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The impact of altitude on infant health in South America

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ABSTRACT

Several studies report that altitude reduces birth weight. However, much remains unknown about effects in various altitude ranges and about the heterogeneity in altitude effects by fetal health endowments. This study estimates the effects of altitude in South America on the means and quantiles of birth weight and gestational age separately for two large samples born at altitude ranges of 5 to 1,280 m and 1,854 to 3,600 m. The study finds significant negative altitude effects on birth weight and gestational age in the low-altitude sample and on birth weight in the high-altitude sample. Altitude effects are larger for infants with very low fetal health endowments. The study finds differences in the effects of several inputs such as socioeconomic status and maternal fertility history and health between the two altitude samples. The study highlights the importance of adverse altitude effects on infant health when evaluating the costs and returns of policies that change the number of individuals who reside at higher altitude in both low and high altitude ranges.

1. Introduction

Several studies evaluate the impacts of altitude on infant and child health and find negative altitude effects on birth weight in the United States (Unger et al., 1988), South America (Hartinger et al., 2006), and other populations (Moore, 2001; Moore et al., 2001). Altitude may constrain fetal growth through fetal exposure to low oxygen levels (Grahn and Kratchman, 1963; Ballew and Haas, 1986; Zamudio et al., 2006). Studies also find larger altitude effects on birth weight and maternal blood and oxygen flow into the fetus among individuals who do not have an ancestry of inhabiting high altitudes relative to individuals who have this ancestry, such as European versus Andean ancestry, providing support for direct biologic altitude effects (Julian et al., 2007, 2009a; Bennett et al., 2008; Postigo et al., 2009).

Altitude may also indirectly affect infant health through impacting relevant social and economic inputs. Altitude may constrain agricultural production and increase costs of transporting fresh food products, which may result in maternal nutritional deficiencies (Niermeyer et al., 1995; Cook et al., 2005; Niermeyer, 2008). Altitude may also reduce social and economic growth in certain areas by increasing communication and development costs. However, altitude effects on economic growth may vary between populations. For example, several large and developed cities are at high altitudes in South America.[1] A few studies find

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[1] Significant variation may exist in economic development between cities at high altitude. For example, the average economic growth in Bogota, Colombia (2,640 m) may exceed that in Quito, Ecuador (2850 m), which in turn may exceed that in La Paz, Bolivia (3,600 m).

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persisting effects of altitude on birth weight after accounting for socioeconomic characteristics (Giussani et al., 2001; López Camelo et al., 2006). However, very few studies account for socioeconomic factors when studying altitude effects on infant health.

Birth outcomes are important infant health measures and major predictors of child development, future health, and human capital (Anderson and Doyle, 2003; Frankel et al., 1996; Gluckman et al., 2008; Victora et al., 2008; Currie, 2009). Low birth weight significantly increases hospital and special education costs (Chaikind and Corman, 1991; Almond et al., 2005). Given that many South American populations live at high altitudes, evaluating altitude effects on birth outcomes is important for identifying potential altitude-health risks and informing public policies to reduce them.

Previous studies focus on assessing the effects of very high altitudes, which may apply to few areas and populations. However, studies of altitude effects within altitude ranges at which several large populations reside are less common. For example, very few studies evaluate altitude effects below 2,000 m. A thorough estimation of altitude effects on birth outcomes at various altitude levels is important for identifying potential non-linearity in these effects.

This study estimates altitude effects on birth weight and gestational age in South America. South American populations are particularly suited for such studies, because several large cities, such as Bogota in Colombia, Quito in Ecuador, and La Paz in Bolivia, are at altitudes between 2,500 and 3,600 m.[2] The large altitude variation within and between South American countries and the large percentages of their populations residing at high altitudes increase study power and generalizability. Furthermore, significant variation in socioeconomic and demographic characteristics exists in South American populations, allowing for evaluating the extent to which these characteristics explain altitude effects on infant health.

2. Study's contribution

The study employs a multi-country sample that has extensive variation in residential altitude and is one of the largest and most representative samples to be employed in studies of altitude and infant health. This sample allows for estimating altitude effects across several South American populations and wide altitude ranges. Unlike several previous studies that focus on isolated geographic areas with extreme altitude differences, this study evaluates the marginal effects of altitude in a low-altitude range from 5 to 1,280 m and a high-altitude range from 1,854 to 3,600 m. The study accounts for several relevant inputs that may correlate with both birth outcomes and altitude. Most previous studies account for a limited number of such inputs.

The study employs quantile regression for estimating the effects of altitude at multiple locations of the conditional distributions of birth outcomes. Previous studies estimate altitude effects on the means of birth outcomes. Such effects may not be representative of the effects at other locations of the outcome distributions. Estimating the effects of altitude at multiple quantiles of the birth outcome distributions evaluates the potential heterogeneity in altitude effects by the net level of unobserved fetal health endowments that determine the child's rank on these distributions (Wehby et al., 2009a).

3. Methods

3.1. Analytical framework

The study employs a reduced-form production function of infant health that includes altitude and other observed relevant factors for infant health. Specifically, we use the following model:

$$\textit{Infant health} = f(\textit{altitude}, \textit{maternal health}, \textit{socioeconomics}, \textit{demographics}, \textit{healthcare characteristics}). \quad (1)$$

Altitude may influence infant health indirectly through its impact on some of the factors in Eq. (1). However, altitude may also correlate with these factors due to potential self-selection into altitude based on human capital, health, and other factors, such as efficiency in household production of health, preferences for living and work environments, ancestry, and physical ability. Omitting these factors from the model may, therefore, result in omitted variable bias in estimating altitude effects. However, in order to gauge the extent to which such factors explain altitude effects, we estimate an additional nested function that excludes these factors.

3.2. Study sample

The study sample includes 63,946 infants born in South America between 1982 and 2008. Of the total sample, 5,803 infants were born in Bolivia, Colombia and Ecuador at altitudes between 1,854 and 3,600 m, and 58,143 infants were born in Argentina, Brazil, Chile and Colombia at altitudes between 5 and 1,280 m. The infants were born in 117 healthcare institutions (primarily hospitals) that are affiliated with the Latin American Collaborative Study of Congenital Anomalies (ECLAMC), which is a surveillance program of birth defects in affiliated hospitals (Castilla and Orioli, 2004).

Health professionals, primarily pediatricians, at the ECLAMC-affiliated healthcare institutions identify infants with birth defects and infants without birth defects in the same institution, and they match unaffected infants one-to-one to affected infants by date of birth and sex.[3] The health professionals enroll the infants into the ECLAMC program before they are discharged from the healthcare

[2] In addition to these cities, several smaller cities are also located at high altitudes such as Ibarra (2,620 m) and Azogues (about 2,883 m) in Ecuador, Cochabamba, Bolivia (2,558 m), Cusco, Peru (3,300 m) and others.

[3] Institutions and health professionals voluntarily join ECLAMC. The health professionals receive standard training and attend yearly retraining and scientific ECLAMC meetings.

institution after birth.[4] The health professionals obtain data on birth outcomes, prenatal factors, socioeconomics, demographics, and other characteristics from interviews with mothers prior to discharge and from the institutional medical records.[5]

As several studies suggest that altitude impacts the risk of certain birth defects (Poletta et al., 2007; Castilla et al., 1999; Orioli et al., 2003) and that several birth defects may reduce birth weight and gestational age (Wehby et al., 2009b,c), this study only includes infants without birth defects. The study sample includes singleton live births with birth weights between 500 and 6,000 g and gestational age between 19.5 and 46.5 weeks in order to avoid data collection errors.[6]

The study sample has a wide geographic and socioeconomic diversity and is one of the largest samples for studying infant health production in South America. The matched selection of unaffected infants to infants with birth defects as described above reduces any potential bias in selecting the unaffected sample based on birth weight or related characteristics.[7] The majority of births in the study countries are born in healthcare institutions.[8]

3.3. Study measures

Infant health is measured by birth weight in grams and gestational age in weeks.[9] The study evaluates altitude as a continuous measure in separate birth outcome functions for the low- and high-altitude samples of the study.[10] Maternal health characteristics include indicators for any acute (such as the flu) and chronic (such as diabetes or hypertension) illnesses during pregnancy. We also include indicators for maternal pregnancy history (numbers of previous live births and stillbirths/miscarriages, difficulty with conception) and exposure to physical shocks during pregnancy.

Socioeconomic status is measured with an index of maternal education and occupational status using principal component analysis (PCA) with maximum likelihood estimation of the polychoric correlations between the latent variables of the observed ordinal scales (Kolenikov and Angeles, 2004).[11] Education and occupational status are both domains of socioeconomic status and may have important effects on health. PCA is a common approach to aggregate multiple indicators of household wealth and socioeconomic status into a single index (Filmer and Pritchett, 2001; Paxson and Schady, 2007). In PCA, the first principal component explains the maximum variance in the index variables. The index is constructed using the scoring coefficients of the first principal component as weights for education and occupational status under the assumption that long-term socioeconomic status explains the maximum variance in education and occupational status. The first principal component explains about 80 and 71.3% of the variance in the low- and high-altitude samples, respectively.[12]

The model includes maternal age, infant's sex and ethnic ancestry.[13] Also included are characteristics of the healthcare institution of birth that may relate to access and quality of healthcare in the communities of the study infants. These are institutional university affiliation, type (maternity hospital, general hospital, and other facility including multi-clinic facility), and ownership (public including national, provincial, and other public, and private).[14] The model also includes time effects in order to account for any changes in birth outcomes over time as well as country fixed effects in order to account for differences between the study countries in birth outcomes and altitude. Table 1 reports the distribution of study variables.

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[4] About 95% of the identified unaffected infants enroll into the ECLAMC program (Participation in ECLAMC, personal communication with Eduardo E. Castilla, ECLAMC Coordinator, on December 4, 2009). If an eligible infant does not enroll in the study, the health professionals identify the next eligible infant, based on the same matching criteria, for potential enrollment into the study.

[5] Health professionals collect data using the same instruments across ECLAMC-affiliated institutions and transmit the data to ECLAMC's headquarters in Brazil (Rio de Janeiro) and Argentina (Buenos Aires) for data entry, quality checking, and storage. Several studies of maternal and infant health have used this data source (Wehby et al., 2009a,b,c,d).

[6] Such restrictions are common in birth outcome studies (Warner, 1995, 1998; Conway and Deb, 2005).

[7] Population-level data on birth outcomes are not easily accessible for all the study countries. The rates of LBW in the samples from Argentina and Brazil are overall comparable to those in other studies using other samples from these countries (Goldani et al., 2004; Kramer et al., 2005). Access to population-level data on other study variables is limited. Some of the available population-level socioeconomic characteristics in Brazil are overall comparable to the ECLAMC sample. For example, about 44% of the population age 0–4 years in 2000 have African ancestry based on self-reported race (IBGE, 2000a). About 41 and 43% of the ECLAMC births in Brazil in 1999 and 2000, respectively, have African ancestry. About 49% of women age 20–39 in 2000 have not completed primary school (IBGE, 2000b). About 45.9% of mothers in the ECLAMC sample in 2000 in Brazil have not completed primary school.

[8] Skilled health professionals attend about 99, 61, 97, 100, 96, and 80% of births in Argentina, Bolivia, Brazil, Chile, Colombia and Ecuador, respectively (WHO database: http://www.who.int/whosis/data/Search.jsp). The majority of these are likely to be institutional births. The estimates are for year 2005 for all countries except for Bolivia (2003) and Brazil (2004). To our knowledge, there are no available data on these rates at the community level and on the characteristics of home births in order to compare to the study sample. The study results are generalizable to the population of infants born in healthcare institutions.

[9] Gestational age is the time between the birth date and the date of last menstrual period.

[10] The study uses altitude at birth institution.

[11] The education measure includes the following eight categories: illiterate, literate without formal schooling, incomplete primary school, completed primary school, incomplete secondary school, completed secondary school, incomplete university, and completed university. Occupation status includes the following eight categories: housewife, unemployed, unqualified worker, qualified worker, independent worker, clerk, boss/owner, and professional/executive. The PCA index does not impose the restriction that education has no direct effects on health. It only incorporates its effects as part of the socioeconomic status index.

[12] Table A1 reports the first principal component scoring coefficients in the two samples.

[13] The mother reports child ancestry. Several children have multiple ancestries. We include non-mutually exclusive indicators for each ancestry.

[14] Direct measures of healthcare supply/quality at the community-level are not readily available.

3.4. Model estimation

The infant health production function is estimated by OLS for "mean effects" and by quantile regression (QR) for "quantile effects". QR estimates altitude effects at different quantiles across the conditional distributions of birth weight and gestational age and evaluates the effect heterogeneity by the net level of unobserved fetal health endowments including biologic, socioeconomic, and environmental factors that determine the infant's rank on the conditional outcome distributions. The model follows Chernozhukov and Hansen (2005):

$$H = Q(A, \boldsymbol{X}, U),\ \text{where}\ U \sim (0, 1), \tag{2}$$

where H represents birth weight or gestational age, A represents altitude and $\mathbf{X}$ includes the other inputs described above. For quantile q $(0 < q < 1)$, $Q(A,\mathbf{X},q)$ is the conditional qth quantile of H, and U is a uniformly distributed "unobserved" endowment level that determines the infant's rank on the conditional distribution of H. QR estimates the effects of A and $\mathbf{X}$ on Q holding U constant at q, and evaluates the heterogeneity in these effects by q (or U):

$$H = Q(\alpha_{0q} + \beta_q A + \boldsymbol{X}\boldsymbol{\lambda}_q) \tag{3}$$

where β is the effect of altitude and $\boldsymbol{\lambda}$ includes the effects of $\mathbf{X}$ on the qth conditional quantile of H.

The QR model is estimated for quantiles 0.1, 0.25, 0.5, 0.75 and 0.9 using standard QR (Koenker and Bassett, 1978; Koenker and Hallock, 2001) which minimizes the sum of weighted absolute deviations between the conditioned and actual H for each q as follows:

$$\min\left[q\sum_{H_i \geq Q_i}^{n}|H_i - Q_i| + (1-q)\sum_{H_i < Q_i}^{n}|H_i - Q_i|\right]. \tag{4}$$

The OLS variance–covariance matrix is estimated by a Huber-type estimator that accounts for the sample clustering within the healthcare institutions of birth (Moulton, 1986; Wooldridge, 2002). The QR variance–covariance matrix is estimated by bootstrap with 500 replications, and differences in quantile effects are tested using standard Wald tests (Hao and Naiman, 2007).

4. Results

4.1. "Mean effects" of altitude

Tables 2 and 3 report the OLS coefficients for the low- and high-altitude samples, respectively. Altitude has significant negative effects on birth weight and gestational age in the low-altitude sample but has significant negative effects only on birth weight in the high-altitude sample. Altitude effects on birth weight are slightly larger (in absolute value) in the low-altitude sample, where altitude reduces birth weight by about 9 g and gestational age by 0.04 weeks per 100 m. In the high-altitude sample, altitude reduces birth weight by about 7 g per 100 m. The model inputs explain up to one-third of the unadjusted altitude effects.

4.2. "Quantile effects" of altitude

4.2.1. Low-altitude sample

Table 4 reports the altitude effects on the conditional quantiles of birth weight and gestational age in the low-altitude sample.[15] Altitude has significant negative effects on the five birth weight quantiles with significantly larger effects at the 0.1 quantile. A In the full specification, altitude reduces the 0.1 and 0.9 quantiles by about 10 and 7 g, respectively, per 100 m. The model inputs explain more than one-third of the unadjusted altitude effects at lower quantiles.

Altitude has significant negative effects on gestational age quantiles with significantly larger effects at the 0.1 quantile. A In the full specification, altitude reduces the 0.1 and 0.9 quantiles by about 0.08 and 0.03 weeks, respectively, per 100 m. The model inputs explain about one-third of the unadjusted altitude effect at quantile 0.1.

4.2.2. High-altitude sample

Table 5 reports altitude quantile effects in the high-altitude sample.[16] In the full specification, altitude reduces the 0.1, 0.25 and 0.75 conditional birth weight quantiles by about 13, 6 and 9 g, respectively, per 100 m (effects at the 0.1 and 0.25 quantiles are marginally significant) but has insignificant effects at the other quantiles. However, differences in effects between quantiles are insignificant. The model inputs explain more than half of the unadjusted altitude effect at quantile 0.5. Unlike other quantiles, the adjusted negative altitude effect at the 0.1 quantile is larger than the unadjusted effect. Altitude has overall insignificant effects on gestational age quantiles in the high-altitude sample.

4.3. Other input effects on birth weight

We focus on comparing other input effects on birth weight between the two altitude samples. Maternal acute illnesses have small negative effects on birth weight mean in both samples, but have significant effects at lower quantiles in the low-altitude sample and insignificant quantile effects in the high-altitude sample. Chronic illnesses have significant negative effects on birth weight only in the low-altitude sample with larger effects at lower quantiles. Difficulty in conception has larger negative effects in the high-altitude sample especially at lower quantiles. The number of previous live births has larger positive "mean effects" in the low-altitude sample, and has insignificant effects at lower quantiles in the high-altitude sample. The number of miscarriages/stillbirths has negative effects on birth weight only in the low-altitude sample with decreasing effects by the quantile order.

[15] Table A2 in Appendix reports the full quantile regression coefficients of the birth weight production function for the 5–1,280 m range. The full results for the gestational age function are available from the authors upon request.

[16] Table A3 in Appendix reports the full quantile regression coefficients of the birth weight production function for the 1,854–3,600 m range. The full results for the gestational age function are available from the authors upon request.

Table 1
Description of study variables.

Variable	Description	Mean (SD)	
		Low-altitude sample	High-altitude sample
Birth weight	Infant's birth weight in g	3235.09 (568.84)	3096.01 (489.08)
Gestational age	Infant's gestational age in weeks	39.06 (2.78)	39.04 (2.6)
Altitude	Altitude at hospital of birth (in 100 m unites)	3.34 (3.11)	28.49 (5.71)
Acute illnesses	Indicator (0,1) for maternal acute illnesses	0.32 (0.47)	0.30 (0.46)
Chronic illnesses	Indicator (0,1) for maternal chronic illnesses	0.12 (0.33)	0.05 (0.21)
Conception difficulty	Indicator (0,1) for difficulty in conception	0.08 (0.27)	0.03 (0.17)
Live births	Number of live births	1.50 (2.00)	1.28 (1.92)
Miscarriages/stillbirths	Number of miscarriages/stillbirths	0.25 (0.72)	0.19 (0.66)
Physical shocks	Indicator (0,1) for exposure to physical shocks in first trimester	0.03 (0.16)	0.02 (0.14)
SES	Socioeconomic status index	0.00 (1.03)	0.00 (1.13)
Maternal age	Maternal age in years	25.49 (6.54)	25.60 (6.39)
Maternal age squared	Maternal age in years squared	692.7 (358.63)	696.14 (353.2)
Male	Indicator (0,1) for a male infant	0.54 (0.50)	0.54 (0.5)
African ancestry	Indicator (0,1) for infant's African ancestry	0.19 (0.39)	0.02 (0.13)
Native ancestry	Indicator (0,1) for infant's Native ancestry	0.75 (0.43)	0.86 (0.34)
European Latin ancestry	Indicator (0,1) for infant's European Latin ancestry	0.45 (0.50)	0.40 (0.49)
European non-Latin ancestry	Indicator (0,1) for infant's European non-Latin ancestry	0.10 (0.31)	0.01 (0.08)
Other ancestry	Indicator (0,1) for infant's other ancestry	0.01 (0.09)	0.003 (0.05)
No university affiliation	Indicator (0,1) for birth at an institution not affiliated with a university	0.36 (0.48)	0.05 (0.22)
Maternity hospital	Indicator (0,1) for a birth at a maternity hospital	0.21 (0.41)	0.28 (0.45)
Other institution	Indicator (0,1) for a birth at an "other-type" healthcare institution	0.01 (0.11)	0.16 (0.37)
Private institution	Indicator (0,1) for a birth at a privately owned healthcare institution	0.03 (0.18)	0.32 (0.47)
State/Province institution	Indicator (0,1) for a birth at province/state owned healthcare institution	0.43 (0.49)	0.10 (0.30)
Local public institution	Indicator (0,1) for a birth at a local publicly owned healthcare institution	0.20 (0.40)	0.13 (0.33)
Brazil	Indicator (0,1) for a birth in Brazil	0.38 (0.49)	
Chile	Indicator (0,1) for a birth in Chile	0.25 (0.43)	
Colombia	Indicator (0,1) for a birth in Colombia	0.01 (0.12)	0.29 (0.45)
Ecuador	Indicator (0,1) for a birth in Ecuador		0.32 (0.47)
Birth year 1983	Indicator (0,1) for birth year of 1983	0.02 (0.14)	0.01 (0.11)
Birth year 1984	Indicator (0,1) for birth year of 1984	0.02 (0.13)	0.01 (0.12)
Birth year 1985	Indicator (0,1) for birth year of 1985	0.02 (0.13)	0.01 (0.12)
Birth year 1986	Indicator (0,1) for birth year of 1986	0.02 (0.14)	0.02 (0.14)
Birth year 1987	Indicator (0,1) for birth year of 1987	0.01 (0.12)	0.02 (0.13)
Birth year 1988	Indicator (0,1) for birth year of 1988	0.02 (0.13)	0.02 (0.13)
Birth year 1989	Indicator (0,1) for birth year of 1989	0.02 (0.13)	0.01 (0.12)
Birth year 1990	Indicator (0,1) for birth year of 1990	0.02 (0.13)	0.02 (0.12)
Birth year 1991	Indicator (0,1) for birth year of 1991	0.03 (0.16)	0.01 (0.10)
Birth year 1992	Indicator (0,1) for birth year of 1992	0.03 (0.18)	0.01 (0.09)
Birth year 1993	Indicator (0,1) for birth year of 1993	0.04 (0.19)	0.01 (0.07)
Birth year 1994	Indicator (0,1) for birth year of 1994	0.04 (0.19)	0.004 (0.07)
Birth year 1995	Indicator (0,1) for birth year of 1995	0.04 (0.19)	0.01 (0.10)
Birth year 1996	Indicator (0,1) for birth year of 1996	0.04 (0.19)	0.02 (0.13)
Birth year 1997	Indicator (0,1) for birth year of 1997	0.03 (0.18)	0.01 (0.12)
Birth year 1998	Indicator (0,1) for birth year of 1998	0.04 (0.19)	0.01 (0.12)
Birth year 1999	Indicator (0,1) for birth year of 1999	0.04 (0.21)	0.02 (0.12)
Birth year 2000	Indicator (0,1) for birth year of 2000	0.07 (0.25)	0.02 (0.13)
Birth year 2001	Indicator (0,1) for birth year of 2001	0.07 (0.26)	0.05 (0.22)
Birth year 2002	Indicator (0,1) for birth year of 2002	0.07 (0.26)	0.08 (0.27)
Birth year 2003	Indicator (0,1) for birth year of 2003	0.07 (0.25)	0.10 (0.31)
Birth year 2004	Indicator (0,1) for birth year of 2004	0.07 (0.25)	0.13 (0.34)
Birth year 2005	Indicator (0,1) for birth year of 2005	0.06 (0.25)	0.14 (0.35)
Birth year 2006	Indicator (0,1) for birth year of 2006	0.04 (0.19)	0.09 (0.29)
Birth year 2007	Indicator (0,1) for birth year of 2007	0.04 (0.19)	0.09 (0.28)
Birth year 2008	Indicator (0,1) for birth year of 2008	0.02 (0.15)	0.06 (0.23)

Notes: Standard deviations (SD) of study variables are in parentheses. The reference country for the 5–1,280 m sample is Argentina. The reference country for the 1,854–3,600 m sample is Bolivia. The reference type of institution of birth is general hospital. The reference ownership of institution of birth is nationally owned healthcare institutions. The reference birth year is 1982.

Table 2
OLS regression coefficients of the birth weight production function in the low-altitude sample.

	Birth weight		Gestational age	
Altitude	−11.6***	−8.59***	−0.060***,a	−0.044***,a
	(3.64)	(2.90)	(0.011)	(0.011)
Acute illnesses		−28.6***		−0.15***
		(6.80)		(0.036)
Chronic illnesses		−55.1***		−0.29***
		(12.0)		(0.065)
Conception difficulty		−15.9*		0.014
		(8.18)		(0.050)
Live births		15.9***		−0.030***
		(1.81)		(0.0096)
Miscarriages/stillbirths		−18.3***		−0.10***
		(3.76)		(0.019)
Physical shocks		−26.6*		−0.16**
		(15.4)		(0.062)
SES		12.4**		0.015
		(5.17)		(0.017)
Maternal age		41.7***		0.17***
		(2.79)		(0.014)
Maternal age squared		−0.67***		−0.0031***
		(0.048)		(0.00024)
Male		106.3***		−0.084***
		(5.79)		(0.025)
African ancestry		−58.4***		−0.11
		(16.2)		(0.078)
Native ancestry		17.9*		0.090*
		(10.1)		(0.046)
European Latin ancestry		11.5		0.12***
		(10.2)		(0.044)
European non-Latin ancestry		21.7**		−0.029
		(9.32)		(0.036)
Other ancestry		−3.90		0.16
		(24.0)		(0.12)
No university affiliation		20.1		0.0037
		(17.6)		(0.071)
Maternity hospital		37.3**		0.056
		(16.5)		(0.080)
Other institution		−51.5*		−0.24
		(28.6)		(0.18)
Private institution		−27.2		−0.22
		(22.0)		(0.15)
State/Province institution		−48.8*		−0.30**
		(26.0)		(0.13)
Local public institution		−52.4*		−0.33**
		(29.0)		(0.13)
Brazil	−99.5***	−78.0***	0.087	0.049
	(22.6)	(25.0)	(0.076)	(0.096)
Chile	146.2***	101.4***	0.22***	−0.14
	(17.3)	(31.4)	(0.079)	(0.14)
Colombia	−142.7	−128.9	−0.61	−0.71
	(89.1)	(80.0)	(0.61)	(0.54)
Birth year 1983	−39.9	−34.3	−0.10	−0.085
	(29.6)	(29.3)	(0.13)	(0.13)
Birth year 1984	−34.3	−28.7	−0.23*	−0.20
	(31.3)	(28.0)	(0.13)	(0.13)
Birth year 1985	−53.1*	−50.5*	−0.32***	−0.33***
	(27.5)	(26.5)	(0.067)	(0.063)
Birth year 1986	−24.1	−20.0	−0.15*	−0.17**
	(34.9)	(36.0)	(0.086)	(0.085)
Birth year 1987	−59.1**	−55.6*	−0.35***	−0.39***
	(28.3)	(28.1)	(0.084)	(0.087)
Birth year 1988	−49.4*	−51.8**	−0.37***	−0.41***
	(26.0)	(23.8)	(0.071)	(0.064)
Birth year 1989	−79.0**	−82.6**	−0.43***	−0.47***
	(34.4)	(32.4)	(0.13)	(0.13)
Birth year 1990	−40.8	−44.2	−0.21*	−0.28***
	(40.8)	(37.5)	(0.11)	(0.10)
Birth year 1991	−11.6	−11.1	−0.23**	−0.28**
	(33.0)	(28.1)	(0.11)	(0.11)
Birth year 1992	−14.1	−22.3	−0.24**	−0.28**
	(42.5)	(35.2)	(0.12)	(0.11)

Table 2 (*Continued*)

	Birth weight		Gestational age	
Birth year 1993	−11.8	−9.04	−0.44***	−0.47***
	(43.5)	(34.8)	(0.13)	(0.13)
Birth year 1994	−23.4	−8.58	−0.43***	−0.41***
	(42.0)	(34.7)	(0.14)	(0.14)
Birth year 1995	−24.0	−3.76	−0.43***	−0.36**
	(40.3)	(32.1)	(0.15)	(0.15)
Birth year 1996	−31.8	−9.56	−0.55***	−0.48***
	(39.7)	(33.4)	(0.14)	(0.14)
Birth year 1997	−22.1	0.36	−0.45***	−0.37***
	(38.4)	(29.4)	(0.097)	(0.094)
Birth year 1998	−31.0	−8.06	−0.44***	−0.38***
	(41.2)	(33.6)	(0.096)	(0.096)
Birth year 1999	−16.9	9.43	−0.43***	−0.35***
	(41.5)	(32.9)	(0.12)	(0.13)
Birth year 2000	−16.5	4.15	−0.41***	−0.29**
	(39.6)	(31.4)	(0.12)	(0.12)
Birth year 2001	−6.33	18.9	−0.37***	−0.24**
	(38.7)	(32.0)	(0.11)	(0.12)
Birth year 2002	−19.7	8.14	−0.41***	−0.27**
	(38.9)	(32.1)	(0.11)	(0.12)
Birth year 2003	−28.4	−2.61	−0.45***	−0.33***
	(40.5)	(33.7)	(0.11)	(0.11)
Birth year 2004	−32.0	−3.11	−0.54***	−0.42***
	(41.4)	(33.6)	(0.13)	(0.13)
Birth year 2005	−48.8	−22.1	−0.80***	−0.66***
	(42.2)	(34.4)	(0.15)	(0.16)
Birth year 2006	−24.3	9.82	−0.59***	−0.47***
	(42.9)	(38.3)	(0.13)	(0.14)
Birth year 2007	−46.9	−21.2	−0.81***	−0.70***
	(45.2)	(37.5)	(0.14)	(0.14)
Birth year 2008	−40.3	−0.83	−0.74***	−0.62***
	(43.4)	(36.8)	(0.16)	(0.17)
Constant	3305.0***	2632.1***	39.6***	37.7***
	(38.0)	(54.5)	(0.093)	(0.23)

Standard errors are in parentheses.
[a] Indicates that the two coefficients are significantly different at $p < 0.05$.
* $p < 0.1$.
** $p < 0.05$.
*** $p < 0.01$.

Socioeconomic status has a small positive "mean effect" on birth weight but opposite patterns of quantile effects in the two altitude samples-effect decreases (increases) in the low- (high-) altitude sample by the quantile order. Maternal age has overall similar significant diminishing marginal positive effects (with age) and decreasing effects by the quantile order in both altitude samples. Male children have higher birth weights than females with increasing differences by the quantile order in both altitude samples. Child's African ancestry has a significant negative effect only in the low-altitude sample with decreasing effects by the quantile order. Native ancestry has a small positive effect in the low-altitude sample but negative effects in the high-altitude sample at the mean and lower quantiles.

Some healthcare institution effects also vary between the two altitude samples. Non-teaching status has larger positive effects at high quantiles in the high-altitude sample. In the low-altitude sample, infants born in maternity hospitals and in "other institutions" have larger and lower birth weight, respectively, than those born in general hospitals, but there are no such differences in the high-altitude sample. There are also differences in institution ownership effects between the two altitude samples.

5. Discussion

This study identifies negative altitude effects on birth weight in South America for both low (5–1,280 m) and high (1,854–3,600 m) altitude ranges. The study finds a 270–280 g decrease in birth weight mean with moving from sea-level (5 m) up to 3,600 m.[17] Larger decreases may occur at lower birth weight quantiles up to 400–420 g at the 0.1 quantile. Altitude may have larger negative effects among infants with poor fetal health endowments (i.e. those at the left margins of the birth outcome distributions) and may increase infant health disparities by widening the ranges between low and high birth weight quantiles (and gestational age quantiles at lower altitude ranges).

The results suggest that altitude primarily affects fetal growth at higher altitude ranges. The lack of negative altitude effects on gestational age at higher altitude ranges may be due to compensatory effects such as potential

[17] We estimate this effect using the marginal altitude effects from the full specification in the two altitude samples and assuming the altitude effects between 1,280 and 1,854 m to be alternatively equal to those in the low- or high-altitude samples.

Table 3
OLS regression coefficients of the birth weight production function in the high-altitude sample.

	Birth weight		Gestational age	
Altitude	−11.0***	−6.88**	−0.0057	−0.011
	(1.31)	(3.03)	(0.0046)	(0.011)
Acute illnesses		−30.6*		−0.15
		(17.3)		(0.11)
Chronic illnesses		−20.4		0.078
		(30.0)		(0.19)
Conception difficulty		−129.3**		−0.41
		(46.9)		(0.37)
Live births		7.21**		−0.064***
		(3.05)		(0.022)
Miscarriages/stillbirths		−0.50		−0.054
		(9.82)		(0.051)
Physical shocks		−6.78		−0.015
		(24.7)		(0.23)
SES		12.6		−0.036
		(8.55)		(0.041)
Maternal age		39.8***		0.17***
		(6.72)		(0.046)
Maternal age squared		−0.60***		−0.0030***
		(0.11)		(0.00078)
Male		95.3***		−0.074
		(14.9)		(0.046)
African ancestry		7.73		0.20
		(31.6)		(0.14)
Native ancestry		−45.7***		0.028
		(14.0)		(0.14)
European Latin ancestry		−3.12		0.092
		(11.3)		(0.063)
European non-Latin ancestry		−32.5		−1.05
		(86.1)		(1.12)
Other ancestry		−66.9		−0.28
		(117.9)		(0.24)
No university affiliation		27.8		0.12
		(50.5)		(0.25)
Maternity hospital		−17.0		−0.44***
		(24.2)		(0.13)
Other institution		4.69		−0.072
		(25.0)		(0.11)
Private institution		−71.1***		−0.13
		(20.1)		(0.12)
State/province institution		−35.8		0.25*
		(35.7)		(0.13)
Local public institution		57.2		−0.47**
		(37.7)		(0.18)
Colombia	−221.2***	−168.8***	−0.25***	−0.44***
	(30.4)	(25.7)	(0.074)	(0.078)
Ecuador	−173.1***	−145.7***	0.23*	−0.15
	(21.9)	(30.8)	(0.12)	(0.16)
Birth year 1983	73.2*	54.7	−0.48	−0.47
	(35.9)	(39.3)	(0.66)	(0.63)
Birth year 1984	30.3	37.4	−0.62	−0.61
	(30.9)	(31.7)	(0.60)	(0.59)
Birth year 1985	63.3***	27.7	0.053	−0.030
	(3.27)	(16.2)	(0.28)	(0.30)
Birth year 1986	64.6**	49.3	0.22***	0.21**
	(25.8)	(38.2)	(0.063)	(0.095)
Birth year 1987	66.6***	72.6**	−0.68	−0.65
	(17.8)	(26.0)	(0.50)	(0.51)
Birth year 1988	−54.5	−24.5	−0.23	−0.12
	(69.2)	(50.9)	(0.16)	(0.11)
Birth year 1989	−88.9	−71.9	−1.11***	−1.14***
	(57.3)	(51.6)	(0.11)	(0.16)
Birth year 1990	4.08	0.20	−0.69***	−0.70***
	(13.1)	(27.4)	(0.059)	(0.080)
Birth year 1991	29.4	20.2	−0.14*	−0.15
	(70.7)	(78.3)	(0.083)	(0.093)
Birth year 1992	−11.5	−11.9	−0.65***	−0.68***
	(9.36)	(12.0)	(0.12)	(0.15)
Birth year 1993	−45.1	−13.7	−0.20**	−0.19***
	(65.8)	(47.6)	(0.074)	(0.065)

Table 3 (*Continued*)

	Birth weight		Gestational age	
Birth year 1994	−172.8**	−133.5***	−0.58***	−0.55***
	(65.8)	(46.2)	(0.074)	(0.063)
Birth year 1995	−89.0	−58.7	−0.44***	−0.39***
	(65.8)	(45.8)	(0.074)	(0.060)
Birth year 1996	−53.5	−24.1	−0.54***	−0.48***
	(101.3)	(87.2)	(0.17)	(0.14)
Birth year 1997	−79.7	−41.9	−0.94***	−0.82***
	(144.3)	(126.5)	(0.12)	(0.076)
Birth year 1998	7.61	30.1	−0.33**	−0.26
	(70.5)	(40.8)	(0.15)	(0.20)
Birth year 1999	20.2	66.8	−0.42**	−0.30**
	(106.3)	(82.1)	(0.17)	(0.13)
Birth year 2000	−16.5	−2.68	−0.61***	−0.51***
	(52.2)	(42.9)	(0.085)	(0.12)
Birth year 2001	4.27	35.1	−0.83***	−0.61***
	(59.1)	(32.6)	(0.12)	(0.20)
Birth year 2002	15.1	51.2	−0.53***	−0.34***
	(76.6)	(50.7)	(0.11)	(0.092)
Birth year 2003	67.4	94.3*	−0.61***	−0.50***
	(77.1)	(52.1)	(0.12)	(0.12)
Birth year 2004	48.7	73.2	−0.90***	−0.87***
	(71.4)	(45.8)	(0.14)	(0.14)
Birth year 2005	53.0	65.6	−0.72***	−0.68***
	(74.5)	(56.0)	(0.096)	(0.13)
Birth year 2006	29.3	51.9	−0.77***	−0.80***
	(81.3)	(61.4)	(0.13)	(0.11)
Birth year 2007	−11.9	30.6	−0.77***	−0.77***
	(86.3)	(66.7)	(0.12)	(0.10)
Birth year 2008	−7.27	37.4	−1.10***	−1.10***
	(87.6)	(67.6)	(0.22)	(0.19)
Constant	3505.8***	2757.0***	39.9***	38.3***
	(96.5)	(131.3)	(0.14)	(0.76)

Standard errors are in parentheses.
* $p < 0.1$.
** $p < 0.05$.
*** $p < 0.01$.

Table 4
Marginal effects of altitude on infant health in the low-altitude sample.

Infant health measure	Mean effect	Quantile effect				
		0.1	0.25	0.5	0.75	0.9
Birth weight						
Unadjusted	−11.6***	−16.6***,b	−10.1***,b	−9.45***,b	−9.47***,b	−8.33***,b
	(3.64)	(1.85)	(1.10)	(0.84)	(0.99)	(1.21)
Adjusted	−8.59***	−9.60***,a	−5.91***,a	−7.49***,a	−8.58***,a	−7.39***,a
	(2.90)	(2.02)	(1.22)	(1.05)	(1.17)	(1.53)
Gestational age						
Unadjusted	−0.06***	−0.12***,b	−0.051***,b	−0.045***,b	−0.048***,b	−0.043***,b
	(0.011)	(0.012)	(0.006)	(0.0041)	(0.004)	(0.005)
Adjusted	−0.044***	−0.078***,b	−0.038***,b	−0.033***,b	−0.037***,b	−0.033***,b
	(0.011)	(0.014)	(0.006)	(0.004)	(0.004)	(0.0052)

Notes: This table presents the marginal effects of altitude on the study birth outcomes in OLS and quantile regression. The adjusted effects are from the full specification that includes all model inputs, and the unadjusted effects are from the nested specification that only includes time and country fixed effects. The standard errors are in parentheses.
[a] Indicates that the effects are different across the quantiles at $p < 0.05$.
[b] Indicates that the effects are different across the quantiles at $p < 0.01$
*** $p < 0.01$.

reductions in environmental pollution. Gragnolati and Marini (2006) report smaller negative effects of very high (≥3500 m) compared to high (2,500 to <3,500 m) altitude on child's height in Peru, suggesting similar compensatory effects with altitude. Further work is needed to identify such compensatory effects.

The study estimates are overall comparable to previous studies that report effects on birth weight mean. However, the estimates from the full specification are smaller than previous studies. This may be due to additional accounting in this study for several relevant inputs for birth outcomes. Previous studies report decreases of about 102–130 g in

Table 5
Marginal effects of altitude on infant health in the high-altitude sample.

Infant health measure	Mean effect	Quantile effect				
		0.1	0.25	0.5	0.75	0.9
Birth weight						
Unadjusted	−11.0***	−7.45***	−9.74***	−12.5***	−11.9***	−13.9***
	(1.31)	(2.33)	(1.75)	(1.92)	(2.00)	(2.65)
Adjusted	−6.88**	−12.9*	−6.37*	−5.57	−9.27**	−7.50
	(3.03)	(7.23)	(3.87)	(3.67)	(4.05)	(5.09)
Gestational age						
Unadjusted	−0.0057	−0.0082	−0.006	−0.0082	−0.016**	−0.016
	(0.0046)	(0.021)	(0.0094)	(0.0069)	(0.0074)	(0.010)
Adjusted	−0.011	−0.04	0.019	−0.00017	−0.019	−0.035
	(0.011)	(0.051)	(0.023)	(0.013)	(0.014)	(0.023)

Notes: This table presents the marginal effects of altitude on the study birth outcomes in OLS and quantile regression. The adjusted effects are from the full specification that includes all model inputs, and the unadjusted effects are from the nested specification that only includes time and country fixed effects. The standard errors are in parentheses.
* Indicates significance at $p < 0.1$.
** Indicates significance at $p < 0.05$.
*** Indicates significance at $p < 0.01$.

birth weight mean with 1,000-meter altitude increase above 1,000 or 2,000 m in Colorado (Jensen and Moore, 1997) and Peru (Mortola et al., 2000). The estimates of altitude effects in the unadjusted models of our study are comparable to those estimates.

Maternal health, socioeconomic, demographic and healthcare characteristics explain a significant part of the negative altitude effects on birth outcomes. Given that self-selection into residing on higher altitude may contribute to the relation between altitude and these factors, excluding such factors may result in a biased estimation of altitude effects on infant health. The results suggest overall an adverse self-selection into higher altitude, with a higher propensity to reside at higher altitudes with lower health and socioeconomic endowments, which may result in overestimation of the negative altitude effects.[18]

The study suggests interactions between infant health inputs and altitude. Examples include the reduction in the negative effects of chronic illnesses and previous miscarriages/stillbirths and the increase in the negative effects of difficulty in conception at higher altitudes. Mean-effect analysis may mask these interactions when input effects vary by unobserved fetal health endowments, such as the increase in the positive effects of socioeconomic status for infants with poor endowments in the low-altitude sample and for infants with high endowments in the high-altitude sample. This may occur if supply of market-based factors for infant health production, such as quality healthcare, is more constrained in the high-altitude sample, which may result in a larger role for socioeconomic status in household production instead of market production of infant health.[19] Another example is the increasing birth weight gap with the number of previous live births between infants with poor and high fetal health endowments in the high-altitude sample. This may be due to a larger maternal time component in childcare costs in this sample, which along with the reduction in maternal time allocated to fetal health production with having more children, may offset the benefits of the pregnancy information capital for pregnancies with low endowments.

The study has implications for public policies aiming at enhancing infant health and for residential policies that may have consequential effects on infant health. To our knowledge, no previous large-scale robust studies have documented the observed negative altitude effects in low-altitude ranges in part due to using arbitrarily specified low-altitude reference categories and due to limited altitude variation in those studies. The study highlights the importance of adverse altitude effects on infant health in both low- and high-altitude ranges when evaluating the costs and returns of residential policies that increase residence at higher altitudes.

The study highlights the importance of designing interventions that have large effects for infants with low fetal health endowments in order to reduce altitude-related gaps between low and high birth weight quantiles and suggests that policies may have different effects in different altitude ranges. Focusing on maternal education or employment programs alone may increase these gaps in populations represented in the high-altitude sample due to

[18] The direction of the bias may depend on the net level of the unobserved endowments that impact infant health. The increase in the negative effects of altitude at the 0.1 conditional quantile of birth weight in the high-altitude sample when adding the other model inputs suggests a positive bias for children with very low fetal health endowments in this sample. This suggests factors that are positively (negatively) correlated with altitude and have positive (negative) effects on the 0.1 quantile of birth weight.

[19] The effectiveness of socioeconomic status in household production of infant health may be higher for pregnancies with high fetal health endowments (i.e. for pregnancies that are less impacted by substituting away from market production of fetal/infant health). On the other side, socioeconomic status in the lower altitude sample may increase maternal efficiency in market production of infant health such as through prenatal care, which has larger returns for infants with poorer fetal health endowments (Wehby et al., 2009a). These results suggest complementarity and substitution effects between socioeconomic status and the net "unobserved" fetal health endowment level in the high- and low-altitude samples, respectively.

potentially larger returns for infants with high endowments but may have opposite effects in populations represented in the low-altitude sample.

The study suggests several questions for future research. These include identifying the role of healthcare provider distribution and quality of care in contributing to altitude effects on infant health and the impacts of human capital, household health production, and area-level economic characteristics on the relationship between altitude and infant health. Finally, evaluating altitude effects on postnatal, child and adult health outcomes is essential for evaluating the long-term altitude effects and identifying needs for and ways of intervening to reduce negative effects.

In conclusion, the study finds negative altitude effects on birth weight and gestational age in low-altitude ranges and on birth weight in high-altitude ranges. The effects are overall larger for infants with low fetal health endowments. Excluding relevant maternal health, socioeconomic, demographic, and healthcare characteristics may generally result in overestimation of the negative altitude effects. The study finds interactive effects on infant health between several relevant inputs and altitude.

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Appendix A

See Tables A1–A3.

Table A1
Principal component analysis scoring coefficients of the socioeconomic status index.

Socioeconomic status components	Low-altitude sample	High-altitude sample
Maternal education		
None—illiterate	−0.36	−0.51
None—literate	0.38	0.14
Primary—incomplete	0.52	0.29
Primary—complete	0.69	0.42
Secondary—incomplete	0.78	0.48
Secondary—complete	1.03	0.76
University—incomplete	1.38	1.14
University—complete	1.68	1.45
Maternal employment/occupational level		
Housework	−1.86	−1.79
Unemployed	−1.56	−1.48
Unqualified worker (blue collar)	−0.84	−1.03
Qualified worker (blue collar)	−0.26	−0.54
Independent worker	0.16	−0.11
Clerk (white collar)	0.66	0.34
Boss, chief, owner	1.15	0.74
Professional, executive	1.55	1.24

Note: This table includes the scoring coefficients of the first principal component that are used to construct the socioeconomic status index.

Table A2
Quantile regression coefficients of the birth weight production function in the low-altitude sample.

	Quantiles									
	0.1	0.1	0.25	0.25	0.5	0.5	0.75	0.75	0.9	0.9
Altitude	−16.6[***,c]	−9.60[***,b]	−10.1[***,c]	−5.91[***,b]	−9.45[***,c]	−7.49[***,b]	−9.47[***,c]	−8.58[***,b]	−8.33[***,c]	−7.39[***,b]
	(1.85)	(2.02)	(1.10)	(1.22)	(0.84)	(1.05)	(0.99)	(1.17)	(1.21)	(1.53)
Acute illnesses		−75.0[***,c]		−30.3[***,c]		−4.35[c]		−4.8[c]		−0.71[c]
		(11.8)		(6.58)		(5.60)		(6.11)		(8.10)
Chronic illnesses		−125.3[***,c]		−67.1[***,c]		−43.9[***,c]		−20.2[**,c]		4.04[c]
		(17.3)		(10.0)		(8.00)		(8.34)		(10.1)
Conception difficulty		−47.7[**]		−24.7[**]		−11.1		−7.63		−1.06
		(21.4)		(11.8)		(9.55)		(10.7)		(13.2)
Live births		17.1[***,b]		11.0[***,b]		12.1[***,b]		15.4[***,b]		17.2[***,b]
		(2.86)		(2.11)		(1.72)		(1.74)		(2.36)
Miscarriages/stillbirths		−48.9[***,c]		−14.3[***,c]		−8.82[**,c]		−7.14[*,c]		4.8[c]
		(9.97)		(5.12)		(3.78)		(4.21)		(5.34)
Physical shocks		−21.4		3.39		−25.4		−17.7		−14.2
		(41.9)		(18.0)		(17.8)		(15.6)		(22.3)
SES		25.0[**,c]		14.9[***,c]		11.9[***,c]		8.23[***,c]		0.93[c]
		(5.38)		(3.36)		(2.88)		(2.89)		(3.79)
Maternal age		52.2[***]		42.8[***]		37.4[***]		37.5[***]		41.0[***]
		(6.07)		(3.61)		(3.09)		(3.30)		(4.00)

Table A2 (*Continued*)

	Quantiles									
	0.1	0.1	0.25	0.25	0.5	0.5	0.75	0.75	0.9	0.9
Maternal age squared		−0.93***,b		−0.72***,b		−0.58***,b		−0.56***,b		−0.6***,b
		(0.11)		(0.067)		(0.056)		(0.060)		(0.072)
Male		65.0***,c		94.7***,c		111.4***,c		123.8***,c		140.1***,c
		(9.70)		(5.82)		(4.94)		(5.54)		(7.24)
African ancestry		−102.9***,c		−75.3***,c		−55.8***,c		−45.6***,c		−29.1**,c
		(19.3)		(11.6)		(9.31)		(9.75)		(12.1)
Native ancestry		21.2		17.1*		15.2**		6.36		9.49
		(15.6)		(9.18)		(7.40)		(7.59)		(11.1)
European Latin ancestry		13.3		10.9		19.0***		8.14		−0.37
		(11.5)		(6.70)		(5.25)		(6.38)		(7.77)
European non-Latin ancestry		14.9		20.7**		29.8***		12.1		21.9*
		(18.4)		(10.2)		(8.98)		(9.15)		(12.5)
Other ancestry		90.0**,c		−22.7c		−76.2**,c		−28.4c		−46.8c
		(37.3)		(29.9)		(32.0)		(23.8)		(41.4)
No university affiliation		26.2**		18.1***		14.0**		14.8**		14.0
		(12.1)		(6.96)		(5.94)		(6.58)		(8.52)
Maternity hospital		50.5***		47.0***		36.0***		27.2***		26.8**
		(14.5)		(8.37)		(7.23)		(7.50)		(10.9)
Other institution		−71.5*,b		−94.7***,b		−68.9**,b		3.53b		16.9b
		(37.5)		(28.3)		(30.3)		(28.8)		(27.6)
Private institution		−4.51		−32.6*		−47.2**		−46.8***		−19.6
		(28.6)		(18.7)		(18.6)		(17.5)		(24.3)
State/province institution		−125.4***		−71.1***		−28.3**		−4.79		−3.85
		(22.1)		(12.5)		(12.1)		(12.4)		(17.1)
Local public institution		−93.1***,a		−60.3***,a		−36.6***,a		−30.7**,a		−34.1**,a
		(21.5)		(11.7)		(11.3)		(12.3)		(15.2)
Brazil	−149.5***	−130.2***	−110.0***	−96.3***	−81.0***	−66.0***	−80.0***	−54.7***	−79.5***	−46.9***
	(13.2)	(16.8)	(7.70)	(10.5)	(6.39)	(9.35)	(7.39)	(9.39)	(8.97)	(12.9)
Chile	198.8***	72.7***	150.1***	78.3***	143.4***	106.0***	124.6***	117.9***	116.5***	114.7***
	(13.9)	(25.8)	(7.73)	(14.6)	(7.39)	(14.6)	(8.30)	(14.9)	(10.5)	(19.0)
Colombia	−184.9***	−241.5***	−203.9***	−193.6***	−121.1***	−98.4***	−145.0***	−99.4***	−137.3***	−91.3**
	(43.4)	(45.5)	(40.6)	(30.8)	(21.3)	(25.5)	(27.2)	(24.3)	(29.5)	(37.2)
Birth year 1983	30.0	8.70	−50.0*	−53.9*	−27.8	−41.0*	−48.7*	−29.9	−8.17	0.081
	(43.4)	(48.3)	(27.9)	(30.7)	(25.8)	(24.0)	(27.1)	(27.5)	(33.1)	(40.2)
Birth year 1984	30.0	37.2	−40.5	−36.7	−30.9	−49.2*	−37.0	−18.7	−20.0	−23.9
	(47.1)	(45.5)	(28.9)	(26.6)	(26.4)	(27.7)	(26.2)	(27.6)	(36.9)	(44.1)
Birth year 1985	−20.0	−7.69	−30.6	−51.6*	−50.0**	−58.4**	−80.0***	−54.5**	−46.9	−35.8
	(50.8)	(55.3)	(25.4)	(29.0)	(22.8)	(25.4)	(27.6)	(26.9)	(36.7)	(41.3)
Birth year 1986	33.4	23.3	−20.5	−34.2	−24.5	−32.0	−18.2	−17.6	10.00	16.9
	(47.4)	(44.3)	(28.1)	(28.2)	(24.0)	(27.3)	(29.0)	(30.7)	(34.6)	(39.5)
Birth year 1987	10.0	−2.30	−40.5	−36.7	−50.6**	−72.8***	−78.7***	−47.9	−70.0*	−36.8
	(51.8)	(57.8)	(28.5)	(29.2)	(24.7)	(27.4)	(29.9)	(34.4)	(36.8)	(41.6)
Birth year 1988	−60.0	−70.2	−60.5**	−74.7**	−27.8	−45.9*	−48.2**	−30.1	−10.0	−1.72
	(65.1)	(53.3)	(29.0)	(34.5)	(29.6)	(26.5)	(22.7)	(31.1)	(35.6)	(45.4)
Birth year 1989	−82.8*	−63.8	−50.6	−80.8**	−37.8	−53.6**	−48.7	−74.8***	−60.0*	−47.9
	(45.4)	(52.1)	(32.3)	(32.5)	(26.0)	(24.0)	(33.8)	(28.6)	(35.7)	(39.7)
Birth year 1990	−10.00	−16.6	−17.1	−33.1	−20.9	−44.7	−40.0	−37.8	−40.0	−34.0
	(44.3)	(46.3)	(26.6)	(27.9)	(26.5)	(27.9)	(24.6)	(27.6)	(34.5)	(37.5)
Birth year 1991	60.0	48.3	−17.1	−32.6	−0.57	−18.4	−48.7**	−25.8	20.0	53.5
	(38.2)	(38.4)	(26.2)	(27.5)	(23.5)	(23.2)	(22.6)	(23.8)	(37.3)	(44.0)
Birth year 1992	30.0	−5.67	−17.0	−27.6	−0.000025	−17.1	−1.78	−1.56	13.1	13.9
	(40.9)	(45.0)	(23.6)	(27.9)	(19.8)	(20.6)	(22.6)	(24.6)	(29.6)	(34.0)
Birth year 1993	10.0	10.2	−12.0	−16.4	1.05	−6.92	−16.9	5.20	50.0	52.4
	(45.7)	(43.8)	(21.3)	(28.3)	(22.6)	(24.1)	(24.6)	(23.2)	(33.8)	(36.2)
Birth year 1994	0.000027	−7.48	−0.61	4.36	−0.57	−4.76	−10.00	23.8	30.0	64.3
	(43.1)	(45.3)	(19.9)	(26.3)	(19.8)	(20.8)	(23.3)	(25.5)	(33.8)	(40.5)
Birth year 1995	23.4	46.8	−5.24	−13.0	−10.9	−21.2	−22.8	−2.43	13.8	36.5
	(38.1)	(41.0)	(24.2)	(26.0)	(23.3)	(21.0)	(23.9)	(24.6)	(35.5)	(35.1)
Birth year 1996	−4.50	20.9	−50.0**	−30.4	−24.5	−28.6	−38.2	−22.6	30.5	45.3
	(39.3)	(40.3)	(23.8)	(26.4)	(23.2)	(20.9)	(26.0)	(23.8)	(30.2)	(35.0)
Birth year 1997	23.4	44.9	−5.00	11.8	−0.57	−2.32	−12.6	8.91	−5.25	25.5
	(41.7)	(42.6)	(24.1)	(29.3)	(22.2)	(22.3)	(24.1)	(23.8)	(29.6)	(37.4)
Birth year 1998	17.5	22.8	−11.0	−3.73	−14.5	−14.7	−46.4**	−6.64	−13.2	15.9
	(40.9)	(41.4)	(22.5)	(26.9)	(20.8)	(20.5)	(20.7)	(23.6)	(31.4)	(34.4)
Birth year 1999	30.0	58.4	−0.61	9.51	−0.57	−0.068	−12.6	14.7	10.00	35.2
	(37.9)	(40.5)	(18.7)	(25.7)	(19.8)	(20.0)	(22.0)	(23.7)	(27.2)	(34.8)
Birth year 2000	22.0	45.7	−0.61	14.6	2.27	5.53	−16.9	4.51	1.08	31.6
	(37.9)	(38.7)	(21.0)	(25.1)	(19.8)	(20.4)	(20.9)	(22.1)	(27.9)	(33.1)
Birth year 2001	50.0	76.8**	−0.10	22.1	6.02	8.34	−8.73	12.6	9.33	30.5
	(33.0)	(36.6)	(21.3)	(24.5)	(19.0)	(20.2)	(20.3)	(22.2)	(26.3)	(34.2)

Table A2 (*Continued*)

	Quantiles									
	0.1	0.1	0.25	0.25	0.5	0.5	0.75	0.75	0.9	0.9
Birth year 2002	79.5**	92.7**	−0.61	11.5	−8.95	−8.42	−47.0**	−5.48	−40.0	−4.01
	(34.4)	(37.2)	(19.0)	(24.2)	(19.0)	(19.3)	(19.6)	(22.4)	(28.0)	(34.3)
Birth year 2003	20.0	37.1	−0.61	10.5	0.48	2.03	−38.7**	−14.5	−30.7	14.4
	(35.3)	(38.4)	(18.7)	(25.0)	(18.3)	(19.6)	(19.4)	(22.9)	(26.0)	(34.0)
Birth year 2004	23.4	67.2*	−20.6	−4.15	−8.37	−0.66	−32.6*	−6.51	−20.1	11.5
	(35.1)	(37.8)	(20.2)	(25.1)	(19.8)	(20.2)	(19.7)	(22.2)	(27.5)	(34.5)
Birth year 2005	−40.5	−24.5	−60.1***	−33.4	−19.7	−17.7	−32.6*	−6.30	−16.3	24.1
	(35.1)	(40.6)	(21.4)	(26.1)	(19.8)	(20.8)	(19.7)	(23.6)	(27.1)	(32.8)
Birth year 2006	9.75	46.1	−20.6	−10.7	−8.37	4.92	−27.0	20.1	−20.0	31.5
	(37.9)	(41.7)	(22.1)	(25.9)	(21.6)	(21.7)	(21.1)	(24.3)	(30.6)	(34.7)
Birth year 2007	−30.2	−10.6	−20.6	−0.40	−14.5	−15.8	−58.7***	−21.7	−35.5	0.79
	(43.3)	(48.3)	(23.9)	(27.8)	(20.3)	(21.5)	(22.4)	(23.4)	(32.7)	(37.0)
Birth year 2008	−40.5	−7.96	−50.6*	−31.8	−8.37	−0.13	−48.2*	17.9	29.5	75.7*
	(43.3)	(44.2)	(28.0)	(28.4)	(24.1)	(26.2)	(25.3)	(24.4)	(34.9)	(39.7)
Constant	2640.8***	1985.5***	3001.1***	2382.1***	3301.0***	2683.9***	3649.2***	2954.3***	3920.4***	3129.1***
	(30.4)	(92.4)	(17.5)	(55.8)	(17.1)	(46.1)	(18.0)	(50.7)	(24.7)	(63.2)

Standard errors in parentheses.

[a] Indicates that the effects are different between the quantiles at $p < 0.1$.
[b] Indicates that the effects are different between the quantiles at $p < 0.05$.
[c] Indicates that the effects are different between the quantiles at $p < 0.01$.
* $p < 0.1$.
** $p < 0.05$.
*** $p < 0.01$.

Table A3
Quantile regression coefficients of the birth weight production function in the high-altitude sample.

	Quantiles									
	0.1	0.1	0.25	0.25	0.5	0.5	0.75	0.75	0.9	0.9
Altitude	−7.45***	−12.9*	−9.74***	−6.37*	−12.5***	−5.57	−11.9***	−9.27**	−13.9***	−7.50
	(2.33)	(7.23)	(1.75)	(3.87)	(1.92)	(3.67)	(2.00)	(4.05)	(2.65)	(5.09)
Acute illnesses		−48.4		−29.6		−30.6*		−18.5		17.2
		(30.3)		(18.2)		(16.8)		(20.8)		(24.4)
Chronic illnesses		−4.59		44.5		−25.5		−58.0		−27.3
		(65.6)		(48.4)		(27.6)		(40.6)		(50.4)
Conception difficulty		−240.9**		−124.2**		−112.3***		−53.1		−110.6**
		(93.6)		(63.1)		(42.5)		(55.6)		(46.3)
Live births		−6.03a		3.67a		10.4**,a		18.4***,a		22.8***,a
		(8.41)		(5.87)		(5.26)		(5.25)		(7.04)
Miscarriages/stillbirths		−3.96		8.39		3.22		17.4		7.10
		(26.9)		(14.0)		(9.95)		(15.2)		(17.6)
Physical shocks		−78.9		−3.27		−16.0		−11.9		−31.7
		(88.1)		(60.1)		(37.6)		(66.0)		(65.0)
SES		10.8		10.2		12.6		23.5**		24.1*
		(15.2)		(9.70)		(9.00)		(11.6)		(12.8)
Maternal age		48.6***		41.8***		37.0***		34.4***		28.2**
		(16.5)		(10.9)		(9.36)		(9.90)		(12.4)
Maternal age squared		−0.87***		−0.67***		−0.56***		−0.48***		−0.34
		(0.30)		(0.21)		(0.17)		(0.18)		(0.22)
Male		52.3**,b		66.9***,b		93.2***,b		110.6***,b		145.9***,b
		(23.9)		(14.7)		(14.6)		(17.2)		(19.9)
African ancestry		59.8		−24.1		−36.7		−40.9		−53.7
		(61.6)		(66.2)		(54.0)		(58.9)		(103.4)
Native ancestry		−82.5*		−83.4***		−29.8		−46.3		−57.7
		(48.4)		(31.7)		(32.0)		(37.2)		(46.1)
European Latin ancestry		−26.1		−22.9		2.99		1.55		−9.05
		(31.9)		(22.5)		(20.2)		(22.3)		(27.2)
European non-Latin ancestry		−35.0		37.5		−38.0		−15.6		−130.9
		(232.7)		(84.2)		(77.1)		(94.1)		(128.3)
Other ancestry		−26.7		−92.3		−155.1		−209.8		−245.9
		(173.2)		(160.5)		(134.7)		(178.3)		(281.0)
No university affiliation		35.2		7.77		30.9		107.4**		119.3*
		(91.2)		(48.3)		(45.4)		(52.1)		(66.6)
Maternity hospital		−81.7		−22.4		2.53		−0.97		−10.1
		(56.9)		(37.9)		(35.1)		(35.4)		(49.9)
Other institution		−9.02		13.6		40.7		−33.4		−41.2
		(65.6)		(44.0)		(28.1)		(44.4)		(51.0)

Table A3 (*Continued*)

	Quantiles									
	0.1	0.1	0.25	0.25	0.5	0.5	0.75	0.75	0.9	0.9
Private institution		−58.5		−55.8*		−75.5***		−125.6***		−107.2**
		(48.2)		(33.4)		(28.3)		(35.8)		(47.6)
State/province institution		−119.6**		−41.1		10.1		−13.5		24.5
		(55.2)		(35.3)		(35.5)		(37.5)		(47.0)
Local public institution		−127.7		66.3		108.8*		49.3		131.2*
		(120.2)		(63.9)		(57.9)		(66.7)		(78.2)
Colombia	−224.5***	−276.1***	−191.2***	−155.7***	−213.0***	−147.2***	−197.0***	−116.5**	−208.9***	−126.2**
	(32.1)	(89.2)	(25.8)	(42.6)	(26.7)	(40.3)	(29.6)	(50.2)	(36.0)	(52.2)
Ecuador	−113.0***	−177.6**	−116.3***	−104.7***	−190.6***	−141.5***	−219.3***	−164.6***	−251.9***	−185.8***
	(29.6)	(72.7)	(24.2)	(39.8)	(25.8)	(37.9)	(25.5)	(42.9)	(32.6)	(52.8)
Birth year 1983	280.0	261.0	131.0	46.7	51.8	71.0	−20.0	54.5	−80.0	−112.2
	(210.7)	(191.4)	(90.0)	(103.4)	(92.5)	(84.4)	(134.4)	(109.2)	(133.5)	(121.3)
Birth year 1984	30.0	73.0	−10.00	−44.0	10.00	20.7	92.0	96.9	−0.0000001	41.8
	(206.7)	(176.9)	(92.8)	(101.5)	(83.9)	(82.3)	(143.3)	(120.3)	(129.3)	(121.4)
Birth year 1985	100.0	114.5	83.8	−17.9	61.8	30.5	22.0	27.7	30.0	−20.5
	(193.5)	(164.3)	(68.7)	(76.1)	(93.3)	(80.8)	(117.6)	(113.6)	(151.4)	(117.8)
Birth year 1986	170.0	88.7	30.0	−28.4	50.0	69.0	100.0	99.4	−10.0	17.7
	(163.8)	(141.7)	(81.9)	(87.2)	(82.0)	(75.4)	(129.8)	(126.6)	(131.1)	(110.3)
Birth year 1987	230.0	204.3	83.8	36.7	141.8*	126.0*	2.00	59.5	−40.0	−51.2
	(160.6)	(148.3)	(90.9)	(87.0)	(74.6)	(71.6)	(109.0)	(108.5)	(127.2)	(107.8)
Birth year 1988	80.0	60.7	−50.0	−75.9	−18.2	5.59	−178.0*	−71.2	−170.0	−33.2
	(166.4)	(143.4)	(73.2)	(87.3)	(84.5)	(72.1)	(103.5)	(100.2)	(176.1)	(130.7)
Birth year 1989	−30.0	−51.9	−90.0	−95.7	−18.2	15.7	−158.0	−62.4	−150.0	−138.2
	(207.9)	(175.0)	(96.6)	(103.9)	(79.7)	(76.9)	(112.7)	(127.6)	(135.3)	(112.2)
Birth year 1990	80.0	29.1	40.0	−5.46	11.8	35.1	−98.0	2.44	−70.0	−75.3
	(267.3)	(238.4)	(80.3)	(83.2)	(76.9)	(71.3)	(114.0)	(110.3)	(131.1)	(127.1)
Birth year 1991	80.0	12.4	90.0	41.3	21.8	18.8	−8.00	25.6	−100.0	−43.1
	(253.5)	(239.8)	(89.7)	(95.7)	(92.7)	(90.1)	(149.0)	(111.1)	(119.9)	(118.8)
Birth year 1992	170.0	167.5	0.0000009	17.3	−8.19	16.8	−78.0	−51.7	−100.0	−54.8
	(267.8)	(244.7)	(112.4)	(105.6)	(87.4)	(77.0)	(120.4)	(125.5)	(154.1)	(148.3)
Birth year 1993	90.0	62.7	−60.0	−74.4	−38.2	29.2	−228.0*	−85.2	−220.0	−49.8
	(175.5)	(149.8)	(128.2)	(128.4)	(116.3)	(118.0)	(135.8)	(126.5)	(176.9)	(158.8)
Birth year 1994	−70.0	−114.2	−210.0	−269.8	−128.2	0.35	−178.0	−59.1	30.0	115.8
	(459.8)	(460.6)	(136.0)	(166.0)	(157.4)	(137.9)	(147.4)	(132.7)	(260.1)	(218.4)
Birth year 1995	−70.0	−84.6	−80.0	−130.7	−118.2	−91.5	−88.0	−22.9	−220.0	−122.7
	(194.9)	(186.7)	(86.8)	(98.9)	(102.9)	(94.5)	(120.1)	(122.1)	(151.5)	(152.1)
Birth year 1996	−40.0	−23.8	−10.0	−13.1	−38.2	19.5	−78.0	24.5	−112.5	−27.9
	(223.8)	(200.2)	(80.3)	(88.7)	(78.5)	(80.9)	(104.2)	(105.6)	(142.2)	(125.8)
Birth year 1997	−190.0	−138.0	−60.0	−65.9	−6.19	56.5	−108.0	−15.6	−160.0	−76.7
	(202.1)	(190.7)	(116.6)	(124.1)	(83.0)	(75.9)	(125.6)	(116.4)	(151.9)	(114.3)
Birth year 1998	50.0	−31.5	50.0	52.4	41.8	106.9	−78.0	21.4	−170.0	−55.6
	(211.3)	(188.1)	(126.4)	(113.5)	(70.8)	(75.7)	(112.2)	(109.7)	(145.5)	(120.2)
Birth year 1999	90.0	70.1	30.0	48.2	−6.19	64.5	−28.0	40.7	20.0	96.1
	(191.8)	(164.3)	(94.0)	(91.2)	(77.4)	(72.9)	(125.0)	(136.4)	(165.9)	(124.9)
Birth year 2000	100.0	45.5	20.0	−85.0	−8.19	11.7	−85.9	5.95	−12.5	13.2
	(203.4)	(177.9)	(77.1)	(78.5)	(84.8)	(84.4)	(118.9)	(129.4)	(135.4)	(110.6)
Birth year 2001	60.0	51.6	33.3	−26.2	28.8	115.9*	−38.0	56.8	−78.2	−60.3
	(163.8)	(147.6)	(66.3)	(74.8)	(67.4)	(69.6)	(92.3)	(93.8)	(120.5)	(105.3)
Birth year 2002	80.0	77.7	33.3	−19.9	41.8	108.7*	−29.0	71.6	−42.2	−29.3
	(154.7)	(134.3)	(72.8)	(74.3)	(63.7)	(65.5)	(92.3)	(94.6)	(119.8)	(99.6)
Birth year 2003	220.0	182.7	53.8	28.1	80.1	129.7**	−25.4	55.0	−12.5	−14.7
	(153.6)	(137.0)	(64.9)	(70.6)	(65.4)	(63.9)	(90.1)	(92.1)	(117.3)	(101.7)
Birth year 2004	150.0	129.8	57.2	16.3	76.8	135.0**	0.000013	71.0	−24.2	6.95
	(152.4)	(135.7)	(65.5)	(71.3)	(66.4)	(63.9)	(88.0)	(93.1)	(117.3)	(97.0)
Birth year 2005	180.0	105.9	40.9	3.39	93.8	132.5**	−25.4	38.2	−20.0	−33.9
	(153.0)	(136.7)	(62.3)	(72.8)	(63.0)	(63.6)	(88.9)	(93.0)	(117.5)	(96.4)
Birth year 2006	130.0	83.2	40.0	24.2	73.8	111.6*	−78.0	23.3	−112.2	−69.9
	(157.1)	(136.0)	(64.4)	(69.2)	(65.6)	(62.7)	(88.3)	(94.9)	(118.6)	(98.6)
Birth year 2007	80.0	38.1	20.0	−14.1	12.9	102.9	−98.0	−27.9	−112.5	−59.0
	(158.8)	(142.4)	(65.8)	(73.1)	(63.2)	(66.2)	(89.8)	(93.9)	(117.0)	(104.8)
Birth year 2008	90.0	39.2	20.0	−41.5	13.8	111.8*	−73.6	36.6	−92.5	−55.1
	(163.3)	(145.9)	(67.2)	(78.9)	(70.8)	(67.3)	(88.3)	(99.9)	(116.7)	(102.0)
Constant	2738.0***	2478.8***	3160.5***	2559.7***	3537.7***	2680.7***	3906.6***	3161.2***	4270.0***	3474.6***
	(177.8)	(394.4)	(83.5)	(214.1)	(89.8)	(202.1)	(112.4)	(226.7)	(144.0)	(278.4)

Standard errors in parentheses.

[a] Indicates that the effects within each model (adjusted and unadjusted) are different between the quantiles at $p < 0.1$.

[b] Indicates that the effects within each model (adjusted and unadjusted) are different between the quantiles at $p < 0.05$.

* $p < 0.1$.

** $p < 0.05$.

*** $p < 0.01$.

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