Early-Life Environment and Adult Stature in Brazil during the period 1950 to 1980*

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Abstract

We study the relationship between environmental conditions at birth and adult stature using cohort-state level data in Brazil. We find that GDP per capita in the year of birth, not infant mortality rate, is a robust correlate of population stature in Brazil during the period 1950-1980. Our results are robust to a battery of robustness checks. Using a useful bracketing property of the (state) fixed effects and lagged dependent variables (heights) estimators, we find that an increase in GDP per capita of the magnitude corresponding to that period is associated with 43%-68% of the increase in adult height occurring in the same time span. Income, not disease, appears to be the main correlate of Brazilian population heights in the second half of the 20th Century.

JEL Classification Codes: I12, O54.
Keywords: infant mortality, income, adult height, bracketing property, fixed effects estimator, lagged dependent variable estimator.

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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, Kock, 2011, 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). 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, Schultz, 2003). 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.

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. At the population level, however, the role of genes appears to be less important than that of environmental conditions in determining stature (Silventoinen, 2003). For this reason, studies have focused on gross nutrition (typically proxied by GDP per capita) and disease burden (usually proxied by infant mortality or postneonatal mortality rates).[1] 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

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[1] Infant mortality rate is measured as the number of infants who die in their first year of life per 1,000 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 1,000 live births.

height of those infants in the same birth cohort who survived into adulthood.[2]

A very intriguing finding is that disease, not income, has been the constraining factor on human growth in developed countries at least after 1950 (Bozzoli et al., 2009, Quintana-Domeque et al., 2011). As pointed out by Bozzoli et al. (2009), and recently emphasized by Coffey (2013), this does not rule out the possibility that income (or nutrition related) constraints were important before 1950 or even nowadays in the more developing world. Indeed, this possibility echoes the work by Komlos (1998), who argues that the decline of average stature in Europe and North America during historical periods of economic growth[3] was associated primarily with economic processes and structural changes (e.g., increase in income inequality, increase in relative price of nutrients) than a deterioration of the disease environment. It is also entirely consistent with Fogel's research (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 population in Brazil, a large developing country.

In Brazil, researchers have used data from the Pesquisa de Orçamentos Familiares (POF) to document positive correlations between stature and education, and stature and wages (Curi and Menezes-Filho, 2009), 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 correlates of individual adult stature, controlling for per capita family income, years of education, demographic characteristics, and income distribution. While their results indicate a positive (concave) relationship between adult stature and the mean GDP during 0-15 years after birth, they do not account for the burden of disease in the year of birth, a potential determinant of adult height which is correlated

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[2] More recently, Quintana-Domeque et al. (2011) find that, in Spain, a reduction in the infant mortality rate of 30 individuals per 1,000 is associated with an increase in average height of about 2.7 cm, about 70% of the gain in average adult stature during the period 1961-1980. In Italy, Peracchi and Arcaleni (2011) find that economic conditions appear to matter more than disease burden for height for cohorts of men born between 1973 and 1978.

[3] Second half of the eighteen century in Europe and the 1930s and the 1940s in both Europe and North America.

with GDP. Neglecting the (potential) influence of disease exposure during childhood on adult stature can be problematic, not only because of previous research documenting the effects of infant mortality rate (IMR) in the year of birth on adult height, but also given the findings in Alves and Belluzo (2004) that a rise in education, sanitation and per capita income contributed to the decline of infant mortality in Brazil during the period 1970-2000, 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.[4]

In this paper we put forward an answer to the question "What are the forces behind the Brazilian human growth in the second half of the 20th Century?" focusing on the role of both income and disease (and its potential interactions) in explaining population heights. Collapsing height data from the POF at the state and year-of-birth level and combining it to data on GDP, IMR and other socioeconomic indicators at the state-year level, we find that income, not disease, is a robust correlate of population stature in Brazil during the period 1950-1980. Using a useful bracketing property of the (state) fixed effects and lagged dependent variables (heights) estimators (Guryan, 2001; Angrist and Pischke, 2009) we find that an increase in GDP per capita of the magnitude corresponding to that period is associated with 43%-68% of the increase in adult height occurring in the same time span. Finally, we also show that per capita income five years before birth is *not* associated with adult height, whereas per capita income during the first five years of life is an important correlate of it.

The paper is organized as follows. Section 2 describes the data sources. Section 3 summarizes the evolution of height, GDP and IMR in Brazil during the period 1950-1980. Section 4 contains the main regression results. Section 5 provides several robustness checks. Section 6 concludes.

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[4] The correlation between IMR and adult height 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). These pair-wise correlations conform to the existing empirical evidence coming from other studies, in terms of both signs and magnitudes. Section 2 provides the data sources.

2 Data Sources

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]

The sample is restricted to individuals born in 1950, 1960, 1970 or 1980, who already attained their adult stature by the time the survey was carried out (i.e., aged at least 21 in 2002-2003). Furthermore, due to both mortality-related selection and shrinking of the elderly, our sample excludes individuals over age 53 in 2002-2003. In order to increase the precision of our estimates, and following Bozzoli et al. (2009), 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 (to avoid fluctuations due to gender mix).[7]

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

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[5] Typically, studies that use measured anthropometric data are from selected populations.

[6] Anthropometric measures were submitted to the 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`

[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. We depart from studies focusing on India (or other Asian populations), where sex ratios differ substantially across regions (states) and time and gender discrimination in the allocation of nutrition and health inputs in early childhood has been well-documented, and do not model the population heights of men and women separately.

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

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 and urbanization), 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]

3 The Evolution of Height, Income and Disease in Brazil

Table 1 summarizes the data on average height, infant mortality rate per 1,000 live births (IMR) and the logarithm of the real per capita gross domestic product (GDP) by four birth 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 the 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,

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

[10] `http://www.ibge.gov.br/seculoxx`. 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 (2013), these indicators are not available for before 1980 at the state level.

[11] The breakdown of the five Brazilian regions into the 20 Brazilian states (in parentheses) is 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 Grosso and Goiás).

a gap that has been previously documented and discussed by Monasterio et al. (2006).[12] Figure 1 (in the appendix) 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.

Table 1. Descriptive statistics by birth cohort and region

	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
South	165.8	165.4	166.2	168.0
Center-West	164.6	165.0	166.3	167.1
Mean	*162.6*	*163.0*	*164.3*	*165.4*
IMR (per 1,000 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	*149.7*	*129.8*	*123.0*	*93.7*
Log(GDP)				
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	7.8	8.7
Center-West	7.2	7.6	7.9	8.2
Mean	*6.8*	*7.1*	*7.4*	*8.2*

Note: **Log(GDP)** is the log of real income per head.
See Footnote 11.

Table 1 also reveals a sharp fall in infant mortality rate between 1950 and 1980, from 150 to 94 infant deaths per 1,000 live births, which reflects a decrease of (roughly speaking)

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

2 deaths per 1,000 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 1,000 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 (in the appendix) both at the beginning and at the end of the period.

Finally, Table 1 shows an improvement in economic conditions during the period 1950-1980, with an annual growth rate of real GDP per capita (log(GDP)) 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 (in the appendix) 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 the evolution of income, mortality or both are indeed responsible for the increase in heights of the Brazilian population during the second half of the 20th century.

4 Main 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 two 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%

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

[14] Azzoni (1997) presents a very detailed analysis of the regional income inequality in Brazil.

of the variation in average height. The parameter estimate is -0.045, much lower than the one found in recent studies for developed countries (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.

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

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
IMR	-0.045^{***}	0.014	-	-	-0.007	0.009	-0.032
	(0.005)	(0.012)			(0.007)	(0.010)	(0.048)
log(GDP)	-	-	2.67^{***}	2.07^{***}	2.40^{***}	2.02^{***}	1.46^{*}
			(0.22)	(0.43)	(0.36)	(0.42)	(0.75)
IMR × log(GDP)	-		-	-	-	-	0.006
							(0.006)
Year dummy variables?	NO	YES	NO	YES	NO	YES	YES
Region dummy variables?	NO	YES	NO	YES	NO	YES	YES
R^2	0.42	0.70	0.63	0.77	0.63	0.77	0.77
Adjusted R^2	0.42	0.67	0.63	0.74	0.63	0.74	0.74
N	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

In columns 3 and 4 we shift our attention to real income per head (measured by the log of real GDP per capita, log(GDP)). Column 3 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 4, does not affect the qualitative relationship between income and height, although the parameter estimate decreases to 2.07.

Finally, columns 5 to 7 consider the role of both disease and income simultaneously. In column 5, 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 fixed effects, column 6, does not change the qualitative relationship between income and height. In the last column we include 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 5 and 6.

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 post-neonatal mortality explanatory power is 62%, similar to the 60% explanatory power of IMR in the very recent cross-region cohort-study of Quintana-Domeque et al. (2011) for Spain. In addition, IMR is not a robust correlate of population height. Although disease rather than income has been the constraining factor in developed countries at least after 1950, the story of human growth appears to be different in Brazil.[15] Similar results are obtained when we estimate regressions separately for male and female heights (results reported in tables A1 and A2 in the appendix) on (estimated) gender specific infant mortality rates.[16]

However, before concluding that income is the driving force of population heights in Brazil, we must acknowledge that several factors could be interfering with our estimates, namely unobserved constant differences across states, migration patterns, the interaction between income and disease, and several omitted (or mismeasured) determinants of height that vary *simultaneously* at the state and year level. Next section provides a battery of checks to assess the robustness of our results.

5 Robustness Checks

5.1 State Fixed Effects versus Lagged Height Variables

Our previous estimates account for both time variation through fixed effects and geographical variation through regional fixed effects. While there is great scope for omitted

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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.

[16] We compute gender specific infant mortality rates by year and state by assuming that the ratio between male and female infant mortality rates (available at the regional level in 1980 from `http://seculoxx.ibge.gov.br`) is the same in 1950, 1960 and 1970, and assuming that is the same among states within the same region. We thank John Komlos for suggesting this approach.

variable bias due to unobserved state differences (we have 5 regions and 20 different Brazilian states), controlling for state fixed effects could mean asking too much from the data, that is, we could be absorbing part of the true "effect" of the variables of interest (IMR and log(GDP)) on adult height. An immediate question is: Can we think of the state fixed effects estimator as providing a lower bound of the income effect on adult height? If so, can we think of finding an upper bound? We address this issue in Table 3.

In column 1 we display the estimates of the relationships between height, mortality and income once we control for year and state fixed effects. As before, we do not find a relationship between infant mortality in the year of birth and the average height of the corresponding cohort. In addition, we still find a positive and statistically significant relationship between average cohort height and the gross domestic product in the year of birth, although (as expected) the point estimate is halved with respect to that in column 6 of Table 2.

Table 3. Regressions of population height on IMR and log(GDP)
State Fixed Effects versus Lagged Dependent Height

	State Fixed Effects	Lagged Dependent Heights		
	(1)	(2)	(3)	(4)
IMR	0.019	0.000	0.002	0.013
	(0.014)	(0.005)	(0.008)	(0.009)
log(GDP)	0.841***	1.40***	1.50**	1.34*
	(0.443)	(0.382)	(0.547)	(0.713)
Height in 1950	-	0.516***	0.210	0.302
		(0.085)	(0.135)	(0.200)
Height in 1960	-	-	0.374***	0.391**
			(0.082)	(0.155)
Height in 1970	-	-	-	0.145
				(0.193)
Year dummy variables?	YES	YES	YES	NO
State dummy variables?	YES	NO	NO	NO
N	80	60	40	20

Note: Standard errors clustered at the state level.
*** p-value < 0.01, ** p-value < 0.05, * p-value < 0.1

Instead of controlling for stated fixed effects, one could include lagged height (dependent) variables. Interestingly enough, the (state) fixed effects and lagged dependent variables (height) estimators have a useful "bracketing property"(under some conditions, see Angrist and Pischke, 2009; Guryan, 2001). In our case, this property can be roughly stated as follows: If log(GDP) is positively correlated with either lagged population height or with fixed determinants of lagged population height, then the state-fixed effect estimate and the lagged-height variables estimate should bracket the estimate of interest. In other words, the estimated (positive) effect of log(GDP) on height using stated-fixed effects will tend to be too small, while the estimated (positive) effect of log(GDP) using lagged-height variables will tend to be too big. This is precisely what we observe when we compare column 1 to columns 2 to 4.

According to our estimates in Table 3, an increase in log(GDP) by 1.4 units – which is the increase experienced by average log(GDP) between 1950 and 1980 – would explain between 43% (1.2 cm = 1.4 × 0.84) and 68% (1.9 cm = 1.4 × 1.34) of the 2.8 cm increase in average height shown in Table 1.

5.2 Migration and exposure to income and disease environments

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.[17] 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.[18] The second issue, 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). The lack of information on whether individuals move (and if so, when) makes us to be uncertain about whether the

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[17] As noted by Bozzoli, Deaton and Quintana-Domeque (2009), our matching of date of birth to IMR and GDP is inevitably imprecise at the level of a single year, if only because the income and disease environments that are relevant for adult height operate not just in the year of birth. This is not a problem since we are interested in allowing the data to pick up trends and changes in trends.

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

matching of average adult cohort heights by state to the infant mortality rates and income levels in the year of birth for the same state is adequately capturing the relevant income and disease environments. For this reason, it is crucial to assess whether migration is biasing our previous estimates and to what extent.

If migration was *random* with respect to individual health (height), our estimated "effects" of both infant mortality and income would be biased towards zero. If not, then we could have either positive or negative biases. Suppose that migration went from poorer regions (in terms of both health status and income) to richer regions, and that healthier (i.e., taller) individuals were more likely to migrate to healthier and richer regions. In that case, we would be overestimating the positive "effect" of income on population heights, since poor regions would became shorter and richer regions would become taller through a *compositional change*. By the same token, we would be overestimating the negative "effect" of infant mortality on population heights. If instead of the healthy, those who decided to migrate were the unhealthy, then we would tend to underestimate the "effect" of income and mortality on population heights.

Our findings of no relationship between infant mortality and height could be explained by a *compensating effect* of shorter people born in high-mortality regions moving to taller and low-mortality regions, such that the negative *biological* effect on population height in the high-mortality region is compensated through a *behavioral* response from shorter individuals in this region moving to the low-mortality and taller region, so that the mean of both regions tend to approach, although the levels of infant mortality are different.

To assess the potential implications of migration for our previous estimates, 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).[19] Table 4 reports the proportions of stayers by regions. In all regions, but the North, the proportion of individuals

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

living in the same state of birth increases monotonically over time (cohort). The Center-West region has the lowest fraction of stayers. During the second half of 20th Century inter-regional 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).

Table 4. Fraction of stayers

	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	0.90
Center-West	0.44	0.46	0.53	0.67

Note: Authors' calculations from PNAD 2003.

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 three different ways. First, we re-estimate regressions of columns 2, 4 and 6 from Table 2 retaining only those pairs of cohort-states with a high fraction (above 0.8) of individuals living in the same state of birth. This amounts to cutting the sample size by 26 observations, as we can see in columns 1, 2 and 3 of Table 5. Second, for the whole sample, in column 4 we weight each observation by the fraction of stayers, giving more weight to observations with a higher fraction of stayers, and in column 5 we include the fraction of stayers as an additional explanatory variable. Finally, we use the bracketing property of the (state) fixed effects (FE) and lagged dependent (LD) variables (heights) estimators in columns 6 and 7 after accounting for the fraction of stayers. Reassuringly, the estimates displayed in this table indicate once again that income, not disease, is a robust correlate of height. Interestingly enough, once we account for the fraction of stayers, the bounds for the “true effect” of income on height become tighter, 1.05-1.39. Hence, we tentatively conclude that migration does not seem to interfere with our previous results.

Table 5. Adjusted for migration regressions of population height on IMR and log(GDP)

	Subsample			**Full sample**		**Bracketing**	
	Fraction of stayers > 0.8			**Weighting**	**Without weights**	**State FE**	**LD Heights**
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
IMR	0.010 (0.013)	-	-0.003 (0.011)	0.005 (0.010)	0.007 (0.010)	0.018 (0.014)	0.014 (0.010)
log(GDP)	-	2.74*** (0.54)	2.80*** (0.58)	2.32*** (0.43)	2.23*** (0.45)	1.05 (0.72)	1.39* (0.76)
Fraction of stayers	-	-	-	-	2.08 (1.81)	1.30 (2.37)	-0.87 (2.19)
Year dummy variables?	YES	YES	YES	YES	YES	YES	NO
Region dummy variables?	YES	YES	YES	YES	YES	NO	NO
State dummy variables?	NO	NO	NO	NO	NO	YES	NO
Lagged dependent heights?	NO	NO	NO	NO	NO	NO	YES
N	54	54	54	80	80	80	20

Note: Lagged dependent heights: Dependent variable in 1950, 1960, and 1970.
(1)-(5): Heteroskedasticity-robust standard errors are reported in parentheses
(6)-(7): Clustered standard errors are reported in parentheses
*** p-value < 0.01, ** p-value < 0.05, * p-value < 0.1

5.3 The interaction between income and disease

In Table 6 we tabulate average cohort statures by IMR and GDP in the year of birth to further explore the role of income and disease, and its interactions in 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 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).

Table 6. Average height by IMR and GDP

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

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

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 is 3.4 cm (p-value < 0.01). In high IMR environments, the mean difference in heights, captured by the second linear combination of parameters, is 3 cm (p-value < 0.01). 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 (first linear combination of parameters): -1.5 cm. However, *only* income differences are associated with 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.

Table 7. Regressions of population height on income and mortality indicators

	(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 × HLGDP	−0.40	−0.05	−0.04
	(1.01)	(0.87)	(0.89)
Fraction of stayers	–	–	0.14
			(1.76)
Year dummy variables?	No	Yes	Yes
Region dummy variables?	No	Yes	Yes
Linear combination of parameters			
HIMR + HIMR × HLGDP	−1.5**	0.07	0.08
	(0.57)	(0.72)	(0.73)
HLGDP + HIMR × HLGDP	3.0***	1.50**	1.50**
	(0.62)	(0.59)	(0.65)
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

5.4 Omitted (or mismeasured) determinants of height

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 other contemporaneous environmental and socioeconomic determinants of population heights that vary simultaneously at the state and year level.

Alves and Belluzzo (2004) find that a rise in education, sanitation and per capita income contributed to the decline in IMR in Brazil during the period 1970-2000. If education and sanitation indicators in the year of birth are having effects on cohort population heights not only through their effect on the disease environment or income but through other channels, our previous estimates could be biased. For this reason, we gather information on other indicators that may be relevant in shaping the disease environment and may allow individuals to use the existing resources more effectively. Variables that are likely to shape the disease environment include the fraction of the population in urban areas 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 in the state and year of birth. Admittedly, these are crude measures. However our purpose for including them is to assess the extent to which our mortality and income measures are capturing other socioeconomic factors.

In Table 8, column 1, we can see that including both the fraction of the population in urban areas and the average years of schooling does not affect our previous estimates: IMR still does not correlate with population height, while log(GDP) does. None of these additional factors appears to be statistically significant, either individually or jointly (as judged by the F-test). However, once we replace the region fixed effects with state fixed effects, these additional factors become statistically significant in explaining population heights and their signs flip, although income remains being a strong correlate of adult height.

Is the effect of income on height related to improvements in nutrition? While we do not have information on nutrition at the state and year level, 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.[20] In addition, and given that Brazil is the eighth most unequal country in the world (UNDP 2005)[21], we also include an indicator of income inequality: the mean log deviation (Theil index).[22] Unfortunately, these measures are only available for two of the four cohorts under analysis, 1970 and 1980 (Brazil Human Development Atlas, UNPD, 1998). Hence, we are forced to dramatically reduce our sample size, down from 80 to 40 observations. Not surprisingly, the estimates in column 3 indicate that both a higher headcount ratio and a higher Theil index in the year of birth are negatively related to average cohort height, while IMR does not correlate with adult height.[23] That the income growth during this period was associated to human growth could be explained by improvements in nutrition is consistent with the fact that while food production went up, relative food prices did not increase between 1950 and 1970.[24]

We now turn to explore whether the relationships between height and mortality, and height and income, are non-monotonic. A non-monotonic relationship between mortality

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

[21] 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).

[22] 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).

[23] 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.

[24] Reis (2012) suggests that part of the improvements in nutritional outcomes in Brazil in the last decade could be explained by the expansion of social programs such as Bolsa Familia (a conditional cash transfer program).

and height is plausible if for low levels of IMR there is a negative relationship with height due to the scarring of survivors, while for high-IMR environments there is a positive effect due to 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), because their biological height potential is higher. According to the estimates in column 4, we do not find evidence of either non-monotonic effects of IMR or log(GDP) on height (F-tests are 1.50 and 1.65, respectively).

Table 8. Regressions of population height on IMR and log(GDP)
Additional and alternative covariates

	(1)	(2)	(3)	(4)
IMR	0.008	0.019	0.007	0.048
	(0.011)	(0.014)	(0.031)	(0.030)
IMR^2	-	-	-	-0.000
				(0.000)
log(GDP)	1.72**	0.979*	-	2.90
	(0.677)	(0.553)		(4.85)
$\log(GDP)^2$	-	-	-	-0.122
				(0.318)
Head Count Ratio	-	-	-0.040**	-
			(0.018)	
Theil Index	-	-	-11.42***	-
			(0.268)	
Urbanization	1.65	-5.66*	-5.26	-4.88
	(4.20)	(3.21)	(5.53)	(3.50)
Average Education	-0.061	0.974***	-1.15	1.41***
	(0.936)	(0.324)	(1.62)	(0.41)
F-test on Urbanization and Education	0.21	5.35**	1.17	5.99***
F-test on IMR and IMR^2	-	-	-	1.50
F-test on log(GDP) and $\log(GDP)^2$	-	-	-	1.65
Decade dummy variable?	NO	NO	YES	NO
Year dummy variables?	YES	YES	NO	YES
Region dummy variables?	YES	NO	NO	NO
State dummy variables?	NO	YES	YES	YES
N	80	80	40	80

Note: (1): Heteroskedasticity-robust standard errors are reported in parentheses.
(2)-(4) Clustered standard errors are reported in parentheses.
*** p-value < 0.01, ** p-value < 0.05, * p-value < 0.1

Table 9. Regressions of population height on IMR and log(GDP): Falsification Test and Pre-adult mortality correction

	(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***
		(0.679)			(0.684)
Pre-adult mortality rate	-	-	0.007	-0.081	0.006
			(0.009)	(0.228)	(0.225)
Year 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

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

Finally, it is important to note that both IMR and GDP in the year of birth may well be correlated with prenatal or postnatal conditions that also matter for adult height. On the other hand, if income at birth 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 falsification or placebo test in Table 9. 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* correlate with 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 is not correlated with adult height, but income during early childhood is an important correlate of it, consistent with the idea that the income environment that is relevant for adult height operates not just in the year of birth. 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.[25]

Our analysis shows that IMR is not a robust correlate of height. Although this finding is consistent with the burden of disease being of much less importance than income in developing countries, there are other plausible alternatives. Perhaps in Brazil IMR is not a good proxy of the disease environment, or selection and scarring effects are exactly offsetting each other. Neither the first nor the second alternative appears to be very plausible in our context. Given the wide range of variation in IMR (from 48.99 to 199.04 per 1,000 live births), if selection and scarring effects were exactly offsetting each other, one would expect to find a non-monotonic relationship between population stature and IMR, 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. This allows us to investigate the role of an alternative measure of the burden of disease in determining adult height.

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.[26] The corresponding ratios are 1.21 in 1950-54, 1.18 in 1960-64, 1.17

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[25] 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.

[26] 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.

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.[27] 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 is correlated with adult height.

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. Controlling for regional and time fixed effects, infant mortality in the year of birth does not correlate with average adult height, while real income per capita does. Our results are robust to a battery of robustness checks. Using a useful bracketing property of the (state) fixed effects and lagged dependent variables (heights) estimators, we find that an increase in the real GDP per capita of the magnitude seen during the period is associated with 43%-68% of the approximately 3 cm increase in average height in the same time span.

While 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, they are consistent with new evidence reported by Coffey (2013) on the determinants of stature in India, a large developing country, and the effects of GDP fluctuations on birth weight in Argentina (Bozzoli and Quintana-Domeque, 2014), given that birth weight and adult height show a strong correlation (Henrik et al.,

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[27] Note that while the infant mortality rate varies both at the state and year levels, the estimated quinquennial ratios only have time-series variation. Not only that, but the estimated quinquennial ratio refers to the whole Latin American and the Caribbean. In addition, we must bear in mind that, if our estimated pre-adult mortality rate was pure white noise, its estimated coefficient would be zero.

1999). Thus, the role of income in the year of birth in explaining adult health is not something affecting only cohorts born in the past, but also cohorts born nowadays in developing countries.

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Appendix

Figure 1: Average height by year of birth: Time trend by Brazilian region

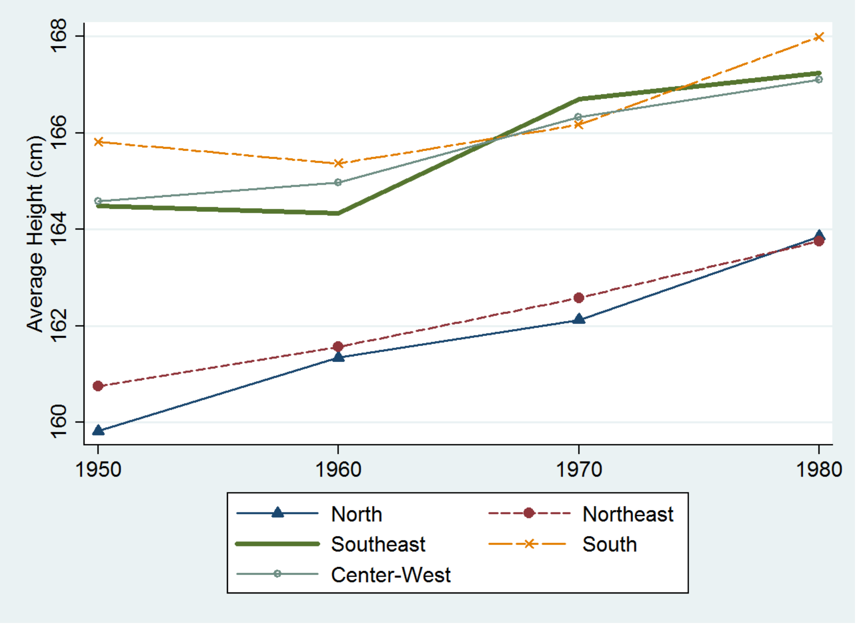

Figure 2: IMR: Time trend by Brazilian region

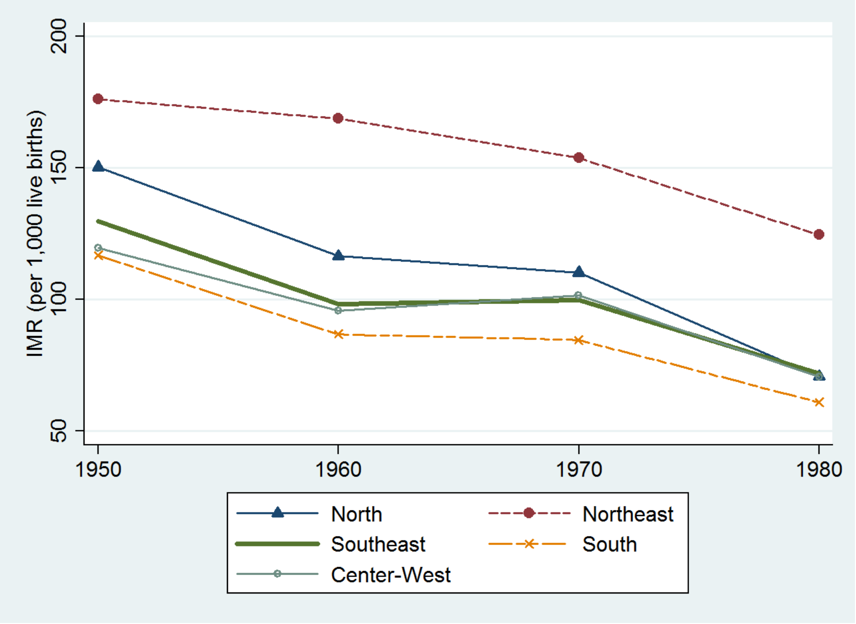

Figure 3: Log(real GDP per capita): Time trend by Brazilian region

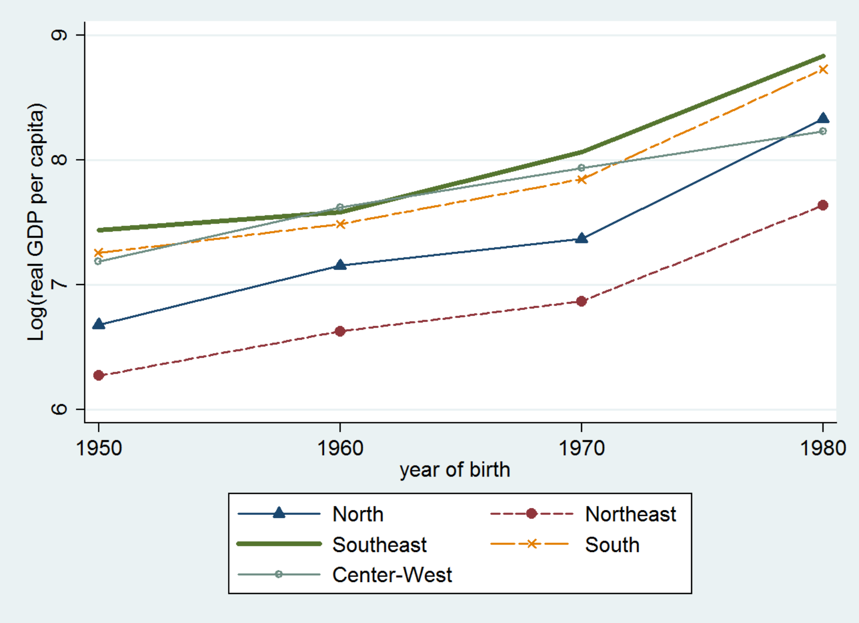

Table A1. Regressions of male height on male IMR and log(GDP)

	(1)	(2)	(3)	(4)	(5)	(6)
IMR^{male}	−0.041***	0.011	-	-	−0.003	0.006
	(0.005)	(0.011)			(0.007)	(0.009)
log(GDP)	-	-	2.63***	2.33***	2.53***	2.30***
			(0.23)	(0.51)	(0.38)	(0.51)
Year dummy variables?	NO	YES	NO	YES	NO	YES
Region dummy variables?	NO	YES	NO	YES	NO	YES
R^2	0.35	0.66	0.57	0.74	0.57	0.74
Adjusted R^2	0.34	0.62	0.57	0.71	0.56	0.71
N	80	80	80	80	80	80

Note: Heteroskedasticity-robust standard errors are reported in parentheses.

$IMR^{male} = \left[\frac{2(1+\pi_s)}{2+\pi_s}\right] \times IMR$ where $\pi_s = \frac{IMR^{male}_{r,1980}}{IMR^{female}_{r,1980}}$, r is region, and s is state.

π_s is computed from `http://seculoxx.ibge.gov.br` where $IMR_{r,1980} = \frac{1}{2} \times \left(IMR^{male}_{r,1980} + IMR^{male}_{r,1980}\right)$.

*** p-value < 0.01, ** p-value < 0.05, * p-value < 0.1

Table A2. Regressions of female height on female IMR and log(GDP)

	(1)	(2)	(3)	(4)	(5)	(6)
IMR^{female}	-0.044***	0.022	-	-	-0.006	0.017
	(0.005)	(0.014)			(0.008)	(0.012)
log(GDP)	-	-	2.64***	1.94***	2.43***	1.86***
			(0.23)	(0.46)	(0.39)	(0.43)
Year dummy variables?	NO	YES	NO	YES	NO	YES
Region dummy variables?	NO	YES	NO	YES	NO	YES
R^2	0.39	0.68	0.61	0.72	0.61	0.73
Adjusted R^2	0.39	0.64	0.60	0.69	0.60	0.70
N	80	80	80	80	80	80

Note: Heteroskedasticity-robust standard errors are reported in parentheses.

$IMR^{female} = \left[\frac{2}{2+\pi_s}\right] \times IMR$ where $\pi_s = \frac{IMR^{male}_{r,1980}}{IMR^{female}_{r,1980}}$, r is region, and s is state.

π_s is computed from `http://seculoxx.ibge.gov.br` where $IMR_{r,1980} = \frac{1}{2} \times \left(IMR^{male}_{r,1980} + IMR^{male}_{r,1980}\right)$.

*** p-value < 0.01, ** p-value < 0.05, * p-value < 0.1