Early-life environment and the stature of the Brazilian adult population*

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Abstract

We study the relationship between the burden of disease and income in the year of birth and adult stature using cohort-state level data in Brazil. We find that GDP in the year of birth, not infant mortality rate, is a robust predictor of population stature in Brazil during the period 1950-1980. An increase in the real GDP per capita of the magnitude for that period explains the one third increase in adult height, or around 1 cm, occurring in the same time span. Our results are robust to control for cohort and region fixed effects, migration adjustments, alternative proxies for gross nutrition, and additional socioeconomic controls in the year of birth. Our results are consistent with income early in life (in the year of birth or early in childhood) determining adult human capital. Given the link between birth weight and adult height, our results echoes the recent findings on the impact of economic fluctuations on birth weight during the Argentine economic crisis of 2001-2002.

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1 Introduction

Over the past three centuries humans in the developed world have become taller and live longer than ever before (Floud et al., 2011). The relationship between adult stature and life expectancy has been established in numerous studies (Batty et al., 2009, Jousilahti et al., 2000, Leon et al., 1995, Waaler, 1984), along with the link between environmental conditions in the year of birth for a given population, as measured by its disease environment and/or available resources, and its adult stature (Bozzoli et al., 2009, Peracchi and Arcaleni, 2011, Quintana-Domeque et al., 2011). Height is a marker of health and nutrition during the critical periods of growth in early life (particularly from conception to age 3), and taller individuals exhibit superior outcomes in a wide range of measures, from happiness or life satisfaction to wages or productivity (Case and Paxson, 2008, Deaton and Arora, 2009, Lundborg et al., 2009). Not surprisingly, understanding the determinants of the changes in body size represents a key part of a comprehensive theory of development, and is of interest to a wide spectrum of researchers, from human biologists and historians to demographers and economists.

Economists have been exploring the determinants of population heights in different contexts. Leaving the role of genes aside, individual stature is a function of net nutrition, which depends on gross nutrition minus the demands exerted on it, mainly through disease, but also through physical exercise.[1] For this reason, studies have focused on two measures of environmental conditions in the year of birth: Gross nutrition (typically proxied by GDP per capita) and disease burden (usually proxied by infant mortality or postneonatal mortality rates).[2] Bozzoli et al. (2009) unveiled evidence that across a range of European countries and the United States there is a strong inverse relationship between post-neonatal (defined as the period from one month to one year of age) mortality and the mean adult height of those infants in the same birth cohort who survived into adulthood. More recently, Quintana-Domeque et al. (2011) find that, in Spain, a reduction in the infant mortality rate (IMR) of 30 individuals per 1000 explains an increase in average height of about 2.7 cm, about 70% of the gain in average adult stature during the period

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[1] At the population level, the role of genes appears to be less important than that of environmental conditions in determining stature (Silventoinen, 2003).

[2] Infant mortality rate is measured as the number of infants who die in their first year of life per 1000 live births. Post-neonatal mortality rate is measured as the number of infants who die between their first month and their first year of life per 1000 live births.

1961-1980.[3]

As pointed out by Bozzoli et al. (2009), and recently emphasized by Coffey (2012), the finding that income (or nutrition related) constraints appear not to be relevant in explaining the adult heights of cohorts born after 1950 in Western countries does not rule out the possibility that these were important constraints before 1950 or even nowadays in the more developing world. Indeed, this possibility echoes the work by Fogel (2004) on the links between income and height. In this paper, we explore the relationship between early-life environment, as measured by income and infant mortality in the year of birth, and the stature of the Brazilian population, a large developing country.

In Brazil, researchers have used data from the Pesquisa de Orçamentos Familiares (POF) to document positive effects of stature on education and wages (Curi and Menezes-Filho, 2008), but also to investigate the determinants of individual height. Monasterio et al. (2006) show the average state GDP per capita of each individual up to 15 years old is one of the main predictors of individual adult stature, controlling for per capita family income, years of education, demographic characteristics, and income distribution. Results indicate a positive (concave) relationship between adult stature and the mean GDP during 0-15 years after birth.

Given the previous research documenting the effects of infant mortality in the year of birth on adult height and the sizeable correlation coefficients between average adult stature and environmental measures (IMR and per capita GDP) in the year of birth across Brazilian states and over the cohorts born in 1950-1980, neglecting the (potential) influence of disease exposure during childhood on adult stature can be problematic. The correlation between IMR and adult height using is -0.65 (p-value=0.0000), between log of real per capita GDP and height is 0.79 (p-value=0.0000), and between IMR and log of real per capita GDP is -0.77 (p-value=0.0000).[4] These pair-wise correlations conform to the existing empirical evidence coming from other studies, in terms of both signs and magnitudes. It is thus fundamental to assess whether the omission of IMR contaminates the "GDP-at-birth-height" gradient.

In this thesis, we put forward an answer to the question "What are the forces behind Brazilian human growth in the second half of the 20th Century?" focusing on the role of

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[3] Peracchi and Arcaleni (2011) find that economic conditions appear to matter more than disease burden for height in Italy for cohorts of men born between 1973 and 1978.

[4] Section 2 provides the data sources.

both income and disease (and its potential interactions) in explaining population heights. Collapsing height data from the POF at the state-year level and combining it with data on GDP, IMR and other socioeconomic indicators at the state-year level, we find that income, not disease, is a robust predictor of population stature in Brazil during the period 1950-1980. Our results are robust to controlling for cohort and region fixed effects, migration adjustments, alternative proxies for gross nutrition, and additional socioeconomic controls in the year of birth (from income inequality to the total fertility rate). In addition, we also show that per capita income five years before birth is not a relevant predictor of adult height, whereas per capita income during the first five years of life is important in predicting height. Finally, we do not find a role for pre-adult mortality rate, which suggests that the absence of a relationship between infant mortality and height is not due to offsetting scarring (of survivors) and selection (of the taller) effects.

Section 2 describes the data sources used in our empirical analysis. Section 3 summarizes the evolution of height, GDP and IMR in Brazil during the period 1950-1980. Section 4 contains the regression results. Section 5 provides several robustness checks. Section 6 concludes.

2 Data

Height data come from the Brazilian Household Budget Survey 2002-2003 (Pesquisa de Orçamentos Familiares - POF) of the Brazilian Institute of Geography and Statistics (Instituto Brasileiro de Geografia e Estatística - IBGE), which provides information on gender, race, year of birth, state of current residence, and anthropometric information (weight and height). The main advantage of the POF survey with respect to many other datasets used in previous studies is that, apart from providing a representative sample of the Brazilian population, anthropometric measures are not self-reported, but actually measured.[5] Height is collected by using a graduated tape measure in which fractions of centimeters are rounded to the nearest integer. Individuals aged 2 or above are measured in vertical position.[6]

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[5] Several existing studies use data sets which report measured anthropometric data, but from selected populations.

[6] Anthropometric measures were submitted to the system of Critique and Imputation System for Quantitative Data (Crítica e Imputação para Dados Quantitativos, CIDAQ). http://www.ibge.gov.br/home/estatistica/populacao/condicaodevida/pof/2003medidas/microdados.shtm

The sample is restricted to individuals born in 1950, 1960, 1970 or 1980, who had already attained their adult stature by the time the survey was carried out (aged at least 21 in 2002-2003, to be on the safe side). Furthermore, due to both mortality-related selection and shrinkage of the elderly, our sample excludes individuals over age 53 in 2002-2003. We compute average height by year of birth and by state of current residence, by summing up the average heights from adult males and females and dividing by two.[7] We depart from studies focusing on India (or other Asian populations), where sex ratios differ substantially across regions (states) and time and sex discrimination in the allocation of nutrition and health in early childhood has been well-documented, and do not model the population heights of men and women separately. This has the advantage of obtaining more precise estimates.

GDP and population size data for all Brazilian states and the years 1950, 1960, 1970 and 1980 come from IPEADATA.[8] Per capita GDP is constructed as the ratio of GDP and population size, and converted to US Dollars using the real exchange rate (2005=100) from the International Monetary Fund (IMF) website.[9] Infant mortality rates and additional socioeconomic indicators (average education, educational inequality, urbanization and demographic density), for all Brazilian states and the years 1950, 1960, 1970 and 1980 are available in the statistics of the 20th Century produced by the IBGE.[10]

Although it would be interesting to perform the analysis decomposing IMR on neonatal mortality and post-neonatal mortality, as in Bozzoli et al. (2009) and Coffey (2012), these indicators are not available for before 1980 at state level.

3 The Evolution of Height, Income and Disease in Brazil

Table 1 summarizes the data on average height, infant mortality rate per 1000 live births (IMR) and the logarithm of the real per capita gross domestic product (GDP) by four

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[7] We only consider whites, blacks and "pardos" (browns in Monasterio et al., 2006). Natives and Asians are less than 1% of the total sample.

[8] In particular, GDP is available at state level annually from 1947 to 1970, and then in 1975, 1980 and 1985. Population size is available at state level in 1950, 1960, 1970 and 1980. `http://www.ipeadata.gov.br`

[9] `http://www.imf.org/external/data.htm`

[10] `http://www.ibge.gov.br/seculoxx`

cohorts and the five Brazilian regions.[11] Average height increased by about 3 cm in thirty years, from 162.6 to 165.4 cm, for cohorts born in 1950 and 1980, respectively, which is about 1 cm per decade, and consistent with the evidence reported by Schultz (2005) using data from the 1989 Health and Nutrition Survey of Brazil (Pesquisa Nacional sobre Saúde e Nutrição). We note that the mean stature of the youngest cohort is 11.6 cm lower than that of Denmark and 2.6 cm lower than that of Portugal, the taller and shorter European cohorts born in 1976-1980 in the study of Bozzoli et al. (2009). Compared to the US, Brazil is 6.6 cm below. There is higher variation at regional level. For the oldest cohort the mean ranges from 159.8 cm in the North to 165.8 cm in the Southeast, i.e. a gap of 6 cm, while for the youngest it ranges from 163.8 cm in the Northeast to 168 cm in the Southeast, i.e. a 4.2 cm difference. Cohorts from Southern regions are taller than cohorts from Northern regions, a gap that has been previously documented and discussed by Monasterio et al. (2006).[12] Figure 1 displays the regional time trends in adult stature, highlighting the differential "human" growth rates by region and the reduction in the gap between the shortest and tallest regions from 1950 to 1980.

[INSERT TABLE 1 ABOUT HERE] [INSERT FIGURE 1 ABOUT HERE]

Table 1 also reveals a sharp fall in infant mortality rate between 1950 and 1980, from 150 to 94 infant deaths per 1000 live births, which reflects a decrease of (roughly speaking) 2 deaths per 1000 live births per year. However, in 1980, the level of IMR in Northeast reached around 125 per 1000 live births, an order of magnitude similar to the one observed in Sub-Saharan African countries (122 in 1975-1980, World Population Prospects, 2010 Revision, United Nations).[13] Indeed, while all regions experienced a substantial drop in IMR, from a reduction in 80 deaths per 1000 live births in the North to 49 in the Center-west, regional disparities in the health environment are persistent across cohorts: A clear constant gap between the North and the South is very visible in Figure 2 both at the beginning and at the end of the period.

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[11] The breakdown of the five Brazilian regions into the 20 Brazilian states (in parentheses) as follows: North (Amazonas and Pará), Northeast (Maranhão, Piauí, Ceará, Rio Grande do Norte, Paraíba, Pernambuco, Alagoas, Sergipe and Bahia), Southeast (Minas Gerais, Espírito Santo, Rio de Janeiro and São Paulo), South (Paraná, Santa Catarina and Rio Grande do Sul) and Center-west (Mato Gross and Goiás).

[12] Although not reported in the table, the variation in mean stature is even higher across states.

[13] `http://esa.un.org/unpd/wpp`

[INSERT FIGURE 2 ABOUT HERE]

Finally, Table 1 shows an improvement in economic conditions during the period 1950-1980, with an annual growth rate of real GDP per capita of about 4.7%. As highlighted by Schultz (2005), economic growth is a potential relevant factor in explaining the human growth of the Brazilian population. Figure 3 displays the regional time trends in log(GDP), highlighting the persistent income differential between the poorest and richest regions over the period under analysis.[14]

The set of stylized facts presented in this section are consistent with both income and disease at birth affecting the evolution of population heights in Brazil during the period 1950-1980. In the next section we use regression analysis to assess whether these stylized facts are robust to covariates adjustments.

[INSERT FIGURE 3 ABOUT HERE]

4 Results

Table 2 presents the main results of our study. It displays estimates from a series of regressions in which mean population height is the dependent variable. The first three columns consider the role of IMR. Column 1 shows that in the 80 pooled time-series cross-section observations for the 20 Brazilian states over 4 years of birth, variation in IMR explains 42% of the variation in average height. The parameter estimate is -0.045, much lower than the one found in recent studies for developed countries (Bozzoli et al., 2009, Quintana-Domeque et al., 2011). Column 2 includes both year of birth and region fixed effects. The explanatory power of the regression increases from 42% to 67% (adjusted R^2s), the estimated coefficient on IMR flips its sign, and the relationship between height and IMR disappears. In Column 3 we replace region fixed effects with state fixed effects: The explanatory power of the regression jumps from 67% to 86%, and there is still no relationship between height and IMR.

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[14] Azzoni (1997) discusses in details the regional inequality of income in Brazil.

[INSERT TABLE 2 ABOUT HERE]

In columns 4 to 6 we shift our attention to real income per head (measured by the log of real GDP per capita). Column 4 shows that 63% of the variation in average height is explained by income. The parameter estimate is 2.67, which is similar to the estimate from Quintana-Domeque et al. (2011). Adding both year of birth and region fixed effects, Column 5, does not affect the qualitative relationship between income and height, although the parameter estimate decreases to 2.07. Similarly, replacing the region fixed effects with state fixed effects, Column 6, does not change the qualitative finding on the positive relationship between income and height, although allowing for state fixed effects reduces the magnitude to 0.73, and the coefficient is not statistically different from zero. An increase in log GDP by 1.4 units – which is the increase experienced by average log GDP between 1950 and 1980 – would explain an increase of between all (2.8 cm) and one third of the increase (1 cm) in average height shown in the Table 1.

Finally, columns 7 to 11 consider the role of both disease and income simultaneously. In Column 7, we show that conditional on GDP, IMR does not play any role in explaining average height, while GDP does. The addition of year of birth and region (state) fixed effects, Columns 8 and 9, does not change the qualitative relationship between income and height. The last two columns consider potential interactions between income and disease by including the interaction of IMR and GDP. This new variable has no power in explaining average height, while IMR and GDP play the same role as in columns 7 to 9.

The explanatory power of IMR (in Column 1) is much lower than the one obtained in recent studies for developed countries for cohorts born between 1950 and 1980. In the cross-country cohort-study of Bozzoli et al. (2009) for several European countries and the United States, the IMR explanatory power is 62%. Its explanatory power is 60% in the very recent within-country cohort-study of Quintana-Domeque et al. (2011) for Spain. In addition, IMR is not a robust predictor of population height. While disease, but not income, has been the constraining factor in developed countries, the story of human growth is very different in Brazil, at least after 1950.[15] The differential role of GDP in our context suggests that lack of nutrition is one of the main constraints to population

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[15] Although we are taking averages over race/color, Monasterio et al. (2006) show that a significant part of the apparent variation by color is in fact a result of the differences in income between colors, not within color groups themselves.

heights in poor developing countries. This is not to say that exposure to disease is not a relevant determinant of adult stature in Brazil, or in developing countries in general, but rather it indicates that the role of disease may be more important in other (critical) periods for human development. This possibility, among many others, is explored in the next section.

5 Robustness Checks

5.1 Migration

Ideally, we would like to estimate the relationship between the average stature of a cohort and its corresponding infant mortality rate (or real income per capita) in its year of birth. This, of course, raises two main complications. The first is that for those currently living in Brazil and randomly selected in the POF survey, we know where they are currently living but not their place of birth.[16] The second complication, and related to the first, is that even if this information was available, we would need to know, for those who actually moved, whether they migrated in the first year of life or after their first year of life but before the puberty growth spurt (van den Berg, Lundborg, Nystedt and Rooth, 2012). This detailed information is required to understand whether they were exposed to the IMR (or GDP) of their region of birth, or the one corresponding to their region of destination. Since the lack of this information can lead to serious biases, depending on whether migration was random or not with respect to IMR and GDP, it is crucial to assess whether migration is biasing our results and to what extent.

To assess the potential implications of not accounting for migration, we compute the proportion of individuals living in the same state of birth (i.e., stayers) for each specific birth cohort (1950, 1960, 1970, and 1980), using information from the 2003 National Household Survey (Pesquisa por Amostra de Domicílios, PNAD).[17] Table 3 reports the proportions of stayers by regions. In all regions, but the North, the proportion of individuals living in the same state of birth increases over time (cohort). The Center-west region has the lowest fraction of stayers. During the second half of 20th Century inter-regional

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[16] We cannot distinguish stayers (individuals living in their state of birth) from the rest of individuals in the POF data.

[17] The PNAD is conducted by the Brazilian Institute of Geography and Statistics (Instituto Brasileiro de Geografia e Estatística – IBGE).

migration was intensive not only from poor regions (e.g., Northeast) to rich regions (e.g., Southeast), but also from poor and rich regions to low population density areas (Center-West and North).

[INSERT TABLE 3 ABOUT HERE]

Migration patterns in Brazil over the period under analysis are not negligible, and some correction must be applied to our previous estimates. We proceed in two different ways. First, we re-estimate our main regressions retaining only those pairs of cohort-states with a high fraction (above 0.8) of individuals living in the same state of birth, in Table 4, columns 1 to 7. This amounts to cutting the sample size by 26 observations. Second, for the whole sample, columns 8 and 9, we include the fraction of stayers as an additional explanatory variable. Reassuringly, the estimates displayed in this table are virtually the same as those obtained in Table 2. Hence, we tentatively conclude that migration does not seem to interfere with our previous results. Income, not disease, is a robust predictor of height.

[INSERT TABLE 4 ABOUT HERE]

5.2 Omitted relevant variables

5.2.1 Disease environment, effective use of resources, and fertility

The regressions estimated so far are informative, albeit a bit parsimonious. While conditions in infancy captured by infant mortality and GDP in the year of birth are definitely important for adult height, our previous specification suffers from omitted variable bias if the infant mortality rate (or the GDP in the year of birth) is highly correlated with prenatal or postnatal conditions that also matter for adult height. For example, Peracchi and Arcaleni (2011) show that income per capita in the year of birth is a proxy for a variety of environmental indicators that are highly correlated with economic conditions.

In an attempt to keep the influence of these other potential influences constant, we gather information on other indicators that may be relevant in shaping the disease environment, may allow individuals to use the existing resources more effectively, or may explain potential selective effects due to fertility decisions. Variables that are likely to shape the disease environment include the fraction of the population in urban areas and demographic density by state and year of birth. The potential differential use of income in generating (and protecting) health is accounted for through the inclusion of the average years of schooling (and a measure of its inequality) in the state and year of birth. Finally, potential selection affecting the quality (or health) of children due to fertility decisions is accounted for using the state total fertility rate in the year of birth. Admittedly, these are crude measures. However our purpose for including them is to assess the extent to which our income measure is capturing other socioeconomic factors.

Columns 1 to 3 in Table 5 include several variables measured in the year of birth, the fraction of the population in the state living in urban areas, demographic density, average years of education and educational inequality. Our point estimates are very similar to those obtained previously. IMR does not predict adult height, while GDP does. In addition, none of these additional factors (i.e., urbanization, demographic density, average education, educational inequality) appears to be statistically significant, either individually or jointly (as judged by the F-test).

[INSERT TABLE 5 ABOUT HERE]

5.2.2 A better measure of (lack of) nutrition: Poverty

Our results indicate that real income per capita in the year of birth is a robust predictor of the cohort average height. Whether improvements in per capita nutrition (or the access to nutrients) are well approximated by increases in real income per head can be further explored by substituting GDP by an alternative income-driven measure: The headcount ratio, which gives the percentage of population below the poverty line.[18] In columns 4 to 6 of Table 5 we assess the relationship between the headcount ratio in the year of birth and average cohort height. Unfortunately, we only have information for the years 1970 and 1980 (Brazil Human Development Atlas, UNPD, 1998). Not surprisingly, a higher headcount ratio in the year of birth is negatively related to average cohort height,

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[18] In Brazil the poverty line was set at half the minimum wage in January 1991 (US$ 47.12 PPP, US$ 1.57 per day).

explaining 55% of its variation, as can be seen in Column 4. Column 5 shows that this relationship is robust to controlling for decade and regional fixed effects. Lastly, we introduce IMR in the year of birth in Column 6: IMR does not predict adult height and the coefficient on our poverty measure remains the same.

5.2.3 The role of income inequality

Brazil is the eighth most unequal country in the world (UNDP, 2005). With a Gini coefficient of 59.3, Brazil is only ahead of Namibia (70.7), Botswana (63.0), Lesotho (63.2), Sierra Leone (62.9), Central African Republic (61.3), Swaziland (60.9), and Guatemala (59.9). Our previous specifications neglected the (potential) direct effect of income distribution. Recent research has explored the role of income inequality in explaining adult heights. In India, Deaton (2008) finds statistically significant effects of income inequality on adult heights in some specifications, but its sign is the opposite of what one would expect. In Spain, Quintana-Domeque et al. (2011) find a negative relationship between the degree of income inequality in the year of birth, measured by the Gini index, and average height. The effect is statistically significant in several specifications, but its statistical significance disappears once the authors control for IMR.

As with poverty, income inequality measures are only available for two of the four cohorts under analysis. Hence, we were forced to dramatically reduce our sample size, down from 80 to 40 observations. Columns 7 to 10 in Table 5 are devoted to analyzing the potential role of income inequality. In Column 7 we run a regression of average height on log real GDP per capita and our income inequality measure, the mean log deviation (i.e., Theil index), from the UNPD (1998). As expected, the Theil index attracts a negative coefficient, although it is far from being statistically significant. The coefficient on GDP remains positive, statistically significant, and higher than in columns 1 to 3. Including IMR, Column 8, does not alter our estimates. The results remain the same when controlling for several confounding socioeconomic factors, regional, and year fixed effects, as shown in Column 9. Finally, Column 10, addresses the issue of nonlinearities, which may be relevant for different reasons. The rationale for the role of income inequality in explaining height is the concavity of the height-to-income relationship at the individual level (Steckel 1995, 2009). In addition, while for low levels of IMR, a negative relationship with height is expected due to the scarring of survivors, for high-IMR environments, a positive effect can be found because of selective survival: weakest individuals at birth (shortest individuals in adulthood) die in the first year of life, so the remaining ones are, on average, taller (see Bozzoli et al. 2009), as their biological height potential is higher. We do not find evidence of nonlinear effects of IMR on height (F-test = 0.14), and weak evidence of a positive and concave relationship between height and income per capita (F-test = 3.14).

5.3 Nutrition and disease revisited: Income, mortality and their interactions

Table 6 tabulates average cohort statures by IMR and GDP in the year of birth to further explore the role of income and disease, and their interactions when explaining population heights. As expected, cohorts living in regions with a high GDP (higher than the median) in the year of birth are taller, while those in cohorts living in regions with a high IMR (higher than the median) in the year of birth are shorter. Furthermore and consistent with our previous results, the role of income appears to be much more important than that of disease: While differences in average height between cohorts living in regions with a high GDP and those living in regions with a low GDP are substantial (3 cm or more), the differences along the disease dimension (high- versus low-IMR regions) are much smaller (1.5 cm or less).

[INSERT TABLE 6 ABOUT HERE]

In Column 1 of Table 7 we estimate regressions of population height on a dummy variable for cohorts in states with an infant mortality rate higher than the median, a dummy variable for cohorts in states with a log GDP higher than the median, and their interaction, hence replicating the results of Table 6. Column 2 includes both region and year of birth fixed effects. Finally, Column 3 includes the fraction of stayers. The results from Column 1 show in row 2 that the average height difference between cohort-region pairs of high- and low-GDP in low IMR environments, which is captured by the coefficient on the high log GDP dummy variable, 3.4 cm, is statistically significant (p-value < 0.01), as well as that in high IMR environments, which is captured by the sum of the coefficients on the dummy variables of high log GDP and the interaction of the dummy variables in row 5, 3 cm. The gap between these differences is not statistically significant, since the coefficient on the interaction of the dummy variables in row 3 is not statistically different from zero. As for the average difference in heights between high- and low-mortality environments, this is only statistically significant in high-income environments, row 4: -1.5 cm. However, only income differences are driving height differences, once we control for region and year fixed effects, Column 2, and accounting for migration, Column 3. The difference in average heights between rich and poor regions is 1.5 cm, no matter what the burden of disease is. All in all, these results reinforce the role of income, not disease, in explaining population heights in our context.

[INSERT TABLE 7 ABOUT HERE]

5.4 Economic conditions before birth and during childhood, and pre-adult mortality

If income at birth (or more generally in the critical period of development) is having a "causal" effect on population heights, economic conditions before birth should not have any effect on heights conditional on income in the year of birth. We implement such a placebo test in Table 8. In Column 1 we regress population height on IMR and log(GDP) in the year of birth, log(GDP) five years before birth, and region and year of birth fixed effects. Reassuringly, the estimates from this column show that income before birth does not predict height, but income in the year of birth does. Column 2 replaces log(GDP) in the year of birth with log(GDP) during early childhood (i.e., 0-5 years after birth). As previously, income before birth does not predict height, but income during early childhood is an important predictor of adult stature. The point estimate is higher than the one corresponding to log(GDP) in the year of birth in Column 1, and its standard error lower, which may reflect that the new variable, the mean of log(GDP)s, contains less (classical) measurement error.[19]

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[19] The log(GDP) 0-5 years after birth is computed as the average of log(GDP) in the year of birth and the log(GDP) 5 years after birth.

[INSERT TABLE 8 ABOUT HERE]

Our analysis shows that IMR is not a robust predictor of heights. Although this finding is consistent with the burden of disease being of much less importance than income in developing countries, a plausible alternative is that in these settings IMR is not a good proxy of the disease environment. One possibility is that selection and scarring effects are offsetting each other, although one would expect to find a non-linear relationship between population stature and IMR if that were the case, and we do not find evidence of that in our data. As a further attempt to investigate this issue, one could control for the mortality rate before the cohort reaches adulthood. Indeed, the high pre-adult mortality rates in the developing world are one of their distinctive features.

Unfortunately, we do not have data on pre-adult mortality rates, either at the state or at the country level in the years of our analysis. Nevertheless, we use the estimated quinquennial ratios of 0-15 mortality to 0-1 mortality in Latin America and the Caribbean for the periods 1950-54, 1960-64, 1970-74 and 1980-84 (Table 4 in Bozzoli et al., 2009) to estimate pre-adult mortality rates as the product of infant mortality rates and the estimated quinquennial ratios.[20] The corresponding ratios are 1.21 in 1950-54, 1.18 in 1960-64, 1.17 in 1970-74 and 1.15 in 1980-84. Column 3 reports the results of a regression of height on log(GDP) and the estimated pre-adult mortality rate, controlling for region and year fixed effects. The role of our estimated pre-adult mortality rate is null.[21] In Column 4, where we add IMR and income before birth, pre-adult mortality rate attracts a negative sign, which is the opposite of what one would expect under selective mortality of the "weakest" (shortest). Finally, Column 5 is a repetition of Column 4 with income in the year of birth being replaced by income during childhood. Neither IMR nor pre-adult mortality rate appears to have any predictive power of adult height.

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[20] The quinquennial mortality ratio for the period 1950-54 is multiplied by the infant mortality rate in the year 1950 to obtain an estimate of the pre-adult mortality rate in 1950. Pre-adult mortality rates for the remaining years are similarly estimated.

[21] Note that while the infant mortality rate varies both at state and year levels, the estimated quinquennial ratios only have time variation. Not only that, but the estimated quinquennial ratio refers to the whole Latin American and the Caribbean. However, accounting or not for cohort and region fixed effects does not make any difference on the estimate on pre-adult mortality rate. Results available from the authors upon request.

6 Conclusion

We have used data on four birth cohorts from twenty Brazilian states to analyze the relationship among infant mortality, real income per capita and adult height for the period 1950-1980. Infant mortality in the year of birth does not explain average adult height, while real income per capita in the year of birth proves to be a good predictor of adult height even after controlling for time fixed effects, regional fixed effects, and other potential factors. An increase in the real GDP per capita of the magnitude seen during the period explains one third of the increase in adult height, or about 1 cm, occurring in the same time span.

Our findings contrast with recent results for developed countries (Bozzoli et al., 2009, Quintana-Domeque et al., 2011), where disease, not income, has been the constraining factor on human growth, at least since 1950, but they are consistent with preliminary results reported by Coffey (2012) on the determinants of stature in India, a large developing county. The role of income in the year of birth in explaining adult health (proxied by stature) in Brazil for the cohorts born between 1950 and 1980 is consistent with recent empirical evidence on the impact of economic fluctuations on child health (proxied by birth weight) in Argentina for the cohorts born between 2000 and 2005 (Bozzoli and Quintana-Domeque, 2013), given the existing evidence linking birth weight and adult stature (Pietilainen et al., 2001; Sørensen et al., 1997; Karlberg et al., 1995; Tuvemo, et al., 1999) and low weight gain during pregnancy with low birth weights in developing countries (Kramer, 1987).[22]

The role of income fluctuations in explaining adult height is not something affecting only cohorts born in the past, but potentially cohorts born nowadays in developing countries.

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[22] Bozzoli and Quintana-Domeque (2013), using data from the national registry of live births for the period 2000-2005 in Argentina (a period marked by a dramatic economic crisis between 2001 and 2002), document a differential effect of economic activity fluctuations on birth weights by trimester of pregnancy and mother's socioeconomic status: low socioeconomic status mothers appear to suffer from nutrition, whereas those of high socioeconomic status do not.

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7 Appendix

Figures

Figure 1: Time trend for adult stature by Brazilian Regions

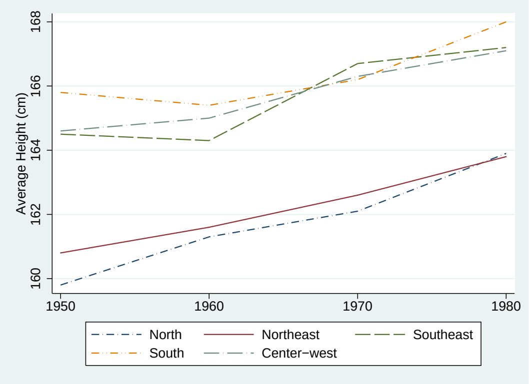


Figure 2: Time trend in IMR by Brazilian Regions

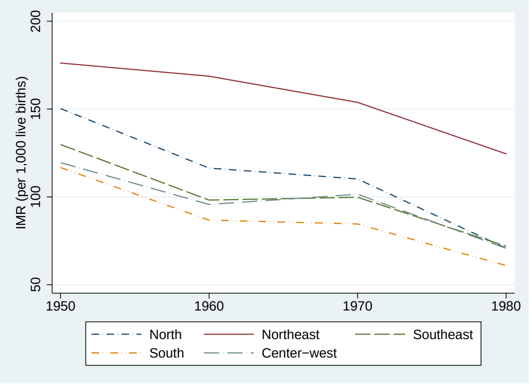
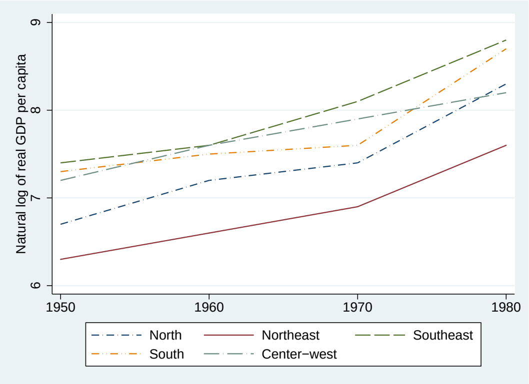


Figure 3: Time trend in log(GDP) by Brazilian Regions



Tables

Table 1: Stature, IMR and log(RGDP) by cohorts and regions in Brazil

	1950	1960	1970	1980
Adult Stature (cm)				
North	159.8	161.3	162.1	163.9
Northeast	160.8	161.6	162.6	163.8
Southeast	164.5	164.3	166.7	167.2
Southeast	165.8	165.4	166.2	168.0
Center-west	164.6	165.0	166.3	167.1
Mean (unweighted)	*162.6*	*163.0*	*164.3*	*165.4*
IMR (per 1000 live births)				
North	150.3	116.4	110.2	70.7
Northeast	176.2	168.7	153.8	124.5
Southeast	129.8	98.2	99.8	71.9
South	116.7	86.8	84.6	60.9
Center-west	119.5	95.7	101.5	70.7
Mean (unweighted)	*149.7*	*129.8*	*123.0*	*93.7*
log(RGDP)				
North	6.7	7.2	7.4	8.3
Northeast	6.3	6.6	6.9	7.6
Southeast	7.4	7.6	8.1	8.8
South	7.3	7.5	7.6	8.7
Center-west	7.2	7.6	7.9	8.2
Mean (unweighted)	*6.8*	*7.1*	*7.4*	*8.2*

Note. See Footnote 11.

Table 2. OLS regressions of population height on IMR and log(GDP)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
IMR	-0.045***	0.014	0.016	–	–	–	-0.007	0.009	0.019	-0.032	-0.004
	(0.005)	(0.012)	(0.013)				(0.007)	(0.010)	(0.013)	(0.048)	(0.034)
log(GDP)	–	–	–	2.67***	2.07***	0.72	2.40***	2.02***	0.84	1.46*	0.56
				(0.22)	(0.43)	(0.54)	(0.36)	(0.42)	(0.52)	(0.75)	(0.60)
IMR x log(GDP)	–	–	–	–	–	–	–	–	–	0.006	0.003
										(0.006)	(0.004)
Cohort dummy variables?	NO	YES	YES	NO	YES	YES	NO	YES	YES	YES	YES
Region dummy variables?	NO	YES	NO	NO	YES	NO	NO	YES	NO	YES	NO
State dummy variables?	NO	NO	YES	NO	NO	YES	NO	NO	YES	NO	YES
R^2	0.42	0.70	0.90	0.63	0.77	0.90	0.63	0.77	0.91	0.77	0.91
Adjusted R^2	0.42	0.67	0.86	0.63	0.74	0.86	0.63	0.74	0.87	0.74	0.86
N	80	80	80	80	80	80	80	80	80	80	80

Note: Heteroskedasticity-robust standard errors are reported in parentheses. *** p-value < 0.01, ** p-value < 0.05, * p-value < 0.1

Table 3: Proportion of stayers by cohorts of birth and regions

	1950	1960	1970	1980
North	0.75	0.74	0.78	0.86
Northeast	0.86	0.89	0.91	0.92
Southeast	0.73	0.76	0.78	0.87
South	0.78	0.85	0.87	0.9
Center-west	0.44	0.46	0.53	0.67

Note: The fraction of stayers (individuals living in the same state where they were born) is computed from the PNAD 2003.

Table 4. Adjusted for migration OLS regressions of population height on IMR and log(GDP)

	Subsample: Fraction of stayers > 0.8							**Full sample**	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
IMR	-0.041***	0.010	–	–	-0.008	-0.003	-0.057	0.007	-0.045
	(0.005)	(0.013)			(0.007)	(0.011)	(0.052)	(0.010)	(0.051)
log(GDP)	–	–	2.48***	2.74***	2.15***	2.80***	2.15**	2.23***	1.55**
			(0.23)	(0.54)	(0.38)	(0.58)	(0.90)	(0.45)	(0.75)
IMR x log(GDP)	–	–	–	–	–	–	0.007	–	0.007
							(0.007)		(0.007)
Fraction of stayers	–	–	–	–	–	–	–	2.08	2.56
								(1.81)	(1.86)
Cohort dummy variables?	NO	YES	NO	YES	NO	YES	NO	YES	YES
Region dummy variables?	NO	YES	NO	YES	NO	YES	NO	YES	YES
R^2	0.46	0.66	0.64	0.75	0.65	0.75	0.76	0.77	0.91
N	54	54	54	54	54	54	54	80	80

Note: The fraction of stayers (individuals living in the same state where they were born) is computed from the PNAD 2003. Heteroskedasticity-robust standard errors are reported in parentheses. *** p-value < 0.01, ** p-value < 0.05, * p-value < 0.1

Table 5. OLS regressions of population height on IMR, log(GDP) and several socioeconomic variables

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
IMR	0.008	0.009	0.005	–	–	0.005	–	0.001	-0.003	0.014
	(0.010)	(0.012)	(0.012)			(0.018)		(0.010)	(0.022)	(0.052)
log(GDP)	1.71**	1.75**	1.68**	–	–	–	2.73***	2.76***	2.35**	9.07
	(0.67)	(0.69)	(0.70)				(0.26)	(0.52)	(1.05)	(5.93)
Additional powers										
IMR2	–	–	–	–	–	–	–	–	–	-0.000
										(0.000)
log(GDP)2	–	–	–	–	–	–	–	–	–	-0.453
										(0.400)
Additional controls										
Head Count Ratio	–	–	–	-0.074***	-0.054***	-0.054***	–	–	–	–
				(0.009)	(0.016)	(0.016)				
Theil Index	–	–	–	–	–	–	-2.42	-2.50	-0.97	-2.76
							(2.78)	(2.88)	(3.67)	(3.79)
Urbanization	1.64	1.31	3.02	–	–	–	–	–	5.55	7.01
	(2.55)	(4.21)	(4.45)						(6.99)	(7.34)
Demographic Density	-0.001	0.002	0.001	–	–	–	–	–	0.005	0.001
	(0.005)	(0.006)	(0.006)						(0.006)	(0.006)
Average Education	–	-0.920	-0.518	–	–	–	–	–	-2.09	-0.931
		(1.25)	(1.27)						(1.88)	(2.03)
Education Inequality	–	-8.17	-6.44	–	–	–	–	–	-7.22	-1.90
		(7.77)	(7.83)						(10.76)	(11.73)
Total Fertility Rate	–	–	0.344	–	–	–	–	–	0.066	0.307
			(0.420)						(0.743)	(0.721)
F-test additional controls	0.22	0.33	0.44	–	–	–	–	–	0.47	0.28
F-test coefficients on IMRs = 0	–	–	–	–	–	–	–	–	–	0.14
F-test coefficients on log(GDP)s = 0	–	–	–	–	–	–	–	–	–	3.14*
Decade dummy variable?	NO	NO	NO	NO	YES	YES	NO	NO	YES	YES
Cohort dummy variables?	YES	YES	YES	NO	NO	NO	NO	NO	NO	NO
Region dummy variables?	YES	YES	YES	NO	YES	YES	NO	NO	YES	YES
R^2	0.77	0.77	0.78	0.55	0.76	0.76	0.67	0.67	0.83	0.84
N	80	80	80	40	40	40	40	40	40	40

Note: Heteroskedasticity-robust standard errors are reported in parentheses. *** p-value < 0.01, ** p-value < 0.05, * p-value < 0.1

Table 6. Average height by IMR and GDP.

		IMR		
		Low	High	Total
GDP	Low	162.7 [9]	161.6 [31]	161.9 [40]
	High	166.1 [31]	164.6 [9]	165.8 [40]
	Total	165.3 [40]	162.3 [40]	163.8 [80]

Note: High ($\geq$ median of the variable). Number of observations in brackets.

Table 7: Income, mortality, and interactions

	(1)	(2)	(3)
HIMR (= 1 if Higher than the median IMR)	-1.1	0.12	0.12
	(0.83)	(0.87)	(0.88)
HLGDP (= 1 if Higher than the median log(GDP))	3.4***	1.5**	1.5**
	(0.80)	(0.74)	(0.74)
HIMR x HLGDP	-0.40	-0.05	-0.04
	(1.01)	(0.87)	(0.89)
Linear combination of parameters			
HIMR + HIMR x HLGDP	-1.5**	0.07	0.08
	(0.57)	(0.72)	(0.73)
HLGDP + HIMR x HLGDP	3.0***	1.50**	1.50**
	(0.62)	(0.59)	(0.65)
Fraction of stayers	–	–	0.14
			(1.76)
Year fixed effects?	No	Yes	Yes
Region fixed effects?	No	Yes	Yes
R^2	0.57	0.73	0.73
Number of observations	80	80	80

Note: Heteroskedasticity-robust standard errors are reported in parentheses. *** p-value < 0.01, ** p-value < 0.05, * p-value < 0.1

Table 8. Economic conditions before birth, during childhood, and pre-adult mortality

	(1)	(2)	(3)	(4)	(5)
IMR	0.009	0.009	–	0.104	0.002
	(0.010)	(0.010)		(0.269)	(0.265)
log(GDP)	1.75**	–	2.02***	1.80**	–
	(0.798)		(0.421)	(0.820)	
log(GDP) 5 years before birth	-0.295	-0.050	–	-0.246	-0.050
	(0.700)	(0.588)		(0.718)	(0.593)
log(GDP) 0-5 years after birth	–	2.05***	–	–	2.05***
		(0.648)			(0.684)
Pre-adult mortality rate	–	–	0.007	-0.081	0.006
			(0.009)	(0.228)	(0.225)
Cohort dummy variables?	YES	YES	YES	YES	YES
Region dummy variables?	YES	YES	YES	YES	YES
R^2	0.77	0.78	0.77	0.77	0.77
N	80	80	80	80	80

Note: See Section 5.4. Heteroskedasticity-robust standard errors are reported in parentheses. *** p-value < 0.01, ** p-value < 0.05, * p-value < 0.1