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Abstract

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Early Childhood Investments and the Quantity-Quality Trade-off*

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July 7, 2020

Abstract

We integrate key insights from the early childhood literature into the quantity-quality model. In theory the adverse effect of shocks to family size diminishes with birth spacing for children already born and rises for newborn siblings. The effect on the older child therefore provides a credible proxy for the quantity-quality trade-off only at short spacing intervals. Using matched mother-child data from NLSY79, we find robust empirical support for this proposition. Cognitive scores of children already born drop following shocks to family size but only when siblings arrive at younger ages. Family resources also matter. The cognitive scores of children drop only in households in which the mother has below median AFQT score.

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1 Introduction

Becker and Lewis (1973) first introduced the notion that differences in children's outcomes may reflect not only family resources but also deliberate choices made by parents, including the trade-off between the number of children and the average quality of children in the household. Following Becker and Lewis (1973), many studies have focused on identifying exogenous shocks to fertility based on the conjecture well summarized in Becker (1981): "If [prices and income] were held constant, an exogenous increase in quantity would raise the shadow price of quality, and thereby would reduce the demand for quality." In one seminal paper testing this proposition, Rosenzweig and Wolpin (1980) used twin births to isolate an unexpected fertility shock from other latent family factors. Using similar methods a large body of research has documented conflicting findings: negative impacts of fertility in developing economies (Rosenzweig and Wolpin (1980); Rosenzweig and Zhang (2009); Liu (2014)) and no effects in developed economies (Black et al. (2005); Angrist et al. (2010)).

This literature has almost exclusively centered attention on the outcomes of older children–children who are born before the shock–rather than the average quality of children. However, the quality of older children is a good proxy for the average quality only when parental investments are reversible. Shocks to family size reduce parental investments in all children but to the extent that investments are irreversible, older children benefit while children born after the shock are more heavily taxed. When parental investments are irreversible, focusing on older children's outcomes will understate the quantity-quality trade-off.

Theory and evidence indicate that investments during early childhood may indeed be irreversible in the sense that parents cannot undo investment decisions made during their children's early childhood. Heckman and co-authors (for instance, Cunha and Heckman (2007) and Heckman et al. (2012)) show that parental inputs are less effective as children age and investments in early childhood complement later investments. Parental inputs matter more in early childhood since cognitive skills are malleable at early ages and early capacities foster children's ability to learn and benefit from further investments as they age (Knudsen et al. (2006); Heckman and Mosso (2014)). These features of the human capital production function suggest that children will not be equally taxed. Those born subsequent to the shock to family size will be more heavily taxed relative to those born before the shock. In addition, the inequality across siblings will depend on the timing of the shock–on whether the shock to family size occurs during the older child's early childhood or during later childhood. In other words, birth spacing matters. In this paper we argue that consideration of birth spacing and attention to all children are critical in assessing the existence of the quantity-quality trade-off.

We begin by presenting a model in which, similar to Becker and Lewis (1973), parents choose own consumption, the number of children, and level of human capital (quality) of each child. We incorporate multiple periods of parental investment in children's human capital. The technology of human capital production in the model has the essential feature suggested by Heckman (2007) and discussed in Almond and Currie (2011): investments in children's human capital in early childhood are less than perfect substitutes for investments in later childhood. We show that shocks to family size which occur prior to any investments in child quality reduce the quality of all children equally while shocks to family size which occur after investments are already made result in higher investments in the firstborn children relative to newborn children. This inequality across siblings increases with birth spacing. In our theory we contrast the firstborn relative to others although our point applies to all older children.

We bring key testable implications from our model section to the data: 1) parental investments and human capital of the firstborn drop following a shock to family size and

2) the drop in investments and human capital of the firstborn diminish with birth spacing. We use matched mother-children data from the National Longitudinal Survey of Youth 1979 (NLSY79) to test our hypothesis empirically. A key advantage of the NLSY is that the data contains detailed information about childhood cognitive abilities and measures of social behavior – measured biannually throughout childhood. Throughout this paper we use the terms cognitive and non-cognitive skills to describe personality attributes associated with cognitive achievement tests (IQ, AFQT, etc.), and behavioral problems not measured by cognitive achievement tests, respectively. Specifically, we use the mathematics and reading recognition components of the Peabody Individual Achievement Tests (PIATs) as measures of cognitive achievement tests, and the Behavioral Problems Index, a measure designed to evaluate the existence and intensity of a range of child behavioral problems to measure non-cognitive performance. We complement our analysis of outcomes with proxy measures of parental investment, the "HOME Inventory Index" in the NLSY.

We begin with simple before-after comparisons, examining outcomes of firstborn children before and after the next sibling's arrival. We address child or family fixed effects in terms of the level of child performance by comparing the same child before and after. While data-intensive, panel data also allows us to control for heterogeneity in growth rates which may reflect a child's ability to learn. We find that there is a significant drop in cognitive outcomes of firstborn children after the birth of a younger sibling. For example, among firstborns who will eventually have additional siblings, cognitive test scores drop 2.8 percentile points (larger than one-tenth of a standard deviation) after the second sibling is born. The HOME index, our measure of parental investment, falls by a similar amount. Disaggregating components of the HOME score, we find evidence that time spent with the firstborns drops with the arrival of additional siblings. This may reflect the fact that time inputs are difficult to smooth across periods even when additional children are fully anticipated or it may be the case that the arrival of additional children and their timing are not fully anticipated.

Important for our story and consistent with the early childhood literature, the negative impacts on cognitive scores diminish with birth spacing. Specifically, at age 10, a child who had a sibling at age 1 has a percentile point gap in cognitive scores of more than 9.17 (roughly 0.4 of a standard deviation) compared to a child with no sibling whereas a child who had a sibling at age 9 has only a 1.04 percentile point gap. With regards to behavioral problems, we find less systematic evidence that the worsening behavior accumulates over time or is dependent on birth spacing.

While the before-after analysis addresses unobserved heterogeneity in terms of children's capacity to learn, it may not necessarily reflect changes due to unanticipated shocks to family size. For our main empirical analysis, we adopt the method of previous papers and examine the effects of twin births on cognitive and non-cognitive outcomes of older children. Consistent with Black et al. (2005) we find that expansions in family size associated with twin births have no overall effects on older siblings when we do not differentiate by birth spacing. However, we find large and statistically significant negative effects of twin-births on cognitive and non-cognitive performance of older siblings when birth spacing is less than the median spacing (35 months).[1] These results reinforce our main finding from the before and after analysis– the quantity-quality trade-off depends on birth spacing. Importantly, these results suggest that the literature using twin births to assess the outcome of older children likely understates the quantity-quality trade-off.

The richness of the NLSY allows us to explore how the negative impacts of siblings vary

[1]To increase our sample size we use outcomes of all older siblings in this analysis. There are 73 older children whose next sibling is a twin. Deleting from the sample children who are not interviewed, or missing mother's data and sibling information, we end up with 63 older children.

by type of home environment. Theory suggests that the impact of fertility shocks on child quality should be larger in disadvantaged families with limited parental resources. Indeed, we find large and statistically significant negative impacts on cognitive and non-cognitive scores as well the home environment only in households in which the mother has a below median AFQT score. Finally, we examine how mothers' labor supply changes after childbirth and whether it varies between high and low AFQT groups. We find that there are disparate work responses between these groups; mothers with high AFQT scores are more likely to leave employment and reduce hours worked following shocks to family size.

Our paper contributes to the quantity-quality trade-off and to the dynamics of skills formation literature. Recent empirical work in the quantity-quality trade-off literature has posed a puzzle by finding little or no effect of shocks to family size on schooling of older children in developed economies. Our results suggest that this is not surprising given what we have learned from the early childhood literature and dynamics of skill formation. The shocks have a large effect when they come early in the older child's childhood. At the same time, this may be the best proxy for the change in the average quality of all children since the later the shock, the more irreversible the investments already made in the older child and the more unequal the parental resources distributed across children born before and after the shock.

We are neither the first to document the importance of the home environment at early ages nor the first to examine the effects of birth spacing on children's outcomes (see, for example, Rosenzweig and Wolpin (1988) and Buckles and Munnich (2012)).[2] However, we

[2] Rosenzweig and Wolpin (1988) find that greater spacing leads to better health outcomes of the younger sibling. In contrast to Rosenzweig and Wolpin (1988), our paper examines the impact of spacing on the older sibling's outcomes. Using miscarriages to instrument for spacing, Buckles and Munnich (2012) find that a one-year increase in spacing has no impact on test scores of younger siblings but raises test scores of older siblings by 0.17 standard deviation. In emphasizing the importance of parental time inputs, our paper is also closely aligned with Price (2008) who finds that parents spend significantly more time with firstborns

are the first to recognize and document that birth spacing matters in how shocks to family size affect the quality of firstborns and newborn children.

We are also not the first to document heterogeneous effects of family size by the home environment. Recently Mogstad and Wiswall (2016) find evidence consistent with substitution between quantity and quality of children in large families and complementarities between quantity and quality in small families. In our paper we find heterogeneous effects by birth spacing and mothers' AFQT. These results, along with our findings regarding mothers' labor supply responses, highlight the importance of parental capacities in addition to parental preferences.

The heterogeneous effects by parental capacities and resources within the U.S. provide a possible explanation for the disparate results documented in the literature across developed and developing countries. If the Scandinavian countries provide better substitutes for parental investment especially at younger ages, we may find notable effects in developing economies and no impacts in more supportive societies.

The paper proceeds as follows. In Section 2 we describe our model of early and late investments in the quantity-quality framework. Section 3 contains our data description. In Section 4 we present our before-after analysis. In Section 5 we present our estimates using twin births. In Section 6 we report results by mother's AFQT and in section 7 we explore a possible mechanism by investigating mother's labor supply by mother's AFQT and birth spacing. Our conclusion is in Section 8.

than children of higher birth order.

2 Early and Late Investments in the Quantity-Quality Model

In the model introduced by Becker and Lewis (1973), parents choose the number of children and investments per child to maximize their well-being from their own consumption, number of children, and quality per child. In this framework *quantity* and *quality* are jointly determined. Rational parents adjust to shocks to family size (for example, birth of twins as opposed to a singleton) by equalizing the marginal utilities from own consumption and spending on children.

The conventional quantity-quality literature assumes only one period of childhood when it evaluates the effect of family size on children's human capital (quality). In benchmark settings in which quality substitutes for quantity (the familiar Cobb-Douglas), parents reduce spending on quality and own consumption following an exogenous increase in family size. Conceptually the one period model imposes equal spending on existing children and others, predicting a drop in the quality of existing children following a shock to family size. Empirically, this literature does not distinguish between the impact of an exogenous increase in family size that occurs during the firstborn's early childhood - reflecting *short birth spacing* - from an exogenous increase in family size later when existing children are older - reflecting *long birth spacing*. In the following model we extend the Becker and Lewis (1973) framework to incorporate birth spacing effects.

2.1 The Basic Setting

Consumption and spending on child quality and quantity are jointly determined by resources, technology, and preferences. With the familiar Cobb-Douglas preferences, parents' overall well-being is captured by the following utility function:

$$U = C^{1-\alpha}\left(N\bar{H}^{\pi}\right)^{\alpha}, \tag{1}$$

where the reference parameters $\alpha \in (0,1)$ and $\pi \in (0,1)$ represent parents' preferences for children (N) over own consumption (C) and child quality $(\bar{H})$ respectively. Since parents may have taste for equality among children the *equality adjusted* measure of children's quality $(\bar{H})$ takes the following CES form:

$$\bar{H} = \left(\sum_{i=1}^{N} {H_i}^{\beta}/N\right)^{1/\beta}, \tag{2}$$

where H_i is child i's human capital. The parameter $\beta \in (-\infty, 1)$ represents parents' taste for equality between children. Parents may not care at all about equality between children in which case $\beta = 1$. In this case, parents invest to maximize the accumulated stock of children's human capital. For any $\beta < 1$, parents substitute aggregate human capital for equality where $\sigma_\beta = (1/(1-\beta))$ is the elasticity of substitution across human capital of each child. The value of children's human capital $(\bar{H})$ increases with parents' taste for quality, π.

Parents are endowed with money and a unit of time which they divide between labor market activities and child-rearing. They allocate their resources by maximizing the following log-linear utility function:

$$\ln U = (1-\alpha)\ln C + \alpha\left(\ln N + \pi \ln \bar{H}\right) \tag{3}$$

subject to their budget constraint:

$$C+N\left(w\tau+I\right)\equiv C+CLD=Y+w, \tag{4}$$

where τ is the fraction of mother's time that is required for birth and child-rearing, and w captures her earnings capacity if she allocates all her time to the labor market. Consequently, $w\tau$ is the forgone earnings, ignoring child quality investments, associated with raising a child. Y stands for all other household income, including partner's earnings. I depicts average direct investment in children's quality and CLD equals total spending on children. This setting is similar to Galor and Moav (2002) but allows for varying parental tastes for equality between children.

Children's human capital follows a technology of production suggested by Heckman (2007) and discussed in Almond and Currie (2011). Human capital at the end of childhood (H) is determined by a sequence of investments at early (I_1) and at older (I_2) ages determined by the following CES production function:

$$H=A\left[\gamma\left(I_1\right)^{\phi}+\left(1-\gamma\right)\left(I_2\right)^{\phi}\right]^{1/\phi} \tag{5}$$

for $\phi\leq 1$ and $0.5\leq\gamma\leq 1$ and where $\sigma_{\phi}=\left(1/\left(1-\phi\right)\right)$ is the elasticity of substitution between early and late investment. γ is the CES share parameter that captures the importance of early investment relative to late investment. We presume $\gamma\geq 0.5$ reflecting the importance of early vs. late investments. A is the total factor productivity term representing a child's *ability to learn*. The optimal ratio of early to late investment is a function of γ and ϕ and:

$$\frac{I_1}{I_2}=\left[\frac{\gamma}{\left(1-\gamma\right)}\right]^{\sigma_{\phi}}. \tag{6}$$

Clearly, the ratio of early to late investment increases with γ and more so when it is relatively easy to substitute between early and late investments ($\sigma_\phi > 1$). A child's human capital by the end of childhood is a linear function of total investment:

$$H = IA\left[\gamma + \lambda^\phi (1-\gamma)\right]^{1/\phi} / (1+\lambda), \tag{7}$$

where $\lambda = ((1-\gamma)/\gamma)^{\sigma_\phi}$.

The optimized values for own consumption, C^*, and total spending on children, CLD^*, are as follows:

$$\begin{aligned} C^* &= (1-\alpha)(w+Y), \\ CLD^* &= a(w+Y). \end{aligned} \tag{8}$$

In this setting the optimal ratio of own consumption to total spending on children is $(1-\alpha)/\alpha$. Assuming all children are (ex-ante) equally *able to learn*, parents invest equal resources per child ($I_i = I$). The optimal *mixture* of child *quantity* and investment per child, *quality*, is shown in the following equations:

$$\begin{aligned} N^* &= \alpha\left(\frac{Y+w}{w}\right)\frac{(1-\pi)}{\tau}, \\ I^* &= \frac{w\pi\tau}{(1-\pi)}, \\ N^*I^* &= \alpha\pi(Y+w), \\ N^*w\tau &= \alpha(1-\pi)(Y+w). \end{aligned} \tag{9}$$

The quantity-quality trade-off is clear. Parental investment per child (I^*) increases and the number of children (N^*) decreases with parents' taste for quality (π), the time required to raise a child (τ), and mother's earnings capacity (w). By choosing this setting we assume that consumption (C) and children (N) are normal goods. Parents consume more of both with non-labor income (Y). Yet, this does not hold for child's quality. Transfers in this setting will be used to finance own consumption and fertility rather than child quality. The productivity of early vs. late investment does not affect the allocation of parental resources between consumption and total spending on children although it affects the allocation of resources between early and late investments. Last but not least, quantity (N^*) and quality per child (H^*) are jointly determined. The negative relationship between the *optimal* quantity and the *optimal* quality per child reflects the opposite influences taste for quality and forgone earnings have on quantity vs. quality and not the causal effect of N on H.

2.2 Shocks to Family Size

Do shocks to family size affect parental investments and consequently children's quality? Do shocks to family size have the same effect on all children? Does the timing of the shock to family size matter? Given the empirical attention on firstborn children we focus on shocks to family size from the perspective of the firstborn child. In the quantity-quality framework parents adjust consumption (C) and investments in children's quality following a shock to family size to maximize the following objective function:

$$\ln U = (1-\alpha)\ln C + \alpha\pi \ln \bar{H}, \tag{10}$$

subject to their net resources when the shock to family size occurs:

$$C + \tilde{N} \cdot I = \left(Y + w - \tilde{N} w \tau\right) - \delta I^*, \tag{11}$$

where $\tilde{N}$ represents the new family size incorporating the shock and $\tilde{N} > N^*$. δI^* represents investments in the firstborn that had already taken place prior to the shock to family size $(0 \leq \delta \leq 1)$.[3] We highlight two scenarios. First, the unconstrained case where the shock to family size occurs prior to any investment in child's quality, that is, $\delta = 0$. Second, the case where the shock occurs sometime in the firstborn's childhood, and investments in the firstborn had already been made based on N^*, that is, $(\delta > 0)$.[4] We discuss the first scenario in this section and discuss the second scenario in section 2.3.

In the first scenario parents split family resources between own consumption $\left(\tilde{C}\right)$ and investments $\left(\tilde{N} \cdot \tilde{I}\right)$ in the following way:

$$\begin{aligned} \tilde{N}\tilde{I} &= \frac{\pi\alpha}{(1-\alpha+\alpha\pi)}\left(Y + w - \tilde{N}w\tau\right); \\ \tilde{C} &= \frac{1-\alpha}{(1-\alpha+\alpha\pi)}\left(Y + w - \tilde{N}w\tau\right). \end{aligned} \tag{12}$$

where $\tilde{N}\tilde{I}$ and $\tilde{C}$ are the optimal spending on child quality and parents' own consumption respectively. Parents with high taste for quality $(\pi = 1)$ spend α and $(1-\alpha)$ from available resources on child's quality and own consumption respectively. The optimal allocation of parental investments between the firstborn child and other siblings depends on the timing of the shock to N, on technology, and on parents' taste for quality and equality. In all scenarios parents allocate $\tilde{N}\tilde{I}^*$ between children to maximize $\bar{H}$. Consider the unconstrained scenario $(\delta = 0)$. In this case parents invest equally less in each child:

$$\tilde{I} = \frac{\pi\alpha}{\tilde{N}\,(1-\alpha+\alpha\pi)}\left(Y + w - \tilde{N}w\tau\right). \tag{13}$$

[3] We assume that a shock to family size increases the number of surviving children only when resources permit, that is, when $w - \tilde{N}w\tau - \delta I^* > 0$

[4] Obviously, if the shock takes place once investments in the firstborn child is completed, that is $\left(\tilde{I} = I^*\right)$, there is no effect on the firstborn's quality.

Investment per child increases with labor (w) and non labor income (Y) and drops with the fixed cost of child rearing ($w\tau$) and family size $\left(\tilde{N}\right)$. Note that in contrast to the optimal mix of child quantity and quality which are jointly determined, here shocks to family size have a negative impact on child quality in the causal sense. An exogenous shock to the number of children reduces parents' own consumption, total spending on children's quality and investment per child. The change in investment per child $\left(\Delta\tilde{I} = \tilde{I} - I^{*}\right)$ is as follows:

$$\Delta\tilde{I} = \frac{\pi(1-\pi)\alpha(Y+w) - \tilde{N}\pi\tau w}{\tilde{N}(1-\alpha+\alpha\pi)(1-\pi)} < 0. \tag{14}$$

Note, the drop $\Delta\tilde{I}$ is larger the higher the mother's wage (w) while it is smaller the higher other income (Y):

$$\frac{\partial\Delta\tilde{I}}{\partial w} < 0, \ \frac{\partial\Delta\tilde{I}}{\partial Y} > 0. \tag{15}$$

We will return to these results later when we investigate the extent to which available family resources (Y) may help shield children from the drop in parental investments and cognitive test scores following a sibling birth.

2.3 Shocks to Family Size over Childhood: Early vs Late

An exogenous increase in the number of children prior to any investment in children's human capital affects all children equally. Each child will be equally taxed to facilitate the unplanned increase in the number of children. Yet, in reality, shocks to family size happen when some resources were already allocated to existing children ($\delta > 0$). For example in the canonical case of shock to family size involving twin births, parents who planned on having two children ($N^{*} = 2$) end up having three children $\left(\tilde{N} = 3\right)$. They adjust their own consumption and investments in children, as discussed in the previous section. The key difference is that early investment in the firstborn – *prior* to the shock to family size – is *irreversible*. Consequently parents no longer invest equal resources in the firstborn (f) and newborn (n) children.

To illustrate, consider a T-period version of a child's human capital production function introduced in equation (5) in which $\gamma_t > \gamma_{t+1}$. Human capital of child j whose family size changed unexpectedly S periods into his or her childhood exhibits the following form:

$$H_j = A\left(\sum_{t=1}^{T}\gamma_t {I_{jt}}^{\phi}\right)^{1/\phi} = A\left(\delta_b I_{jb}^{\phi} + \delta_a I_{ja}^{\phi}\right)^{1/\phi} \tag{16}$$

where I_{jb} and I_{ja} stand for parental investment in child j per period *before* and *after* the shock to family size. δ_b and δ_a are the corresponding CES weights:

$$\begin{aligned} \delta_b &= \sum_{t=1}^{S-1}\gamma_t^{1/(\phi-1)}\gamma_1^{(1-\phi)/\phi}, \\ \delta_a &= \sum_{t=S}^{T}\gamma_t^{1/(\phi-1)}\gamma_S^{(1-\phi)/\phi}. \end{aligned} \tag{17}$$

First, $I_{jb} \geq I_{ja}$ reflecting the drop in investment following a shock to family size. However, an unplanned birth of a sibling S periods into the firstborn's childhood ($S \leq T$) affects parental investments in the firstborn and the newborn unequally. This is due to the *irreversibility* of investment during the early S periods of the firstborn's childhood. The table below depicts optimal parental investments in the firstborn and newborn children, as well as their human capital, for different combinations of taste (β) and productivity (ϕ) parameters. Two main results emerge. First, parental investment in human capital is not equal across children regardless of taste or productivity parameters. Second, human capital is not equal across children as long as parents do not have an extreme taste for equality between children, that is, as long as ($\beta < -\infty$) and early and late investments are not perfect substitutes ($\phi = 1$) as the the early childhood literature indicates.

Investments in the Firstborn and Newborn Children			
ϕ \\ β	1	$(-\infty, 1)$	$-\infty$
1	A: $\tilde{I}_f > \tilde{I}_n,\ \tilde{H}_f > \tilde{H}_n$	B: $\tilde{I}_f > \tilde{I}_n,\ \tilde{H}_f > \tilde{H}_n$	C: $\tilde{I}_f > \tilde{I}_n,\ \tilde{H}_f > \tilde{H}_n$
$(-\infty, 1)$	D: $\tilde{I}_f > \tilde{I}_n,\ \tilde{H}_f > \tilde{H}_n$	E: $\tilde{I}_f > \tilde{I}_n,\ \tilde{H}_f > \tilde{H}_n$	F: $\tilde{I}_f > \tilde{I}_n,\ \tilde{H}_f = \tilde{H}_n$
$-\infty$	G: $\tilde{I}_f > \tilde{I}_n,\ \tilde{H}_f > \tilde{H}_n$	H: $\tilde{I}_f > \tilde{I}_n,\ \tilde{H}_f > \tilde{H}_n$	I: $\tilde{I}_f > \tilde{I}_n,\ \tilde{H}_f = \tilde{H}_n$

In the most likely cases–cases D, and especially E–a shock to family size results in higher investment in the firstborn child relative to newborn children, and consequently the human capital of the firstborn is also higher.[5] In other words, in these cases, the outcomes we measure for the firstborn likely *understate* the quantity-quality trade-off.

So far, we have compared investments and outcomes across siblings following a shock to family size. How do investments and outcomes differ for the firstborn and also across siblings as birth-spacing (S) rises? Intuitively, the drop in investment in the firstborn is smaller as birth spacing increases due to the fact that the amount of irreversible investment increases with S. Consequently inequality of investments across siblings also increases with S:

$$S^{'} > S \Longrightarrow \Delta I_f\left(S'\right) > \Delta I_f\left(S\right), \Delta I_n\left(S'\right) < \Delta I_n\left(S\right) \tag{18}$$

What about human capital of siblings? Clearly, human capital of newborn children drops

[5]This is assuming that early and late investments are complements, but not perfect complements.

with birth spacing. For subsequent children, parents keep the ratio of early to late investment as in the optimal plan and therefore the drop in human capital is proportional to the drop in parental investment, $\tilde{H}_n = H_n^* \cdot \left(\tilde{I}_n / I_n^*\right)$. This does not hold for the firstborn. If parents had no taste for equality they should invest in the firstborn and keep their human capital as in the original plan. For parents with some taste for equality, they substitute *efficiency* for *equality*. The overall effect on the firstborn's human capital depends on the marginal cost and the marginal benefit of equality. For each level of substitution between early and late investment (ϕ) there is a taste for equality ($\bar{\beta}$) that equates efficiency and equality. For any $\beta > \bar{\beta}$ the gap between the human capital of the firstborn and the newborn children increases with birth spacing:

$$S^{'} > S \Longrightarrow \Delta H_f\left(S'\right) > \Delta H_f\left(S\right), \qquad if\ \beta > \bar{\beta}(\phi) \tag{19}$$

Intuitively, as long as parents do not have a strong preference for equality, the smaller drop in investments in the firstborn that results from increased birth spacing will result in a smaller drop in human capital of the firstborn.[6]

We are not the first paper to study the effect of parental preferences on the quality-quantity trade-off. Mogstad and Wiswall (2016) shows that an increase in the number of children can have negative or positive effects on existing children depending on the complementarity between quantity and quality of children in parental preferences. We are the first paper, however, to highlight the importance of parental investments in early childhood and the complementarity between early and late investments in determining how shocks to family size influence firstborns' and newborns' cognitive outcomes.

It is worth emphasizing that a large body of research identifies and quantifies the effect

[6]In the appendix, we provide derivations of these main theoretical results.

of family size on the average quality of children using the firstborn's outcomes. However, the estimated effects may be understating the quantity-quality trade-off. The effects on firstborn children serve as a credible proxy for the change in average quality only when siblings arrive at younger ages–reflecting short birth spacing–and understate the quantity-quality trade-off when siblings arrive at older ages.

3 Data

The National Longitudinal Survey of Youth - 1979 (NLSY) provides a unique opportunity to evaluate the quantity-quality trade-off by birth spacing as it contains information on childhood development from early to older ages. We match mothers from the 1979 survey with all their children from the Children and Young Adult survey, resulting in a sample containing 4,922 mothers and 11,464 children, of whom 4918 are firstborn. We keep older children with at least one younger sibling who are themselves not twins, who have non-missing mother's data, and non-missing data on siblings resulting in 5,509 older children, of whom 3187 are firstborn. Children were surveyed biannually from 1986 to 2010. By matching children to their mothers we can identify siblings, as well as the precise timing of when family size expands.

The matched NLSY mother-child data contains detailed information about childhood cognitive and non-cognitive abilities as well as longer term outcomes. Throughout this paper we use the terms cognitive and non-cognitive skills to describe personality attributes associated with cognitive achievement tests (IQ, AFQT, etc.), and behavioral problems not measured by cognitive achievement tests. Children aged 5 to 14 are given Peabody Individual Achievement Tests (PIATs) that measure cognitive skills in mathematics, reading recognition, and reading comprehension.[7] We report results of the combined math and reading recognition scores which were constructed by taking a simple average of the two.[8] It has been shown that non-cognitive skills also contribute to performance on cognitive achievement tests controlling for IQ (Borghans et al. 2011). Hence our interpretation of these cognitive performance measures is that they mostly reflect cognitive ability but not exclusively so–they also reflect non-cognitive ability.

Our proxy for non-cognitive performance is the Behavioral Problems Index (BPI), a measure designed to evaluate the existence and intensity of a range of child behavioral problems. The NLSY survey calculates the index for children aged 4 to 14 from subindices which measure particular problems including antisocial behaviors, anxiety, dependence, headstrongness, hyperactivity, and social problems. It is formed using 28 questions asked of mothers about their child's behavior. It is worth noting that there is a sharp divide among social scientists on how to measure non-cognitive skills. Psychologists primarily measure non-cognitive skills using psychological scales based on self-reported surveys or observer reports such as the "Big Five". Following Tyler (1973), who advocated capturing non-cognitive skills using measures of behavior, a growing body of research documents notable associations between behavioral measures and non-cognitive skills (Heckman et al. (2014); Jackson (2012); Kautz and Zanoni (2015)). We follow the lessons from these findings and use the BPI index. Indeed, behavioral ratings predict legal labor market outcomes as well as illegal and illicit activities better than psychological scales such as the Big Five (Almlund et al. 2011).

To measure parental investment, the NLSY asks questions to construct a HOME (Home

[7] For 1986 to 1992 children aged 5 and older were given PIAT tests. This was changed to children aged 5 to 14 in 1994 and subsequent surveys. We include all respondents in our main analysis; results are robust to excluding children aged 15 and older. A similar change in age eligibility is true for respondents of the BPI as well. Details available upon request.

[8] We have also examined math and reading scores separately. We find somewhat stronger results for math and weaker results for reading when we disaggregate. Results are available upon request.

Observation Measurement of the Environment-Short Form) score, "a unique observational measure of the quality of the cognitive stimulation and emotional support provided by a child's family." Examples of these questions include how many books a child has, how often parents read to the child, and whether parents assist with homework. Questions are a combination of mother response and interviewer observation. HOME scores have been shown to be a significant determinant in a child's development (Mott (2004), Todd and Wolpin (2007), Cunha and Heckman (2007), Cunha et al. (2010), and others). The HOME Inventory is available for children aged 0 to 15 but the set of questions used in assessing the Inventory measure differ by age of the child. To standardize across ages we use the NLSY formed percentile measure of the HOME score. To probe whether it is parental time or resources that account for changes in home environment, we also report separately answers to the questions: "How often does the mother read stories to the child?"and "About how many books does the child have?"

We construct a data set where we match test scores, HOME and behavioral index measures of older siblings with the birthdate of each sibling who follows. While HOME scores are measured from birth, the behavioral problem index is measured for children 4 years of age or older and NLSY PIAT tests are only administered to children 5 years of age or older. Therefore, the number of children-year observations vary by the outcome of interest. Further specific details are available in the table notes and in the appendix. Table A.1 presents summary statistics of our sample of firstborn children with at least one younger sibling. Table A.2 presents summary statistics of all older children with at least one younger sibling.

4 Evidence from the Before-After Analysis

We estimate the quantity-quality effects on children's cognitive and non-cognitive performance over childhood. Our theoretical discussion pointed to several key implications. First, parental investments and human capital of the firstborn drop following a shock to family size (as shown in equation (14)). Second, the drop in investments and human capital of the firstborn following a shock to family size are smaller as birth spacing increases (as shown in equations (18) and (19)). In this section we focus on outcomes of the firstborn at 2nd parity since it presents the cleanest before and after scenario in terms of the presence of a younger sibling.

We estimate the following equation:

$$P_{it} = b_0 + b_D D_{it} + b_X X_{it} + \varepsilon_{it} \tag{20}$$

where P_{it} denotes child i's test score measured in year t and X_{it} are controls which include the child's age and its square, child's gender and race and mother's observables such as age at first birth, schooling, religion and measures of cognitive and non-cognitive performance in teenage years. Specifically we use mother's AFQT scores (percentiles fixed effects), Rosenberg Self Esteem and Rotter Locus of Control scores as well as an Illicit Index calculated for the mother.[9] We compare children with and without a sibling present as indicated by D_{it}.

[9] Illicit Index measures, based on 20 questions, engagement in aggressive, risk taking, disruptive, "break-the-rules" behavior of individuals as teenagers (see Heckman and Rubinstein (2001) and Levine and Rubinstein (2017)). Definitions and further details are available in the Appendix. Some of the questions composing the Illicit Index allow for yes or no answers and other questions offer answers that yield information on the frequency with which the person engages in a delinquent activity. Following Levine and Rubinstein (2017) we code the responses to all questions as one or zero based on whether the respondent did or did not engage in the activity.

We report our findings in Table 1. The table contains results for cognitive outcomes proxied by the weighted average of math and reading recognition scores and non-cognitive outcomes proxied by BPI index. The first two columns report the OLS regression coefficient estimated controlling for child and mother observables (Column 1) and controlling for child fixed effect (Column 2). The third column includes child fixed effects but also disaggregates the "after" period into the 0-3 years following a sibling birth and 3+ years after. The results reported in the table highlight three findings. First, children have lower cognitive scores and have more behavioral problems following the birth of a younger sibling. Second, the drop in performance persists and appears to grow as time passes. This rules out the possibility that the birth of an additional child is a disruptive but transitory shock which quickly dissipates as the household adjusts. Third, child/family time invariant factors matter–comparisons between the OLS and the child fixed effects specifications depict negative sorting into having an additional child on the cognitive performance of the firstborn and positive selection on non-cognitive performance of the firstborn.

According to the OLS estimates reported in Column (1), an additional sibling is associated with a 4.1 percentile point drop in cognitive scores of the older sibling. The fixed effects estimate reported in Column (2) is -2.8 percentile points. The smaller coefficient suggests negative sorting into having the next child. Since the standard deviation is 24 percentile points (see Table A.1), the size of the fixed effects estimate translates into larger than one-tenth of a standard deviation change in the cognitive performance measure. With regards to behavioral problems, the OLS coefficient is small and not significant at the 5 percent level of significance. However, the fixed effects coefficient reported in Column (2) suggests that the arrival of the younger sibling leads to a 3.8 percentile point increase in behavioral problems. The comparison of the OLS and FE columns suggests positive selection on firstborn behavior. In other words, parents are more likely to have the second child earlier if the first child has fewer behavioral problems. Column (3) compares the short-run and long-run differences. With regards to cognitive scores, we find no evidence that the drop in performance is transitory–performance appears to worsen over the longer run. With regards to behavioral problems, there is no evidence that performance worsens over time.

We have so far examined children's outcomes. A critical element of our argument following the framework introduced by Becker and co-authors and our model in section 2 is that this drop in child performance reflects a drop in parental investments. The matched mother-child data of the NLSY provides rich detail on a child's home environment. We utilize these measures to shed light directly on the parental inputs that may underlie the observed quantity-quality trade-off.

Table 2 reports our estimates of the impact of an additional child on the home environment score as well as the subcomponents, parental time and resources spent on children. The top panel of Table 2 shows that home environment score falls after the arrival of an additional child. Interestingly, parental investment measures are permanently lower as shown in Column (2). The bottom panel probes a bit further whether parental time vs. resources spent on children are impacted. We report the impact of a second sibling on whether the mother reads to the child more than once per week. We also report the impact of the younger sibling on whether the older child has 3 or more books. We find a clear indication of declines in parental time but not much decline in terms of resources, at least as crudely proxied by the number of books.

The key implication from the theory incorporating early and late investments is that the adverse effects of shocks to family size diminish with birth spacing. In the before-after analysis we examined outcomes of firstborns before and after the sibling arrival. Since all firstborns in our sample eventually have a sibling, the comparison is across children who have siblings earlier vs. later. In the following specification we estimate the effects of years since sibling birth, T_{it}, as well as its interaction with age, $A_{it}T_{it}$, to capture the effect of birth spacing on the human capital stock of the firstborn. We estimate:

$$P_{it} = a_0 + a_A A_{it} + a_{A2} A_{it}^2 + b_T T_{it} + b_{TA} A_{it} T_{it} + b_{T2} T_{it}^2 + \varepsilon_{it} \tag{21}$$

where P_{it} again denotes child i's test score measured in year t, A_{it} is the child's age, and T_{it} equals years since sibling birth. The interaction between A_{it} and T_{it} measures the effect of birth spacing controlling for age and time since sibling birth. We expect the coefficient b_T to be negative reflecting the negative impact of longer exposure to a younger sibling. We expect the coefficient b_{TA} to be positive reflecting the positive impact of longer birth spacing.

We report the estimates in Table 3. Column (1) and Column (4) report the before-after fixed effects estimates taken from Table 1. In Column (2) we allow the effect to accumulate over time, T_{it}, and birth spacing, $A_{it}T_{it}$. Estimates in Column (2) suggest that there might be some immediate impact of the sibling and yet the estimated adverse effect is small and not statistically significant. There is also a notable cumulative effect with additional years of exposure. Finally, birth spacing matters. The age-years since birth interaction has a positive coefficient, confirming our proposition that the impact of siblings is smaller for children who are treated at older ages–that is, children who have longer birth spacing to their next sibling. For behavioral outcomes, while there is a strong immediate impact on the older sibling, there is less evidence of an accumulation effect. The age-years since birth interactions are also small and not statistically significant. In the bottom panel we report the estimated effects by birth spacing evaluated at 10 years of age. The coefficients imply that at age 10, firstborn children with one year of birth spacing experienced an 11.25 percentile points drop in cognitive score whereas firstborn children with nine years of birth spacing experienced almost no change in their cognitive performance (1.2 and statistically insignificant).

In Column (2) we controlled for child fixed effects which addressed heterogeneity in terms of levels of ability. However, the timing of births may be correlated with the ability to learn. In particular, parents may delay having the second child when the first child has higher capacity to learn. Panel data allows us to control for not only differences in fixed ability levels but also child-specific trends or growth rates. While this is theoretically possible, it is difficult to put into practice given the large number of parameters to estimate and the fact that we do not have many observations in the before period in many cases. We instead proxy for child-specific growth rates in learning with trends which vary by mother's AFQT percentile. These results are reported in Column (3).

Turning to the cognitive scores reported in Column (3), the treatment effect of sibling arrival as well as the age-years since birth interactions are more muted when we include mother's AFQT-specific trends, consistent with the interpretation that parents delay having a second child when their firstborn has a greater capacity to learn. Not controlling for mother's AFQT percentiles, a proxy for child-specific ability to learn, would lead us to overstate the quantity-quality effect. Note, however, that the age-years since birth interactions are still positive and significant, suggesting that even controlling for heterogeneity in child quality in both levels and growth rates, children who are exposed to an additional sibling at older ages experience a significantly smaller negative impact. Again summing up the coefficients in the bottom panel, the coefficients imply that at age 10, a child who has a sibling at age 1 has a cognitive score more than 9.15 percentile points lower than a child with no sibling whereas a child who had a sibling at age 9 has only a 0.98 percentile point gap.

With regards to behavioral outcomes, the impact of an additional sibling is even bigger (leading to more behavioral problems) when we control for the mother's AFQT-specific trends. This suggests that children who are better behaved acquire an additional sibling at earlier ages. Not controlling for mother's AFQT percentiles lead us to understate the quantity-quality effect. However, there is again little evidence of an accumulation effect and little evidence that age at which the sibling arrives matters.

5 Twin Births and Birth Spacing

Our before-after analysis shows that firstborn children are adversely affected when their younger sibling arrives and consistent with the early childhood literature, this effect is large and significant only when the sibling arrives within a short birth spacing interval. There are two potential concerns with our before-after analysis. First, because NLSY-PIAT tests are administered to children 5 years or older our before-after analysis is based on a sample of children with relatively longer birth spacing. These are not the typical families as Figure 1 indicates. Figure 1 shows the distribution of spacing between the first and second-borns in the full-sample and in our fixed effects sample of children who had a valid PIAT test score measured both before and after the birth of the next sibling (shown in blue). Each bin corresponds to 6 months. As the figure shows, the modal spacing between first and second-borns is 1 to 3 years (shown in red) while the spacing in our fixed effects sample is 5 years or greater. Another concern is that while our theory addresses the impact of unanticipated shocks to family size, the before-after analysis may not be reflecting shocks. Families may be anticipating and timing the births of additional siblings.

To address these concerns, in this section we present results from an alternative estimation strategy which follows Rosenzweig and Wolpin (1980) and many others. We use twin births as unanticipated shocks to family size. Some occur during the older sibling's early childhood and others as they age. While birth spacing may be planned, the interaction between twin births and birth spacing is not. We utilize this natural source of variation in family size by birth spacing to estimate the quantity-quality trade-off by birth-spacing. To increase our sample size we include twin births at all parities and regress outcomes of all older children (controlling for birth order) on whether the next birth is a singleton or twins.[10] Specifically, to measure the impact of shocks to family size by birth spacing, we estimate the following equation:

$$P_{it} = \beta_0 + \beta_T TWIN_i + \beta_{TS} TWIN_i S_i + \beta_S S_i + \beta_M M_i + \beta_X X_{it} + \varepsilon_{it} \tag{22}$$

where P_{it} denotes performance of child i on cognitive and non-cognitive assessments measured in year t. $TWIN_i$ is an indicator equal to 1 if the next younger sibling is a twin and 0 if the next younger sibling is a singleton. S_i is an indicator equal to 1 if birth spacing between child i and the next younger sibling is greater or equal to 35 months, which is the median spacing. X_{it} includes additional spacing controls in months and months squared, and child controls such as birth order, race, gender, and age fixed effects. M_i is a vector of mother's characteristics including cognitive and non-cognitive performance measured during her teenage and young adult years (AFQT, self-esteem, locus of control, and illicit behavior as teenager). The key parameters of interest are β_T, and β_{TS} which are the effects of a twin birth (relative to a singleton birth) on the older child's performance for birth spacing $<$ median spacing and $>=$median spacing respectively.

[10] Table A.3 reports the number of children with twin siblings at next parity by birth order. There are 73 older children whose next sibling is a twin. Deleting children who are not interviewed, have missing mother's data, or have missing sibling information, we end up with 63 older children.

We report our findings in Table 4. We report regression coefficients on three outcomes of interest: (i) aggregate cognitive score, (ii) math score and (iii) behavioral problems score. We also report coefficients for Home Inventory score. For the cognitive and non-cognitive performance measures we do not make restrictions based on age. For home scores, we report the results up to when the child is 9 years of age. The odd columns report the twin birth effect imposing one common effect. The even columns report the twin birth effects allowing for differential effects by birth spacing. Two main facts emerge. First, consistent with Black et al. (2005) we find no overall significant effect of expansions in family size associated with twin births when we do not differentiate by birth spacing. Second, we find an adverse effect of twin birth on cognitive and non-cognitive performance that depreciates with birth spacing. The effect of twin birth on cognitive score of the older sibling is -6.481 percentile points for birth spacing $<$ median spacing. However, the twin effect on cognitive score of the older sibling is a non-significant 2.96 percentile points increase for spacing$>=$ median spacing. For behavioral problems, having a twin sibling increases behavioral problems for short spacing although this effect is not significant. The impact of a twin sibling on the older child's home environment is negative (-4.572 percentile points) for short spacing although the effect is not significant. Again, there is little impact of twin birth on the home environment when spacing is $>=$ median spacing. To summarize, we find notable and statistically significant adverse effects of a shock to family size–a twin birth–on the older sibling's cognitive performance, but only at short spacing intervals.

6 The Quantity-Quality Effect in More and Less Disadvantaged Households

An important lesson from the early childhood literature is that children from disadvantaged environments especially benefit from early investments. To the extent that additional siblings take away important parental resources, the quantity-quality trade-off may be especially large for children growing up in disadvantaged homes where resources are already scarce. Equation 15 in section 2 showed that available family resources (Y) help shield children from the drop in parental investments and cognitive test scores following a sibling birth. In what follows we investigate heterogeneity in the quantity-quality trade-off by mother's AFQT score. Specifically, we use (i) before-after comparison and (ii) twin birth, to estimate the impact of family size on older siblings by mother's AFQT.[11]

Table 5 extends the before-after analysis first reported in Table 1 by reporting the coefficients on the "after sibling birth" dummy variable separately for children with below median and above median AFQT mothers, where the cutoffs are defined by race. There are strikingly different results by mother's AFQT score. For children of mothers with below median AFQT scores, the arrival of younger siblings has large and significant negative effects on cognitive skills while for children with mothers with above median score, the effects are much smaller and not significant. With regards to the behavioral problems index, however, the results are opposite. It is the children of high AFQT mothers who are more likely to act up when a younger sibling arrives.

Effects by Mother's AFQT may be confounded by race. Column 2 and column 3 present

[11] Following the literature we interpret mother's AFQT as a a proxy measure of the stock of human capital of the mother which determines her earnings potential rather than as a measure of IQ or innate ability. Mother's AFQT also proxies for availability of spousal earnings in that higher AFQT mothers are much more likely to marry and have positive spouse earnings as shown in Table A.1.

results separately by race. We find a strong AFQT gradient for children of white mothers, consistent with the overall numbers. Among black and Hispanic mothers shown in column 3 we continue to observe a strong AFQT gradient for cognitive scores although there are no differential effects by AFQT for behavioral outcomes and in fact larger drops in the HOME environment index for higher AFQT households.

In Table 6 we investigate whether shocks to family size associated with twin births have differential effects on older sibling's outcomes by mother's AFQT. We estimate equation 22 separately for children of mothers with below median AFQT scores and children of mothers with above median AFQT scores. The format of the table is similar to Table 4. We report the results for children of below median AFQT mothers in the odd columns and the results for children of above median AFQT mothers in even columns. As was the case with Table 4 we show the effect of twin birth for spacing $<$ median spacing (35 months). The results are striking. The negative impact of twin birth on children's cognitive scores is entirely driven by children of mothers with below median AFQT scores with short spacing, <median spacing, to the next younger sibling. Relative to having a singleton sibling, older children with twin younger siblings experience a -11.97 percentile drop in cognitive scores at short spacing. These results are reversed if they have spacing>= median spacing (non-significant increase of 7.5 percentile points). There is no significant negative impact for children with mothers with above median AFQT scores. Behavioral problems also exhibit a similar pattern. Among children with low AFQT mothers, there is 7.9 percentile point increase in behavioral problems. Again, the negative impact of twin birth is not significant at longer spacing and actually reverses if the children have spacing >= median spacing to the next sibling and the mother has above median AFQT score. We also find a significant negative impact of twin birth on HOME scores for children with low AFQT mothers with a short birth spacing interval– a twin birth leads to a drop of 13.7 percentile points in HOME score.

To summarize, our results show that a shock to family size impacts older siblings negatively in terms of deteriorating home environment, cognitive and non-cognitive scores when these children are subjected to the shock in early childhood. These negative impacts are also only apparent in households in which the mother has limited resources–as proxied by her AFQT score– to absorb the shock in family size.[12]

7 The Quantity-Quality Trade-off and Mother's Labor Supply

A large body of research documents the importance of parental time investment on children's formation of skills, especially during their early childhood. Therefore, in theory, a shock to family size should have a larger adverse effect in families that are less flexible in adjusting parents' or mothers' labor supply. The lack of flexibility may reflect a lack of resources, Y. In section 2 we showed that the drop in parental investments in response to a shock to family size should be smaller for families with greater resources Y. In this section we explore one possible mechanism for the differential impacts of shocks to family size by mother's AFQT score–more flexible labor supply adjustments by high AFQT mothers who have greater resources.[13]

We take advantage of the NLSY79 work history data to assess the effect of births, both singletons and twins, on mothers' work hours. The NLSY79 work history data provide weekly

[12]We are not the first paper to point out heterogeneous effects. Mogstad and Wiswall (2016) find substitution between quantity and quality in large families and complementarities between quantity and quality in small families. We are the first paper to document heterogeneous effects by mother's cognitive abilities and resources.

[13]On the other hand, the lack of flexibility in mother's labor supply may also reflect lower taste for child quality which we cannot rule out.

records of the respondent's total number of hours worked. We use these data to construct for each mother in our sample hours worked before and after the birth of each child.

Figure 2 shows mothers' labor supply responses to twin and singleton births. We focus on mothers' labor supply at first parity since this provides the cleanest picture of how mothers respond to births, both anticipated and unanticipated. At subsequent parities, mothers may not adjust hours very much due to the fact that they are already at a low level. We show weekly hours worked (averaged over 6-month intervals) following birth(s) relative to the weekly hours averaged over the year prior to pregnancy, 12-24 months before birth. We report separately by mother's AFQT score (Figure 2(a) and Figure 2(b)). The figure shows that in the case of below median AFQT mothers, mothers reduce hours worked following the birth but there is not much difference between singleton and twin births after two years. In the case of above median AFQT mothers, however, there is a substantial difference in mothers' adjustments in labor supply. Hours worked among mothers of twins are substantially below mothers of singletons until about 5 years (60 months) which is about the age that children enter kindergarten. Thus, high AFQT mothers delay returning to work in response to a shock in family size. To the extent that mother's AFQT score proxies for her earnings potential, this suggests that the income effect may be dominating the substitution effect. What is likely the case, however, is that mother's AFQT is also a strong predictor of non-labor income such as saving and spousal earnings. These mothers have the resources to delay returning to work.

The differential effects by mother's AFQT score provide insight into why empirical studies have found a quantity-quality trade-off in some but not all contexts. In countries with a comprehensive welfare system and a strong public education system parental resource constraints may not be binding for educational outcomes. In a country such as the U.S. with limited income support programs and limited quality public education, lower ability mothers with limited monetary resources may face a real trade-off between quantity of children and the resources she can devote to investing in their skills.

8 Conclusion

In accordance with the existing literature, we test for the quantity-quality trade-off by examining the impact of shocks to family size on older children's cognitive and non-cognitive outcomes and their home environment. Consistent with the main lessons of the early childhood literature pioneered by Heckman and others, we find significant negative impacts only when the shocks come in early childhood–in other words, when there is short spacing between the older and younger siblings. We argue that this may present a more accurate picture of the existence of the quantity-quality trade-off since the negative impact on older children (who were born before the shock was realized) likely understates the negative impact on all children. We also find that the quantity-quality trade-off is largely due to what happens in families of low AFQT mothers. The strong differences across mother's AFQT score suggest that resource availability or institutions are important in determining the extent of the quantity-quality trade-off. High AFQT mothers of all races appear to face less of a trade-off than mothers with low AFQT scores. Differences in mother's AFQT scores are correlated with a wide set of lifestyle differences that could explain these differences. For instance, having worse child care coverage, maternity policies, or flexibility in household labor supply could all make the presence of an additional child more detrimental to other children in the household.

The heterogeneity of results by parental ability and resources may help reconcile conflicting findings in the literature previously mentioned. One potential explanation for the difference in our results in contrast to Black et al. (2005) is institutional differences between Norway and the U.S. In particular, at the margin, parental investments may matter more in the U.S. where a substantial fraction of young men and women, particularly from lower income backgrounds, are at risk of not finishing high school. Understanding the mechanisms underlying these differentials in the quantity-quality trade-off remains an important question for future research.

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Table 1: Effect of Sibling Birth on Firstborn's Cognitive and Non-cognitive Skills

Cognitive Ability	(1)	(2)	(3)
After sibling birth	4.098***	-2.812**	
	(1.161)	(1.108)	
0-3 years after			-2.519**
			(1.115)
3+ years after			-4.011***
			(1.263)
N	10645	10645	10645
Child Fixed Effects	No	Yes	Yes
Behavioral Problems	(1)	(2)	(3)
After sibling birth	1.649	3.875***	
	(1.432)	(1.235)	
0-3 years after			3.960***
			(1.234)
3+ years after			2.870*
			(1.476)
N	11897	11897	11897
Child Fixed Effects	No	Yes	Yes

Data are from the Children of the NLSY79, 1986-2010. Our sample is all firstborns who are themselves not twins and have at least one younger sibling. Children who were not interviewed, have missing mother's data, or missing sibling birth date are excluded. The dependent variable is achievement scores of the first born and "after sibling birth" is a dummy variable for presence of the second-born. Cognitive ability is constructed by averaging a child's PIAT math and reading recognition test score percentiles. Behavioral problems is the percentile of child measurement on the behavioral problem index survey instrument. Column (1) pools child-year observations. Columns (2) and (3) include child fixed effects. All regressions include controls for child age fixed effects, and are weighted by children weights provided by the NLSY. Column (1) also controls for child's gender and mother's race, age at first birth, AFQT score (percentiles fixed effects and actual score), Rosenberg score, Rotter score, Illicit Behavior index, and religion. Top panel has fewer observations due to the fact that PIAT scores are available for children aged 5 (or older) while BPI is available for children aged 4 (or older). Robust standard errors are clustered at the individual child level.

$*$: significant at 10% level. $**$: significant at 5% level. $***$: significant at 1% level.

Table 2: Effect of Sibling Birth on Home Environment of Firstborn Children

	(1)	(2)
Panel A: HOME Inventory		
After sibling birth	-3.030***	
	(1.009)	
0-3 years after		-3.066***
		(1.010)
3+ years after		-4.925***
		(1.357)
N	14218	14218
Child Fixed Effects	Yes	Yes
Panel B: Mother Reading to Child and Number of Books		
Mother Reads to Child More than Once a Week	(1)	(2)
After sibling birth	-0.049**	
	(0.021)	
0-3 years after		-0.054**
		(0.022)
3+ years after		-0.072**
		(0.035)
N	6842	6842
Child Fixed Effects	Yes	Yes
Child Has 3 or More Books	(1)	(2)
After sibling birth	-0.001	
	(0.008)	
0-3 years after		-0.003
		(0.009)
3+ years after		-0.012
		(0.015)
N	6842	6842
Child Fixed Effects	Yes	Yes

Data are from the Children of the NLSY79, 1986-2010. Our sample is all firstborns who are themselves not twins and have at least one younger sibling. Children who were not interviewed, have missing mother's data, or missing sibling birth date are excluded. "HOME Inventory" is based on NLSY questions designed to measure quality of the cognitive stimulation and emotional support provided by the child's family. The HOME score is reported for each child and is available for children aged 0 to 15. We use the NLSY formed percentile measure of the HOME score. Panel B reports whether the mother reads to the child more than once per week and whether the child has 3 or more books. These questions are asked until age 9. We keep children up to age 8 to ensure all children are asked the question. We further exclude observations with missing data on home inventory (Panel A) or on reading and number of books (Panels B). All regressions include child FE, controls for child age, and are weighted by children weights provided by the NLSY. Robust standard errors are clustered at the individual child level.

$*$: significant at 10% level. $**$: significant at 5% level. $***$: significant at 1% level.

Table 3: Effect of Sibling Birth on Firstborn's Cognitive and Non-cognitive Skills by Birth Spacing

	Cognitive Ability			Behavioral Problems		
	(1)	(2)	(3)	(4)	(5)	(6)
After sibling birth	-2.812**	-1.413	-1.101	3.875***	4.279***	4.396***
	(1.101)	(1.282)	(1.223)	(1.227)	(1.440)	(1.398)
Years since birth		-3.698***	-2.953***		-0.741	-0.383
		(0.846)	(0.841)		(1.085)	(1.096)
Age X Years since birth		0.408***	0.320***		0.016	-0.055
		(0.098)	(0.095)		(0.126)	(0.128)
N	10645	10645	10645	11897	11897	11897
Child Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Mother AFQT percentile X Age	No	No	Yes	No	No	Yes
Effects at age 10:						
Birth Spacing = 1	-2.81**	-11.25***	-9.15**	3.88***	2.46	2.42
Birth Spacing = 2	-2.81**	-8.85**	-7.24**	3.88***	2.32	2.01
Birth Spacing = 3	-2.81**	-6.77**	-5.59*	3.88***	2.27	1.75
Birth Spacing = 6	-2.81**	-2.51	-2.14	3.88***	2.62	1.93
Birth Spacing = 9	-2.81**	-1.20	-0.98	3.88***	3.74**	3.54**

Data are from the Children of the NLSY79, 1986-2010. Our sample is all firstborns who are themselves not twins and have at least one younger sibling. Children who were not interviewed, have missing mother's data, or missing sibling birth date are excluded. The dependent variable is achievement scores of the firstborn and "after sibling birth" is a dummy variable for presence of the second-born. "Years since birth" refers to years since birth of the second-born. Cognitive ability is constructed by averaging a child's PIAT math and reading recognition test score percentiles. Behavioral problems is the percentile of child measurement on the behavioral problem index survey instrument. All regressions include child FE, controls for child age, and are weighted by children weights provided by the NLSY. Robust standard errors are clustered at the individual child level. Columns 1-3 have fewer observations due to the fact that PIAT scores are available for children aged 5-14 while BPI is available for children 4-14. Column (1) reproduces results reported in Table 1, column (2). Column (2) reports years of treatment and age-years since birth interactions which reflects spacing effects when years of treatment are controlled for. Column (3) also controls for mother's AFQT percentile interacted with age. Columns (2) and (3) include quadratic terms in age and years since birth. Bottom rows summarize the effects of all coefficients when the first born is 10 years of age under four different spacing scenarios: 1, 2, 3, 6, and 9 years.

$*$: significant at 10% level. $**$: significant at 5% level. $***$: significant at 1% level.

Table 4: Effect of Twin Births on Older Siblings' Skills and Home Environment by Birth Spacing

	Cognitive Score		Math Score	
	(1)	(2)	(3)	(4)
Twin Birth	-2.211	-6.481**	-3.017	-7.172**
	(2.522)	(2.981)	(2.675)	(3.112)
Twin Birth X Spacing>=Median		9.441*		9.199*
		(4.933)		(5.204)
N	16511	16511	16676	16676
Twin Effect for Spacing>=Median		2.960		2.026
		(3.920)		(4.168)

	Behavioral Problems		Home Inventory	
	(1)	(2)	(3)	(4)
Twin Birth	-1.635	3.239	-2.659	-4.572
	(4.347)	(5.345)	(2.872)	(3.499)
Twin Birth X Spacing>=Median		-11.175		5.604
		(8.562)		(5.960)
N	18251	18251	10187	10187
Twin Effect for Spacing>=Median		-7.937		1.033
		(6.679)		(4.823)

Data are from the Children of the NLSY79, 1986-2010. Our sample is all children who are themselves not twins and have at least one younger siblings. Children who were not interviewed, have missing mother's data, or missing sibling birth date are excluded. The dependent variable is achievement scores or "HOME Inventory" score of the older child and the estimates are coefficients on a dummy variable equal to 1 if the next birth is a twin birth and 0 if it is a singleton birth. We report interaction of this indicator for twin birth with a dummy variable equal to 1 if spacing to the next sibling is >=35 months (the median spacing) and 0 if spacing is <35 months. No age restrictions are made for cognitive scores, math scores, and behavioral problems. Home scores are reported for children who are 9 years of age or younger. For detailed description of the measures see table notes for Table 1 and Table 2. All regressions include controls for birth order, race, gender, and age fixed effects for the child, as well as mother controls such AFQT score (percentiles fixed effects and actual score), Rosenberg score, Rotter score, and Illicit Behavior index. Regression is weighted by children weights provided by the NLSY. Robust standard errors are clustered at the individual child level.

$*$: significant at 10% level. $**$: significant at 5% level. $***$: significant at 1% level.

Table 5: Effect of Sibling Birth on Firstborn's Cognitive and Non-cognitive Skills by Mother's AFQT Score

	Full Sample	White mothers	Black/Hisp mothers
Cognitive Ability			
Below median AFQT	-5.042***	-5.196**	-3.442**
	(1.600)	(2.155)	(1.723)
Above median AFQT	-0.289	0.238	-0.294
	(1.378)	(1.785)	(1.828)
N	10645	5498	5147
Child Fixed Effects	Yes	Yes	Yes
	Full Sample	White mothers	Black/Hisp mothers
Behavioral Problems			
Below median AFQT	2.022	1.179	5.663**
	(1.619)	(2.018)	(2.220)
Above median AFQT	5.869***	6.340***	5.745***
	(1.748)	(2.353)	(1.841)
N	11897	6276	5621
Child Fixed Effects	Yes	Yes	Yes
	Full Sample	White mothers	Black/Hisp mothers
HOME Inventory			
Below median AFQT	-4.171***	-5.495***	1.267
	(1.383)	(1.636)	(1.950)
Above median AFQT	-2.082*	-2.182	-3.098*
	(1.173)	(1.412)	(1.681)
N	14218	7690	6528
Child Fixed Effects	Yes	Yes	Yes

Data are from the Children of the NLSY79, 1986-2010. Our sample is all firstborns who are themselves not twins and have at least one younger sibling. Children who were not interviewed, have missing mother's data, or missing sibling birth date are excluded. The dependent variable is achievement scores of the firstborn and the estimates are coefficients on "after sibling birth" dummy variable for presence of the second-born. For detailed description of the measures see table notes for Table 1 and Table 2. Below and above median AFQT are dummies for whether a mother's AFQT score is above or below the median score by race. Column 3 reports results pooled for black and hispanic mothers but the median thresholds are defined within race. All regressions include controls for child fixed effects, child age, and are weighted by children weights provided by the NLSY. Robust standard errors are clustered at the individual child level.
$*$: significant at 10% level. $**$: significant at 5% level. $***$: significant at 1% level.

Table 6: Effect of Twin Births on Older Siblings' Skills and Home Environment by Birth Spacing and Mother's AFQT

	Cognitive Score		Math Score	
	(1)	(2)	(3)	(4)
Twin Birth	-11.968**	-3.821	-11.582**	-5.073
	(5.398)	(3.540)	(5.276)	(3.940)
Twin Birth X Spacing>=Median	19.476**	2.617	14.403*	7.432
	(8.057)	(6.048)	(7.846)	(7.019)
N	8776	7735	8881	7795
Twin Effect for Spacing>=Median	7.508	-1.205	2.821	2.359
	(5.925)	(4.876)	(5.782)	(5.761)
Mother's AFQT	<=50	>50	<=50	>50
	Behavioral Problems		**Home Inventory**	
	(1)	(2)	(3)	(4)
Twin Birth	7.936*	0.605	-13.732**	-1.780
	(4.598)	(8.039)	(6.521)	(3.984)
Twin Birth X Spacing>=Median	-5.736	-15.750	5.794	6.082
	(11.534)	(10.050)	(8.888)	(6.755)
N	9717	8534	5169	5018
Twin Effect for Spacing>=Median	2.199	-15.145**	-7.938	4.301
	(10.531)	(5.903)	(6.074)	(5.429)
Mother's AFQT	<=50	>50	<=50	>50

Data are from the Children of the NLSY79, 1986-2010. Our sample is all children who are themselves not twins and have at least one younger siblings. Children who were not interviewed, have missing mother's data, or missing sibling birth date are excluded. The dependent variable is achievement scores or "HOME Inventory"score of the older child and the estimates are coefficients on a dummy variable equal to 1 if the next birth is a twin birth and 0 if it is a singleton birth. We report interaction of this indicator for twin birth with a dummy variable equal to 1 if spacing to the next sibling is >=35 months (the median spacing) and 0 if spacing is <35 months. No age restrictions are made for cognitive scores, math scores, and behavioral problems. Home scores are reported for children who are 9 years of age or younger. For detailed description of the measures see table notes for Table 1 and Table 2. Below and above median AFQT are dummies for whether a mother's AFQT score is above or below the median score by race. All regressions include controls for birth order, race, gender, and age fixed effects for the child, as well as mother controls such AFQT score (percentiles fixed effects and actual score), Rosenberg score, Rotter score, and Illicit Behavior index. Regression is weighted by children weights provided by the NLSY. Robust standard errors are clustered at the individual child level.

$*$: significant at 10% level. $**$: significant at 5% level. $***$: significant at 1% level.

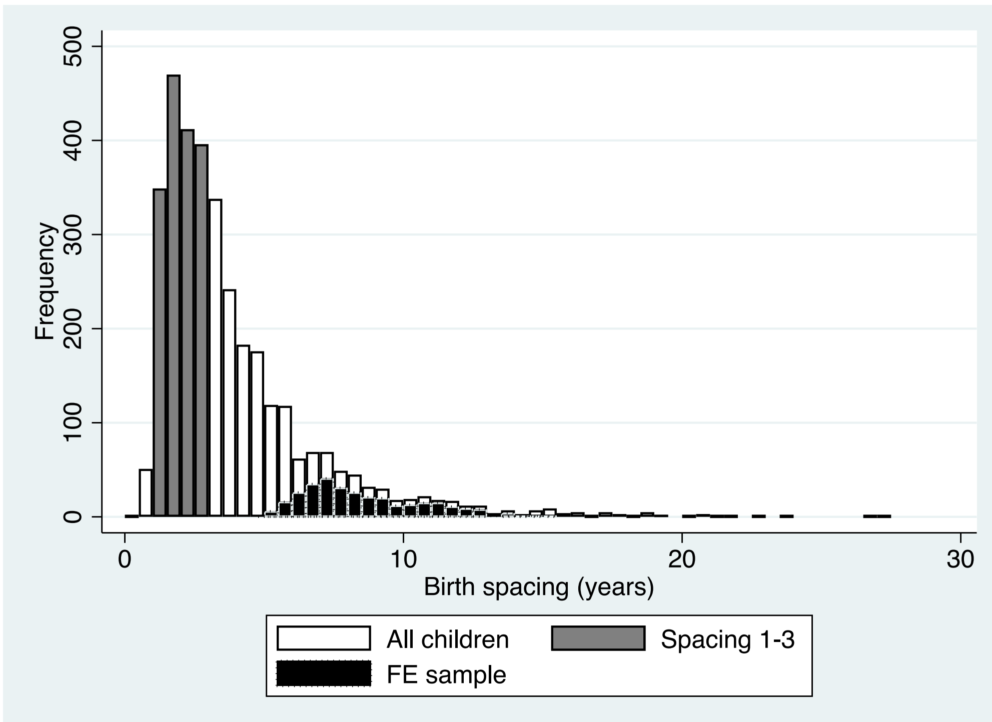
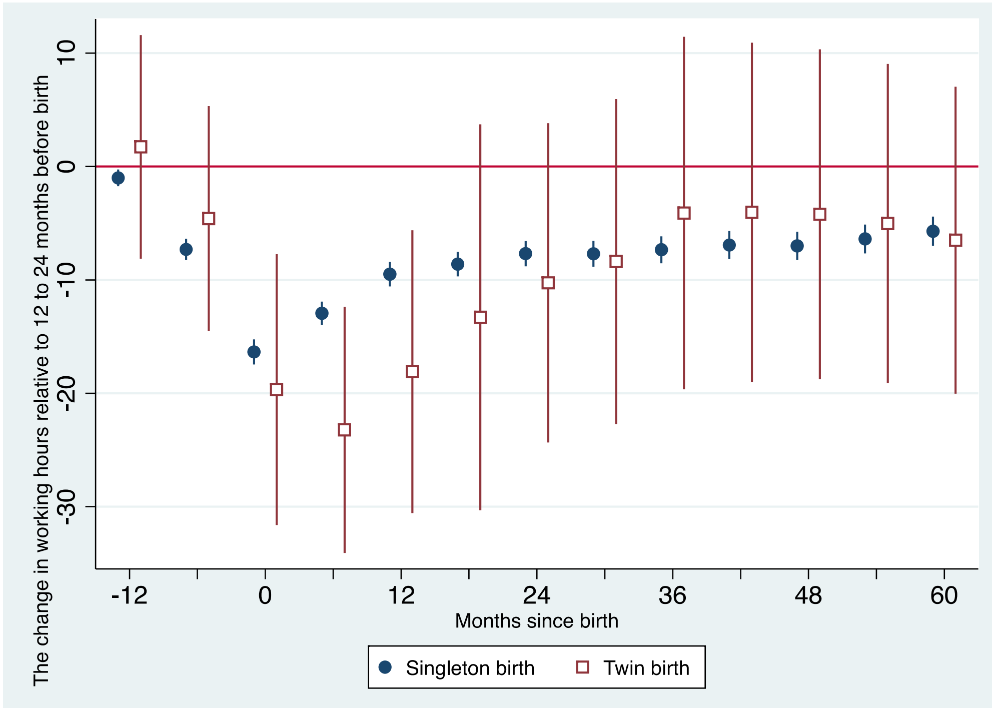
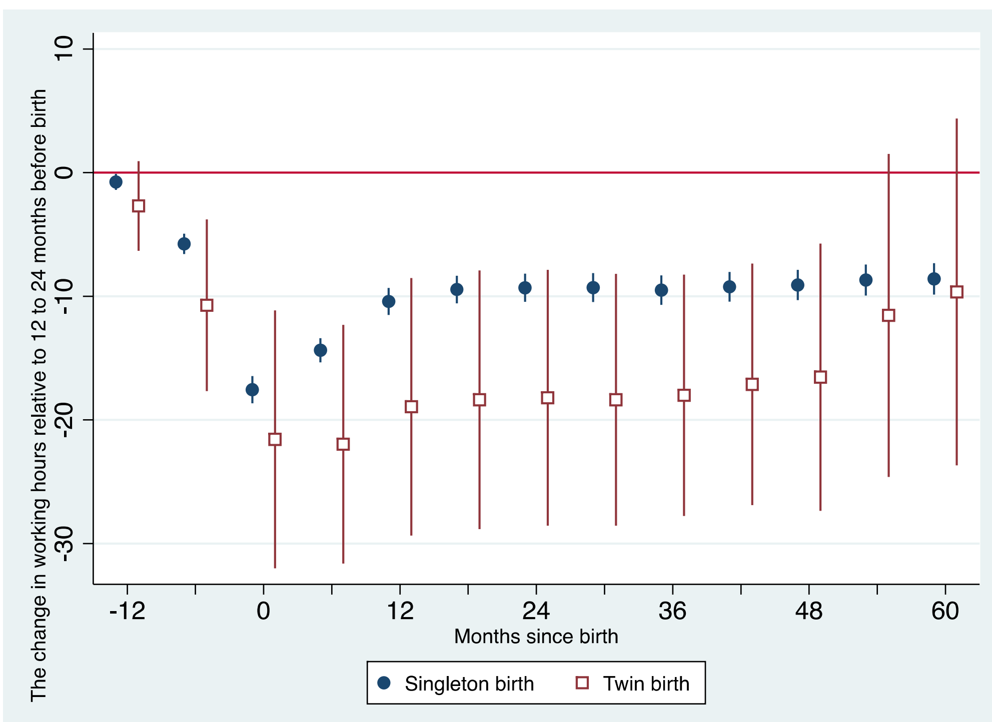


Figure 1: Distribution of birth spacing to next sibling for NLSY firstborns.

Data are from Children of the NLSY79, 1986-2010. Sample is all children who are both firstborns and whose mother has at least one more birth. ‘FE sample’ refers to firstborn children who had a valid PIAT test score measure both before and after the birth of their next sibling.



(a) Below Median AFQT



(b) Above Median AFQT

Figure 2: Drop in Mother's Hours Worked Following First Birth

Data are from Children of the NLSY79, 1986-2010. Sample is all mothers at first parity, some who had a singleton birth and others who had twin births. The figure shows drop in weekly hours relative to average weekly hours during the year prior to pregnancy, 12-24 months prior to birth.

A Tables

Table A.1: Firstborns with One or More Siblings: Summary Statistics

	All	FE=No	FE=Yes	Low AFQT	High AFQT
Children					
N	3187	2873	314	1701	1486
Age in 2010	25.9	25.8	26.7	27.7	24.1
Black	0.14	0.14	0.21	0.15	0.14
Hispanic	0.07	0.07	0.10	0.07	0.07
White	0.79	0.80	0.69	0.78	0.79
Birth weight (oz)	117.3	117.6	115.0	116.0	118.7
Number of Siblings	2.7	2.7	2.5	2.7	2.6
Next Birth Twin	0.010	0.01	0.02	0.01	0.01
Age of mother at birth	23.2	23.4	22.0	21.5	24.9
Mother AFQT Pct- mean	47.6	48.2	41.7	25.9	69.4
Mother Rotter Score	8.7	8.7	9.0	9.3	8.1
Mother Rosenberg Score	22.2	22.2	21.9	21.2	23.2
Mother Illicit Index	-0.31	-0.32	-0.21	-0.25	-0.37
Mother Schooling (yrs)	13.6	13.6	13.4	12.4	14.8
Mother Married	0.76	0.78	0.59	0.69	0.84
Mother Earnings (mean)	18600	18694	17712	12024	24993
Spouse Earnings (mean)	46490	46927	40812	40114	51641
Spacing mean (months)	46.3	40.5	102.3	48.1	44.5
Spacing median (months)	36	34	95	38	35
Child-Year Observations: Means					
N	15282	13568	1714	7450	7832
Cognitive Score	61.8	62.1	59.6	53.9	69.0
Math Score	58.6	59.0	55.4	50.5	66.1
Behavioral Problems	59.4	59.0	62.3	62.5	56.6
Home Score	58.2	58.4	56.1	52.4	63.1
Child-Year Observations: Standard Deviations					
Cognitive Score	23.7	23.7	23.6	23.4	21.6
Math Score	26.9	26.9	26.5	26.0	25.4
Behavioral Problems	27.4	27.6	25.7	27.5	27.1
Home Score	27.2	27.2	26.9	28.5	24.9

Data from Children of the NLSY79, 1986-2010. Our sample is all firstborns who are themselves not twins and have at least one younger sibling. Children who were not interviewed, have missing mother's data, or missing sibling birth date are excluded. For the top panel, the child is the unit of observation. For the second panel, a child-year is the unit of observation. "FE Sample" refers to children with observations before and after the sibling's birth. "Low AFQT" refers to below median and "High AFQT" refers to above median mother's AFQT score which is defined by race. Statistics calculated using NLSY sampling weights.

Table A.2: Children with One or More Younger Siblings: Summary Statistics

	All	Low AFQT	High AFQT	Next Birth Singleton	Next Birth Twin
Children					
N	5509	3119	2390	5446	63
Age in 2010	24.9	26.5	23.2	24.9	22.6
Black	0.16	0.17	0.15	0.16	0.15
Hispanic	0.08	0.09	0.07	0.08	0.11
White	0.76	0.74	0.78	0.76	0.74
Birth weight (oz)	118.3	116.7	120.1	118.3	117.9
Number of Siblings	3.2	3.3	3.1	3.2	4.2
Birth Order	1.6	1.7	1.5	1.6	1.9
Next Birth Twin	0.012	0.009	0.015	0.0	1.0
Age of mother at birth	24.2	22.8	25.9	24.2	26.3
Mother AFQT Pct- mean	46.0	24.9	69.0	45.9	48.9
Mother Rotter Score	8.8	9.3	8.2	8.8	8.7
Mother Rosenberg Score	22.0	21.0	23.1	22.0	22.9
Mother Illicit Index	-0.32	-0.25	-0.39	-0.32	-0.28
Mother Schooling (yrs)	13.4	12.2	14.7	13.4	13.8
Mother Married	0.75	0.66	0.84	0.75	0.71
Mother Earnings (mean)	14591	9145	20559	14497	22379
Spouse Earnings (mean)	46960	39380	53248	46906	51534
Spacing mean (months)	46.4	48.0	44.7	46.4	48.9
Spacing median (months)	35	36	35	36	35
Child-Year Observations: Means					
N	27659	14616	13043	27310	349
Cognitive Score	59.4	51.4	67.3	59.4	59.4
Math Score	56.6	48.3	64.8	56.6	56.3
Behavioral Problems	58.9	61.1	56.6	58.9	55.0
Home Score	53.7	47.7	59.4	53.8	51.0
Child-Year Observations: Standard Deviations					
Cognitive Score	24.6	24.2	22.3	24.6	26.9
Math Score	27.6	26.7	26.0	27.6	29.1
Behavioral Problems	28.0	28.3	27.5	28.0	30.8
Home Score	28.6	29.4	26.7	28.6	30.0

Data from Children of the NLSY79, 1986-2010. Our sample is all children who are themselves not twins and have at least one younger siblings. Children who were not interviewed, have missing mother's data, or missing sibling birth date are excluded. For the top panel, the child is the unit of observation. For the second panel, a child-year is the unit of observation. "FE Sample" refers to children with observations before and after the sibling's birth. "Low AFQT" refers to below median and "High AFQT" refers to above median mother's AFQT score which is defined by race. Statistics calculated using NLSY sampling weights.

Table A.3: Twin Births by Parity

Birth Order	Next Birth Singleton	Next Birth Twin	Next Birth Total
1	4833	35	4918
2	3724	19	3743
3	1770	10	1780
4	644	6	650
5	218	3	221
6	86	0	86
7	37	0	37
8	15	0	15
9	8	0	8
10	4	0	4
11	2	0	2
Total	11391	73	11464

Data from Children of the NLSY79 sample, 1986-2010.

B Model Derivations and Propositions

B.1 The Basic Setting

1. *Equation 6:* Investment can be either early or late. Since the cost of both investments is the same, return on early investment should equal return on late investment. Thus,

$$\gamma\phi I_1^{\phi-1} = (1-\gamma)\phi I_2^{\phi-1} \Rightarrow$$
$$\frac{I_1}{I_2} = \left(\frac{1-\gamma}{\gamma}\right)^{\frac{1}{\phi-1}} \equiv \left(\frac{\gamma}{1-\gamma}\right)^{\sigma_\phi}$$

where $\sigma_\phi = (1/(1-\phi))$.

2. *Equation 7:* By derivation 1, $I_1 = I_2\left(\frac{\gamma}{1-\gamma}\right)^{\sigma_\phi} \equiv \frac{I_2}{\lambda}$, where $\lambda = ((1-\gamma)/\gamma)^{\sigma_\phi}$. By equation 5,

$$\begin{aligned} H &= A\left[\gamma\left(I_1\right)^{\phi} + (1-\gamma)\left(I_2\right)^{\phi}\right]^{1/\phi} \\ &= AI_1\left[\gamma + (1-\gamma)\lambda^{\phi}\right]^{1/\phi} \\ &= \frac{AI}{1+\lambda}\left[\gamma + (1-\gamma)\lambda^{\phi}\right]^{1/\phi} \end{aligned}$$

where the last equality is $I = I_1 + I_2 = I_1(1+\lambda)$

3. *Optimization Results (equations 8 and 9):* parents are maximizing equation 3. Using the human capital production function under the optimal ratio of early to late investment, equation 7, the objective function can be re-expressed as

$$\ln U = (1-\alpha)\ln C + \alpha \ln N + \alpha\pi \ln I + \alpha\pi \ln \tilde{A},$$

where $\tilde{A} = \frac{A}{1+\lambda}\left[\gamma + (1-\gamma)\lambda^{\phi}\right]^{1/\phi}$. Using the budget constraint specified in equation 4, the optimal levels of consumption, investment and number of children maximize

$$\ln \tilde{U} \equiv (1-\alpha)\ln C + \alpha \ln\left(\frac{Y+w-C}{w\tau + I}\right) + \alpha\pi \ln I.$$

The optimal levels of consumption, investment and number of children are

$$\begin{aligned}
\frac{\partial \tilde{U}}{\partial C} &= \frac{1-\alpha}{C} - \frac{\alpha}{Y+w-C} = 0 \Rightarrow C^* = (1-\alpha)(Y+w) \\
\frac{\partial \tilde{U}}{\partial I} &= -\frac{\alpha}{w\tau + I} + \frac{\alpha\pi}{I} = 0 \Rightarrow I^* = \frac{w\pi\tau}{(1-\pi)} \\
N^* &= \frac{Y+w-C^*}{w\tau + I^*} = \frac{\alpha(Y+w)(1-\pi)}{w\tau}
\end{aligned}$$

B.2 Shocks to Family Size - Prior to Investment

4. *Optimization Results (equations 12 and 13):* Parents are maximizing equation 10. Since $\delta = 0$, we can use the optimal ratio of early to late investment - equation 7 - to re-express the the objective function as

$$\ln U = (1-\alpha)\ln C + \alpha\pi \ln I + \alpha\pi \ln \tilde{A},$$

where $\tilde{A} = \frac{A}{1+\lambda}\left[\gamma + (1-\gamma)\lambda^{\phi}\right]^{1/\phi}$. Using the budget constraint specified in equation 11, the optimal levels of consumption and investment maximize

$$\ln \tilde{U} \equiv (1-\alpha)\ln(Y - w - \tilde{N}w\tau - \tilde{N}I) + \alpha\pi \ln I.$$

The optimal levels of consumption and investment are

$$
\begin{aligned}
\frac{\partial \tilde{U}}{\partial I} &= -\frac{(1-\alpha)\tilde{N}}{Y - w - \tilde{N}w\tau - \tilde{N}I} + \frac{\alpha\pi}{I} = 0 \Rightarrow \tilde{I} = \frac{\pi\alpha}{\tilde{N}\,(1-\alpha+\alpha\pi)}\left(Y + w - \tilde{N}w\tau\right) \\
\tilde{C} &= Y - w - \tilde{N}w\tau - \tilde{N}\tilde{I} = \frac{1-\alpha}{(1-\alpha+\alpha\pi)}\left(Y + w - \tilde{N}w\tau\right)
\end{aligned}
$$

5. *Equations 14 and 15:* Using derivations 3 and 4,

$$
\begin{aligned}
\Delta\tilde{I} \equiv \tilde{I} - I^* &= \frac{\pi\alpha}{\tilde{N}\,(1-\alpha+\alpha\pi)}\left(Y + w - \tilde{N}w\tau\right) - \frac{w\pi\tau}{(1-\pi)} \\
&= \frac{\pi\alpha(Y+w)}{\tilde{N}\,(1-\alpha+\alpha\pi)} - \frac{\pi\alpha w\tau}{(1-\alpha+\alpha\pi)} - \frac{w\pi\tau}{(1-\pi)} \\
&< \frac{\pi\alpha(Y+w)}{N^*\,(1-\alpha+\alpha\pi)} - \frac{\pi\alpha w\tau}{(1-\alpha+\alpha\pi)} - \frac{w\pi\tau}{(1-\pi)} \\
&= \frac{w\pi\tau}{(1-\alpha+\alpha\pi)}\left(\frac{1}{1-\pi} - \alpha\right) - \frac{w\pi\tau}{(1-\pi)} = 0
\end{aligned}
$$

where the third row holds since $\tilde{N} > N^*$. Furthermore, by deriving $\Delta\tilde{I}$ by Y and w, we can see that the drop in the change in investment per child increases with the mother's wage and decreases with other income.

$$
\begin{aligned}
\frac{\partial \Delta\tilde{I}}{\partial Y} &= \frac{\pi\alpha}{\tilde{N}\,(1-\alpha+\alpha\pi)} > 0 \\
\frac{\partial \Delta\tilde{I}}{\partial w} &= \frac{\pi\alpha}{\tilde{N}\,(1-\alpha+\alpha\pi)} - \frac{\pi\alpha\tau}{(1-\alpha+\alpha\pi)} - \frac{\pi\tau}{(1-\pi)} \\
&= \frac{\pi(\alpha - \alpha\pi - \tau\tilde{N})}{\tilde{N}(1-\alpha+\alpha\pi)(1-\pi)} \\
&< \frac{\pi(\alpha - \alpha\pi - \tau N^*)}{\tilde{N}(1-\alpha+\alpha\pi)(1-\pi)} \\
&= \frac{\pi\left(\alpha - \alpha\pi - \alpha(1-\pi)\left(\frac{Y+w}{w}\right)\right)}{\tilde{N}(1-\alpha+\alpha\pi)(1-\pi)} < 0
\end{aligned}
$$

where the fourth row holds since $\tilde{N} > N^*$.

B.3 Shocks to Family Size - After Initial Investment

Let $H_j(I_j^{(1,S-1)}, I_j^{(S,T)})$ be j's human capital, defined as a function of $I_j^{(1,S-1)}$ total investment in the first $S-1$ periods and $I_j^{(S,T)}$ total investment from year S to T. This function correctly characterizes j's human capital. Although the optimal investment ratio might not hold when comparing investments up to and after period $S-1$, any child - firstborn or newborn - experiences the optimal yearly investment ratio within periods up to and after $S-1$ periods.[14]

In terms of notation, let $I_f^{*(t,t')}$ denote the optimal total investment (realized or planned) in the firstborn before the shock (N^* children), while $\tilde{I}_j^{(t,t')}$ denotes optimal investments after the shock ($\tilde{N} > N^*$ children). Furthermore, $\tilde{I}_j$ and $\tilde{H}_j$ denote optimal total investment and the consequent human capital, constrained by pre-shock investments (if they exist).

Proposition 1. *a shock to family size results in a weakly higher investment in the firstborn child relative to newborn children $\tilde{I}_f \geq \tilde{I}_n$, and consequently the human capital of the firstborn is also weakly higher $\tilde{H}_f \geq \tilde{H}_n$. When $\beta > -\infty$, the inequalities are strict.*

Proof. The proof is done by cases. Proving the proposition is done using the following lemma 1.

(a) *Case 1 - $\phi \in (-\infty, 1), \beta > -\infty$:* Since the cost of investment in the firstborn and the newborn are the same, the marginal utility from investment in each child

[14] Newborns experience optimal yearly investment ratio throughout all T periods.

should be the same. Since $H_j\big(I_j^{(1,S-1)}, I_j^{(S,T)}\big)$ is strictly concave in both arguments, the optimality condition implies

$$\frac{\partial H_n\big(\tilde{I}_n^{(1,S-1)}, \tilde{I}_n^{(S,T)}\big)}{\partial I_n^{(S,T)}}(\tilde{H}_n)^{\beta-1} = \frac{\partial H_f\big(I_f^{*(1,S-1)}, \tilde{I}_f^{(S,T)}\big)}{\partial I_f^{(S,T)}}(\tilde{H}_f)^{\beta-1}$$

Suppose $\tilde{H}_n \geq \tilde{H}_f$. Then, $\frac{\partial H_n\left(\tilde{I}_n^{(1,S-1)}, \tilde{I}_n^{(S,T)}\right)}{\partial I_n^{(S,T)}} \geq \frac{\partial H_f\left(I_f^{*(1,S-1)}, \tilde{I}_f^{(S,T)}\right)}{\partial I_f^{(S,T)}}$. Since (i) the cross-derivative is positive, (ii) the second derivative is negative and (iii) $\tilde{I}_n^{(1,S-1)} < I_f^{*(1,S-1)}$ (by lemma 1), late investment (periods S to T) in the firstborn is higher $\tilde{I}_f^{(S,T)} > \tilde{I}_n^{(S,T)}$. This implies that $\tilde{H}_n < \tilde{H}_f$, which is a contradiction. Furthermore, since the investment ratio in the firstborn is non-optimal, $\tilde{H}_n < \tilde{H}_f$ implies $\tilde{I}_n < \tilde{I}_f$.

(b) *Case 2 - $\phi = 1$:* When $\phi = 1$, since $\gamma_t > \gamma_{t+1}$, investment in children occurs only in the first period. Since optimal investment per-child decreases with number of children, $\tilde{H}_n < \tilde{H}_f$ and $\tilde{I}_n < \tilde{I}_f$.

(c) *Case 3 - $\phi < 1, \beta \to -\infty$:* $\beta \to -\infty$ imply that the individual only cares about the minimum level of human capital. Hence, in optimum, human capital is the same for both new-born and first-born $\tilde{H}_n = \tilde{H}_f$. In addition, since the investment ratio in firstborns is distorted $\tilde{I}_n < \tilde{I}_f$.

(d) *Case 4 - $\phi \to -\infty, \beta > -\infty$:* Suppose $\tilde{H}_n \geq \tilde{H}_f$. By lemma 1 $\tilde{I}_n^{(1,S-1)} < I_f^{*(1,S-1)}$. Thus, $\tilde{I}_n^{(S,T)} \geq \tilde{I}_f^{(S,T)}$. For a sufficiently small $\varepsilon_1, \varepsilon_2 > 0$, an investment path $I_n = (\tilde{I}_n^{(1,S-1)} - \varepsilon_1, \tilde{I}_n^{(S,T)} - \varepsilon_2)$,[15] $I_f = (I_f^{*(1,S-1)}, \tilde{I}_f^{(S,T)} + \varepsilon_1 + \varepsilon_2)$ generates a higher aggregate level of human capital. When $\tilde{H}_n > \tilde{H}_f$ inequality decreases and the utility increases. If $\tilde{H}_n = \tilde{H}_f$ inequality increases. Yet, when $\beta < -\infty$, for sufficiently small $\varepsilon_1, \varepsilon_2 > 0$ the utility increases as well. Thus, the investment path $(\tilde{I}_f, \tilde{I}_n)$ is

[15] $\varepsilon_1, \varepsilon_2$ are chosen such that the optimal ratio of investment in the newborn holds.

not optimal, which is a contradiction. Therefore, $\tilde{H}_n < \tilde{H}_f$. Furthermore, since the investment ratio in the firstborn is non-optimal, $\tilde{I}_n < \tilde{I}_f$.

□

Lemma 1. *When $\phi < 1$, the total investment in the firstborn up to the shock $I_f^{*(1,S-1)}$ is larger than the total investment in the newborn in the first $S-1$ periods $\tilde{I}_n^{(1,S-1)}$.*

Proof. By way of contradiction, suppose $I_f^{*(1,S-1)} \leq \tilde{I}_n^{(1,S-1)}$. Since the newborn's investment path is optimal throughout all T periods, $I_f^{*(S,T)} \leq \tilde{I}_n^{(S,T)}$, and consequently by the budget constraint $\tilde{H}_n \geq H_f^* > \tilde{H}_f$. Yet, by (i) $\tilde{H}_n > \tilde{H}_f$ (if $\beta < 1$), and (ii) $I_f^{*(S,T)} > \tilde{I}_f^{(S,T)}$ (by $H_n^* > \tilde{H}_n$), and (iii) strict concavity of $H_j(\cdot,\cdot)$ (by $\phi < 1$), the marginal return on investment in the firstborn is higher than in the newborn, which is a contradiction to optimality of investment. □

Proposition 2. *When $\phi < 1$, as birth-spacing (S) of an unexpected birth rises, investment in the firstborn child increases and investment in newborn decreases, i.e. $\tilde{I}_f(S) \equiv I_f^{*(1,S-1)} + \tilde{I}_f^{(S,T)} < \tilde{I}_f(S')$, and $\tilde{I}_n(S) \equiv \tilde{I}_n^{(1,S-1)} + \tilde{I}_n^{(S,T)} > \tilde{I}_n(S')$, for any $S' > S$.*

Proof. Let $\big(\tilde{C}(S), \tilde{I}_f(S), \tilde{I}_n(S)\big)$ be the optimal of consumption and investment when the shock occurs at firstborn's period S. By definition of optimality, the marginal utility from consumption equals the marginal return from investment in both the firstborn and the newborn. Suppose that the shock occurred in $S' > S$. It cannot be the case that both consumption and investment do not change (i.e., $\big(\tilde{C}(S), \tilde{I}_f(S), \tilde{I}_n(S)\big) \neq \big(\tilde{C}(S'), \tilde{I}_f(S'), \tilde{I}_n(S')\big)$), since in that case both the marginal utility from consumption and the marginal return from investment in the newborn would not change, yet due to the exacerbated distortion in investment ratio, the marginal return from investment in the firstborn would increase. If $\beta = 1$, the marginal return from investment in the newborn is constant which implies that consumption would not change, investment in the firstborn increases and investment in the newborn decreases. If $\beta < 1$, the marginal return from investment in the newborn is decreasing with investment. Therefore, consumption and investment in the newborn decrease, while investment in the firstborn increases. $\square$

Corollary 1. *When $\phi < 1$, as birth-spacing (S) of an unexpected birth rises, the newborn's human capital decreases, i.e. $\tilde{H}_n(S) \equiv H(\tilde{I}_n^{(1,S-1)} + \tilde{I}_n^{(S,T)}) > \tilde{H}_n(S')$, for any $S' > S$.*

Proof. By proposition 2, investment in the newborn increases as birth-spacing increases. Since investment in the newborn is done optimally across all periods, the newborn's human capital decreases. $\square$

Corollary 2. *For every $\phi < 1$ there exists a lower threshold $\bar{\beta}(\phi) < \infty$, such that if $\beta > \bar{\beta}(\phi)$ as birth-spacing (S) of an unexpected birth rises, the firstborn's human capital increases, i.e. $\tilde{H}_f(S) \equiv H(I_f^{*(1,S-1)} + \tilde{I}_f^{(S,T)}) > \tilde{H}_f(S')$, for any $S' > S$.*

Proof. Suppose birth spacing equals S. By optimality of investment, the marginal return on investment in the firstborn in period T must equal the marginal return on investment in the firstborn in period 1

$$\tilde{A}^{\beta}\tilde{I}_{n1}^{\beta-1}(S) = A^{\phi}\tilde{H}_f^{\beta-\phi}(S)\gamma_T\tilde{I}_{fT}^{\phi-1}(S) \Rightarrow$$

$$\frac{\tilde{A}^{\beta}}{\gamma_T A^{\phi}} = \tilde{I}_{n1}^{1-\beta}(S)\frac{\tilde{H}_f^{\beta-\phi}(S)}{\tilde{I}_{fT}^{1-\phi}(S)} \tag{23}$$

where $\tilde{A} = A\left(\sum_{t=1}^{T} \gamma_T(\gamma_1/\gamma_T)^{\frac{1}{\phi-1}}\right)^{\frac{1}{\phi}}$ Suppose birth spacing equals $S > S'$. The right hand side of equation 23 would not change. Thus, since the human capital production function is concave, when $\beta = 1$ human capital of the firstborn increases $\tilde{H}_f$.

□

C Data Appendix

Here we discuss details of how we form our main estimating sample as well as details on constructing our main variables. We match mothers from the 1979 National Longitudinal Survey of Youth - 1979 (NLSY) survey with all their children from the Children and Young Adult survey, resulting in a sample containing 4,922 mothers and 11,464 children, of whom 4411 are firstborn. We keep firstborn children with at least one sibling, non-missing mother's data, non-missing data on siblings resulting in 3187 children. Children were surveyed biannually from 1986 to 2010. We match children with their siblings based on birth order which allows to create a "sibling-pair" data set where we match test scores, HOME and behavioral index measures of older siblings with the birthdate of each subsequent younger sibling.

Variable Definitions:

- **Cognitive Ability Measure**

  Our proxy for cognitive ability is formed using a child's test score performance on the Peabody Individual Achievement Tests (PIATs) for mathematics and reading recognition. These tests are administered to children aged 5 and older from 1986 to 1992 and then children aged 5 to 14 in 1994 and subsequent surveys. We include all respondents in our main analysis. Results are robust to excluding children aged 15 and older. Our measure of cognitive performance is formed by averaging each child's percentile performance in the math PIAT and the reading recognition PIAT. Children without a valid score in either test are omitted from the sample.

- **Behavioral Problems Measure**

  Our proxy for non-cognitive ability is the Behavioral Problems Index, a measure designed to evaluate the existence and intensity of a range of child behavioral problems. It is formed using 28 questions asked of mothers about their child's behavior. The questions were asked about children of at least 4 years of age. Similar to the PIAT tests, the NLSY changed the age of the BPI test administration between 1992 and 1994. Our main sample includes all children with a valid BPI and are robust to excluding children aged 15 and older.

- **Parental Investment: HOME Inventory and subcomponents**

  To measure parental investment, the NLSY asks questions to construct a HOME (Home Observation Measurement of the Environment-Short Form) score, "a unique observational measure of the quality of the cognitive stimulation and emotional support provided by a child's family." Examples of these questions include how many books a child has, how often parents read to the child, and whether parents assist with homework. Questions are a combination of mother response and interviewer observation. HOME scores have been shown to be a significant determinant in a child's development (Mott (2004), Todd and Wolpin (2007), Cunha and Heckman (2007), Cunha et al. (2010), and others). The HOME Inventory is available for children aged 0 to 15 but the set of questions used in assessing the Inventory measure differs by age of the child. To standardize across ages we use the NLSY formed percentile measure of the HOME score.

- **Mother's Years of Schooling**

  Years of Schooling is mother's maximum number of years of schooling, so it does not vary over time for a respondent.

- **Mother's Religion**

  This reports the religion that mother was raised in. 10 categories including: Baptist, Episcopalian Lutheran, Methodist, Presbyterian, Roman Catholic, Jewish, Other and None.

- **Mother's AFQT**

  Armed Forces Qualifications Test score measures the aptitude and trainability of the respondent. We use the 2006 revised variable. This AFQT score is measured as a percentile of the NLSY79 survey, with a median value of 50000.

- **Mother's Illicit Index**

  Illicit Index is constructed based on the answers to 20 questions in the 1980 survey, where 17 are questions about "delinquency" and 3 are about run ins with the "police." For each question, we assign the value one if the person engaged in that activity and zero otherwise. We average for each respondent and then standardize the values, so that the Illicit Activity Index has a mean of zero and a standard deviation of one in the NLSY79 sample.

- **Mother's Rosenberg Self-Esteem**

  Rosenberg Self-Esteem score is based on a ten-part questionnaire given to all NLSY79 participants in 1980. It measures the degree of approval or disapproval of one's self. The values range from six to 30, where higher values signify greater self-approval.

- **Mother's Rotter Locus of Control**

  Rotter Locus of Control measures the degree to which respondents believe they have internal control of their lives through self-determination relative to the degree that external factors, such as chance, fate, and luck, shape their lives. It was collected as part of a psychometric test in the 1979 NLSY79 survey. The Rotter Locus of Control ranges from 4 to 16, where higher values signify less internal control.