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Economic gradients in early child neurodevelopment: A multi-country study

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Abstract

Little is known about the importance of household wealth for child neurodevelopment very early in life including during infancy. Previous studies have focused on specific developmental domains instead of more holistic multi-domain measures of neurodevelopment and on economic effects for the “average” child instead of evaluating the heterogeneity in economic gradients by different levels of developmental ability. Furthermore, not much is known about whether economic gradients in early child neurodevelopment are country-specific or generalizable between populations. We evaluate wealth gradients in child neurodevelopment, an important predictor of future health and human capital, between ages 3 and 24 months in four South American countries. We also assess the heterogeneity in these gradients at different locations of the neurodevelopment distribution using quantile regression. Employing a unique dataset of 2032 children with neurodevelopment measures obtained by physicians in 2005–2006, we find a large positive wealth gradient in neurodevelopment in Brazil. The wealth gradient is larger for children at higher neurodevelopment rankings, suggesting that wealth is associated with child development inequalities in the form of a wider gap between low and high achievers on neurodevelopment in Brazil. This result highlights the need to target poverty in Brazil as a key factor in health and human capital disparities earlier in life rather than later as early developmental deficits will be carried forward and possibly multiplied later in life. More importantly, small or insignificant wealth gradients are generally found in the other countries. These results suggest that wealth gradients in child neurodevelopment are country-specific and vary with population demographic, health, and socioeconomic characteristics. Therefore, findings from previous studies based on specific populations may not be generalizable to other countries. Furthermore, wealth gradients in child neurodevelopment appear to be dynamic rather than fixed and sensitive to population characteristics that modify their intensity.

Keywords

Argentina; Brazil; Chile; Ecuador; Child development; Socioeconomic status; Wealth; Disparities

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Appendix A. Supplementary data

Supplementary data related to this article can be found at <http://dx.doi.org/10.1016/j.socscimed.2012.11.038>.

Introduction

Child development on physical, psychosocial, and cognitive domains is influenced by a complex set of socioeconomic, environmental, and genetic contributors (Maggi, Irwin, Siddiqi, & Hertzman, 2010). Among these, socioeconomic factors are especially important since they may affect access to several social, behavioral, and environmental inputs for child development (Hertzman et al., 2010). Early stressors linked to socioeconomic status may also influence child development through epigenetic mechanisms (Essex et al., 2011; Hertzman & Boyce, 2010), although much more work is needed in this area. Socioeconomic gradients have been reported across a wide spectrum of child health and development indicators such as birth weight (Currie, 2009), survival (Houweling & Kunst, 2010), emotional and social development (Oliver, Dunn, Kohen, & Hertzman, 2007), cognitive/executive functioning (Sarsour et al., 2011), and brain functions (Sheridan, Sarsour, Jutte, D'Esposito, & Boyce, 2012) with children from higher socioeconomic status households having better outcomes. Early child health and development indicators are important predictors of future physical and mental health and wellbeing as well as human capital (Currie, 2009; Jefferis, Power, & Hertzman, 2002; Victora et al., 2008; Wadsworth & Kuh, 1997). There are several pathways through which early child health and development may influence subsequent health outcomes. One suggested channel with empirical evidence in the association between child cognitive ability and cardiovascular health during adulthood is through adult socioeconomic achievement and health behaviors (Power, Jefferis, & Manor, 2010). Certain physical traits during childhood such as body weight and height have also been linked to cortisol levels during adulthood, suggesting a potential role for the hypothalamic–pituitary–adrenal axis (Power, Li, & Hertzman, 2006). Therefore, interventions that improve early child development may have cumulative long-run benefits that exceed those of treatments and interventions to restore or improve health later in life (Cunha & Heckman, 2007; Shonkoff, Boyce, & McEwen, 2009). The World Health Organization has highlighted socioeconomic inequalities in child development as a key contributor to health disparities throughout life and emphasized the importance of reducing child development inequalities especially through devising policy interventions that increase investments in early development on all domains as an effective approach for reducing health disparities later in life (CSDH, 2008).

Among the many measures of child health and development, child neurodevelopment early in life including in infancy and early childhood before school age is a particularly relevant measure encompassing several functional and behavioral milestones that are indicative of normal development and predictive of future health and wellbeing. Neurodevelopment represents the child's achievement on cognitive, fine- and gross-motor, language, and social adaptation skills (Patel, Pratt, & Greydanus, 2002). Regular evaluation of the child's performance on neurodevelopmental milestones early in life is recommended as part of routine pediatric care practices (American Academy of Pediatrics Staff, 2001). Similar to other indicators of child health and development, several studies have documented significant positive associations between improved early child neurodevelopment and future health and human capital including higher educational achievement and cognitive performance (Murray, Jones et al., 2006; Murray, Jones, Kuh, & Richards, 2007; Taanila, Murray, Jokelainen, Isohanni, & Rantakallio, 2005). For example, standing at an earlier age, which is an important gross-motor milestone, is positively associated with higher cognitive performance during adulthood (Murray, Veijola et al., 2006).

As mentioned above, an established literature has documented socioeconomic gradients in several measures of child physical, social, cognitive, and language development. However, little is known about the importance of family wealth for child neurodevelopment very early in life including during infancy (the first two years of life). The majority of prior work

examining socioeconomic gradients in development has focused on specific neurodevelopmental domains such as language in children after age 3 years, generally finding positive wealth or income effects. For example, Paxson and Schady (2007) evaluated the effects of household wealth on child language development, measured by Peabody Picture Vocabulary Test, in a sample of children age 3–6 years from Ecuador. Measuring wealth with an index based on asset and housing quality conditions and generated using principal component analysis, the study found significant positive associations between wealth and language development scores. Maternal and father's education had also positive associations with language development. Only a few published studies have evaluated socioeconomic gradients in more holistic neurodevelopment measures or in multiple neurodevelopmental domains earlier in childhood. Ghuman, Behrman, Borja, Gultiano, and King (2005) studied a sample of children age 0–36 months from the Philippines. Neurodevelopment was assessed using the Revised Early Child Development Checklist, an instrument developed in the Philippines that included several neurodevelopmental domains. Adjusting for parental education, the study found insignificant effects of an index of family asset ownership and housing quality indicators on three of four studied neurodevelopment domains, except for receptive language skills where the index had positive effects – a one standard deviation (SD) increase in the asset index was associated with a 0.05 SD increase in receptive language. Ermisch (2008) studied the role of parental behaviors in economic gradients in child cognitive and behavioral outcomes measured by the British Ability Scales Naming Vocabulary scale (BAS), Bracken School Readiness Assessment (BSRA), and Strengths and Difficulties Questionnaire (SDQ) in a sample of children age 3 years from the UK. Income was measured around 9 months of life. The study reported large income gradients in child development, with children from higher income households performing significantly better on the cognitive and behavioral scales.

There are some key gaps in the literature on socioeconomic backgrounds and early child development that we attempt to address in this paper. As indicated above, the majority of studies focus on specific developmental areas (physical, cognitive, language, or psychosocial), and very few ones use more holistic multi-domain measures of neurodevelopment. More importantly, less than a handful of studies evaluate socioeconomic gradients in neurodevelopment during infancy, and the majority study children after the first three years of life. While important, studies evaluating child development or neurodevelopment later in childhood may not reveal whether socioeconomic gradients originate earlier in life. In this regard, evaluating the role of family wealth in neurodevelopment very early in life including during the first two years of life is essential for identifying the earliest neurodevelopmental period that is sensitive to economic effects. This is needed for developing appropriately timed and cost-effective policies and interventions that can enhance early child development and result in large cumulative returns. To address this gap, we focus on studying wealth gradients in neurodevelopment within the first two years of life.

Another gap in the literature on neurodevelopment or non-physical development domains is that most studies focus on economic effects for the “average” child (a child at average development), instead of evaluating the heterogeneity in economic gradients by different levels of developmental ability. Developmental ability (or endowment) can be thought of as a latent all-encompassing index of genetic, socioeconomic, and environmental factors that determine the child's ranking on the distribution of the development measure, conditional on observed characteristics. Children at higher ranks of the development distribution are expected to have a greater developmental ability, conditional on observed differences. Since previous studies focus on estimating the income/wealth gradients at the “mean” of the development measures, their estimates apply to a child at an “average” developmental ability but may not apply to a child below or above average. Wealth gradients may vary for

children with different abilities/endowments through interplays between wealth and the latent factors that influence developmental ability. For example, if household wealth and the physical environment are complements, the development of children in healthier physical environments may be more sensitive to household wealth (such as through wealthier parents having more quality time for healthy outdoor recreational activities) compared to those in worse physical environments (where both wealthy and poor parents may not engage as much in outdoor activities). Therefore, economic gradients may vary between more and less developmentally endowed children. Such heterogeneities will be masked by evaluating these gradients for children at “average” development and generalizing them to other children. We address this gap by employing an analytical model – quantile regression – that can evaluate the heterogeneity in wealth gradients at different rankings (quantiles) of the neurodevelopmental measure distribution.

Finally and most importantly, it is unclear whether economic gradients in early child neurodevelopment and non-physical development indicators are country-specific or generalizable between populations. Previous studies have reported differences between countries in socioeconomic gradients in certain child health measures such as child survival (Houweling & Kunst, 2010) and obesity (Wang, 2001). Wealth gradients in neurodevelopment may vary between countries for several reasons such as differences in social and economic infrastructures, welfare policies, healthcare systems, environmental factors, and culture. For example, household wealth may be less relevant for early child neurodevelopment in countries with a more established safety net system for enhancing maternal and child health in poor families where differences in individual wealth may not necessarily translate into sharp disparities in access to basic inputs needed for optimal child neurodevelopment such as adequate nutrition, good quality preventive pediatric care, and a clean and hazard-free physical household environment. Also, wealth effects depend on the supply and price of such inputs and are more relevant in settings with limited supply of these inputs. For example, in settings with a limited availability of pediatricians or family physicians, the price of routine pediatric care may be higher than settings with more of these health professionals (holding other variables constant). The same applies to food and housing prices. Environmental and urban planning policies may also modify wealth effects. For example, wealth may become less relevant in communities with public access to quality outdoor recreational areas such as parks that may provide a healthy and stimulating environment for the child. Culture may also play an important role in modifying wealth effects. For example, informal childcare opportunities through grandparents or family members vary between countries depending on family-living arrangements. Availability of informal care reduces the demand for formal childcare arrangements and may stimulate child neurodevelopment (such as through grandparents playing with or reading to the child), potentially limiting wealth gradients. The cost and quality of parental activities with their children and household investments in child development may also vary between countries resulting in a wide range in both the type and frequency of these activities and investments across countries as previously shown (Bornstein & Putnick, 2012). Evaluating such heterogeneity in wealth gradients by country requires comparisons using similarly collected data across countries. To our knowledge, very few studies of child neurodevelopment or non-physical development indicators especially early in life have been able to compare economic gradients across different countries using similarly collected data and the same analytical model. We address this gap by separately studying and comparing wealth gradients across four South American countries using a dataset with the same variables, measurement techniques, and data collection and management procedures across all countries.

In sum, we make several contributions to the literature by studying wealth gradients in child neurodevelopment between 3 and 24 months of life in four South American countries using

a unique dataset. We also evaluate the heterogeneity in wealth gradients by developmental ability using quantile regression. There is overall an underrepresentation of populations from less developed countries including from South America in the literature on economic gradients in non-physical child development indicators especially very early in life. To our knowledge, very few studies of economic indicators and early child neurodevelopment or non-physical development have been done in South American populations. Therefore, in addition to the aforementioned contributions, our study sheds light on the relationship between household wealth and early child neurodevelopment specifically in South American populations.

Methods

Data sample

The data we employ are from a study that aimed at collecting neurodevelopmental data on infants without health complications in South America in 2005–2006, referred to hereafter as the “parent study” (McCarthy et al., 2012; Wehby, McCarthy, Castilla, & Murray, 2011; Wehby, Prater, McCarthy, Castilla, & Murray, 2011). Our sample consists of 2032 children between 3 and 24 months of age who participated in that study in four South American countries: Argentina (664 children), Brazil (516 children), Chile (388 children), and Ecuador (464 children). The children were recruited in the parent study at 32 pediatric care practices during routine well child visits to physicians (mostly pediatricians) affiliated with the study. The study-affiliated physicians evaluated the child’s neurodevelopment and collected data using the same instrument and questionnaires across all study sites. Demographic and socioeconomic data were obtained from interviews with the mothers during the visits. All neurodevelopmental, demographic, and socioeconomic data were specifically obtained for the parent study. Before initiating recruitment and data collection, all study physicians received training in study procedures and data collection methods including in neurodevelopment assessment. Details on the parent study and collected data are provided elsewhere (McCarthy et al. 2012; Wehby, Murray, McCarthy, & Castilla, 2011; Wehby, in press). Data collection was approved by the University of Iowa IRB.

Given its focus on normal child neurodevelopment, only children without major health complications were enrolled into the parent study providing the data for our paper. Specifically, only children with normal birth weight (≥ 2500 g), gestational age (≥ 37 weeks), and Apgar scores (≥ 6), and without major complications including requiring oxygen after birth, neonatal intensive care use, major surgery, illness requiring regular treatment (>2 weeks), and developmental delay were enrolled in that study. Therefore, our paper evaluates economic gradients in neurodevelopment among children without health complications since only such children were enrolled in the parent study. We discuss below the implications of these sample selection criteria for the interpretation of our results. No child enrolled in the parent study is dropped from our analysis based on health, neurodevelopment, wealth, or other characteristics. All children with data on the study variables are included in the analysis.

Measures

Neurodevelopment—The study-affiliated physicians evaluated child neurodevelopment using the Bayley Infant Neurodevelopmental Screener (BINS) (Aylward, 1995). The BINS is a standardized instrument that screens infants between ages 3 and 24 months for risk of developmental delays or neurological problems. The instrument covers four areas of abilities including basic neurological, expressive, receptive, and cognitive functioning. The BINS has good reliability (test–retest reliability of 0.71–0.84 and inter-rater reliability of 0.79–0.96) and validity (internal consistency of 0.73–0.85) and is predictive of performance on

diagnostic instruments (Aylward, 1995; Aylward & Verhulst, 2000). The study physicians administered the BINS after receiving training and assessment of their reliability in using the instrument. The average reliability of the physicians in administering the BINS was about 84% (McCarthy et al., 2012). The BINS was translated into Spanish and Portuguese and the accuracy of translations was verified before initiating data collection (McCarthy et al., 2012).

The BINS consists of 11–13 items depending on the infant's age group and the total score ranges from 0 for failing all items to 11–13 for passing all items. The total score can be classified based on the instrument's norms into two or three categories for the risk of neurodevelopmental problems. We employ the binary measure of high versus low risk status as one measure of neurodevelopment. Being in the high risk status – risk indicator is equal to 1 – implies that the child is at a high risk of neurodevelopmental problems. Furthermore, similar to previous studies using such data (Wehby, McCarthy et al., 2011; Wehby, Parter et al., 2011), we generate a continuous measure from the total BINS score that represents the neurodevelopmental performance of each child relative to the other study children of the same age and from the same country as the child. This “neurodevelopment rate” measure represents the percentage deviation of the child's total BINS score from the BINS score mean of the subsample matched to the child by age in months and country. The measure is centered at 0 and ranges from negative (indicating below average neurodevelopment) to positive (indicating above average neurodevelopment) values. In contrast to the binary measure, an increase in the neurodevelopment rate measure indicates better neurodevelopment. This measure provides more variation than the binary risk status measure, is intuitive to interpret, and allows for evaluating how wealth gradients in neurodevelopment vary by developmental ability using quantile regression as we describe below.

Wealth—Measuring wealth is challenging particularly in less developed countries due to income interruptions and fluctuations, self-report biases/errors in income and consumption measures, and lack of data on prices and expenditures. In this study, we focus on measuring “permanent” wealth, which is more relevant for child development than transient income. We do so by employing multiple measures of asset ownership and household quality and aggregating them into a wealth index using principal component analysis (PCA). This approach has been shown to provide an appropriate measure of long-run household wealth (Filmer & Pritchett, 2001). The PCA is based on maximum likelihood estimation of polychoric correlations between latent variables underlying the employed ordinal indicators for household assets and quality (Kolenikov & Angeles, 2004). The items aggregated in the index include owning a radio, TV, refrigerator, and car; employing a worker in the household; working on the family's agricultural land; source of drinking water; type of toilet/sewage facility; principal house flooring type; and number of household individuals per sleeping room. Data on the wealth indicators were collected during the interviews with the mothers. These indicators are commonly used in global surveys of population health and demographics in less developed countries such as the Demographic and Health Surveys by the World Bank. All the included indicators have reasonable variation in the country samples as shown in Appendix Tables A1–A4. Different groupings were used for some variables (such as for toilet/sewage facility and principal type of flooring in dwelling) across countries in order to account for the rarity of certain categories in some countries. Some variables including working on the family's agricultural land and source of drinking water were omitted from the wealth indices for certain countries due to their limited variation and in order to improve the fit of the PCA model. Details of differences in variable categories and exclusions from the wealth index by country are in Appendix Tables A1–A4.

PCA decomposes the variation in these items into orthogonal components/equations. By construction, the first principal component explains the largest portion of the common variation, followed by the second component, and so forth. We use the scoring coefficients of the first component as weights for the wealth index items. The assumption made with using PCA to generate this index is that long-run household wealth explains the largest common variation in the employed household asset and quality items. We show below that this index is valid with increasing values indicating higher wealth. The index is centered at 0 by construction and ranges from negative to positive values.

Control variables—Our models include several observed human capital and demographic characteristics of the household that may affect both wealth and child development. Specifically, we control for maternal age, education, and marital status, child's racial/ethnic ancestry and sex, and number of adult household members. Also included are area fixed effects (at the study site level) in order to account for environmental and neighborhood effects related to both wealth and development. Table 1 shows the distribution of the model variables.

Empirical model and estimation

Since wealth gradients in child neurodevelopment may vary between countries due to differences in economic, social, environmental, and healthcare systems as well as culture as discussed above in detail, we evaluate the wealth gradients separately for each country given the potential differences in some of these factors between the study countries. We first estimate the wealth gradients in average neurodevelopment using OLS for the neurodevelopment rate and probit for the binary risk indicator, adjusting for all the control variables listed above. We estimate two specifications, one with the continuous wealth index, and another with indicators for the index quartiles in order to evaluate if wealth has non-linear effects on child neurodevelopment.

As mentioned above, evaluating wealth gradients in “average” neurodevelopment may be misleading, as these effects may vary by child developmental ability/endowment. Identifying such heterogeneity is important for understanding whether wealth gradients are associated with increased (or reduced) developmental inequalities in the form of a wider (or narrower) gap between children ranking at the opposite sides of the neurodevelopment rate distribution (i.e. children with low and high developmental ability). Therefore, we employ quantile regression (QR) to evaluate how wealth affects the entire neurodevelopment rate distribution including the spread of the distribution. Unlike OLS which estimates wealth gradients for the “average” child, QR allows for evaluating how these wealth gradients vary at various locations of the neurodevelopment rate distribution. In doing so, QR evaluates the heterogeneity in wealth gradients by latent developmental ability/ endowment levels, since these are expected to determine the child's ranking on the neurodevelopment rate distribution conditional on observable characteristics. QR can be modeled as follows:

$$D=Q(W, \mathbf{X}, U) \quad (1)$$

where D is the neurodevelopment rate measure, W is wealth, $\mathbf{X}$ is a vector of control variables, and $U \sim (0, 1)$ is a uniformly distributed ranking variable that represents the “unobserved” developmental ability/endowment. Conditional on W and $\mathbf{X}$, the child's rank on the distribution of D is determined by U . In other words, children of similar W and $\mathbf{X}$ will rank at different locations of D 's distribution because of U . For quantile q ($0 < q < 1$), $D = Q(W, \mathbf{X}, q)$ is the q th conditional quantile of D . QR may be thought of as essentially holding U constant at q when estimating the association between W and $\mathbf{X}$ at the q th quantile Q . QR

evaluates the heterogeneity in the associations the effects of W and $\mathbf{X}$ by q (or U) by estimating different parameters for the effects of W at different q s as follows:

$$D = Q(\alpha_{0q} + \beta_{0q}W + \mathbf{X}\lambda_q) \quad (2)$$

QR is estimated at a specific q by minimizing the sum of weighted absolute residuals using the *whole* sample *not* by stratifying based on the dependent variable (Koenker & Bassett, 1978; Koenker & Hallock, 2001):

$$\min \left[q \sum_{D_i \geq Q_i}^n |D_i - Q_i| + (1 - q) \sum_{D_i < Q_i}^n |D_i - Q_i| \right] \quad (3)$$

where n is the number of observations. We estimate QR for the continuous neurodevelopment rate measure described above first at quantiles 0.1, 0.25, 0.5, 0.75, and 0.9 which provide good coverage of the entire distribution. We test the differences in wealth effects between various quantiles using standard Wald tests (Hao & Naiman, 2007). Where heterogeneous wealth gradients are observed at these five quantiles, we estimate QR for 19 quantiles from 0.05 to 0.95 (in increments of 0.05). The standard errors are estimated using 2000 bootstrap replications.

Results

Validity of the wealth index

We first evaluate the validity of the PCA constructed wealth index by checking the distributions of the household assets and quality indicators across the index quartiles separately for the study countries. These results along with the scoring coefficients of the wealth index are shown in Appendix Tables A1–A4. The expectation is that within each country, asset ownership and household quality should improve with increasing index values. In most cases, household assets and quality increase across the wealth index quartiles. For example, about 34%, 16%, 18%, and 67% of the households in the lowest wealth quartiles in Argentina, Brazil, Chile, and Ecuador, respectively, do not have a refrigerator, but all households in the highest wealth quartiles have a refrigerator. Similarly, the percentage of households with 1 or 2 individuals per sleeping room is 21%, 11%, 43% and 22% in the lowest wealth quartiles in Argentina, Brazil, Chile, and Ecuador, respectively, compared to 97%, 87%, 95%, 98% in the highest wealth quartiles, respectively.

We further evaluate the validity of the wealth index by evaluating whether it is associated with observed human capital characteristics in the expected direction. Wealth is expected to be positively correlated with maternal education and occupational status. As can be seen in Appendix Tables A1–A4, the wealth index is consistently and positively correlated with higher human capital. For example, the rate of completed maternal university education is 0%, 4%, 8%, and 27% in the first, second, third, and fourth wealth quartiles, respectively, in Argentina. Also, the rate of a high maternal occupational status (boss, chief, owner, professional, or executive) is 0%, 3.5%, 8%, and 18% in the first, second, third, and fourth wealth quartiles, respectively, in Argentina. Similar trends are observed in the other countries.

Wealth gradients

Marked differences in wealth gradients are observed between the study countries. Except for Brazil, there are small and generally insignificant associations between wealth and

neurodevelopment in the other studied South American countries. Large wealth gradients are observed in Brazil, with wealth being positively associated with neurodevelopment particularly for children ranking at higher levels of the neurodevelopment rate distribution. Therefore, wealth is associated with an increased inequality in the form of a wider gap between children on the left and right tails of the neurodevelopment rate distribution in Brazil. We describe the results for each country below. The wealth effects are listed in Table 2. Table 3 shows the effects of the control variables in the OLS and probit models for the neurodevelopment rate and risk status measures, respectively. Detailed results for the effects of the control variables in the quantile regression models for neurodevelopment rate when using the linear wealth index are included in Tables A5–A8 in the Appendix. The quantile regression results for these covariates were overall comparable when using the wealth quartile indicators instead of the linear wealth index (detailed results for those models are available from the authors upon request).

Argentina—Wealth is positively associated with neurodevelopment rate in Argentina especially at higher quantiles, but the association is relatively small. A one SD increase in the linear wealth index is associated with an increase in neurodevelopment rate by 0.06 SDs (marginally significant) at the mean, and by 0.1 SDs at the 0.75 and 0.9 quantiles; these effects are derived by multiplying the wealth regression coefficient by the SD of the wealth index (1.13) and dividing it by the SD of the neurodevelopment rate (13.68). None of the wealth quartile coefficients in the neurodevelopment rate model are significant. The linear and non-linear wealth effects in the probit model for being at high risk of neurodevelopment problems (referred to hereafter as high risk status) are positive (which is opposite to the expected sign) but very small and insignificant.

Maternal education has insignificant effects, except for the mother completing university education, which is significantly and negatively related to high risk status. Children of non-married mothers have lower neurodevelopment rates compared to those of married mothers. Finally, male children have lower neurodevelopment rates than females.

Brazil—Significant wealth gradients in neurodevelopment are observed for Brazil, with a one SD increase in household wealth associated with an increase in neurodevelopment rate by 0.14 SDs at the mean and a decrease in the probability of high risk status by 5 percentage-points, or by 25% at mean probability of high risk status. Also, the wealth gradients are more pronounced at the higher quantiles of neurodevelopment rate (median and above) than at lower quantiles where differences in neurodevelopment by wealth are smaller and insignificant. The largest observed gradients are between those on the opposite extremes of the wealth index; children in the fourth wealth quartile have a higher neurodevelopment rate by 0.36 SDs at the mean and by 0.6 SDs at the 0.9 quantile as well as a lower probability of high risk status by 0.13 percentage-points compared to those in the first wealth quartile. On the other hand, the differences in neurodevelopment rate between children in the first and fourth wealth quartiles are insignificant at the 0.1 and 0.25 quantiles. The difference in neurodevelopment rate between children in the fourth versus first wealth quartile is significantly larger at the 0.9 quantile compared to the 0.1 quantile. Children in the third wealth quartile have a higher neurodevelopment rate at the 0.9 quantile by about 0.5 SDs compared to those in the first wealth quartile; this difference is significantly different from those between these two wealth categories at the 0.1 and 0.25 quantiles of neurodevelopment rate. Finally, the increase in neurodevelopment rate for children in the second wealth quartile compared to the first quartiles is largest at the 0.25 quantile (0.32 SD) and median (0.35 SD) but is insignificant at other quantiles. Fig. 1 shows the wealth gradients at neurodevelopment rate quantiles 0.05 through 0.95 in increments of 0.05. These plots indicate that these gradients are generally largest for children at high neurodevelopment quantiles and smallest for those at low quantiles.

Very few other variables are related to child neurodevelopment in the Brazilian sample. Children of mothers who attended a university have a higher average neurodevelopment rate. In contrast, maternal age and being unmarried are associated with an increased likelihood of the child being at high risk of neurodevelopmental problems. Finally, male children have lower neurodevelopment rate at the mean compared to females.

Chile—In general, there are no significant associations between wealth and neurodevelopment in the Chilean sample. The linear wealth index has coefficients of the expected sign but none are statistically significant. A large and significant decrease in the 0.9 quantile of neurodevelopment rate is observed with being in the second wealth quartile compared to the first quartile (which is opposite to what is expected). In contrast, being in the third wealth quartile relative to the first is associated with a lower probability of being at high risk of neurodevelopmental problems by about 1.6 percentage points (statistically significant).

Large maternal education gradients in neurodevelopment rate are observed in the Chilean sample. Mothers who attended high school have children of higher neurodevelopment rate compared to those with lower education by 0.35–0.58 SDs at the mean and 0.6–0.8 SDs at the 0.9 quantile; differences at lower quantiles are smaller and generally insignificant. The mother being unmarried but in a stable relationship is negatively associated with neurodevelopment rate at the mean. Also, native ancestry is associated with a large decrease in neurodevelopment rate at the 0.1 quantile. In contrast, an increase in the number of household adults is associated with an increase in neurodevelopment rate especially at lower quantiles.

Ecuador—In the sample from Ecuador, wealth gradients in average neurodevelopment rate and high risk status are generally insignificant but have the expected sign. The linear wealth index is positively related to the median of neurodevelopment rate (marginally significant); a one SD increase in wealth is associated with an increase in neurodevelopment rate by 0.15 SDs. Also, being in the fourth wealth quartile is positively and significantly associated with the median of neurodevelopment rate – an increase in neurodevelopment median by 0.44 SDs compared to the first wealth quartile.

The other model variables have generally insignificant effects in this sample except for a large decline in neurodevelopment rate at the 0.5 and 0.75 quantiles of neurodevelopment rate for children of single mothers compared to married ones. Maternal incomplete secondary education is associated with a decrease in neurodevelopment rate at the 0.5 quantile compared to lower education (marginally significant), while male children have a marginally lower neurodevelopment rate at the median compared to females.

Discussion

The study finds notable differences in wealth gradients in child neurodevelopment between the included South American countries. A large positive wealth gradient is observed in Brazil. In contrast, differences in neurodevelopment by wealth in Argentina, Chile, and Ecuador are much smaller and less consistent than in Brazil. These results suggest that wealth gradients in early child neurodevelopment are country-specific and vary between populations. An important implication of this result is that findings from previous studies based on specific populations may not be generalizable to other countries. Furthermore, this suggests that wealth gradients in child neurodevelopment are dynamic rather than fixed and are sensitive to population characteristics that may modify their intensity. Future research studies of wealth and other socioeconomic gradients in child development should consider

this potential heterogeneity when discussing the generalizability of their results for other populations.

We find significant positive wealth gradients in early child neurodevelopment in the first two years of life in Brazil, especially for children who rank on the higher quantiles of the neurodevelopment rate distribution. Since wealth gradients are largest at the right tail of this distribution, wealth may be related to neurodevelopment inequalities in the form of a wider range between children ranking at the opposite sides of the neurodevelopment rate distribution. Therefore, wealth may play an important role in early neurodevelopment disparities in Brazil.

Identifying the sources of heterogeneity in wealth gradients between the study countries and the pathways leading to larger wealth gradients in Brazil than the other three countries is beyond the scope of this paper and deserves future research. However, observable economic and social differences between these countries suggest that these may play a role in modifying the association between wealth and child neurodevelopment. The Brazilian sample has a notably lower maternal education than the other samples, with about 46% of the mothers not having attended secondary school, compared to 25%, 31%, and 16% for Argentina, Chile, and Ecuador, respectively. This suggests larger educational disparities in the Brazilian sample, and consequently greater wealth differences than the other country samples. In other words, variation in the constructed wealth index may reflect larger differences in real wealth in the sample from Brazil compared to the other countries.

Between-country differences in demographic and cultural characteristics, economic growth, welfare systems, and healthcare infrastructures may also contribute to intensifying or attenuating wealth gradients in child neurodevelopment. Among the four countries, Brazil ranks the second lowest on population income and health expenditure per capita after Ecuador, the highest on GINI coefficient indicating economic inequality and on homicide rates, and the second highest on under-five mortality after Ecuador (see country comparisons on these indicators in Appendix Table A9). Also, among the study countries, the Brazilian population is the most racially diverse (see Table 1) with significant racial disparities in health and economic status especially by African ancestry (Nyarko, Lopez-Camelo, Castilla, & Wehby, 2012; Telles, 1992; Telles, 2004; Telles & Lim, 1998). Such economic and social differences may increase the relevance of household wealth relative to other inputs for child health and neurodevelopment in Brazil. For example, the greater economic inequality in Brazil suggests (similar to the higher educational disparities) that a change in the constructed wealth scales by the same unit indicates a larger difference in real wealth and income in Brazil than in the other countries. Ranking highest on homicide rates suggests that the difference in physical safety between wealthier and poorer households in Brazil may exceed on average that in other countries. This may translate into greater differences in maternal stress and access to outdoor activities that are important for child development such as routine healthcare visits, obtaining fresh food products, and recreational activities between wealthier and poorer households in Brazil than the other countries. Of course, research is needed to formally study the role that these channels may play in modifying wealth gradients between the study countries. As discussed above, differences in quality and prices of household and market-level inputs needed for child health and development such as routine pediatric care, adequate nutrition, availability of quality childcare (including both informal and formal), parent information and skills in providing optimal care and investing in the child such as by spending time in playing with or reading to the child (Wehby, McCarthy et al., 2011), and a clean and hazard-free physical environment (both in and outside the household) may also contribute to the variation in wealth gradients between countries. We leave these potential channels for future research studies.

The results highlight an important role, mainly in Brazil, for household wealth in early child neurodevelopment, which may be considered an early form of human capital given its strong correlations with long-term human capital. This gradient highlights the need to target poverty as a key factor in health and human capital disparities earlier in life rather than later as early developmental deficits will be carried forward and possibly multiplied later in life. The observed wealth gradients are not explained by differences in early physical growth since only healthy children with normal birth outcomes (including birth weight ≥ 2500 g and gestational age ≥ 37 weeks) and without health complications were enrolled into the parent study providing the data for our study. This suggests that wealth gradients in neurodevelopment can occur through other pathways besides physical health. Indeed, previous work has shown that socioeconomic gradients in child neurodevelopment in the study infants are largely explained by differences in direct household investments in child neurodevelopment such as through reading to the child and involving the child in specific playing activities (Wehby, McCarthy et al., 2011).

To our knowledge, this is the first study to compare wealth gradients in very early child neurodevelopment between different countries using the same data source and analytical approach. The study is novel and provides important implications, but has some caveats that warrant discussion and highlight additional future research opportunities. This is an observational study that evaluates the association between wealth and neurodevelopment but is unable to infer the causal effects of wealth. We cannot employ methods that estimate causal effects such as instrumental variables due to the lack of instruments for wealth (i.e. measures of an exogenous change in wealth). Even though we control for several relevant control variables, it is still possible that there are other omitted variables such as paternal IQ and human capital and parenting skills that relate to both wealth and child neurodevelopment. Another limitation is that samples are of moderate size and may not adequately represent the entire child population in the study countries. However, the large socioeconomic and demographic diversity in the study samples (Table 1) suggest that they are likely to be representative of a large percentage of the child population in the study countries. A part of wealth gradients in neurodevelopment in the general population may occur through fetal growth and postnatal health. However, this pathway is mostly held fixed in this study since the sample is limited to children with normal birth outcomes and without health complications. Even though the majority of children are without health complications, the wealth gradients in neurodevelopment observed in this study may underestimate those in the entire child population including children with health complications. Therefore, additional studies using large and population-based samples are needed to identify the total wealth gradients in early child neurodevelopment in the study countries. Also, more work is needed to identify the pathways through which wealth effects on neurodevelopment develop.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Fig. 1.
Wealth effects on neurodevelopment rate in Brazil.

Note: The graph shows the effects of wealth measures on neurodevelopment rate quantiles (solid line). The x-axis is labeled with the quantile at which the effects are estimated. The y-axis represents the effect. The 95% confidence intervals of the effects on quantile are in the shaded area. The dashed line represents the OLS effect of wealth measures at the mean of neurodevelopment rate. All wealth quartile effects are estimated with the first quartile as the omitted/reference category.

Table 1

Distribution of study variables.

Variable	Description	Argentina	Brazil	Chile	Ecuador
Neurodevelopment rate ^a	Child neurodevelopment rate relative to other children of similar age	0.00 (13.68)	0.00 (15.06)	0.00 (14.40)	0.00 (13.16)
High development risk ^a	0/1 indicator for being at high risk of neurodevelopmental problems	0.13 (0.34)	0.21 (0.41)	0.22 (0.42)	0.25 (0.43)
Linear wealth index	PCA derived wealth index based on asset ownership and household quality	0.00 (1.13)	0.00 (0.93)	-0.003 (0.95)	0.00 (1.14)
Maternal secondary school incomplete ^b	0/1 indicator for incomplete maternal secondary schooling	0.25 (0.44)	0.15 (0.36)	0.18 (0.39)	0.17 (0.37)
Maternal secondary school complete ^b	0/1 indicator for complete maternal secondary schooling	0.30 (0.46)	0.26 (0.44)	0.39 (0.49)	0.28 (0.45)
Maternal university incomplete ^b	0/1 indicator for incomplete maternal university education	0.11 (0.31)	0.043 (0.20)	0.12 (0.33)	0.20 (0.40)
Maternal university complete ^b	0/1 indicator for complete maternal university education	0.09 (0.29)	0.09 (0.29)	0.15 (0.36)	0.19 (0.39)
Maternal age	Maternal age in years	26.97 (6.47)	26.30 (6.37)	28.05 (6.70)	26.89 (6.55)
Maternal age squared	Maternal age in years squared	768.99 (369.73)	732.14 (358.70)	831.83 (390.20)	765.95 (381.40)
Mother is single ^c	0/1 indicator for single mothers	0.16 (0.36)	0.17 (0.37)	0.19 (0.39)	0.13 (0.33)
Mother in stable relationship ^c	0/1 indicator for mother in a stable but unmarried relationship	0.44 (0.50)	0.45 (0.50)	0.29 (0.46)	0.22 (0.41)
African ancestry ^d	0/1 indicator for child having African ancestry		0.46 (0.50)		
Native ancestry ^d	0/1 indicator for child having Native Ancestry	0.54 (0.50)	0.19 (0.39)	0.55 (0.50)	0.35 (0.48)
Male child	0/1 indicator for a male child	0.50 (0.50)	0.51 (0.50)	0.49 (0.50)	0.51 (0.50)
Number of household adults	Total number of adults living in the household	3.13 (1.91)	2.99 (2.06)	3.5 (1.66)	3.84 (2.13)

Note: The Table reports the means and standard deviations (in parentheses) of the study variables.

^aDerived from the Bayley Infant Neurodevelopment Screener. Copyright © 2004. Harcourt Assessment Inc. Used with Permission. All rights Reserved.

^bThe reference category is complete primary schooling or less.

^cThe reference category is married.

^dThe reference category is other ancestry.

Table 2

Wealth effects on child neurodevelopment.

Neurodevelopment rate							High risk status
OLS		Quantile regression/quantiles					Probit
-	0.1	0.25	0.5	0.75	0.9	-	
Argentina							
Linear wealth index	0.69* (0.34)	0.89 (0.91)	0.22 (0.73)	0.26 (0.61)	1.18** (0.52)	1.22* (0.71)	0.0005 (0.0005)
Second wealth quartile	-0.74 (1.86)	-2.57 (2.78)	-1.48 (1.99)	1.34 (1.77)	0.73 (1.49)	2.03 (2.00)	0.0022 (0.0016)
Third wealth quartile	0.45 (1.52)	0.96 (2.61)	-0.48 (1.95)	0.69 (1.74)	0.43 (1.60)	0.54 (2.13)	0.0021 (0.0028)
Fourth wealth quartile	1.32 (1.50)	0.54 (3.06)	0.01 (2.27)	1.10 (2.11)	1.53 (1.77)	1.84 (2.35)	0.0006 (0.0019)
Brazil							
Linear wealth index	2.16* (1.02)	0.89 (1.67)	1.63 (1.26)	1.86* (1.03)	2.38** (1.02)	3.78*** (1.05)	-0.0527** (0.0210)
Second wealth quartile	3.69* (1.78)	0.73 (3.96)	4.88** (2.46)	5.29** (2.23)	1.25 (2.12)	4.32 (2.65)	-0.0853*** (0.0329)
Third wealth quartile	3.99* (1.94)	-3.63 (3.58)	0.71 (3.33)	4.76* (2.78)	4.11 (2.62)	7.62** (2.96)	-0.0535 (0.0465)
Fourth wealth quartile	5.38** (2.11)	4.38 (3.80)	4.58 (3.19)	5.89** (2.61)	5.80* (3.23)	8.97** (3.64)	-0.1265*** (0.0303)
Chile							
Linear wealth index	1.13 (0.71)	1.88 (1.94)	1.92 (1.51)	0.53 (1.14)	1.52 (1.09)	-1.13 (1.44)	-0.0101 (0.0078)
Second wealth quartile	-2.37 (1.37)	-1.31 (4.57)	0.40 (3.31)	-1.43 (2.45)	-3.86 (2.52)	-7.70*** (2.70)	0.0218 (0.0165)
Third wealth quartile	1.63 (2.20)	2.28 (4.15)	1.98 (3.17)	0.42 (2.44)	1.26 (2.53)	-2.89 (2.46)	-0.0158** (0.0078)
Fourth wealth quartile	0.82 (2.35)	2.28 (5.44)	2.56 (3.69)	0.53 (2.57)	0.12 (2.88)	-1.60 (3.87)	-0.0039 (0.0267)
Ecuador							
Linear wealth index	0.55 (0.96)	1.51 (1.48)	0.92 (1.46)	1.78* (0.91)	-0.07 (1.00)	-0.74 (1.37)	-0.0222 (0.0375)
Second wealth quartile	0.23 (1.04)	1.25 (3.70)	0.55 (2.87)	2.49 (1.88)	0.85 (2.22)	-2.28 (3.21)	-0.0372 (0.0461)
Third wealth quartile	0.65 (1.71)	1.22 (3.91)	-1.10 (3.29)	3.29 (2.33)	0.28 (2.95)	0.93 (3.60)	-0.0050 (0.0722)
Fourth wealth quartile	2.21 (2.88)	1.14 (5.49)	4.29 (4.08)	5.75*** (2.68)	-0.69 (3.46)	-2.50 (4.25)	-0.1015 (0.1098)

Note: The Table reports the effects of wealth measures on child neurodevelopment by country. Standard errors are in parentheses. *, **, and *** indicate $p < 0.1$, < 0.05 , and < 0.01 , respectively. The effects of the linear wealth index are estimated in a separate regression from the wealth quartile effects. The effects of the second, third and wealth quartiles are in reference to the first quartile (omitted category).

Table 3

Effects of other model variables on neurodevelopment.

	Argentina			Brazil			Chile			Ecuador		
	Neuro-development rate		High risk status	Neuro-development rate		High risk status	Neuro-development rate		High risk status	Neuro-development rate		High risk status
	OLS		Probit	OLS		Probit	OLS		Probit	OLS		Probit
Incomplete secondary school	-0.42 (0.89)		-0.26* (0.15)	2.28 (1.45)		-0.32* (0.18)	8.35** (2.11)		-0.47* (0.24)	-2.73 (2.00)		0.23 (0.26)
Complete secondary school	0.41 (1.49)		-0.25 (0.18)	0.63 (1.35)		-0.05 (0.19)	5.07** (1.15)		-0.18 (0.28)	-1.24 (2.41)		0.29 (0.30)
Incomplete university	0.02 (1.33)		-0.10 (0.16)	4.89** (1.96)		-0.45 (0.32)	4.82 (2.81)		0.06 (0.14)	1.91 (2.43)		-0.10 (0.26)
University graduate	0.97 (1.34)		-0.90*** (0.30)	4.33 (3.39)		-0.17 (0.16)	1.46 (1.27)		0.18 (0.14)	0.74 (3.42)		0.05 (0.39)
Maternal age	0.13 (0.54)		-0.05 (0.06)	-1.07 (0.60)		0.13* (0.07)	0.04 (0.48)		0.02 (0.08)	-0.54 (0.46)		-0.00 (0.05)
Maternal age squared	-0.00 (0.01)		0.00 (0.00)	0.02 (0.01)		-0.00* (0.00)	0.00 (0.01)		-0.00 (0.00)	0.01 (0.01)		0.00 (0.00)
Mother is single	-5.04* (2.68)		0.41 (0.30)	-1.74 (1.27)		0.36* (0.22)	-0.99 (1.35)		-0.00 (0.14)	-4.79* (2.32)		0.34 (0.24)
Mother is in a stable relationship	-2.14** (0.77)		0.16 (0.14)	-3.61** (1.18)		0.36* (0.21)	-2.18* (0.88)		0.15 (0.17)	1.57 (1.24)		0.01 (0.12)
African ancestry				-0.63 (1.29)		0.30 (0.25)						
Native ancestry	-1.86 (1.62)		0.16 (0.16)	2.12 (2.10)		0.14 (0.32)	-1.24 (0.93)		-0.10 (0.09)	1.39 (1.63)		-0.15 (0.10)
Male child	-4.17*** (0.75)		0.46*** (0.11)	-2.48* (1.07)		0.11 (0.13)	-1.17 (0.77)		0.14 (0.10)	-1.31 (0.84)		0.05 (0.14)
Household adults	0.30 (0.52)		-0.03 (0.04)	0.31 (0.35)		-0.01 (0.04)	1.12*** (0.20)		-0.11*** (0.03)	0.18 (0.41)		-0.02 (0.03)
Observations	664		516	388		464						
R ² (OLS)/pseudo R ² (Probit)	0.233		0.251	0.168		0.143	0.267		0.21	0.105		0.06

Note: The Table lists the effects of the control variables on neurodevelopment rate from the OLS model and on the probability of high risk status (marginal/incremental effects) from the probit regression. Standard errors are in parentheses. *, **, and *** indicate $p < 0.1$, <0.05 , and <0.01 , respectively. The models include the linear wealth index effects (in Table 2) and area fixed effects, which are not shown (along with the intercept) in this table for brevity.