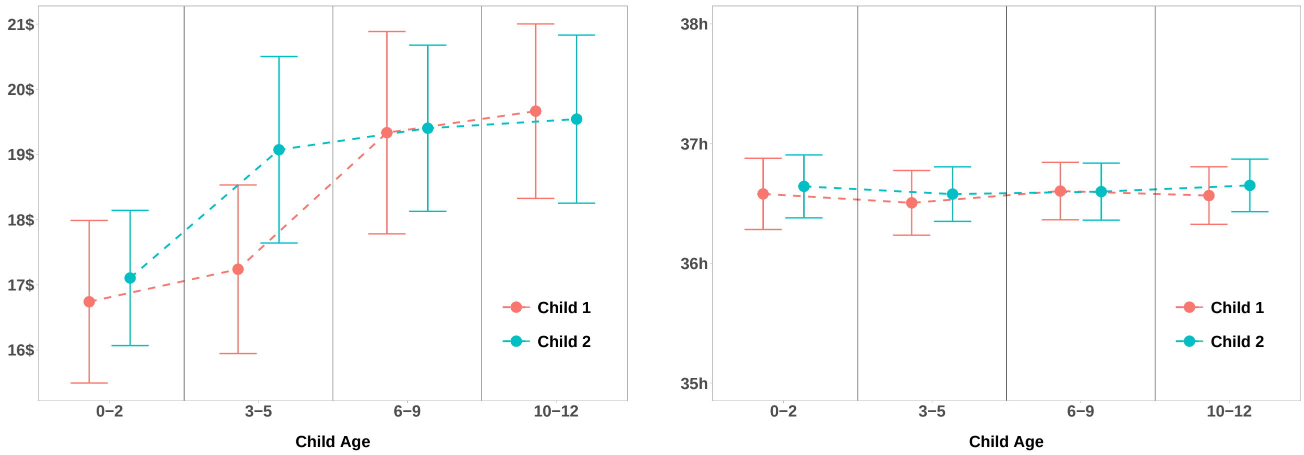
Table 9: HOME items assigned to time and expenditure input categories

Time	Expenditure
	Age 0-2
How often child gets out of the house?	How many children books child has?
How often mother reads to the child?	How many role-playing toys child has?
How often mother takes child to grocery?	How many push or pull toys child has?
How often child eat with mom and dad?	
How often mother talks to child while working?	
	Age 3-5
How often mother reads to the child?	How many children books child has?
Number of hours the TV is on each day	How many magazines family gets regularly?
How often child taken to an outing?	Does the child have a record or tape player?
How often child eat with mom and dad?	
	Age 6-9
How often mother reads to the child?	How many children books child has?
How often family gets together with relatives?	Is there a musical instrument child can use at home?
How often child spend time with father?	Does family get a daily newspaper?
How often child eat with mom and dad?	Does the child get special lessons or do extracurricular activities?

Notes: List of HOME items from the CNLSY79 assigned to the time and expenditure input categories. Subscores for both categories are constructed by summing the 0-1 recoded measures of the respective HOME items.

Figure 7: Household labor market wages and working hours during the childhood periods of siblings

(a) Average per-parent hourly wage (b) Average per-parent weekly working hours



Notes: Sample mean of wages and working hours averaged across parents in the household over the age periods of the two siblings. Wages are obtained by dividing the per-parent average real annual income from labor (in 2002 dollars) by the corresponding working hours. Confidence intervals are at the 95% level.

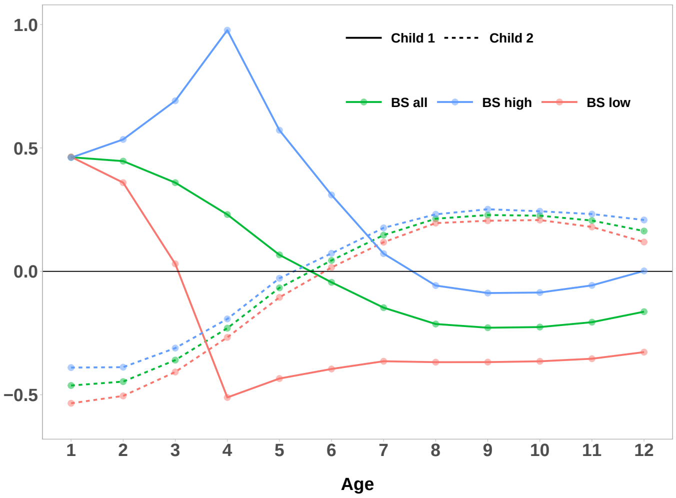
Table 10: Preference parameter estimates

	Estimate	SE
Mean of α_1 (leisure)	0.12	0.008
Mean of α_2 (consumption)	0.06	0.004
Mean of α_3 (child 1 quality)	0.73	0.019
Mean of α_4 (child 2 quality)	0.08	0.007
Std of α_1	0.13	0.007
Std of α_2	0.06	0.003
Std of α_3	0.24	0.014
Std of α_4	0.09	0.008
	Terminal payoff to child quality	
Intercept of ψ_1 (child 1)	0.02	0.020
Slope (birth spacing) of ψ_1 (child 1)	-0.00	0.004
ψ_2 (child 2)	2.92	0.325
Discount factor β	0.94	0.010

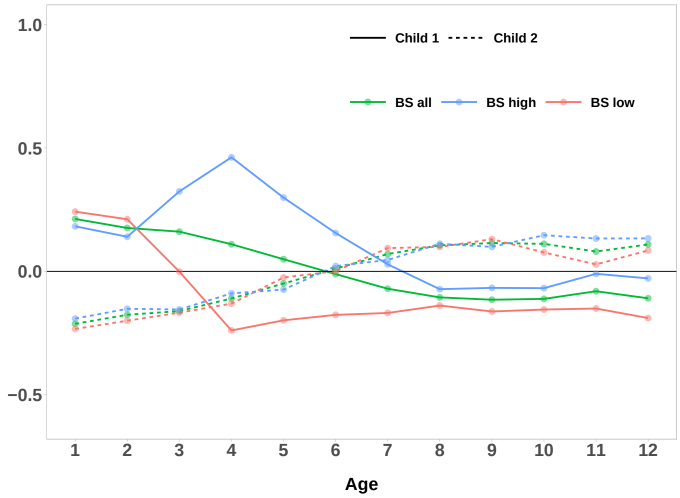
Notes: Preference parameter estimates based on 300 bootstrap samples of the SMS estimation procedure.

Figure 8: Model predictions: relative investments and child quality of siblings, across birth spacing

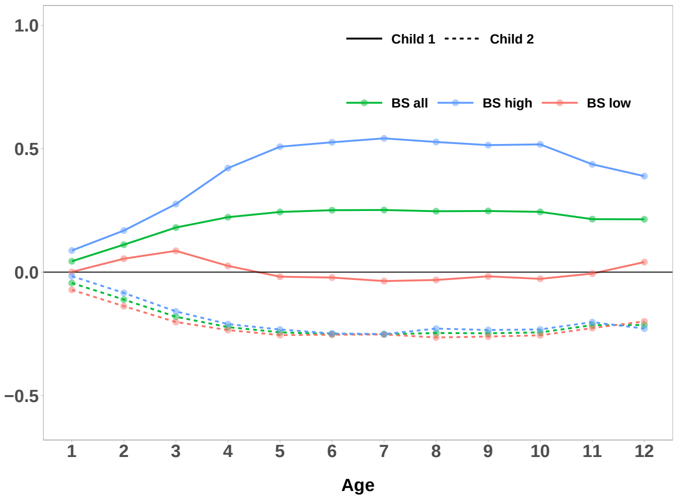
(a) Std time investments



(b) Std expenditure investments



(c) Std accumulated child quality



Notes: *BS low* (*high*) includes simulated households that observe birth spacing below (above) the simulated sample (1000 households) average at 3.65, while *BS all* includes all households. Figures (a) and (b) report the standardized mean time and expenditure inputs chosen by the simulated households for child 1 and child 2 up to age 12, while figure (c) shows the standardized accumulated child quality over age.

Table 11: Input price reductions and the birth order gap in child quality

	Price reductions before and after birth of child 2					
	Resource dilution - R			Full model - UR		
	Intercept	Slope	Mean predicted gap	Intercept	Slope	Mean predicted gap
No reduction	0.019	-0.118	-0.413	0.125	-0.165	-0.477
20% Time input	0.020	-0.121	-0.423	0.129	-0.169	-0.488
20% Expenditure input	0.019	-0.120	-0.418	0.126	-0.167	-0.483
20% Both inputs	0.020	-0.123	-0.428	0.131	-0.171	-0.493
	Price reduction only after birth of child 2					
	Intercept	Slope	Mean predicted gap	Intercept	Slope	Mean predicted gap
20% Time input	0.012	-0.115	-0.409	0.117	-0.162	-0.473
20% Expenditure input	0.016	-0.117	-0.412	0.122	-0.164	-0.476
20% Both inputs	0.009	-0.114	-0.407	0.115	-0.161	-0.472
	Input complementarity in production function ($\rho = -1.86$)					
	Price reduction before and after birth of child 2					
	Intercept	Slope	Mean predicted gap	Intercept	Slope	Mean predicted gap
No reduction	0.018	-0.116	-0.405	0.121	-0.161	-0.468
20% Time input	0.019	-0.118	-0.413	0.124	-0.165	-0.477
20% Expenditure input	0.018	-0.118	-0.412	0.124	-0.164	-0.476
20% Both inputs	0.019	-0.120	-0.420	0.127	-0.168	-0.485
	Price reduction only after birth of child 2					
	Intercept	Slope	Mean predicted gap	Intercept	Slope	Mean predicted gap
20% Time input	0.013	-0.114	-0.402	0.116	-0.159	-0.466
20% Expenditure input	0.014	-0.114	-0.403	0.116	-0.159	-0.466
20% Both inputs	0.008	-0.112	-0.399	0.111	-0.157	-0.463

Notes: Intercept and birth spacing slope of the birth order gap in std child quality, with mean predicted gap, based on the simulated household choices (simulated sample of size 1000) under input price reductions of 20%. The bottom panel evaluates the model and the price reductions under time/expenditure input complementarity, calibrating the substitution parameter $\rho = -1.86$, which represents the average over the substitution parameter estimates found by Caucutt et al. (2020).

A2. Heterogeneity across Family Size

This section of the Appendix documents the heterogeneity in the relationship between birth spacing and birth order differences in HOME and PIAT scores for larger families of up to four children. The specification in (1) is augmented to account for higher birth orders of siblings, as well as their interactions with time delays between the births of the sibling pairs:

$$\begin{aligned}\Delta y_{j,s,o} =& \beta_0 + I_{s3}^{o2} + I_{s3}^{o3} + I_{s4}^{o2} + I_{s4}^{o3} + I_{s4}^{o4} + \text{birth spacing}_j \cdot \beta_1 + \\ & \text{birth spacing}_{j,s,o} \cdot (I_{s3}^{o2} + I_{s3}^{o3} + I_{s4}^{o2} + I_{s4}^{o3} + I_{s4}^{o4}) + X_{j,s,o} \cdot \beta_2 + \epsilon_{j,s,o}. \end{aligned} \qquad (1^A)$$

An observation characterizes a sibling pair, that is a child born of order o referenced to the firstborn, in household j of size s. The dependent variable $\Delta y_{j,s,o} = y_{j,s,o} - y_{j,s,1}$ is the birth order gap between child born of order o and the firstborn in family j of size s for: (a) mean standardized HOME scores between the ages of 0 and 11, and (b) mean standardized PIAT scores between the ages of 6 and 11. The explanatory variables consist of a constant, interpreted as the conditional birth order gap for the second child in families of two children, and a set of dummies I_s^o for the birth order o of the sibling pair in family of size s. Birth spacing is included and interacted with those birth order-family size dummies. A set of controls $\Delta X_{j,s,o}$ accounts for differences between siblings in each pair with respect to their gender, the presence of the father in the household, the years of schooling of the mother during their childhood, their participation in a regular child care at age 0-3, and whether at least one miscarriage occurred between their births. β_2 is a parameter vector.

Specification 1^A is estimated excluding birth spacing and its interactions (A) and including those (B) separately. Estimation results for families of white mothers are reported in table 12 for HOME scores and table 13 for PIAT scores. Estimation results for the HOME scores are also reported for the *Cognitive* and *Emotional* HOME categories defined by the U.S. Bureau of Labor Statistics. For PIAT scores, results for *Math*, *Reading Recognition* and *Reading Comprehension* subscores are reported as well.

From columns (A) in tables 12 and 13, birth order differences in HOME and PIAT scores increase with the order of the child across family sizes. With some exceptions, from columns (B), the birth spacing coefficient for higher birth orders is for the most part not significantly different than that for the second child in families of size two, with the exception of the third child in families of four children.

Table 12: Birth spacing OLS estimates of the birth order gap in standardized HOME scores, across family size

	HOME		Cognitive		Emotional	
	(A)	(B)	(A)	(B)	(A)	(B)
Constant (Base: Birth Order=2 | Size=2)	-0.25***	-0.025	-0.22***	-0.085	-0.23***	-0.049
	(0.036)	(0.051)	(0.039)	(0.061)	(0.048)	(0.074)
Birth Spacing (Base: Birth Order=2 | Size=2)		-0.065***		-0.041**		-0.053***
		(0.012)		(0.016)		(0.018)
𝟙[Birth Order=2 | Size=3]	-0.0071	-0.072	0.0059	-0.10	0.028	0.0027
	(0.046)	(0.11)	(0.048)	(0.12)	(0.062)	(0.13)
Birth Spacing * 𝟙[Birth Order=2 | Size=3]		0.0050		0.026		-0.0053
		(0.039)		(0.040)		(0.041)
𝟙[Birth Order=3 | Size=3]	-0.12**	-0.38***	-0.11*	-0.34***	-0.064	-0.25*
	(0.054)	(0.11)	(0.058)	(0.12)	(0.070)	(0.14)
Birth Spacing * 𝟙[Birth Order=3 | Size=3]		0.066***		0.050**		0.050**
		(0.018)		(0.021)		(0.025)
𝟙[Birth Order=2 | Size=4]	0.036	-0.080	0.040	0.016	0.052	-0.0052
	(0.060)	(0.080)	(0.066)	(0.091)	(0.080)	(0.12)
Birth Spacing * 𝟙[Birth Order=2 | Size=4]		0.022		-0.0019		0.0058
		(0.025)		(0.025)		(0.043)
𝟙[Birth Order=3 | Size=4]	-0.063	-0.065	-0.16*	-0.0084	0.057	-0.031
	(0.082)	(0.15)	(0.085)	(0.18)	(0.10)	(0.19)
Birth Spacing * 𝟙[Birth Order=3 | Size=4]		0.024		-0.0089		0.033
		(0.026)		(0.033)		(0.033)
𝟙[Birth Order=4 | Size=4]	-0.22**	-0.0040	-0.26***	0.16	-0.080	0.0050
	(0.087)	(0.20)	(0.097)	(0.20)	(0.100)	(0.26)
Birth Spacing * 𝟙[Birth Order=4 | Size=4]		0.014		-0.021		0.021
		(0.025)		(0.026)		(0.034)
Controls	✓	✓	✓	✓	✓	✓
N	1171	1171	1171	1171	1171	1171
R^2	0.054	0.092	0.054	0.076	0.034	0.049

Notes: OLS regressions are based on the sample described in table 1 and each column reports the estimates of a separate regression. Each sibling pair, referenced to the firstborn in a household, is characterized by a single observation. The dependent variable is the mean birth order gap in standardized HOME scores, observed between the ages of 0 and 11 and flexibly adjusted for the age at assessment. Results for the *Emotional* and *Cognitive* subscores (categorized by the U.S. Bureau of Labor Statistics) of HOME are also reported. The controls include differences between child 1 and child of order o with respect to their gender, presence of the father in the household and years of schooling of the mother during childhood, participation in a regular child care at age 0-3, and whether at least one miscarriage occurred between the births.
*** p<0.01, ** p<0.05, * p<0.1. Robust standard errors in parentheses.

Table 13: Birth spacing OLS estimates of the birth order gap in standardized PIAT scores, across family size

	PIAT		Math		Recognition		Comprehension	
	(A)	(B)	(A)	(B)	(A)	(B)	(A)	(B)
Constant (Base: Birth Order=2 | Size=2)	-0.19***	0.085	-0.15**	0.20*	-0.16**	0.0072	-0.19***	-0.040
	(0.062)	(0.10)	(0.065)	(0.10)	(0.062)	(0.10)	(0.066)	(0.11)
Birth Spacing (Base: Birth Order=2 | Size=2)		-0.078***		-0.10***		-0.047*		-0.043*
		(0.023)		(0.022)		(0.024)		(0.024)
𝟙[Birth Order=2 | Size=3]	-0.14*	-0.16	-0.10	-0.26	-0.16*	-0.14	-0.15*	-0.044
	(0.085)	(0.18)	(0.087)	(0.17)	(0.088)	(0.20)	(0.092)	(0.19)
Birth Spacing * 𝟙[Birth Order=2 | Size=3]		-0.014		0.030		-0.020		-0.050
		(0.053)		(0.046)		(0.062)		(0.052)
𝟙[Birth Order=3 | Size=3]	-0.25***	-0.16	-0.16*	-0.040	-0.25***	-0.12	-0.27***	-0.31
	(0.087)	(0.19)	(0.092)	(0.19)	(0.090)	(0.20)	(0.091)	(0.20)
Birth Spacing * 𝟙[Birth Order=3 | Size=3]		0.019		0.024		-0.00026		0.024
		(0.032)		(0.031)		(0.035)		(0.033)
𝟙[Birth Order=2 | Size=4]	0.023	-0.19	-0.042	-0.46***	0.078	0.014	-0.045	-0.039
	(0.13)	(0.19)	(0.13)	(0.18)	(0.14)	(0.20)	(0.13)	(0.21)
Birth Spacing * 𝟙[Birth Order=2 | Size=4]		0.049		0.11***		0.0086		-0.013
		(0.037)		(0.040)		(0.036)		(0.046)
𝟙[Birth Order=3 | Size=4]	-0.11	-0.66***	-0.096	-0.72***	-0.083	-0.47*	-0.15	-0.63**
	(0.11)	(0.23)	(0.11)	(0.23)	(0.12)	(0.24)	(0.12)	(0.26)
Birth Spacing * 𝟙[Birth Order=3 | Size=4]		0.11***		0.13***		0.077**		0.092**
		(0.037)		(0.038)		(0.037)		(0.038)
𝟙[Birth Order=4 | Size=4]	-0.26*	-0.40	-0.41***	-0.63	-0.044	-0.34	-0.27*	-0.47
	(0.13)	(0.34)	(0.14)	(0.38)	(0.12)	(0.30)	(0.15)	(0.35)
Birth Spacing * 𝟙[Birth Order=4 | Size=4]		0.059		0.080*		0.057		0.045
		(0.039)		(0.041)		(0.036)		(0.041)
Controls	✓	✓	✓	✓	✓	✓	✓	✓
N	1171	1171	1169	1169	1168	1168	1133	1133
R^2	0.023	0.046	0.044	0.073	0.027	0.038	0.018	0.028

Notes: OLS regressions are based on the sample described in table 1 and each column reports the estimates of a separate regression. Each sibling pair, referenced to the firstborn in a household, is characterized by a single observation. The dependent variable is the mean birth order gap in standardized PIAT scores, observed between the ages of 6 and 11 and flexibly adjusted for the age at assessment. Results for the *Math*, *Reading Recognition* and *Reading Comprehension* subscores are also reported. The controls include differences between child 1 and child of order o with respect to their gender, presence of the father in the household and years of schooling of the mother during childhood, participation in a regular child care at age 0-3, and whether at least one miscarriage occurred between the births.
*** p<0.01, ** p<0.05, * p<0.1. Robust standard errors in parentheses.

A3. Supplemental Reduced Form Analyses

Table 14: Birth spacing OLS estimates of the birth order gap in standardized HOME scores

	HOME		Cognitive		Emotional	
	(a)	(b)	(a)	(b)	(a)	(b)
Constant (Birth Order=2)	-0.24***	-0.042	-0.22***	-0.13*	-0.23***	-0.073
	(0.049)	(0.064)	(0.056)	(0.076)	(0.060)	(0.089)
Birth Spacing (Yrs)		-0.059***		-0.029		-0.049**
		(0.015)		(0.019)		(0.021)
Controls	✓	✓	✓	✓	✓	✓
N	518	518	518	518	518	518
R^2	0.042	0.080	0.051	0.058	0.017	0.034

Notes: OLS regressions are based on the sample described in table 1 and follow the specification 1, including and excluding birth spacing. The second column replicates column (2) panel (a) of table 2. Corresponding estimations are reported for the *Emotional* and *Cognitive* subscores (categorized by the U.S. Bureau of Labor Statistics) of HOME.
*** p<0.01, ** p<0.05, * p<0.1. Robust standard errors in parentheses.

Table 15: Birth spacing OLS estimates of the birth order gap in standardized PIAT scores

	PIAT		Math		Recognition		Comprehension	
	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)
Constant (Birth Order=2)	-0.25***	-0.020	-0.18**	0.10	-0.23***	-0.099	-0.24***	-0.089
	(0.079)	(0.12)	(0.082)	(0.12)	(0.081)	(0.12)	(0.089)	(0.12)
Birth Spacing (Yrs)		-0.071***		-0.088***		-0.042*		-0.046*
		(0.024)		(0.025)		(0.025)		(0.025)
Controls	✓	✓	✓	✓	✓	✓	✓	✓
N	518	518	516	516	517	517	507	507
R^2	0.0087	0.028	0.049	0.078	0.0083	0.015	0.0082	0.015

Notes: OLS regressions are based on the sample described in table 1 and follow the specification 1, including and excluding birth spacing. The second column replicates column (2) panel (b) of table 2. Corresponding estimations are reported for the *Math*, *Reading Recognition* and *Reading Comprehension* subscores.
*** p<0.01, ** p<0.05, * p<0.1. Robust standard errors in parentheses.

Table 16: Birth spacing OLS estimates of the birth order gap in standardized HOME scores for families of black and hispanic mothers

	HOME		Cognitive		Emotional	
	(a)	(b)	(a)	(b)	(a)	(b)
Constant (Birth Order=2)	-0.35***	-0.081	-0.30***	-0.093	-0.26***	0.0065
	(0.075)	(0.080)	(0.073)	(0.083)	(0.090)	(0.11)
Birth Spacing (Yrs)		-0.075***		-0.057***		-0.076***
		(0.015)		(0.016)		(0.022)
Controls	✓	✓	✓	✓	✓	✓
N	233	233	233	233	233	233
R^2	0.081	0.18	0.077	0.13	0.033	0.10

Notes: OLS regressions are based on two-child families of black and hispanic mothers from the NLSY79 under the same criteria used to build the sample for two-child families of white mothers described table 1. The estimated specification follows 1, including and excluding birth spacing. Estimates are reported for the birth order gap in standardized HOME scores between the ages of 0 and 11 as the dependent variable, as well as for the gap in *Emotional* and *Cognitive* subscores (categorized by the U.S. Bureau of Labor Statistics). Controls include differences between child 1 and child 2 with respect to their gender, presence of the father in the household and years of schooling of the mother during childhood, participation in a regular child care at age 0-3, and whether at least one miscarriage occurred between the births.
*** p<0.01, ** p<0.05, * p<0.1. Robust standard errors in parentheses.

Table 17: Birth spacing OLS estimates of the birth order gap in standardized PIAT scores for families of black and hispanic mothers

	PIAT		Math		Recognition		Comprehension	
	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)
Constant (Birth Order=2)	-0.040	0.057	0.14	0.27	-0.11	-0.080	-0.22*	-0.14
	(0.12)	(0.16)	(0.13)	(0.17)	(0.13)	(0.17)	(0.12)	(0.17)
Birth Spacing (Yrs)		-0.027		-0.036		-0.0092		-0.022
		(0.028)		(0.025)		(0.028)		(0.031)
Controls	✓	✓	✓	✓	✓	✓	✓	✓
N	233	233	233	233	233	233	229	229
R^2	0.014	0.019	0.022	0.031	0.012	0.013	0.025	0.028

Notes: OLS regressions are based on two-child families of black and hispanic mothers from the NLSY79 under the same criteria used to build the sample for two-child families of white mothers described table 1. The estimated specification follows 1, including and excluding birth spacing. Estimates are reported for the birth order gap in standardized PIAT scores between the ages of 6 and 11 as the dependent variable, as well as for the gap in *Math*, *Reading Recognition* and *Reading Comprehension* subscores. Controls include differences between child 1 and child 2 with respect to their gender, presence of the father in the household and years of schooling of the mother during childhood, participation in a regular child care at age 0-3, and whether at least one miscarriage occurred between the births.
*** p<0.01, ** p<0.05, * p<0.1. Robust standard errors in parentheses.

Table 18: Birth spacing OLS estimates of the birth order gap in standardized HOME scores across childhood periods

	0-5						6-11						12-17					
	HOME		Cognitive		Emotional		HOME		Cognitive		Emotional		HOME		Cognitive		Emotional	
	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)
Constant (Birth Order=2)	-0.20***	-0.0088	-0.16**	-0.067	-0.20**	-0.067	-0.24***	-0.077	-0.24***	-0.13*	-0.19***	-0.0050	-0.27***	-0.21*	-0.30***	-0.23*	-0.053	0.015
	(0.070)	(0.10)	(0.077)	(0.11)	(0.082)	(0.11)	(0.047)	(0.068)	(0.050)	(0.069)	(0.057)	(0.091)	(0.081)	(0.12)	(0.083)	(0.12)	(0.090)	(0.16)
Birth Spacing (Yrs)		-0.059**		-0.028		-0.039*		-0.048***		-0.032*		-0.056**		-0.017		-0.020		-0.019
		(0.024)		(0.024)		(0.022)		(0.016)		(0.017)		(0.022)		(0.027)		(0.027)		(0.034)
Controls	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
N	513	513	505	505	506	506	518	518	513	513	514	514	399	399	383	383	354	354
R^2	0.069	0.085	0.057	0.060	0.042	0.048	0.047	0.069	0.062	0.072	0.022	0.040	0.031	0.032	0.083	0.085	0.0046	0.0057

Notes: OLS regressions are based on the sample described in table 1 and follow the specification 1, including and excluding birth spacing. Separate regressions are estimated using as dependent variable the birth order gap in standardized HOME scores between the ages of 0-5, 6-11, 12-17. Corresponding estimations are reported for the *Emotional* and *Cognitive* subscores (categorized by the U.S. Bureau of Labor Statistics) of HOME. Controls include differences between child 1 and child 2 with respect to their gender, presence of the father in the household and years of schooling of the mother during childhood, participation in a regular child care at age 0-3, and whether at least one miscarriage occurred between the births.
*** p<0.01, ** p<0.05, * p<0.1. Robust standard errors in parentheses.

Table 19: Birth spacing OLS estimates of the birth order gap in standardized early childhood and teenage cognitive ability test scores

	0-5						12-17							
	Motor+Peabody		Motor		Peabody		PIAT		Math		Recognition		Comprehension	
	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)
Constant (Birth Order=2)	-0.23*	-0.25	-0.078	-0.039	-0.19	-0.054	-0.24***	-0.26**	-0.26***	-0.13	-0.13	-0.16	-0.22**	-0.33***
	(0.14)	(0.17)	(0.16)	(0.21)	(0.16)	(0.19)	(0.088)	(0.13)	(0.097)	(0.15)	(0.091)	(0.13)	(0.091)	(0.12)
Birth Spacing (Yrs)		0.0074		-0.014		-0.044		0.0039		-0.037		0.0062		0.031
		(0.029)		(0.055)		(0.030)		(0.025)		(0.031)		(0.026)		(0.024)
Controls	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
N	290	290	214	214	257	257	382	382	382	382	381	381	380	380
R^2	0.053	0.053	0.12	0.12	0.049	0.054	0.051	0.052	0.063	0.068	0.026	0.026	0.050	0.053

Notes: OLS regressions are based on the sample described in table 1 and follow the specification 1, including and excluding birth spacing. Separate regressions are estimated using as dependent variable the birth order gap in standardized Motor and Social Development (MSD) and Peabody Picture Vocabulary Test (PPVT) scores between the ages of 0 and 5, and standardized PIAT (in addition to the *Math*, *Reading Recognition* and *Reading Comprehension* subscores) between the ages of 12 and 17. Controls include differences between child 1 and child 2 with respect to their gender, presence of the father in the household and years of schooling of the mother during childhood, participation in a regular child care at age 0-3, and whether at least one miscarriage occurred between the births.
*** p<0.01, ** p<0.05, * p<0.1. Robust standard errors in parentheses.

Table 20: Birth spacing OLS estimates of the birth order gap in standardized noncognitive ability test scores

	BPI+SPPC		BPI		SPPC-Scholastic		SPPC-Worth	
	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)
Constant (Birth Order=2)	-0.047	-0.067	0.013	0.050	-0.29	-0.24	-0.098	-0.16
	(0.079)	(0.12)	(0.072)	(0.11)	(0.25)	(0.27)	(0.20)	(0.23)
Birth Spacing (Yrs)		0.0062		-0.011		-0.063		0.077
		(0.028)		(0.025)		(0.14)		(0.16)
Controls	✓	✓	✓	✓	✓	✓	✓	✓
N	516	516	511	511	150	150	150	150
R^2	0.010	0.028	0.011	0.029	0.0013	0.063	-0.054	0.011

Notes: OLS regressions are based on the sample described in table 1 and follow the specification 1, including and excluding birth spacing. Separate regressions are estimated using as dependent variable the birth order gap in standardized Behavioral Problem Index (BPI) and the Self Perception Profile for Children (SPPC) in Scholastics and self Worth scores between the ages 6 and 11. Controls include differences between child 1 and child 2 with respect to their gender, presence of the father in the household and years of schooling of the mother during childhood, participation in a regular child care at age 0-3, and whether at least one miscarriage occurred between the births.
*** p<0.01, ** p<0.05, * p<0.1. Robust standard errors in parentheses.

Table 21: List of targeted moments by the MSM estimation procedure (**Appendix A4**)

Mean time HOME scores (age: 0-2,3-6,6-9): 3 moments
Standard deviation time HOME scores child 1 (age: 0-2,3-6,6-9): 3 moments
Standard deviation time HOME scores child 2 (age: 0-2,3-6,6-9): 3 moments
Mean standardized time HOME scores child 1 (age: 0-2,3-6,6-9): 3 moments
Mean standardized time HOME scores child 2 (age: 0-2,3-6,6-9): 3 moments
Mean expenditure HOME scores (age: 0-2,3-6,6-9): 3 moments
Standard deviation expenditure HOME scores child 1 (age: 0-2,3-6,6-9): 3 moments
Standard deviation expenditure HOME scores child 2 (age: 0-2,3-6,6-9): 3 moments
Mean standardized expenditure HOME scores child 1 (age: 0-2,3-6,6-9): 3 moments
Mean standardized expenditure HOME scores child 2 (age: 0-2,3-6,6-9): 3 moments
Mean working hours age of child 1 (per-parent household average) (age: 0-2,3-5,6-9,10-12,13-15): 5 moments
Mean working hours age of child 2 (per-parent household average) (age of child 1: 0-2,3-5,6-9,10-12,13-15): 5 moments
Standard deviation working hours age of child 1 (per-parent household average) (age: 0-2,3-5,6-9,10-12,13-15): 5 moments
Standard deviation working hours age of child 2 (per-parent household average) (age of child 1: 0-2,3-5,6-9,10-12,13-15): 5 moments
Mean PIAT scores (age: 6-7,8-9,10-11,12-13,14-15): 5 moments
Standard deviation PIAT scores (age: 6-7,8-9,10-11,12-13,14-15): 5 moments
(auto)Correlation standardized PIAT scores (age: 6-9∼10-12,6-9∼13-15,10-12∼13-15): 3 moments
Correlation between standardized time HOME and PIAT scores (age: time(0-2,3-5,6-9)∼ PIAT(6-9,10-12,13-15)): 9 moments
Correlation between standardized expenditure HOME and PIAT scores (age: expenditure(0-2,3-5,6-9)∼ PIAT(6-9,10-12,13-15)): 9 moments
Correlation between standardized time HOME child 2 and PIAT scores for child 1*: 8 moments
Correlation between standardized time HOME child 1 and PIAT scores for child 2*: 6 moments
Correlation between standardized expenditure HOME child 2 and PIAT scores for child 1*: 8 moments
Correlation between standardized expenditure HOME child 1 and PIAT scores for child 2*: 6 moments
Correlation between standardized PIAT scores across siblings (age: 6-9,10-12,13-15): 3 moments
Correlation between hours of work and standardized time HOME scores age of child 1 (age: 0-2,3-5,6-9): 3 moments
Correlation between hours of work and standardized time HOME scores age of child 2 (age: 0-2,3-5,6-9): 3 moments
Correlation between hours of work and standardized expenditure HOME scores age of child 1 (age: 0-2,3-5,6-9): 3 moments
Correlation between hours of work and standardized expenditure HOME scores age of child 2 (age: 0-2,3-5,6-9): 3 moments

Notes: *The cross-sibling correlation between HOME and PIAT scores are based on observations for periods during which both siblings are born. If investment in child 1 occurred before the birth of child 2, this observation does not contribute to the related measure of correlation.