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Birth Weight and Early Childhood Physical Health: Evidence from a Sample of Latin American Twins

Low birth weight is considered one of the leading causes of infant mortality and adverse health conditions during childhood and throughout life. Most developed countries have therefore implemented health policies related to the improvement of birth weight of newborns. Examples include Medicaid and the Special Supplemental Nutrition Program for Women, Infants, and Children (WIC), both in the United States. Most of the existing literature evaluating the effects of nutritional programs targeted to pregnant and nursing women in developed countries emphasizes their positive effects on birth outcomes and the physical development of children, yet developing countries are still resistant to implementing social welfare programs aiming to enhance the nutritional status and prenatal care of pregnant women in order to improve the health of their babies.[1]

There is, however, an open discussion on whether birth weight is important in determining health status profiles and labor productivity later in adulthood or if this indicator of early nutritional status (arguably, in utero nutritional condition) captures other unobservable factors. Moreover, empirical evidence

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I am especially grateful to Jere Behrman, Raquel Bernal, César Calvo, Vadim Marmer, Kevin Milligan, and Hugo Ñopo for valuable comments and advice. I also thank Jorge Agüero, Juan José Díaz, Fernando Fernández, and Mariel Bedoya for comments on earlier versions of the paper.

[1] There are, however, a few exceptions in Latin American countries, yet not fully managed by governments. The *Instituto de Nutricion de Centro America y Panamá* (INCAP) conducted a series of long-term studies over the past forty years in Guatemala. Empirical studies based on the INCAP initiative in Guatemala found positive effects of in utero exposure to nutritional programs on birth outcomes and physical growth during early childhood (Behrman and others 2009), educational attainment (Maluccio and others 2009), and hourly wages (Hoddinott and others 2008) later in adulthood.

is based on data sets linking clinical birth records with outcomes later in life, potentially introducing additional biases such as attrition and selection caused by the survival condition of individuals, reinforcing skepticism about the results. Altogether, these facts call into question the role of birth weight as a key indicator for the design of health-related policies and the effectiveness of government policies attempting to improve the healthcare of expectant mothers to reduce the prevalence of low birth weight.

This paper focuses on determining the causal effect of birth weight on physical health for a sample of children in developing countries and contributes to the empirical literature regarding the effects of birth weight throughout the life span in three different ways. First, in contrast to previous empirical studies focusing on adult outcomes, this paper examines the effects of birth weight on the physical development of children under age five. Early developmental stages can have long-term effects on health, educational, and labor market outcomes, which can mediate the birth weight and educational or labor market gradients during adulthood.[2] Second, in contrast to the existing literature focusing solely on developed countries, the paper provides evidence for ten Latin American countries using data from Demographic and Health Surveys (DHS). Finally, information included in the data set allows testing whether postnatal health investments (namely, breastfeeding and vaccination) can potentiate health and nutritional investments made by parents during periods prior to the birth of their children.

One particular concern is that the effect of birth weight on the physical health of infants might be spurious due to omitted unobservable factors. In this regard, children's birth weight and physical growth are mutually determined by genetics, environmental conditions to which the mother was exposed during pregnancy, family background, and socioeconomic status, among other factors. For this reason, cross-sectional estimates of the effects of birth weight on physical growth may contain confounding factors.

To isolate the effects of variations of birth weight from unobservable factors, I use twin-pair fixed effects from a sample of twins born in ten Latin American countries. Information on twins' weight at birth and physical health is obtained from a pooled sample of different years from the DHS data sets of each country. Since twins are exposed to the same conditions during pregnancy and the very moment of birth (for example, maternal stress, length of pregnancy, and institutionalized delivery), twin-based estimates successfully

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[2] Almond and Currie (2010); Behrman and Rosenzweig (2004); Black, Devereux, and Salvanes (2007); Royer (2009).

identify the effect of physical growth under age five. The key insight of this approach is to assume that differences in birth weight between twins are purely due to nutritional intake within the womb, which depends on either the fetal position or the connection between the umbilical cord and the placenta, both of which are determined by nature.

There are five important findings. First, consistent with previous empirical studies, cross-sectional estimates indeed overstate the effect of birth weight on children's physical growth relative to twin-based estimates. Second, results arising from twin comparisons suggest that increasing birth weight significantly increases the height-for-age *z* score and body mass and reduces the probability of chronic undernourishment before the age of five. Third, results from twin comparisons are significantly smaller than sibling fixed-effects estimates. In addition, results from dizygotic twins are almost identical to results from same-sex twins (which contain a larger share of monozygotic twins). Combined, these results suggest that genetics, family background, and zygosity are not as relevant as conditions to which the fetus was exposed during pregnancy for determining birth outcomes. Fourth, the effects of birth weight on early childhood physical health are larger for the low-birth-weight population (birth weight of less than 2,500 grams), which implies that public policies seeking to increase birth weight might have greater benefits for children born to mothers at risk of delivering babies with adverse nutritional and health status. Finally, postnatal health investments, such as vaccination and breastfeeding, do not contribute to correcting detrimental effects on children's physical development caused by adverse birth outcomes.

Since birth weight directly affects physical development during early childhood, independently of the postnatal health investments parents can make to mitigate the effects of low birth weight on their children's physical development, programs aimed at improving birth weight might have larger benefits for babies across their life cycle than interventions occurring during the first years of life.[3] These programs include, but are not limited to, enhancing maternal nutrition during pregnancy, improving prenatal care, encouraging prenatal medical visits, promoting early detection of pregnancy, and providing counseling for future mothers. In fact, this study finds that programs targeted at increasing birth weight may have long-lasting positive effects unlike other social welfare programs (such as conditional cash transfers).

The paper unfolds as follows. After opening with a literature review, the paper introduces the theoretical framework, discusses the possible sources

[3] Almond and Currie (2011).

of endogeneity when establishing the causal relationship between birth weight and early childhood physical health, and outlines the identification strategy. Subsequent sections describe the data and present the results. I then discuss the potential bias affecting twin-based estimates and compare the results with those of other social welfare programs. The final section concludes.

Literature Review

In this section, I discuss the existing literature exploring the effects of birth weight on different outcomes measuring individual well-being, in both the short and long run. I begin by discussing how birth weight is determined and then present the previous empirical findings with regard to the effects of birth weight over the life cycle.

Etiology of Birth Weight

The epidemiological literature on the determinants of birth weight recognizes two causes affecting the weight of newborns: intrauterine growth retardation (IUGR) and prematurity.[4] The former is often referred to as being small for gestational age and is defined as the average growth of the fetus per week of pregnancy; the latter is usually defined as a gestational age of thirty-seven weeks or less. Hence, variations in birth weight are related to both the mother's weight gain during pregnancy and the interruption of gestational length, which is usually between thirty-eight and forty-two weeks.

Among the leading causes of IUGR, the literature points out low energy intake, which leads to low gestational weight gain; a low pregnancy body mass index; short stature; cigarette smoking; and pregnancy-induced hypertension. Birth order is also considered to be one of the most important determinants of birth weight, with firstborns being more likely to suffer from low birth weight (defined as less than 2,500 grams).[5] Maternal nutrition during pregnancy has also been proved to contribute to adequate weight at birth.[6] This relationship seems to be nonlinear, however: because the fetus feeds on the nutrients remaining in the mother's body, starvation must pass a threshold level before the weight of the fetus is significantly affected.[7] In addition,

4. Kramer (1987, 2003).
5. Verhoeff and others (2001); Kramer (2003).
6. Almond and Mazumder (2008).
7. Tanner (1978).

evidence from the medical literature suggests that birth weight is not affected by the anemia status of the mother.[8] In developing countries, malaria is also considered a risk factor for IUGR.

The etiologic determinants of preterm delivery are often related to multiple births, acute infections, high maternal blood pressure, and anxiety and other psychological factors. Recent empirical evidence suggests that hard work and maternal stress are also linked to premature births and low birth weight.[9]

Other determinants of birth weight are pregnancy-specific factors such as the number of prenatal care visits, the mother's age at the time of conception, spacing, the number of past pregnancies, and the existence of fetal mortality in a mother's pregnancy. Finally, the sex of the child is also considered a determinant of weight at birth, with boys being heavier.

Effects of Birth Weight over the Life Cycle

Since birth weight cannot be randomly allocated across individuals, quasi-experimental methods have been used to identify the effects of birth weight on health, schooling, wages, IQ, and test scores in different stages of an individual's life. The most credible evidence comes from twin-based estimation techniques. This section describes some of the evidence regarding the effects of birth weight on individuals' outcomes at different developmental stages.

There is a large literature on the relationship between weight at birth and adult health, educational, and labor market outcomes, but few studies analyze the effects of birth weight on childhood well-being. First, evidence suggests that low birth weight is associated with higher infant mortality risk.[10] Almond, Chay, and Lee study the impact of increasing birth weight on infant mortality (that is, death before the first twenty-eight days and in the first year of life), Apgar score, ventilator use, and hospital costs in a sample of twins born in the United States between 1983 and 2000.[11] Cross-sectional results indicate that birth weight is associated with a significant reduction of the infant mortality rate (number of deaths per thousand live births). Surprisingly, however, when twin

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[8] Levy and others (2005).

[9] On the link with premature births, see Hobel and others (1999), Glynn and others (2001), and Eskenazi and others (2007); on low birth weight, see Camacho (2008) and Mansour and Rees (2011).

[10] Oreopoulos and others (2008).

[11] Almond, Chay, and Lee (2005). The Apgar score is an alternative measure of an infant's health at birth, which assigns a score ranging from zero to ten. The measure is based on five tests of newborn health performed at one minute and five minutes after birth. Each of the five factors scores from zero to two; they are summed to achieve the final score. The factors included are heart rate, respiratory effort, muscle tone, reflex irritability, and color.

fixed effects are included in the regressions, the impact of birth weight on the infant mortality rate drops nearly to zero. The authors therefore conclude that unobservable genetic factors, the intrauterine environment of the fetus, socioeconomic factors, and maternal behaviors contribute to the overstatement of the effect of birth weight on infant mortality in cross-sectional estimates.

Other studies focus on the cognitive development of children, using tests scores as a proxy for the cognitive development of schoolchildren. Loughran, Datar, and Kilburn, for instance, use twin-based estimates to assess the causal relationship between birth weight and school achievement for a sample of children born in the United States, while Bharadwaj, Eberhard, and Neilson do the same for Chile.[12] The studies find a positive effect between birth weight and math and reading scores in the United States and math scores for first to eighth grades in Chile. Del Bono and Ermisch find similar results using data on children born in the United Kingdom.[13]

Lastly, the effects of birth weight on child health status have also being explored. Evidence indicates that low-birth weight is associated with a higher risk of asthma and other respiratory diseases at age three.[14] Aside from this, the medical literature documents significant effects of weight at birth on adult hypertension, although Zhang, Brenner, and Klebanoff find no statistical significant effects of birth weight on blood pressure at age seven using twin-based estimates from a sample of 119 pairs of identical twins and 86 pairs of (same-sex) fraternal twins born in the United States.[15] This result suggests that high-blood-pressure diseases are not observed until early adulthood or later in life.

With regard to adult outcomes, the long-lasting effects of early undernourishment and newborn health status have been widely documented. There are at least three potential channels through which birth weight may have implications for adult outcomes. First, birth weight has a significant effect on adult height, which has been related to wage premiums in the labor market.[16] Behrman and Rosenzweig use a fixed-effects model to examine the long-run consequences of increasing birth weight in a subset of the Minnesota Twin Registry (namely, female monozygotic twins).[17] They find that increasing birth weight by one pound (454 grams) increases adult height by 0.6 inches (1.52 centimeters). Black, Devereux, and Salvanes use data on all Norwegian births over the period 1967 to 1997, obtained from the Medical Birth Registry

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[12] Loughran, Datar, and Kilburn (2004); Bharadwaj, Eberhard, and Neilson (2010).

[13] Del Bono and Ermisch (2009).

[14] Brooks and others (2001).

[15] Zhang, Brenner, and Klebanoff (2001).

[16] Case and Paxson (2008).

[17] Behrman and Rosenzweig (2004).

of Norway, and include mother fixed effects for every twin pair registered in the data set.[18] They find that increasing birth weight by 7.5 percent (200 grams approximately) among men would lead to an increase in adult height by a half a centimeter.

Second, birth weight has also been found to have an effect on educational attainment. Conley and Bennett include family fixed effects in their regressions on a sample of siblings born in the United States; they find that low birth weight is negatively associated with the probability of completing high school.[19] Using a sample of twins born in the United States, Royer finds that birth weight is positively associated with educational attainment.[20] Nevertheless, Miller, Mulvey, and Martin find no significant effects of birth weight on schooling.[21] Overall, there appears to be a direct relationship between birth weight and educational attainment, but there is an open discussion on whether differences in schooling among identical individuals (such as twins) are driven by the relationship between birth weight and test scores in childhood or the relationship between birth weight and childhood diseases that lead to absenteeism, grade repetition, or school dropout.

Finally, there is evidence suggesting an intergenerational link between the mother's weight at birth and the nutritional status of newborns. Currie and Moretti, who use a data set of all live births in California during a forty-year period, find a strong intergenerational correlation between the birth weight of mothers and their children.[22] However, the authors suggest that poverty status and the mother's birth weight interact in the production function of the birth weight of children. This result can be complemented by Currie's earlier finding suggesting that the association between birth weight and adult outcomes can be cushioned by socioeconomic status.[23]

Methodology

The conceptual framework followed in this analysis is based on the health capital model postulated by Grossman and extended by Maccini and Yang.[24] Health production functions consider individual health at time t, H_t, to be a

[18] Black, Devereux, and Salvanes (2007).

[19] Conley and Bennett (2000).

[20] Royer (2009). Similar results are found by Behrman and Rosenzweig (2004) and Black, Devereux, and Salvanes (2007).

[21] Miller, Mulvey, and Martin (2005).

[22] Currie and Moretti (2007).

[23] Currie and Hyson (1999).

[24] Grossman (1972); Maccini and Yang (2009).

function of initial health conditions, H_0, human capital investments in all previous periods, E, wealth, Y, and community environment, C, in all periods. This process can be summarized in the following health production function:

$$H_t = h(H_0, E_1, \ldots, E_t, Y_0, \ldots, Y_t, C_0, \ldots, C_t, \mathbf{X}),$$

where **X** is a vector containing time-invariant individual and regional characteristics. The initial health endowment, H_0, is determined by a genetic component determined at conception, G, initial wealth, Y_0, community environment at the time of pregnancy and delivery, C_0, and conditions experienced early in life (for example, the in utero environment), N.

$$H_0 = k(G, Y_0, C_0, N).$$

The idea that environmental conditions in utero can affect long-run health status is known as critical period programming. Barker first postulated that inadequate nutrition in utero "programs" the fetus to have adverse metabolic features that can lead to future diseases.[25] Nutrition literature suggests that individuals stunted early in life are more prone to suffer from diseases such as cardiovascular problems, high blood pressure, diabetes, and obesity. However, initial health conditions can be mitigated by human capital investments and an individual's wealth in succeeding periods.

Fetal programming is not within the scope of this paper, since this hypothesis focuses mainly on effects later in the life cycle. Instead, I explore how nutritional conditions in utero affect growth factors early in life. In particular, this paper focuses on determining how birth weight—as a proxy for nutritional conditions in utero—can have immediate or medium-lasting effects on child human physical capital accumulation. Doing so, however, requires that the initial health endowment, H_0, should vary only due to factors different from parental control, family background, and genetic transmissions.

While there is an open discussion in the medical science about what indicator correctly measures nutritional conditions in utero, this paper takes birth weight as the indicator that best describes nutritional status and health conditions at the time of birth, as is common in the health-related empirical literature of early childhood development in economics. Thus, birth weight is often

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[25] Barker (1992).

considered to be the “primary measure of [a] baby’s health in most analysis of infant health and welfare in economic research.”[26]

Identification Strategy

To formally establish the effect of birth weight on anthropometry or nutritional status, let

$$h_{ik} = \alpha + \beta \mathrm{BW}_{ik} + \mathrm{X}_i \gamma + u_k + a_i + \varepsilon_{ik} \qquad (1)$$

represent the relationship between early childhood physical development and health conditions at birth, where h_{ik} is the underlying anthropometric or nutritional status indicator of child k born to mother i, BW_{ik} is birth weight, $\mathbf{X}_i$ is a vector of mother-specific (observable) determinants of health (such as race, age, education, and socioeconomic status), u_k denotes the (observable and unobservable) environmental conditions to which the mother was exposed while pregnant with the k-th child (for example, length of pregnancy, mother’s exposure to pollution, and supply of hospitals in the municipality of residence), a_i reflects mother-specific unobservable determinants of health (such as genetic factors), and ε_{ik} is an idiosyncratic error term, assumed to be independent of all observable and unobservable factors.[27]

The central parameter of interest is β. If it is statistically significant and positive, it suggests that birth weight has a substantial impact on infant nutritional (and potentially health) status before age five, and any intervention that seeks to increase birth weight will generate almost immediate social benefits. If birth weight is uncorrelated with family background and genetic inheritances, then estimating β by ordinary least squares (OLS) yields unbiased parameters. Because birth weight is determined by maternal health, family background, and other unobservable factors, the term a_i is assumed to be

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[26] Almond, Chay, and Lee (2005). In contrast to the majority of studies exploring the effects of birth weight on different outcomes throughout the life cycle, Behrman and Rosenzweig (2004) use a measure of fetal growth (birth weight divided by gestational length) instead of birth weight only. The authors normalize birth weight by gestation to ensure that the indicator suppresses the effect of preterm births and to increase comparability between multiple and singleton births. On the use of birth weight as a proxy for nutritional status at the very moment of birth, see Currie (2011).

[27] Postpartum determinants such as breastfeeding and vaccinations are not included in equation 1. Furthermore, postpartum health investments are subject to parental control, which can be influenced by birth weight. The results section reports on regressions that explore whether postpartum health investments can mediate the birth weight–physical development gradient of children.

correlated with BW_{ik}, which implies, in this particular scenario, that cross-sectional estimates of β will overstate the true effect of BW_{ik} on h_{ik}.

Alternatively, using the within-sibling estimator (that is, the coefficients resulting from the linear deviations of the child characteristics to the brotherhood mean in a sample of children born to the same mother) fails to control for the environmental conditions to which the mother was exposed during the pregnancy of a given child in the family. Moreover, medical literature documents that siblings share only 50 percent of their genetic material, so there are many differences across siblings that may be correlated with birth weight.

To overcome differences in parental background, genetic inheritances, and environmental exposure across pregnancies, I examine a sample of twins born in Latin American countries and include fixed effects (FE) for any twin pair in the regressions. Since twins share the same prenatal care and length of pregnancy while being in their mother's womb, a model that differentiates the birth weights of twins (FE estimation) yields unbiased estimates of the parameter of interest, β. Formally, I estimate the following equation:

$$h_{i2} - h_{i1} = \beta(\mathrm{BW}_{i2} - \mathrm{BW}_{i1}) + (\varepsilon_{i2} - \varepsilon_{i1}), \tag{2}$$

where the subscripts 1 and 2 index the first and second-born infants of a twin pair, respectively. Under the condition that differences in birth weights are uncorrelated with differences in the error terms within twins, the twin FE estimator of β in equation 2 is consistent. This strategy, however, relies on three important assumptions.

First and foremost, I assume that any given difference in the weight of twins at birth is due to nutritional intake in the womb. As described in the literature review section, variation in birth weight can arise because of either gestational length or intrauterine growth retardation (low fetal growth rate). For twins, gestational length is identical. This implies that differences in birth weight within twin pairs are solely due to differences in fetal growth rates. The medical literature points out that when there are two placentas (commonly associated with fraternal twins), nutritional differences arise because of position inside the womb. The better the fetus is positioned, the better the nutritional intake (better ingestion of the nutrients from his or her mother's body). In the case of a single placenta, nutritional differences can arise due to differences in the location of the union of the umbilical cords with the placenta and differences in the position of the fetuses inside the placenta.[28]

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[28] See Bryan (1992); Phillips (1993).

Second, this estimation approach relies on the assumption that there are no ex ante differences between twins, so that the assumption of perfect exchangeability that underlies the twin FE estimator is validated. This assumption means that either the first- or second-born infant of a twin pair must have the same likelihood of being the infant born with a greater or lesser weight.

Lastly, to successfully establish the causal relationship between birth weight and anthropometric or nutritional status during early childhood, the birth weight variation in the sample of twins must be sufficiently large to provide reliable information on how differences in birth weight result in different outcomes for children. This assumption is reviewed in the section describing the data used for the empirical analysis.

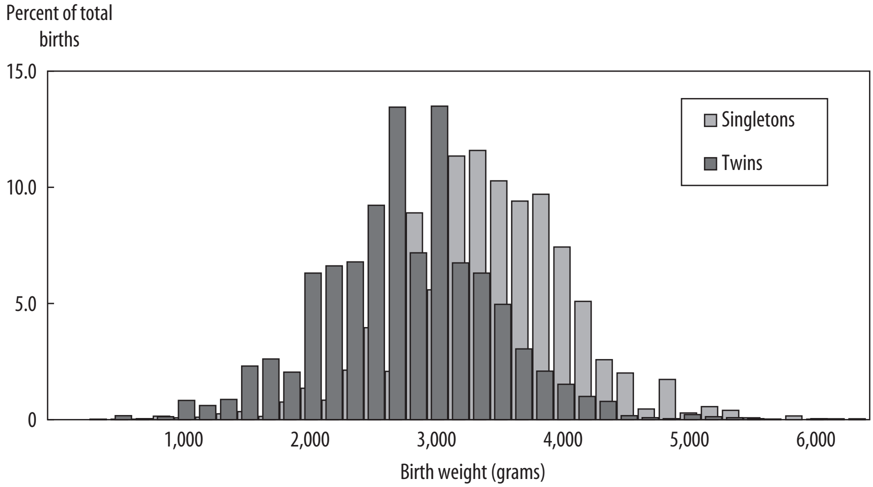
The medical literature distinguishes two types of twins: identical and fraternal. In the case of identical (or monozygotic) twins, the two infants share the same placenta during pregnancy. This is because a single fertilized ovum divides into two zygotes sometimes during the first thirteen days after conception, such that the twins share the same DNA. Conversely, fraternal (or dizygotic) twins occur when two eggs are fertilized by two separated sperm at the time of conception. Fraternal twins, which are more common than identical twins, do not share the same placenta inside their mother's womb and do not have the same DNA.

Identical and fraternal twins must be identified in the sample because differences in genetic composition within a pair of twins could potentially be correlated with congenital anomalies, which affect each infant in a different way. One of the potential limitations of the data sets used for the empirical analysis is that they do not allow identifying monozygotic versus dizygotic twins. However, under some (rather testable) assumptions, I am able to reduce the probability of including fraternal twins in the sample used for the empirical analysis, thereby narrowing the estimates to accurately capture the effects of monozygotic twins. The methodology used for a reliable identification of identical twins is explained later in the paper.

External Validity and Functional Forms

When implementing the FE estimator using a sample of twins, three problems arise immediately. First, twins are considerably smaller than singletons, at almost 770 grams lighter. The smaller size of twins compared to nontwins implies that coefficients resulting from the twin-based estimation may not be generalizable to a larger population of interest. Figure 1 depicts

FIGURE 1. Distribution of Birth Weights: Twins and Singletons



the distribution of birth weight for twins and singletons, where twins' birth weights are in the left tail of the singletons' distribution.

One alternative for checking the external validity of twin-based estimates is to compare resulting coefficients obtained through OLS from the sample of singletons with the coefficients arising from pooled OLS estimation over the sample of twins. This comparison ensures, first, that the physical health outcomes of singletons and twins are characterized by the same production function and, second, that omitted-variable biases are similar in both subsamples.[29] Hence, if there is no major difference between the two coefficients, then inferences from the twin FE estimator can be generalized to the entire population.

Another alternative is to weight regressions based on the individual position across the birth weight distribution (sample weights). As figure 1 depicts, the supports of the two distributions overlap except for the extreme values (lowest and highest) of the birth weight spectrum, so the weighted within-twin estimates are expected to be more generalizable to the population as a whole, including singletons. The weighted within-twin estimates are also adequate to control for the presence of nonlinearities.

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[29] Almond, Chay, and Lee (2005).

The second issue is whether spacing has a direct impact on children's physical development. The channel through which spacing can affect children's outcomes is by narrowing the family budget, which changes parental resource allocation behavior. The closer the siblings are spaced, the more restricted is the family's investment in their children's human capital, because family resources have to be divided between more than one child at the same time. In families with more than one child, the allocation of resources to children reflects a competition across siblings, given a fixed-resource constraint. Under a particular scenario of forward-looking parents and no credit constraints, decisions involving resource allocation to even the first child are based on expectations about the characteristics of subsequent children in the family, so spacing is not relevant in resource allocation across children given that parents incorporate fertility decisions in their utility function.

However, when access to credit markets is imperfect and parents do not take into consideration the potential characteristics of the marginal child, competition across siblings for family resources is unavoidable. This fact is reflected in the way that one child obtains more resources at the expense of another. In the case of twinning, the family budget becomes even tighter given that (1) multiple births are, naturally, unexpected and (2) the spacing between children is null. Under the assumption that spacing is positively correlated with child physical development and given a common resource constraint that prevents families from optimally allocating resources to children, the twin FE estimator will understate the impact of birth weight on child growth. This is because the birth spacing of twins is zero, the lowest possible value.

Nevertheless, empirical studies suggest that spacing between singleton births does not affect child outcomes.[30] Following Behrman and Rosenzweig, I examine the relationship between birth weight and height for 31,322 siblings aged zero to fifty-nine months.[31] Mother fixed effects, as well as an interaction term between the interval between each sibling's birth in months and his or her birth weight, are included in the regression. The *t* statistic associated with the interaction term between spacing and birth weight is low, so that the null hypothesis of no statistical significance cannot be rejected.[32] This result could be interpreted as spacing having no effect on child physical development.

Third, the effect of birth weight is not necessarily linear across the entire population. Because birth weight can have different effects on the underlying

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[30] See Olneck (1977).

[31] Behrman and Rosenzweig (2004).

[32] Results are not shown, but are available on request.

outcomes as one moves along the birth weight distribution, the average effect obtained from the FE regressions may be driven by some segments of the distribution more than others. That is, weight at birth may have a significant impact on child physical development outcomes only for a subset of the birth weight distribution. To assess this, I explore how birth weight affects early physical development at a threshold of 2,500 grams (children with low birth weight versus children in the normal range of birth weight); gradients for each segment are reported, as well.[33]

Data and Descriptive Statistics

To implement the twin FE estimator, I use data sets available from the Demographic Health Surveys (DHS) in ten Latin American and Caribbean countries, namely, Bolivia, Brazil, Colombia, the Dominican Republic, Guatemala, Haiti, Honduras, Nicaragua, Paraguay, and Peru.[34] DHS data sets from these countries include information on both birth weight and anthropometric outcomes of children, which are needed for the empirical analysis. Table 1 provides information on DHS data sets by country and year.

DHS surveys contain detailed information on women aged fifteen to forty-nine (that is, within the fertile age range as defined by the World Health Organization) who were interviewed with regard to pre- and postnatal care, marital status, fertility preferences, domestic violence, and other topics of interest; and information on children aged zero to fifty-nine months in terms of health conditions, birth outcomes (such as birth weight), immunization, and so forth. DHS surveys also include a section containing information on anthropometric measures of both the interviewed women and their children who were at home at the time of the interview and are zero to fifty-nine months old.[35]

Children's information is obtained directly from the mother, who must therefore be at home at the time of the interview. This restriction causes the exclusion of (1) children whose mother was alive but not at home at the time

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[33] The small sample size does not allow observing differences in estimates for more than two segments. I therefore choose the low-birth-weight threshold as the cutoff in order to make discussable conjectures for infant health policy purposes.

[34] The DHS data sets are available online at www.measuredhs.com.

[35] All women aged fifteen to forty-nine years who were at home at the time of the interview were eligible (including both household members and visitors). The number of selected women per household depends on the number of available women in the fertile age range. Selection was randomly assigned using the total number of eligible women and each woman's date of birth.

TABLE 1. Countries and Years Considered in the Analysis

		No. observations			
Country	*Year*	*All singletons*	*Siblings (nontwins)*	*All twins*	*Same-sex twins*
Bolivia	1994; 1998; 2003; 2008	17,174	3,456	198	140
Brazil	1996	3,600	686	38	32
Colombia	1995; 2000; 2005; 2010	25,932	3,716	380	260
Dominican Republic	1991; 1996; 2002; 2007	23,836	6,952	450	310
Guatemala	1995; 1998	8,704	2,766	74	60
Haiti	1994; 2000; 2005	1,136	167	30	20
Honduras	2005	5,806	952	78	56
Nicaragua	1998; 2001	8,751	1,784	126	86
Paraguay	1990	2,369	660	48	40
Peru	1992; 1996; 2000; 2004; 2008; 2009; 2010; 2011; 2012	62,349	10,173	876	636
Total		159,657	31,312	2,298	1,640

of the interview (for example, the mother works outside home or the child does not live with the mother) and (2) children whose mother is not alive. Mother's availability, then, can bias the results in an unknown direction. In an earlier paper, however, I find some evidence that there is no ex ante bias arising from selection on mother's availability at the time of the survey.[36]

The mother provides the information on her children's birth weight based on each child's growth record (that is, the birth weight recorded by the obstetrician or medical personnel attending the birth) or from memory. The latter implies the possibility of introducing measurement error in birth weight information. Nonetheless, under the assumption that recall bias is fixed for a given mother, twin-based estimates remove this confounding factor affecting identification. To take a conservative position regarding the possibility of any remaining bias affecting the twin-based estimates, I tested whether the twin-based estimates contain significant differences arising from maternal recall and objective measures of birth weight in the empirical analysis.

The full sample contains information on 159,657 singletons, of which 31,322 are nontwin siblings. Of the 2,298 twins in the sample, 1,982 twins have different birth weights.[37] In the empirical analysis, the sample is further

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[36] Saldarriaga (2012).

[37] This sample is used for comparisons across all twins and same-sex twins in the empirical analysis in the results section, since introducing fixed effects in the regressions mechanically excludes twins with equivalent birth weights.

restricted to same-sex twins to ensure that a larger proportion of twins are monozygotic twins, for whom differences in birth weight are not likely to be driven by genetic differences as in the case of fraternal twins.[38] Moreover, given that the twin FE estimator excludes by default the group of same-sex twins with the same birth weight (because differences in birth weight are constant across the twins and the FE removes every common characteristic within twins), the final sample contains 820 twin pairs (1,640 observations).[39] I discuss how zygosity can affect the estimates in the results section.

Table 2 presents summary statistics for the sample of singletons, (nontwin) siblings, all twins, and same-sex twins with different birth weights. The average birth weight for a singleton is 3,280 grams, versus 2,500 grams for twins. The percentage of singletons born with low birth weight is 8 percent, while for twins this figure is roughly 47 percent. Furthermore, the statistics show that twins are likely to have more retardation in growth rates relative to singletons, which is confirmed by the fact that twins are, on average, less tall for their age and more prone to undernourishment than singletons. However, there are no noticeable differences in body mass index. Twins differ from singletons in that they are more likely to be born at higher parities, have longer spacing with respect to the preceding birth, have older mothers, and thus be conceived at higher ages. Table 2 shows no significant differences between all twins and same-sex twins.

Figure 2 plots the distribution of differences in birth weight for the full sample of same-sex twins (including those with exactly the same birth weight). Almost 21 percent of the same-sex twins have equal birth weights. For the rest, the average absolute difference in birth weight is 292 grams. This average difference can be considered large enough to obtain sufficient variation and, therefore, reliable estimates from the twin FE estimator.

Lastly, to check whether twins differ according to their birth order, table 3 shows summary statistics for the sample of same-sex twins for the first-born twin and the second-born twin. Two important differences arise from these twin comparisons: the first-born twin seems to be heavier, on average, than the second-born twin; and the incidence of low birth weight is slightly higher among second-born twins. There are no significant differences for the rest of the variables. Whether birth order is relevant for determining disparities in birth weight across twins is discussed in the results section.

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[38] Studies on twinning identify that roughly one-third of all multiple births are identical twins, and two-thirds of fraternal twins are likely to be same-sex twins. This figure implies that almost 50 percent of all same-sex twins are likely to be monozygotic.

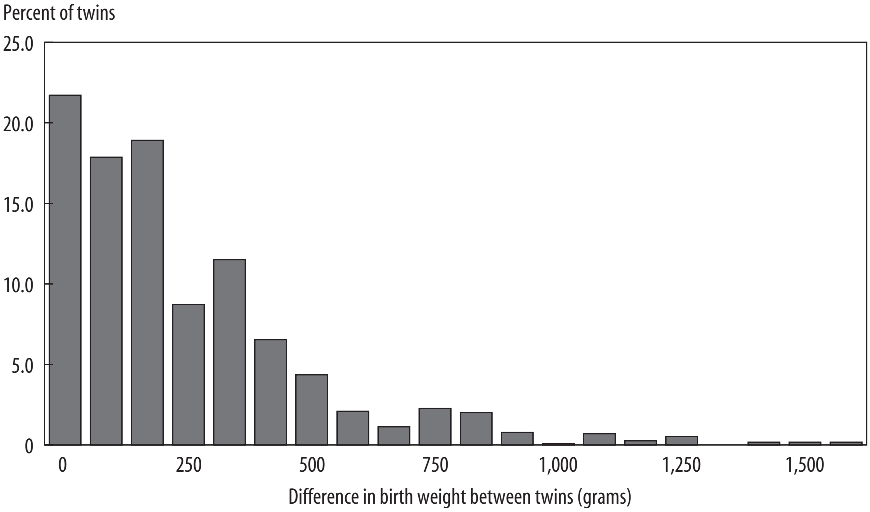
[39] I also exclude triplets and quadruplets from the sample.

TABLE 2. Summary Statistics: Singletons and Twins

	Singletons				Twins			
	All singletons		Siblings (nontwins)		All twins		Same-sex twins	
Variable	*Mean*	*Std. deviation*	*Mean*	*Std. deviation*	*Mean*	*Std. deviation*	*Mean*	*Std. deviation*
Child's characteristics								
Birth weight	3,287.18	610.88	3,248.67	643.39	2,509.37	607.75	2,489.54	613.22
Low birth weight[a]	0.08	0.27	0.10	0.30	0.47	0.50	0.48	0.50
Height for age (z score)	−0.89	1.26	−1.10	1.31	−1.22	1.25	−1.25	1.26
Stunted	0.17	0.38	0.23	0.42	0.25	0.43	0.26	0.44
Body mass index	16.70	1.74	16.62	1.73	16.50	1.67	16.55	1.70
Age in months	29.05	17.09	29.75	17.47	27.99	16.72	28.23	16.67
Male	0.51	0.50	0.51	0.50	0.50	0.50	0.49	0.50
Birth order	2.77	2.07	3.21	2.17	3.67	2.26	3.67	2.32
Preceding birth interval (months)	33.35	37.15	27.07	23.48	53.47	33.81	51.71	32.98
Has been breastfed	0.95	0.21	0.95	0.22	0.92	0.28	0.91	0.29
Months of breastfeeding	12.42	9.64	11.31	10.76	15.73	22.25	16.16	22.86
Completed vaccination	0.64	0.42	0.63	0.48	0.64	0.48	0.63	0.48
Mother's characteristics								
Age	28.43	5.39	30.32	6.59	30.25	6.51	29.92	6.70
Schooling	7.62	4.39	6.71	4.30	7.96	4.58	7.80	4.56
Age at first birth	20.08	4.22	19.63	4.01	20.62	4.42	20.44	4.47
Age at child's birth	25.81	6.63	25.39	6.13	27.91	6.45	27.56	6.63
Height (centimeters)	156.48	59.39	154.36	45.39	153.49	6.18	153.09	7.25
No. observations	159,657		31,322		1,982		1,640	

a. Less than 2,500 grams.

FIGURE 2. Distribution of Differences in Birth Weight of Twins



Outcomes

Three dependent variables are defined for the empirical analysis: one for anthropometric measures (the height-for-age z score) and two for nutritional status (whether the child is stunted and body mass index). The z score for height for age is included in the DHS data sets. Anthropometric z scores are based on the international reference standard established by the National

TABLE 3. Summary Statistics: Twins, by Birth Order[a]

	Birth order			
	First-born		*Second-born*	
Variable	*Mean*	*Std. deviation*	*Mean*	*Std. deviation*
Birth weight	2,523.36	623.34	2,495.72	601.41
Low birth weight[b]	0.46	0.50	0.48	0.50
Height (centimeters)	82.97	13.97	82.72	13.98
Weight (kilograms)	11.71	3.79	11.54	3.75
Height for age (z score)	−1.22	1.25	−1.29	1.27
Stunted	0.25	0.44	0.26	0.45
Body mass index	16.62	1.69	16.48	1.70
No. observations	820		820	

a. The sample is composed of same-sex twins with different weights at birth.

b. Less than 2,500 grams.

Center for Health Statistics (NCHS) (a division of the Centers for Disease Control and Prevention, CDC) and the World Health Organization (WHO). They take into account sex, age (measured by differentiating the exact day of birth from the exact day of the interview), height in centimeters, and weight in kilograms.[40] The indicator for stunting takes the value of one if the child's height for age is less than 2.0 standard deviations below the reference mean. Body mass index (BMI) is a universal measure for thinness. It is considered a proxy for human body fat, although it does not measure the percentage of body fat. To obtain the BMI, the individual's body weight (measured in kilograms) is divided by the square of his or her height (measured in meters).

Results

This section first describes the results separately for singletons, siblings, and twins and then discusses nonlinearities, heterogeneous effects, and postnatal investment.

Singletons

Table 4 presents the results for the *z* score of height for age, stunting (chronic undernutrition), and BMI for the sample of singletons. The first column shows the results of the unconditional OLS regressions; the second column adds country-by-year indicators to the regression (model 1); and the third column adds the full set of controls, including child characteristics, birth characteristics, maternal characteristics, and postnatal investments in child health (model 2).[41] All three regressions estimate the effect of birth weight (scaled

[40] For more information, see Rutstein and Rojas (2006).

[41] Child characteristics include a dummy variable for sex and indicators for the child's age in months (7–11, 12–23, 24–47, 48–59; base is less than six). Birth characteristics include indicators for birth order (second, third, fourth, fifth and higher; base is firstborn), and preceding birth interval indicators (less than one year, 12–23 months, 24–47 months, 48+ months; base is zero months which represents the firstborn child). Maternal characteristics include the mother's age at the time of the child's birth, indicators for the mother's year of birth, the mother's age at first birth, indicators for the mother's schooling (primary, secondary, some college; base is no education), and indicators for the mother's height in meters (1.60–1.70, 1.71–1.80, 1.81+; base is less than 1.60). Finally, postnatal investments in child health include months of breastfeeding and an indicator for completed immunization for age according to the DHS standards and the Pan American Health Organization.

TABLE 4. Singleton OLS Estimates: Effect of Birth Weight on Height for Age, Stunting, and BMI[a]

Dependent variable	*Unconditional OLS* *(1)*	*Model 1* *(2)*	*Model 2* *(3)*
Height for age (*z* score)	0.062***	0.062***	0.059***
	(0.001)	(0.001)	(0.001)
	[0.042]	[0.122]	[0.237]
Stunting	–0.011***	–0.011***	–0.011***
	(0.001)	(0.001)	(0.001)
	[0.021]	[0.084]	[0.152]
Body mass index	0.141***	0.142***	0.140***
	(0.001)	(0.001)	(0.001)
	[0.020]	[0.041]	[0.113]
No. observations	159,657	159,657	159,657

***Statistically significant at the 1 percent level.

a. Huber-White corrected standard errors are in parentheses; *R* squared statistics are in brackets. Model 1 includes country-by-year fixed effects. Model 2 also adds child characteristics (age in months and sex), birth characteristics (birth order and preceding birth interval indicators), maternal characteristics (age of the mother at the time of child's birth, year of birth indicators, age at first birth, schooling and height indicators), and investments in child health (months of breastfeeding and an indicator for completed immunization for age). Birth weight is measured in hundred grams.

in 100 grams) on the three dependent variables. In the case of height for age, the unconditional OLS coefficient indicates that an increase of a hundred grams in weight at birth augments height for age by roughly 0.062 standard deviation. The point estimate remains virtually unchanged when country-by-year indicators are added to the regression (model 1). However, adding the full set of controls (model 2) causes the coefficient to drop to 0.059.

For the indicator of stunting or chronic undernourishment (a height for age less than –2.0 standard deviations), the resulting OLS point estimate is –0.011 and is statistically significant at conventional levels. This implies that increasing birth weight by 100 grams reduces the probability of being stunted by 1.1 percentage points, which represents a reduction of 6.3 percent (–0.011 from a base of 0.174) in the prevalence of chronic undernourishment before age five. No considerable variations are observed when the country-by-year indicators and the full set of controls are added to the regression (columns 2 and 3, respectively).

With regard to the cross-sectional effects of birth weight on BMI, the bivariate analysis in column 1 shows that increasing birth weight by 100 grams augments body mass by 0.141. The point estimate is very similar to the unconditional model when the regression includes country-by-year fixed effects (column 2) and the full set of controls, including child, birth, and maternal characteristics, as well as postpartum health inputs (column 3).

TABLE 5. Sibling FE: Effect of Birth Weight on Height for Age, Stunting, and BMI[a]

Dependent variable	*Unconditional OLS* *(1)*	*Model 1* *(2)*	*Model 2* *(3)*
Height for age (*z* score)	0.059***	0.056***	0.057***
	(0.001)	(0.006)	(0.007)
	[0.037]	[0.915]	[0.918]
Stunting	–0.010***	–0.009***	–0.009***
	(0.000)	(0.002)	(0.002)
	[0.019]	[0.897]	[0.898]
Body mass index	0.140***	0.127***	0.125***
	(0.001)	(0.010)	(0.009)
	[0.022]	[0.890]	[0.900]
No. observations	31,332	31,332	31,332

***Statistically significant at the 1 percent level.

a. Huber-White corrected standard errors are in parentheses; *R* squared statistics are in brackets. Model 1 includes mother fixed effects for all siblings (nontwins) born to the same mother. Model 2 also adds child characteristics (age in months and sex), birth characteristics (birth order and preceding birth interval indicators), maternal characteristics (age of the mother at the time of child's birth), and investments in child health (months of breastfeeding and an indicator for completed immunization for age). Birth weight is measured in hundred grams.

Siblings

As discussed above, the error term from OLS estimates still contains unobservable characteristics of the mother's health, family background (a_i), and factors associated with each child's birth (u_k), as described in equation 1. To control for unobservable characteristics that are constant across every pregnancy the mother had, I include mother fixed effects for all siblings (nontwins) born to the same mother. While this estimation technique removes time-invariant maternal health characteristics (a_i) from the error term, it also significantly reduces the sample size, since all singletons without surveyed siblings are mechanically removed from the sample.

Table 5 reports the results for the sample of siblings. As before, column (1) shows the unconditional OLS regression; column 2 adds mother fixed effects (model 1), and column 3 includes the full set of controls (model 3). With regard to the effect of birth weight on the height-for-age z score, the unconditional OLS point estimate for siblings is very similar to the coefficient for the full sample of singletons, which suggests that reducing the sample to include only siblings does not significantly bias the parameters. These results show that increasing birth weight by a hundred grams augments height for age by 0.059 standard deviation. The point estimate drops to 0.056 when mother fixed effects are added into the regression (column 2) and remains virtually unchanged when the full set of controls are included (column 3).

The effects of birth weight on stunting for the subsample of siblings are similar to those of the whole sample of singletons. In general, increasing birth weight by 100 grams reduces the probability of being stunted by 0.01 percentage points before age five. This effect is statistically significant at conventional levels and is not affected by the inclusion of additional controls.

Finally, the results show that the effects of birth weight on BMI are similar for siblings only and for all singletons. Nonetheless, when mother fixed effects are included in the regression (column 2), the point estimate drops to 0.127. When additional controls are included (column 3), the point estimate drops to 0.125. This implies that family and background characteristics (which are invariant across pregnancies) are presumably biasing the results upward (downward in the case of stunting).

Twins

Although time-invariant maternal characteristics (such as genetic inheritances and health status) are removed when mother FE are introduced in the regressions for the subsample of siblings, the disturbance term in equation 1 still contains unobservable factors related to each child's pregnancy and birth. Given that twins are exposed to the same conditions during pregnancy (including air pollution, maternal stress, maternal nutrition, length of pregnancy, and so forth) and at the time of delivery (such as medical services and the use of cesarean section), including twin FE plausibly removes all these remaining factors that can potentially affect identification of the parameter of interest. As discussed earlier, differences in birth weight across twins are given by the intrauterine nutritional intake of the fetuses, which is orthogonal to family background or genetic inheritance.

Table 6 presents the results from the pooled OLS and twin FE regressions for the sample of same-sex twins. The sample is restricted to same-sex twins because this sample is likely to include a larger fraction of identical twins. The pooled OLS estimate for the height-for-age z score is almost identical to the cross-sectional bivariate estimate shown in the first column of the table. However, when twin FE are included, the point estimate drops to 0.042, remaining statistically significant at the 1 percent level. The pooled OLS point estimate for stunting is also very similar to the cross-sectional estimate. When FE are included, however, the resulting point estimate is nearly 30 percent smaller than the cross-sectional estimate of the effect of birth weight on the prevalence of chronic undernourishment. This result suggests that increasing birth weight by a hundred grams reduces the probability of chronic undernourishment by

TABLE 6. Pooled OLS and Twin FE: Effect of Birth Weight on Height for Age, Stunting, and BMI[a]

	Singletons	*Twins*			
Dependent variable	*Unconditional OLS (1)*	*Pooled OLS (2)*	*FE (3)*	*Weighted (4)*	*Card information (5)*
Height for age (*z* score)	0.062***	0.059***	0.042***	0.040***	0.048***
	(0.001)	(0.005)	(0.007)	(0.012)	(0.016)
	[0.042]	[0.020]	[0.926]	[0.934]	[0.933]
Stunting	–0.011***	–0.009***	–0.007**	–0.007*	–0.016**
	(0.000)	(0.002)	(0.003)	(0.004)	(0.008)
	[0.021]	[0.009]	[0.832]	[0.886]	[0.910]
Body mass index	0.141***	0.141***	0.064***	0.050***	0.089***
	(0.001)	(0.007)	(0.012)	(0.018)	(0.039)
	[0.020]	[0.022]	[0.836]	[0.867]	[0.818]
No. observations	159,657	1,640	1,640	1,640	972

***Statistically significant at the 1 percent level.

a. Huber-White corrected standard errors are in parentheses; *R* squared statistics are in brackets. The cross-sectional unconditional OLS estimates in column 1 are repeated from table 4. The twin estimates (columns 2 through 5) are based on a restricted sample of same-sex twins. Column 2 shows the resulting OLS estimates of the effect of birth weight on physical health of children under age five using the sample of same-sex twins. Column 3 shows the resulting coefficients when maternal fixed effects for every pair of twins are added in the regressions. Column 4 shows the resulting coefficients of the twin FE model when weighting by the individual position across the birth weight distribution. Columns 5 shows the resulting coefficients when the sample of same-sex twins is restricted to include only pairs of twins for whom information on birth weight comes from the birth certificate. No additional controls are added in the regressions. Birth weight is measured in hundred grams.

0.7 percentage point (statistically significant at the 5 percent level). With regard to BMI, the pooled OLS coefficient for the sample of same-sex twins is identical to the cross-sectional estimate for the whole sample of singletons. When FE are included in the regression, the point estimate is more than 50 percent smaller than the cross-sectional estimate, suggesting the existence of considerable upward bias in the OLS estimates. Results from twin FE estimates suggest that increasing birth weight by a hundred grams augments body mass by 0.064, with a statistical significance of 1 percent.[42]

The results remain basically unchanged when individual sample weights are used in these regressions (table 6, column 4). The point estimate of the effect of birth weight on the height-for-age z score is 0.040 and still statistically significant at the 1 percent level. For chronic undernourishment, the coefficient remains unchanged, although it is statistically significant at

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[42] No overlap is observed when comparing the 95 percent confidence intervals (not shown) between the resulting coefficients from the pooled OLS and FE regressions except for the case of stunting (which is a binary variable). These comparisons support the statistical difference between estimates drawn from the two specifications. I thank Kevin Milligan for making this point clear.

lower confidence levels. The point estimate of the effect of birth weight on body mass drops to 0.050, with a statistical significance of 1 percent. These results corroborate the fact that the twin-based estimates can be generalized to a larger population of interest, arguably singletons. Finally, to address the potential biases introduced by maternal recall when reporting children's birth weight, I ran the twin FE regressions on the subsample of twins for whom information on birth weight comes from the child's growth record (column 5). The point estimates are higher than the nonweighted twin FE estimates, suggesting that maternal recall introduces a negative bias to the coefficients.

Taken together, the evidence from the twin FE estimates presented in table 6 implies that common genetic factors and conditions experienced by the mother during pregnancy are positively correlated with birth weight. Furthermore, results from tables 5 and 6 suggest that genetic inheritances are not strong predictors of the health status of children before age five, whereas conditions experienced during the gestational period are crucial in determining physical development in early childhood.

Nonlinearities

Table 7 presents estimates for the underlying outcomes disaggregated by birth weight range for the sample of same-sex twins. Specifically, the sample is divided into two groups, with a birth weight threshold of 2,500 grams.[43] As the table shows, the effects of birth weight on stature, stunting, and body mass are larger (in absolute terms) for the subsample of twins weighing less than 2,500 grams at birth. Increasing birth weight by 100 grams for children born with a low birth weight improves height for age by 0.104 standard deviation, while the same increase for children with an adequate birth weight increases height for age by 0.045 standard deviation (less than a half of the effect relative to the low-birth-weight subsample).

With regard to stunting, increasing birth weight by 100 grams in the low-birth-weight population reduces the probability of being chronically undernourished by 2.5 percentage points (statistically significant at the 1 percent level). Interestingly, the point estimate of –0.01 is no longer statistically significant for the subsample of children born with adequate weight, which

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[43] The subsamples used for this estimation include only twin-pairs for whom both twins are in the same birth weight range. In other words, I exclude from the subsamples every twin pair in which one of the twins weighed less than 2,500 grams and the other weighed more than 2,500 grams.

TABLE 7. Twin FE: Effect of Birth Weight on Height for Age, Stunting, and BMI, by Birth Weight Range[a]

	Splines	
Dependent variable	*Less than 2,500 grams (1)*	*2,500 grams or more (2)*
Height for age (*z* score)	0.104***	0.045***
	(0.019)	(0.013)
	[0.943]	[0.942]
Stunting	–0.025**	–0.010
	(0.010)	(0.007)
	[0.842]	[0.885]
Body mass index	0.102***	0.064***
	(0.031)	(0.022)
	[0.877]	[0.894]
No. observations	780	822

***Statistically significant at the 1 percent level.

a. Huber-White corrected standard errors are in parentheses; *R* squared statistics are in brackets. Birth weight is measured in hundred grams.

suggests that the effect of birth weight on stunting is being driven mainly by the subsample of low-birth-weight children.

Finally, the effect of birth weight on BMI is also larger for the low-birth-weight sample. Increasing birth weight by 100 grams in this subsample improves body mass by 0.10 (statistically significant at the 1 percent level), while the point estimate is 0.064 for children born with adequate weight (statistically significant at the 1 percent level).

Heterogeneous Effects

Table 8 reports the twin FE estimates for the sample of all twins and same-sex twins and also disaggregates the same-sex twins by gender. To examine the effects of zygosity, I compare the results from the entire sample of twins (including male-female twins) with the results from the sample of same-sex twins, which is more likely to contain a larger proportion of identical twins. The estimates for identical twins are almost the same as the estimates for fraternal twins.[44] These results suggest that zygosity is not an important determinant in the health production function of same-sex twins. Thus, the assumption that the FE estimates for same-sex twins may contain zygosity

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[44] This is consistent with the findings of Black, Devereux, and Salvanes (2007).

TABLE 8. Twin FE: Effect of Birth Weight on Height for Age, Stunting, and BMI[a]

Dependent variable	*All twins* *(1)*	*Same-sex twins* *(2)*	*Boys* *(3)*	*Girls* *(4)*
Height for age (*z* score)	0.044***	0.042***	0.046***	0.039***
	(0.006)	(0.007)	(0.010)	(0.009)
	[0.918]	[0.926]	[0.921]	[0.929]
Stunting	–0.008***	–0.008**	–0.014**	–0.004
	(0.003)	(0.003)	(0.006)	(0.003)
	[0.829]	[0.832]	[0.797]	[0.869]
Body mass index	0.066***	0.064***	0.077***	0.055***
	(0.012)	(0.012)	(0.017)	(0.016)
	[0.812]	[0.836]	[0.861]	[0.797]
No. observations	1,982	1,640	802	838

***Statistically significant at the 1 percent level.

a. Huber-White corrected standard errors are in parentheses; *R* squared statistics are in brackets. Birth weight is measured in hundred grams.

factors in the error term which are correlated with birth weight can be discarded. A comparison of the sibling FE estimates (table 5), which found negligible effects of genetic inheritance or family background on children's health production function, and the coefficients presented in columns 1 and 2 of table 8 indicate that genetics are not as relevant for determining physical development during the first years of life as the conditions to which the fetus was exposed during the gestational period.

The samples segmented by gender show that the physical development response to increasing birth weight is larger for boys. In particular, increasing birth weight by 100 grams augments height for age by 0.046 standard deviation for male same-sex twins (statistically significant at the 1 percent level), while this effect is 0.039 standard deviation in the case of girls (statistically significant at the 1 percent level). The results also show that the impact of birth weight on the probability of being chronically undernourished is mainly driven by boys rather than girls. In this regard, a 100 gram increase in birth weight reduces the probability of being stunted before age five by 1.4 percentage points for boys (statistically significant at the 5 percent level), while this coefficient is not statistically different from zero in the case of girls. Lastly, the effect of birth weight on body mass is also larger for boys (with a point estimate of 0.077) than for girls (0.055), with a statistical significance of 1 percent for both coefficients.[45]

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[45] The *t* statistics (not shown in the tables) from the test of differences in the impact of birth weight on the underlying outcomes between boys and girls are as follows: 2.81 (height for age); –4.23 (stunting); and 1.97 (BMI).

In addition, I test whether twins exhibit differences due to birth order. Since the birth weight of the second-born twin is slightly lower than that of the first-born twin (table 3), I ran an additional regression including fixed effects for every twin pair, as well as an indicator for birth order and an interaction term between the twins' birth order and their birth weight. The *t* statistics for the interaction terms between birth weight and birth order are significantly smaller in all regressions (not shown), so the null hypothesis of no differences due to the birth order of twins cannot be rejected. These results validate the perfect exchangeability assumption described earlier.

Different maternal characteristics could also be correlated with how birth weight affects children's physical development. This information might be crucial in orienting public policies toward assisting more disadvantaged pregnant women, with the objective of enhancing the health status of newborns. For instance, if the returns to birth weight are larger for children born to younger mothers, it might be effective to focus public expenditures on pregnant teenagers, who are often associated with negligence and at-risk pregnancies given their low motherhood skills. Maternal schooling is another strong predictor of children's health status in different developmental stages. There are at least two reasons why exploring heterogeneous effects of birth weight on children's growth and body mass conditional on mother's schooling could be of interest. The first is related to the prepartum determinants of newborn health. Since more-educated women tend to detect their pregnancy earlier and take better care of themselves during pregnancy, women's schooling can lead to better birth outcomes and therefore to better physical health conditions for their children. The second reason is related to postnatal health investments. Given that more-educated mothers are also more informed about vaccination schemes, breastfeeding practices, growth records, and child care, it can be inferred that the effect of birth weight on physical development could potentially be greater for children born to more-educated mothers. Mother's schooling could also mitigate adverse birth outcomes (such as low birth weight) because of the direct effects of education on wealth and also because more-educated mothers are more likely to invest more in their children if their children face unfavorable health conditions.

Table 9 reports the effects of birth weight on the underlying outcomes according to the mother's age at the time of her child's birth and the mother's schooling. Splitting the sample based on the age of the mother at the time of birth indicates that the effects of birth weight on the *z* score, stunting, and body mass are larger for children born to older mothers. This result is

TABLE 9. Twin FE: Heterogeneous Effects on Maternal Characteristics[a]

	Maternal characteristic			
	Age at child's birth		*Schooling*	
Dependent variable	*Less than 25 years old (1)*	*Age 25 or more (2)*	*Primary only (3)*	*Some high school (4)*
Height for age (*z* score)	0.035***	0.047***	0.027***	0.058***
	(0.010)	(0.009)	(0.009)	(0.009)
	[0.942]	[0.917]	[0.928]	[0.912]
Stunting	–0.004	–0.011***	–0.005	–0.011***
	(0.005)	(0.004)	(0.005)	(0.004)
	[0.863]	[0.814]	[0.839]	[0.792]
Body mass index	0.063***	0.065***	0.052***	0.077***
	(0.019)	(0.015)	(0.016)	(0.017)
	[0.815]	[0.845]	[0.819]	[0.844]
No. observations	598	1,042	696	944

***Statistically significant at the 1 percent level.

a. Huber-White corrected standard errors are in parentheses; *R* squared statistics are in brackets. Birth weight is measured in hundred grams.

consistent with a hypothesis of increasing responsibility regarding prenatal healthcare as the mother ages. Finally, when the sample is broken down by maternal schooling (namely, primary education only versus some high school education), the coefficients are larger for children born to more-educated mothers, as predicted.

Postnatal Investments

Postnatal inputs, such as breastfeeding, vaccination, and early stimulation, are crucial in determining children's physical development and, consequently, their socioeconomic outcomes later in life.[46] However, how these postnatal health investments can help correct the growth profiles of disadvantaged toddlers (that is, with low birth weight) remains an open question. To investigate whether postnatal health investments can correct the problem of growth and development generated by malnutrition during the fetal period, I ran a set of regressions including interactions between birth weight and indicators of exclusive breastfeeding and completed vaccination for children

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[46] On breastfeeding, see Bhandari and others (2003); on vaccination, see World Bank (2001); on early stimulation, see Gertler and others (2013).

TABLE 10. Twin and Sibling FE: Heterogeneous Effects, by Postnatal Health Investments[a]

	Siblings		*Twins*
Dependent variable	*Breastfeeding (1)*	*Vaccination (2)*	*Breastfeeding (3)*
Height for age (*z* score)	0.004	0.013	–0.015
	(0.013)	(0.014)	(0.014)
Body mass index	0.019	0.015	–0.023
	(0.020)	(0.025)	(0.026)
No. observations	28,288	15,444	140

***Statistically significant at the 1 percent level.

a. Coefficients correspond to the interaction term of birth weight (measured in hundred grams) and the indicator of exclusive breastfeeding (columns 1 and 3) for children ages 6 to 59 months and completed vaccination (column 2) for children ages 18 to 59 months. The model includes birth weight (measured in hundred grams) and indicators of exclusive breastfeeding and completed vaccination, respectively. Huber-White corrected standard errors are in parentheses.

from six to fifty-nine months old and from eighteen to fifty-nine months old, respectively. These regressions are presented using both the sibling and twin samples.

Because of the reduced number of observations in the twin sample, however, only the interaction term between birth weight and exclusive breastfeeding is included. Moreover, since mother fixed effects are incorporated, this sample only includes children who exhibit differences in levels of breastfeeding and vaccination (both of which rely on parents' decisions). The idea is to verify whether postnatal investments, such as breastfeeding and vaccination, can somehow potentiate the positive effects found from adequate fetal nutrition during pregnancy (or mitigate the negative effects of inadequate birth weight).

Table 10 shows the coefficients for the interaction terms between birth weight and indicators of exclusive breastfeeding and completed vaccination for a given age. The associated *t* statistics are considerably low in all the regressions. Hence, the results suggest that postnatal investments in child health do not mitigate stunting caused by low birth weight in newborns. The results also provide evidence on the relationship between health investments during pregnancy and early childhood. In particular, postnatal interventions (breastfeeding and immunization) do not potentiate or complement investments in health prior to childbirth, so reassigning resources aimed at young children's health and nutrition from the prenatal period to the postnatal period is not likely to mitigate the initial adverse effects of bad parental investments.

Discussion

The relevance of the results of this analysis depends on two key issues: whether the results of twin studies can be generalized to the population as a whole and how the results of prenatal health programs compare to other policy options. This section addresses these issues in turn.

Generalizability of Twin-Based Estimates

The results from the OLS regressions on the sample of singletons and the pooled OLS regressions on the sample of same-sex twins reveal that there are no major differences between twins and singletons in terms of their health production functions or omitted variable biases. Moreover, the weighted regressions do not present significantly different coefficients, and the statistical significance is similar, providing additional evidence for the generalizability of the results shown in the previous section. Nevertheless, singletons and twins present some systematic differences that need to be addressed in order to understand whether the results represent an upper or lower bound of the true effect of birth weight on a child's growth.

The length of pregnancy is one of these systematic differences. Singletons are more likely to be carried to term than twins, which may account for differences in causal effects. As mentioned in the etiology of birth weight, the length of pregnancy is positively associated with birth weight. Additionally, the results show that the effects of birth weight on physical development are largest for the low-birth-weight population, which includes a significant share of preterm births. Hence, if twins are more likely to be preterm and thus more likely to be in the low-birth-weight population, twin-based estimates can potentially overestimate the effect of birth weight on physical development. Unfortunately, the DHS questionnaires do not register information on length of pregnancy, so the data do not support comparisons between preterm and regular-term twins or the construction of alternative outcomes such as fetal growth. However, some evidence suggests that the developmental outcomes of preterm singletons and twins do not vary significantly.[47]

Another caveat is that twinning per se might influence maternal prenatal behavior. For instance, a twin pregnancy requires additional care (such as a special diet, more prenatal care visits, and additional fetal growth measurements), which might promote healthier prenatal practices among women

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[47] See Allen (1995).

pregnant with twins than women carrying singletons. On the other hand, twinning requires more financial resources than singleton births, so there might be a potential selection of parents who decide to give birth to twins. If more careful and healthier mothers or wealthier families are more likely to give birth to twins (or less likely to decide to prevent or terminate a multiple birth), then the twins who survive the whole gestational period can be expected to represent the strongest members of the potential population. Since the results show that the effects of birth weight on physical health in early childhood are not linear (decreasing with birth weight), then the twins FE estimates are probably biased toward zero.

Two additional effects must also be considered in the twin-based estimates: selection on infant mortality and congenital anomalies. First, the same-sex twin sample includes only individuals for whom we observe the underlying outcomes, such that infants who died before the survey took place are not included in the sample. How this could affect the results depends on how birth weight is related to infant mortality. If healthier children (heavier children) are the most likely to survive, then the sample used for the empirical analysis contains the strongest children from the entire spectrum of live births that occurred in the previous five years of a given survey. Since birth weight has a larger effect on child growth for children born with low birth weight, the resulting twins FE estimates understate the true causal effect of birth weight on the physical development of children.

Second, the role of congenital anomalies in determining infant mortality and ventilator use immediately after birth is discussed by Almond, Chay, and Lee.[48] The authors find that when children with congenital anomalies are excluded from the sample of twins, the effect of birth weight on infant mortality and on the probability of ventilator use drops (in absolute terms) by more than half, which implies that congenital anomalies may introduce a negative bias. Unfortunately, information on these anomalies at the time of birth is unavailable, so it is not possible to exclude twins with congenital anomalies from the sample. Given the effects of congenital anomalies, the twin FE estimates presented in the empirical analysis are again likely to be downwardly biased.

Taken as a whole, it is feasible to consider that the results presented in this article represent conservative estimates of the true causal relationship between birth weight and physical health during early childhood, and twin-based estimates can be generalized to a larger population of interest, say, singletons.

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[48] Almond, Chay, and Lee (2005).

Comparison of Results

For policy purposes, it is useful to extend the analysis by comparing the results with those obtained through other social assistance programs in the region. The most direct way of assessing the functionality of a program is to compare its predicted benefit with the counterfactual result had the beneficiary been given a certain amount of money (say, the per capita cost of implementing the program). Conditional cash transfer (CCT) programs can therefore serve as a valid comparator for the purposes of illustration. Besides, "virtually every country in Latin America has such a program."[49]

I begin the analysis by establishing two questions. First, how large is the effect of the program aimed at increasing birth weight compared to that of CCTs? Second, is there any difference between the duration of the effect of the program to increase birth weight and that of CCTs? For credible comparisons, I use the height-for-age z score, since it is the most popular measure of infant physical development and is widely used to assess the effects of welfare programs on child growth.

In a comprehensive study of CCTs, Fiszbein and Schady review six programs in five countries (Brazil, Colombia, Ecuador, Honduras, and Nicaragua).[50] According to the review, CCTs have a positive and significant effect on child growth in only two of the six programs (*Familias en Acción* in Colombia and *Red de Protección Social* in Nicaragua), ranging from 0.16 to 0.17 standard deviation.[51] The remaining studies find negative yet not statistically significant effects of CCTs on the height for age of children under age five. To the extent that these two results hold for every CCT program in Latin America (a rather strong assumption), this implies that the results shown in this document represent between 24.7 percent and 26.3 percent of the effects of CCTs on child growth, and almost 62 percent in the case of children born with low birth weight.

While this comparison suggests that programs aimed at increasing birth weight (for example, counseling and weight gain during pregnancy) are not as powerful as CCTs in increasing child growth (and thus reducing undernourishment), an examination of the duration of the impacts leads to a different interpretation. For instance, Attanasio and others find that the impacts of CCTs on child growth are driven mainly by the effects on children under age

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[49] Fiszbein and Schady (2009).

[50] Fiszbein and Schady (2009).

[51] On the Colombian program, see Attanasio and others (2005); on Nicaragua, see Maluccio and Flores (2004).

two, while other studies that decompose the effects by the developmental age of children do not find statistically significant effects.[52] This result suggests that CCTs do not have lasting effects on physical growth throughout childhood.

In contrast, a deeper analysis (not shown) reveals that birth weight does have a lasting effect on physical development of children zero to fifty-nine months old. When the effects of birth weight are decomposed by developmental age, the impacts of birth weight on the height-for-age *z* score are found to be positive and statistically significant at the 1 percent level. For instance, increasing birth weight by 100 grams raises height for age by 0.052 standard deviation (standard error: 0.01) for children under two years, 0.034 standard deviation (standard error: 0.009) for children between twenty-four and forty-eight months, and 0.036 standard deviation (standard error: 0.015) for children between forty-nine and fifty-nine months.

Overall, it seems plausible that programs targeting an increase in birth weight (or a reduction in the incidence of low birth weight) across newborns would lead to sizable and permanent effects on physical growth in early childhood. These effects would also affect additional margins such as educational attainment and thereby wages during adulthood, which could intensify the potential gains from programs to increase birth weight. Although these comparisons are made on the basis of the existing literature documenting the impacts of other welfare programs on child growth, a deeper analysis in terms of monetary costs and benefits is needed in order to implement such programs focused on the nutrition and health practices of pregnant women in Latin America and the Caribbean. Regrettably, this analysis is not within the scope of this paper.

Conclusions

This paper explores the relationship between birth weight and physical health before age five. Within-twin variation in birth weight is used to deal with the problem of unobservables, which are often associated with genetic inheritances, environmental conditions to which the fetus was exposed during pregnancy and delivery, and family background.

Consistent with recent studies, the OLS estimates are found to overstate the causal relationship between birth weight and early childhood health.[53] Genetic endowments and family background, in particular, seem to bias the

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[52] Attanasio and others (2005).

[53] Almond, Chay, and Lee (2005); Black, Devereux, and Salvanes (2007).

OLS results upward. However, when twin-based estimation techniques are used for identification, the coefficients significantly drop, but are still statistically significant at conventional levels. This suggests that the conditions to which the fetus was exposed during gestation and at the very moment of birth (for example, maternal stress, length of pregnancy, institutionalized delivery, cesarean section, and so on) account for most of the omitted factors captured by cross-sectional estimates.

More generally, an additional 100 grams in birth weight would increase height for age by 0.04 standard deviation, increase body mass by 0.06 kg/m^2, and reduce the probability of being chronically undernourished by 0.7 percentage point. Extrapolating the latter twin-based result to the population of singletons, increasing birth weight by 100 grams would reduce the prevalence of chronic undernourishment by 4.11 percent (–0.70 percentage point from a baseline of 17.00 percent).

Results also suggest that increasing birth weight has larger effects on children born with low birth weight. In contrast to other social welfare programs (arguably, conditional cash transfers), interventions aimed at increasing birth weight have sizable and long-lasting effects on the physical development of children. Lastly, the results suggest that neither breastfeeding nor vaccination contributes to mitigating the detrimental effects on child growth caused by adverse birth outcomes.

For policy purposes, these results imply that interventions to promote the early detection of pregnancy, enhance prenatal care, urge pregnant women to attend prenatal checkups, and encourage weight gain during the gestational period might have substantial positive effects on health at birth and, through this channel, on physical development during early childhood. Needless to say, further evidence is needed before asserting that prenatal health investments are more important than postnatal ones for enhancing physical development in the early years of life and thereby improving quality of life.

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