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The Double African Paradox : What does selective mortality tell us ?

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Abstract -

I study the relationship between height stature and child mortality in West Africa. This is motivated by two things : understanding the determinants of height, widely used health indicator, and explaining the « double African paradox ». This paradox comes from the fact that Africans are relatively tall in spite of extremely unfavorable income and disease environments ; this the level paradox. The second paradox is that African height stature decreased in recent years, despite better health conditions and lower child mortality ; this is the trend paradox. These stylized facts are surprising as both child mortality and height stature are viewed as health indicators, so that we expect a negative correlation between the two. To study this paradox, I focus on West African countries only, where child mortality levels are very high. For Benin, Burkina Faso, Côte d'Ivoire, Ghana, Mali, Nigeria and Senegal, I use Dhs (Demographic and Health Surveys) data to measure child mortality (before 5) at the region × period level using the retrospective birth history of mothers. I want to test to what extent the paradox can be explained by selective child mortality. More generally, there is a need to understand how much child mortality levels and trends affect the study of height stature in Africa. Instrumentation can not be used in this context as I would need an event that increases or decreases mortality without affecting nutrition and regardless the distribution of heights. Consequently, I build a statistical model that I estimate linearly and nonlinearly. I first show that the correlation between adult height and mortality within region is not significantly negative in this setting. By estimating a nonlinear relationship between height and child mortality, I show that in high mortality contexts, when child mortality decreases selective mortality decreases as well, so that more short people survive. I am able to explain some differences in height levels between African countries and countries where selective mortality is lower. I also manage to explain why height stature did not increase as much as expected in Africa compared to the decrease in child mortality rates in the second half of the 20^{th} century.

Key words : Height, Child Mortality, Selection, West Africa.
Jel classification codes : I1, I3, J1, O1.

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1 Introduction

To describe health standards and evaluate the impact of health policies, we need comprehensive information on the determinants of health indicators. This article offers an original interpretation of the relationship between height and child mortality in Sub-Saharan Africa, focusing on the regional context rather than on the national context as already done in the literature. I start with two striking stylized facts. First, Africans are relatively tall in spite of extremely unfavorable income and disease environments, and in particular in spite of very high child mortality rates. This is the « African Paradox » put forward by Bozzoli, Deaton, and Quintana-Domeque (2009). African women are generally taller than Indian, Bangladeshi, and Nepali women (See Figure 3 in the Appendix) in spite of much lower income. This finding is very surprising as height stature and child mortality are both considered as good proxies for health conditions and nutrition during childhood. I call this African specificity regarding the correlation between child mortality rates and the level of height the « level paradox ». Second, if child mortality decreased in Sub-Saharan Africa during the last decades, adult height stature did not increase in this very region. Yet, height and child mortality are correlated in opposite ways with the same factors. Height is positively correlated with nutrition and negatively correlated with pathogens prevalence. These correlations reverse for child mortality. Hence one might expect a negative correlation between those two indicators. Empirically, it is what I observe both in level and in trend outside Sub-Saharan Africa. In places where child mortality rates are high, mean adult heights are low. Similarly, in places where child mortality rates decreased due to socioeconomic development and health progresses, mean adult heights increased. Akachi and Canning (2008) argue however that in Sub-Saharan Africa only the decrease in child mortality rates was not correlated with an increase in height stature ; this is the « trend paradox ». Figure 4 shows yearly evolutions for child mortality and adult height at the regional level. I see that the evolutions of child mortality and height stature in West Africa follow similar patterns : in regions where mortality decreased, height stature decreased as well.

To sum up, the link between height and child mortality is very specific in Sub-Saharan Africa : it is the « Double African paradox », both in level and in trend :

- Africans are relatively tall in spite of extremely unfavorable health conditions and low levels of income.
- Height stature did not increase during the last decades, even though child mortality rates have significantly decreased, indicating an improvement of health conditions.

The level paradox could be explained by several mechanisms. It could come from the fact that Africans have a greater genetic potential for growth in height stature. It could also be explained by a specificity in African health infrastructures or nutrition [1] that would have a greater positive impact

1. Differences in terms of diet for instance.

on height stature than on child mortality. Yet, those evidences do not provide a credible explanation for the trend paradox. How genetics, infrastructures or nutrition could explain the recent decline in both height stature and child mortality in Sub-Saharan Africa ? Some authors relate the negative height trend observed in Africa to the worsening of living conditions, but then why did child mortality decreased in the same time ?

The main contribution of this paper is to describe precisely the link between height and child mortality in the context of sub-saharan Africa and to provide a partial answer to the double African paradox. I provide evidence that a major part of this paradox can be explained by selection, defined by Bozzoli, Deaton, and Quintana-Domeque (2009) as « the indirect positive effect that comes from mortality selectively removing the least healthy (or shorter) members of the population, so that the survivors are healthier (or taller) ». Child mortality rates are so high in Sub-Saharan Africa that it creates a survivorship bias : shorter individuals are more likely to die so that only the tallest individuals survive, which explains the double paradox. Due to selective mortality, observed adult heights are upward biased because the shortest died. Besides, when child mortality rates decrease, the impact of selection decreases as well and mean heights do not increase as much as they would have in the absence of selection. The main innovation is that I do not take for granted that the relationship between child mortality and height is linear, and that I propose a region-level rather than country-level analysis. With this within-region analysis, I control for the immediate health and nutritional environment and all the unobservables that may impact height in the region [2]. Furthermore, a regional study provides greater variability for mean heights and child mortality, which helps identification. I include seven countries that belong to the same region : West Africa. Focusing on West Africa, I control for the gene pool : mechanisms put forward are not driven by African genetic differences. In the region studied, child mortality rates are among the highest in the World. This, joined with a nonlinear analysis, helps capturing a nonlinear effect at high mortality rates.

> « The possible non-monotonicity of the relationship between height and infant mortality, which are interesting predictions of the analysis, are unlikely to be apparent in low mortality environments. » (Bozzoli, Deaton, and Quintana-Domeque 2009)

The relationship between height stature and child mortality in West Africa is an important issue to understand the « double African paradox » and to provide the reader with a clear view on the determinants of height stature. Indeed, height stature is a widely used proxy for long-term health conditions. Since works by Fogel (1994) , Steckel (2008a), Komlos and Baten (2004), height has been very much used in development economics and economic history. Height developments are related to three components : genetics, pathogens and nutrition, the latter two during childhood (it is generally argued that height is mainly determined between 0 and 5). In a large enough population, the distri-

2. For instance, I control for the fact that in Cote d'Ivoire and Ghana, despite worst health conditions in the North, mean heights are relatively taller.

bution of genetics is normal, so that mean heights are mainly explained by two main determinants : nutrition, for which socioeconomic status can be used as a proxy, and health environment, including both pathogens and health infrastructures. Furthermore, the study of height stature provides an insight into living conditions in contexts where we often have no other well-being measures. For instance, in Cogneau and Rouanet (2009), we find with survey data that the pace of increase in height stature experienced by successive cohorts born in Cote d'Ivoire and Ghana during the late colonial period (1925-1960) is almost as high as the one observed in France and Great-Britain over the 1875-1975 period. We then provide evidence that a significant share of the increase in height stature may be related to the early stages of urbanization and of cocoa production. This study contributes greatly to the description of living conditions evolution in those two countries during the colonial period.

Child mortality and height stature are useful health indicators and it is thus essential to understand their determinants and to describe their interaction. Most studies using anthropometric as an health indicator treat their samples as if they were a representative sample of birth cohorts they consider. If selective mortality induces a significant bias on mean heights, this is no longer true, and conclusions coming from the study of height trends may be false. Alter (2004) underlines this issue : « If height is related to the risk of dying, changes in mortality will alter the distribution of heights in the adult population ». This is an even more important issue in West African countries where health conditions are very low compared to other developing countries.

Identifying precisely the impact of selective mortality is not an easy task. To identify a causal impact, one would need to instrument mortality changes by a variable that impacts height only through mortality. I would for instance need a natural experiment that led to an exogenous variation in the number of deaths, all along the height distribution, and that did not directly impact height. To that respect, standard instruments such as rainfall records, vaccination campaigns, conflicts, can not be used. Either they do not satisfy the exclusion restriction, either they affect individuals heterogeneously regarding their height. Consequently, I need to build a specific statistical model to describe the impact of selective mortality.

As a matter of fact, the literature does not say much on the link between height and mortality. A few articles look at the relationship between height stature and adult mortality. Studying a Norwegian cohort, Waaler (1984) shows that the probability of death between 40 and 69 years old is twice as large for smallest individuals as for tallest individuals. Fogel (1994) makes the hypothesis that death probability is negatively correlated with height stature, and correlates the decline in mortality rates in Europe during the 19th Century with the increase in height stature. Alter (2004) brings together several studies and shows that the negative association between height and the risk of dying has been remarkably consistent in various contexts. Those articles suggest that differential mortality might

be an issue. Studying height stature for individuals below 40 allows to get rid of any bias due to differential adult mortality ; however, biases due to child mortality remain, in particular in contexts where child mortality rates are high.

Two recent articles use the Chinese Great Famine (1959-1961) as a natural experiment to study the impact of a negative nutrition shock inducing deaths on height stature. Gorgens, Meng, and Vaithianathan (2007) show that this famine induced 20 to 30 millions additional deaths among children. Their first result is that survivors are not significantly smaller than the cohorts born just before the famine. This « non-result » comes from the compensation between a selection effect (positive impact on adult height) and an undernutrition effect (negative impact on adult height). Showing that taller individuals were more lucky to survive during the famine, they put forward a « survival of the fittest » mechanism. To disentangle undernutrition and selection effects, the authors look at surviving cohorts' children. They find that those children are taller than children whose parents were born before the famine because they inherit from the greater height potential of their parents (who were selected by the famine). Meng and Qian (2009) use another methodology. They estimate the long-term impact of famine on survivors, observing height stature, education and occupation. They argue that selective mortality implies an « attenuation bias ». Those who belong to the lower part of height and income distributions died, and only the richest and healthiest survived. The estimated effect of the famine [3] is based on the survivors only and is biased downward. To overcome this bias, the authors look at the impact of the famine on the top decile (q90) of the height distribution, where the attenuation bias shall have a lower impact. They find that coefficients are significantly higher in absolute terms for the top decile, which confirms that mortality is selective. These two studies put forward a selective mortality mechanism. One might fear nonetheless that the results are context-specific : the authors exploit one of the most dramatic event of famine in history. The impact of undernutrition relative to selection is probably much higher than in West Africa where child mortality rates are structurally very high.

Two articles offer a macroeconomic analysis of the relationship between height and child mortality, using cross-country regressions. Bozzoli, Deaton, and Quintana-Domeque (2009) study childhood determinants of adult height, making the assumption that the disease environment during childhood can be described by infant mortality. To explain the African paradox, the authors develop a model of selection and stunting. According to this model, the early life burden of nutrition and disease is responsible for mortality in childhood which leads to selection. This early life burden also leaves a residue of long-term health risks for survivors (stunting), with a negative impact on adult height. The stunting effect implies a negative correlation between height and infant mortality : in places where infant mortality rates are high, the health environment is unfavorable and people are small.

3. Measured by mean heights of famine's cohorts.

On the contrary, the selection effect leads to a positive correlation between height and mortality. The authors predict that selection can dominate stunting at high enough mortality rates. They show that the correlation between height and infant mortality within and between developed countries is negative, and that this same correlation is smaller in absolute terms in Sub-Saharan Africa. Akachi and Canning (2008) start from the fact that health improving models we observed in Europe centuries ago and more recently in developing countries do not work in African countries. Outside of Africa, an improvement in nutrition joint with health public policies leads to a decrease in infant mortality rates and to an improvement in health. In Sub-Saharan Africa however, cohort average height has been declining slightly over the last fifty years while infant mortality has declined rapidly. Using Dhs data from African countries, the authors explain height stature by nutrition and exposition to pathogens during childhood (proxied by infant mortality). They find that the coefficient for infant mortality is negative, but much less so than in non-African developing countries. They argue that health policies implemented in Africa implied a direct decline in mortality, but not in morbidity, which explains why the mortality decline was not correlated with an height increase. I argue that the results found by the authors could as well be explained by a decrease of selective mortality over time, that led to the survival of more and more small individuals and to a decline in average height stature.

A more recent work describes the extent of the survivorship bias on mean adult heights and asks whether the size is large enough to account for the African paradox. Moradi (2010) focuses on the « level paradox » trying to explain what he calls the « African dummy ». Using cross-sectional data on developing and richer countries, he first shows that African women are 5 cm taller than one might expect from the nutrition and health conditions present at birth. He then uses figures coming from a Gambian study in which children were followed and measured from birth to maturity. Under a certain number of assumptions, he finds that the effect of selective mortality is about 2 cm, that is almost one third of the height paradox. Using another data set, he shows that Ethiopians are taller in adulthood, relative to a reference population of the same age and sex, than in childhood. He provides evidence that this pattern does not hold in Brazil or Guatemala. From these findings, he concludes that at the age around puberty, African populations catch-up and become tall. He gives further evidence of this mechanism showing that height improves from age 4 to age 20 among a large sample built from Dhs data. According to him, the height paradox comes from this growth catch-up at puberty by which African populations end up 5 to 6 cm taller than they would have been otherwise. This study is very interesting in that it brings to light another potential mechanism for the African paradox. In any case, the conclusions of this study are not in contradiction with Moradi (2010). The fact that he finds increasing z-scores from children to mothers is in line with the fact that I bring to light a paradox for adult heights only, and not for children. It seems to be the case, actually, that the specificity of the correlation between height and child mortality in Africa is partly driven by this adult-child difference

(see section 4.3 for a study of this difference).

To another extent, several epidemiological studies that describe the link between malnutrition and mortality were led in Sub-Saharan Africa using anthropometric indicators. Those studies generally focus on one country, or even one region, which allows them to follow a given cohort of individuals and to use duration models. For instance, Fawzi, Herrera, Spiegelman, Amin, Nestel, and Mohamed (1997) follow a cohort of 30.000 children under 6. They find that mortality risk is higher fort undernourished children. Their main conclusion is that public policies should be oriented toward breastfeeding and morbidity reduction. In the same vein, Sterky, Mellander, and Wall (1987) and Salama, Assefa, Talley, Spiegel, van der Veen, and Gotwa (2001) relate nutrition to mortality in Guinea-Bissau and Ethiopia. These studies aim at providing efficient public policies to fight against malnutrition in Sub-Saharan Africa, but do not provide a complete view of the extent of selective mortality.

As was mentioned earlier, standard econometric methods for identification, such as instrumentation, can not be used in this context. Consequently, to answer the questions asked, I build a statistical model using a panel of West African regions. It allows me to measure the correlate of a change in child mortality in terms of heights, in a given region. I look both at children and adults' heights. I use Dhs (Demographic and Health Surveys) surveys on Benin, Burkina Faso, Cote d'ivoire, Ghana, Nigeria, Mali and Senegal. These data provide geographic coordinates for every household in the survey. Starting from these, I divide the region into Gps regions. Every individual is assigned to one of the regions, according to his place of residence. Child mortality rates are computed at the region $\times$ survey cohort level level using these data.

The aim of this paper is not to describe a causal relationship between child mortality and height, as an exogenous shock on child mortality that would allow to identify such a causal relationship does not exist. The identification strategy is based on non idiosyncratic changes in mortality, that concern every individuals in a given region. I am aware that those shocks may also impact height levels, so that the observed correlation between height and mortality might be biased. However, I build a statistical model to describe all the mechanisms at stakes, in order to control as much as possible for such biases, and to show that if anything biases should bias downward the correlation. I also use nonlinear econometrics to describe the relationship between height and mortality, looking both at child and adult heights.

2 Data and descriptive results

2.1 Demographic and Health Surveys

Dhs surveys (Demographic and Health Surveys) were collected from 1990 to 2000 in Benin, Burkina Faso, Cote d'Ivoire, Ghana, Mali, Nigeria and Senegal. For each country, there are several surveys, implemented at different times. Those surveys contain stratified samples of women aged 15 to 49 that are asked about their reproductive history. They also provide the height of mothers aged 15 to 49, and that of children under 3 (under 5 for a couple of surveys).

Surveys do not contain a systematic geographical partition of countries (regions, counties, etc.) that would be constant from one year of survey to another and that could be used to add region fixed effects in the specification. I thus have to construct such « regions ». To do so, I keep surveys that provide the geographic localization of villages. In these surveys, I know Gps coordinates (latitude and longitude) of villages. From them, I construct 83 « Gps regions », that are defined geographically and thus fixed from one survey to another. To construct these regions, I proceed as follow :

1. I build a grid of squared zones, of side one and a half degree of longitude/latitude. The surface of those square is around 25.000 km^2. Zones do not stop at national frontier, they can be transborder. I only avoid squared zones to contain villages in both Ghana and Benin as I do not have data on Togo.
2. I then review every zone, starting from the lower latitude and lower longitude (ie from the far south-west point of the whole region).
3. If there are less than 5 clusters in a zone for a given survey year, I aggregate the given zone with one of the neighboring zone.
4. The criterion is the following. I keep the smallest neighboring zones, to avoid the formation of huge zones. Among these selected zones, I select the one which center point (average latitude and longitude) is the closest from the center point of the zone to be aggregated.

The identification strategy depends greatly on the definition of those regions. As will be described later in the text, I implement within-region regressions to control for any unobservables defined at the regional level. The main issue concerning the definition of regions regards their size. If defined regions are too small, their should not be enough variation within the region to identify an effect. On the contrary, if regions are too big, there should be enough variation within the region, but I may aggregate geographical places that differ a lot. Consequently there is a trade-off between identification and precision. It seems to me that using 83 regions for a geographical area containing 7 countries is reasonable. To give an example, in this setting, Senegal contains 11 Gps regions, against 14 administrative regions. To check that results are not driven by the definition of regions, I will be able to implement robustness checks (see section 4.4).

Dhs data are provided with survey weights that ensure the representativity of the sample at the country level. Nonetheless, sample size of surveys is not proportional to population size. As I want to obtain a representative sample of the seven West African countries studied, I reweigh the whole sample taking into account the representativity of each survey's sample. Using Fao population statistics, I compute a sampling rate equal to the number of mothers in the survey implemented in country j and year i, divided by the total population of country j in year i. For each observation, I divide the existing weight by the corresponding sampling rate. This allows me to build a representative sample for the panel of West African countries that are studied. Table 4 shows computed sampling rates for each survey.

2.2 Height, z-score and child mortality

For the purpose of this analysis, I want to construct two health indicators : child mortality and height.

Dhs data provide the birth history of mothers. In particular I know the day of birth and death of each of their children, along with the child gender and mother's characteristics. I use this information to compute child mortality at the region × period level. I define 4 periods or « survey cohorts »by aggregating years of survey as follows : 1992-1994, 1995-1998, 2002-2003, 2005-2008 (there were no survey conducted between 1999 and 2001 in countries of interest). Let's take the example of a region that contains villages from both Côte d'ivoire and Burkina Faso. I have data on Cote d'ivoire for years 1994 and 1998, and on Burkina Faso for years 1992 and 1998. From this information, I am able to compute mortality rates for the first (1992 Burkina Faso and 1994 Côte d'ivoire) and the second (1998 Burkina Faso and Côte d'Ivoire) period in this region.

I checked that the results did not change much if I considered infant mortality (mortality before 1), child mortality (mortality before 5), or even mortality between 1 and 5 [4]. I chose to focus on child mortality because the computation of this indicator is based on a larger number of individuals, which reduces the risk of measurement error. The computation of infant mortality is threatened by many measurement errors, in particular because mothers tend to round their children's death age to one. More generally :

> « Childhood mortality, up to age 5, if often more accurately measured than infant mortality rates because of uncertainty about birth dates » (Bozzoli, Deaton, and Quintana-Domeque 2009)

I chose to compute age-specific death rates, rather than crude death rate. A crude death rate is the ratio between the number of under-five deaths and living births, during a given period. I prefer the age-specific death rate, which is more accurate given the data. The age-specific death rate is the

4. Results available on request.

ratio of the number of children dead before 5 and the number of births, for a *given birth cohort*. This rate approximates the probability to die before 5 for a given cohort, which makes its interpretation very intuitive. It also controls for differences in the age distributions for populations that are being compared. To compute child mortality, I only keep children born 60 to 180 months (5 to 15 years) prior to the survey, ie those who have been fully exposed to child mortality risk. I also focus on children who have always lived in the village, to avoid potential migration biases. I then compute the share of those children which died before 5 in a given region. For instance for the DHS III on Benin 1996, I focus on birth cohorts 1981-1991, and I compute the share of those children that died before age 5. For infant mortality, I consider children born 60 to 180 months before the survey, and among them compute the share which died before 1. I thus compute child mortality rates at the regional level for each survey cohort. I will be able to relate those rates to anthropometric indicators, heights and zscores.

DHS surveys provide the height of mothers aged 15 to 49. I assume that height growth is achieved at age 20, and focus on mothers aged 20 to 30. Those data only allow me to relate mothers' height to mortality rates faced by their children. The figure 5 describes how the computation of stature and mortality rates relate to the survey year. Ideally, I would want to relate height of mothers to mortality rates they actually faced. To do so, I would need survey data on a large enough time span (30 years), in order to compute mean heights using more recent surveys, and to relate them to child mortality rates computed with older surveys. On average, I only have a gap of 10 years between two surveys for a same country which is not enough [5]. Consequently I relate mothers' height to the child mortality rate prevailing in the region 5 to 15 years before the survey. I am aware that such regressions are imperfect. However, restricting to mothers aged less than 30 allows to relate mothers' height to child mortality rates that are less *far* from their year of birth. Also, it seems credible to assume that apart from major crises (war conflict, epidemics, etc.) child mortality trends were relatively constant during the time span of this study. In Figure 6, we see that at the national level, infant mortality rates decreased constantly since the 1950s. In the data, the great majority of regions do not face trend reversion during the period (the evolution is either positive or negative, all along the period) [6]. I thus assume that when I relate height trends to mortality rates computed at the region $\times$ period level, I do say something about mortality trends 15 or 20 years ago.

5. Also there are often only two points in time, so that if I attributed earlier mortality rates to mothers, I could not run within region regressions.

6. The only notable exception is between period 1 and period 2, i.e. between 1993 and 1996, when mortality rates significantly increase on average, and increase in regions where they decrease in later periods. I was thus afraid that the estimates might be biased by the fact that I attribute negative mortality trends to mothers that actually faced positive mortality trends. As a robustness check, I run the same regressions removing the first period ; it does not change the results significantly. I also check that estimates did not vary when using child mortality rates computed with children born 15 to 20 (rather than 5 to 15) years before the survey.

To overcome this simultaneity issue, I also study the link between child mortality and child height. DHS surveys provide the height of children aged 0 to 35 months at the time of the survey (59 months for more recent surveys ; I do not use those heights in order to have a constant baseline for the computation of mean heights). I either consider child height directly, by controlling for gender dimorphism and age trends, either consider z-score. The z-score Z_i of an individual i is defined relative to a reference population, of the same age and gender :

$$Z_i = \frac{H_i - MH}{\sigma}.$$

Where H_i is the height of individual i (in cm), MH is the median height of the reference population, and σ is the standard-error of heights in the reference population. Z_i measures the distance, in terms of standard errors, between the individual height and the height of the reference population. Using data from the World Health Organization [7], I compute z-score for each child with non missing height. I only analyze heights and zscores of children that are at least one year old. Below this age z-score and heights are generally considered as non robust, and the measurement error on reported age is higher. I also set to missing heights and z-scores of children whose z-score are greater than 6 in absolute terms. What I empirically observe in survey data is that misreport of age come from monthly age rather than from yearly age. As a result, the measurement error due to misreport decreases when the child grows older. I also restrict the sample to children less than 3 years old to study a constant sample over time.

At the end of the day, I compute mothers' height, children's heights and zscores and mortality rates from different periods. I sum up the exact computation periods in figure 5.

The reader has to keep in mind that height determinants before 5 might not be the same as determinants of adult heights. As a consequence she should not expect to find the same results for children and adults.

2.3 Descriptive statistics on the paradox

In the sample, the average mortality rate faced by children is 19%. This number is very high it means that almost 1 out of 5 children in those seven countries die before the age of 5. At the same time, observed adult heights are relatively high. Table 5 gives mothers' mean height and children mean z-score by country and survey year. Those descriptive statistics already give account for the level paradox : the region studied is characterized by both tall adult heights and high child mortality rates.

Table 1 shows weighted trends of mortality rates and anthropometric indicators. In the first

7. www.who.int/childgrowth/standards

column, I provide the level of height and mortality in the sample. In the second column, I regress mothers' and children's heights or z-scores on birth year and I regress mortality rates on survey year, adding region fixed effects ; in each case, regressions are weighed. In the third column, I provide the estimated trend interacted with a dummy « Native », indicating if the mother or children has always lived in the village. For children's height, I also control for age, gender, and the interaction between the two.

TABLE 1 – Changes in height and mortality

	Number of observations	Level	Trend within GPS region	Trend within × Native
Height of mothers	42,665	160.1	-0.0742***	0.00158
Height of children	40,454	79.6	0.0832**	-0.00322
Children z-score	40,454	-1.8	0.0328***	-0.00103
Infant mortality	213	12%	-0.00194***	
Child mortality	213	19%	-0.00467***	

Sample of children : aged 12 to 35 months.
Sample of mothers : aged 20 to 30 years old.

I find in the chosen sample the trend paradox underlined by Akachi and Canning (2008) : adult heights decrease while mortality rates also decrease significantly [8]. This result can be seen in Figure 4, which provides a map of the yearly evolution of mothers' height and child mortality in the 7 countries studied. Regions in which child mortality decreased more are also regions in which height stature decreased. I argue that this pattern reveals selective mortality, and will try to identify precisely the impact of mortality at the regional level.

I also find that children's heights and zscores increased significantly during the same period. The height paradox thus concerns adults, but not children. An explanation of this fact could be that selection effects only impact adult heights. This would be the case if child mortality selects children that will *potentially* be taller at adult ages, but are not *actually* taller when children.

The main assumption is that part of the height paradox comes from the fact that when mortality rates decrease, selective mortality decreases as well, less tall people are selected, and as a consequence mean heights decrease. The aim of this work is to test this hypothesis.

3 Methodology and specification

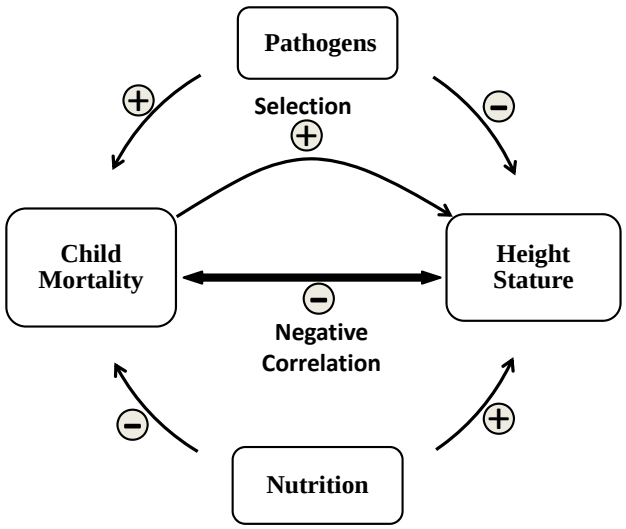
3.1 Modeling the link between child mortality and height

I ask whether the link between height and child mortality is monotonous, using West African survey data. The relationship between height and child mortality is a complex one, I try to sum up

8. Results are coherent with those of Akachi and Canning (2008) : they find that infant mortality rates per thousand decreased by 1,7 and that adult height decreased by 0,023 (samples differ).

the main mechanisms that are at stake in the following graph (Figure 1).

FIGURE 1 – The link between height and child mortality



According to Angus Deaton, height stature is determined during childhood both by nutrition and exposure to pathogens, and hence directly linked to the health environment of individuals. Child mortality is also determined by nutrition and infections, but with the order reversed. Nutrition has a negative impact on mortality because it provides « greater resistance to disease » (Alter 2004), whereas higher exposure to pathogens is correlated with an increase in child mortality rates. This leads us to expect a negative relationship between those two indicators. We indeed observe such a negative relationship outside of Sub-Saharan Africa, both in level and in trend. But this negative relationship is not unique : child mortality might have a positive impact on height stature through selection. Several anthropometric studies have shown that, within a given population, the probability to die was relatively higher for shorter people. This selective mortality implies that when child mortality is high, observed mean adult heights might be upward-biased, because the shortest died. To this selection effect, one can add another mechanism through which child mortality could impact positively height stature : « sibling rivalry » (Moradi 2010). Within the household, if the number of deaths increases, the quantity of food per capita increases as well. As a consequence, all things being equal, children might be better nourished in high child mortality contexts. This effect adds to the selection bias, and those two effects may weaken, or even reverse, the initial negative relationship between height stature and child mortality [9].

I focus on the exposition to pathogens that can affect height in two opposite ways. For a given amount of nutrition, bad health conditions have a negative impact on height, via stunting, and an

9. I will not be able to disentangle a pure selective mortality effect from an household allocation effect. What I estimate is the total impact of child mortality, both through selection and through reallocation of resources.

indirect positive effect, via selection. I propose to observe the correlation between height stature and health environment, focusing on the nonlinear impact of child mortality on height stature.

Starting from Figure 1, I provide a model that will help to specify the estimated equations. I start with the two following equations that relate height stature (H) and child mortality (M) to nutrition (N) and pathogens (P). I assume that each of the coefficients are positive [10].

$$H = \alpha N - \beta P + \Theta_M M \ (+u)$$

$$M = -\gamma N + \delta P \ (+v)$$

There are three main determinants of height : nutrition, pathogens and genetics. I add a fourth determinant, that I want to estimate : selective child mortality, whose impact is supposed to be positive and equal to Θ_M. In the above equation, residuals u should capture genetics. However, the distribution of genes is supposed to be normal in a given population. As regressions will be clustered at the regional level and thus explain regional mean heights, the impact of genetics is null in this context of analysis, under the assumption that the gene pool is constant over the period of analysis. Similarly for mortality, v can denote the effect of genetical weakness inherited from parents, but given the specification, I can assume that v is null.

I assume that nutrition and exposition to pathogens can be modeled in the following way :

$$N = \Theta_N Y + \epsilon$$

$$P = -\Theta_P Y - \xi V + \eta$$

Where Y denotes socioeconomic development and can be proxied by income or consumption. Nutrition is positively correlated with socioeconomic development. Conversely, exposition to pathogens decreases by Θ_P when the level of development increases. Here, I follow Klasen (2006), who argues that resources at the household level increase the ability to acquire more calories and to invest more in health and nutrition of children. As such, it has a positive impact on nutrition, and a negative impact on the exposition to pathogens.

When using P, the exposition to pathogens, as a determinant of height, I want to capture the *net* health environment. By *net* health environment I mean the *gross* health environment (prevalence rates, for instance), corrected by the access to medical care or by the individual demand for health. This is why the equation of P contains two terms. V describes any variable that has a direct effect on height through pathogens, and not through nutrition, and that is therefore a proxy for the gross

10. Section 3.3 and tables 6 and 7 provide descriptive evidence that height (resp. child mortality) is positively (resp. negatively) correlated with the level of wealth and with the number of medical institutions in the cluster.

health environment. It could be for instance vaccination rates. Y describes the protection against pathogens brought by economic development. I further assume that $Cov(Y, \epsilon) = 0$, $Cov(Y, \eta) = 0$ and $Cov(V, \eta) = 0$.

At the end of the day, I get the following equations for child mortality and height :

$$H = (\alpha\Theta_N + \beta\Theta_P)Y + \beta\xi V + \Theta_M M + \alpha\epsilon - \beta\eta \quad (1)$$

$$M = -\gamma\Theta_N Y - \delta\Theta_P Y - \delta\xi V - \gamma\epsilon + \delta\eta \quad (2)$$

In equation (1), I relate height to socioeconomic status, gross exposition to pathogens and mortality. The estimate of Θ_M might be biased by some unobservables : $\alpha\epsilon - \beta\eta$. I see that M is correlated with the residuals ϵ and η in equation (2). As such, M is not an exogenous variable in equation (1). I wish to predict the sign of the bias on the selection coefficient. To do so I compute the covariance between the endogenous variable and the residuals :

$$\begin{aligned} Cov(M, \alpha\epsilon - \beta\eta) &= Cov(-\gamma\Theta_N Y - \delta\Theta_P Y - \delta\xi V - \gamma\epsilon + \delta\eta, \alpha\epsilon - \beta\eta) \\ &= -\alpha\gamma\sigma_\epsilon^2 - \beta\delta\sigma_\eta^2 + (\alpha\delta + \beta\gamma)Cov(\epsilon, \eta) - \alpha\delta\xi Cov(V, \epsilon) \quad (3) \end{aligned}$$

The first two terms are negative, as all coefficients are assumed to be positive. Furthermore, $Cov(\epsilon, \eta)$ is the covariance of nutrition's unobservables and pathogens' unobservables. It is very likely that unobservables that have a negative impact on pathogens (for instance, health improving campaign) have a positive impact on nutrition. I thus expect the covariance between ϵ and η to be negative. Similarly, it seems credible to assume that $Cov(V, \epsilon) \geq 0$, ie unobservables that positively affect nutrition (health campaigns, positive income shocks, etc.) are positively correlated with the prevalence of vaccination in a given region. Under these assumptions, I find that the covariance computed in equation (3) is negative. That means that impact of selective mortality is underestimated when height is modeled following equation 1. This bias reveals that I do not control completely for exposition to pathogens, hence I do not absorb completely the negative correlation between height and mortality, modeled in Figure 1. This means that the linear results I will obtain will diminish the impact of selective mortality : what I obtain is a lower bound of the selection effect. To overcome this limit, I will propose nonlinear econometric methods that will allow me to describe and quantify better the selection effect.

3.2 The empirical strategy

The estimated equation

I build the empirical strategy starting from equation (1), keeping in mind that according to equation (3) I tend to underestimate the positive impact of selective mortality on height. I want to relate height stature to child mortality, controlling for socioeconomic status and vaccination rates. Furthermore, I want to estimate this equation within regions (using regions fixed effects) and to use the regions as clusters. This allows me to control for genetics determinants, and for the regional health environment. I do not know the place of birth of individuals, as a result I am only able to attribute to each individual the child mortality rate that is prevalent in her region of residence. In order to avoid a migration bias, I interact child mortality with a dummy equal to one if the individual always lived in her current place of residence.

I estimate the following equation :

$$H_{izt} = \alpha + \beta_1 M_{zt} + \beta_2 M_{zt} \times N_{izt} + \delta N_{izt} + \gamma Y_{izt} + \eta X_{izt} + \lambda V_{zt} + \mu_z \ (+\nu_t) + \epsilon_{izt} \qquad (4)$$

Where :

- H_{izt} is the anthropometric measure (height or zscore) of individual i (child or mother) in region z and survey cohort t [11].
- M_{zt} is a measure of child mortality in region z and survey cohort t.
- N_{izt} is equal to one if the individual (mother or child) always lived in the village.
- Y_{izt} is a vector of socioeconomic variables characterizing the household in which individual i lives (see below for the description of control variables).
- X_{izt} is a set of controls that will vary with the endogenous variable.
- V_{zt} measures the vaccination rate in region z and survey cohort t.
- λ_z is a region fixed effect.
- ν_t is a survey cohort or time fixed effect.

Standard errors are clustered at the regional level. This seems relevant as long as child mortality, the main explicative variable, is computed regionally. As such, using regions as clusters returns to calculate the regional average for each of the endogenous and exogenous variables, and to run regressions using these averages. This is all the more relevant here that it allows to get rid of genetic determinants of height stature [12].

By adding fixed effects, I estimate the parameters within-region, with and without controlling for the general trend [13]. The within-region analysis is necessary to account for regional differences.

11. see section 2.2
12. see section 3.1
13. The data do not provide enough points in time to control for region-specific time trends

Bozzoli, Deaton, and Quintana-Domeque (2009) insist that « in Africa, there is enormous diversity of average heights across countries, presumably reflecting local nutritional, environmental, and disease conditions (or even genetic differences). » Regions might be characterized by various levels of public health, access to health care, nutritional intakes or genetics. More generally, a within-region analysis allows to get rid of any unobservable that might affect height stature at a regional level. I assume that given the region and the socioeconomic status of the individual, nutrition intakes are constant among individuals. Under this assumption, a within-region analysis controlling for the socioeconomic status absorbs nutrition fixed effects ; this is exactly what I do in equation 4. Similarly, I assume that by controlling for the regional vaccination rate, I absorb the effect of pathogens. In that context, height differences I exploit for identification come from differences in child mortality and from some residuals (presumably non-idiosyncratic : non-regional epidemiological or nutritional shocks for instance, that are unobservable and bias the estimates). In an additional specification, I absorb the general trend, as mortality and height trends are significant over the period (see Table 1). As a consequence, the identification strategy relies one regions where child mortality has more or less decreased than the average. For those regions, I observe the correlate of a child mortality change in terms of height.

It seemed relevant to focus the analysis on the effect of child mortality rates not only on individuals observed in the village at the time of the survey, but more precisely on those who always lived in the village. Consequently, I interact the child mortality variable M_{zt} with a dummy N_{izt} which is equal to one if the individual (either the mother or the child) always lived in the village. As a result, in this specification, $\beta_1 + \beta_2$ captures the correlate of a child mortality rate change in terms of height stature, for individuals that were actually living in the village when children, and that thus actually faced the child mortality rate M_{zt}.

Control variables

1. The socioeconomic status (Y_{izt})

We saw in Figure 1 that theoretically height stature and child mortality were both correlated with the socioeconomic status through nutrition. The data do not provide any information on household or individual nutritional intakes. Yet, I aim at running regressions for a given level of nutrition. To approximate this setting, I control for the socioeconomic status of the individual, using three distinct variables : wealth index, mother's education and place of residence (urban or rural). This amounts to assuming that within a Gps region, if mother's education, place of residence and household's assets are held constant, nutritional intakes are the same between households. This specification is far from being perfect, but nutritional intakes' data do not exist at the individual or regional level.

The first variable I control for is a wealth index. Dhs surveys do not ask households about their income, but do ask them about their assets. I follow Hohmann and Garenne (2009) and compute

an absolute wealth index that is the sum of binary variables that describe households' assets. These authors show that such an index is efficient to describe the socioeconomic status of an individual, in particular with DHS data. They insist that it is relevant to describe population or health (mortality, nutrition) dynamics. I only keep binary variables recommended by the authors that are non-missing in each survey. I use the following variables : the household has electricity, owns a radio, a television, a refrigerator, a bike, a motorcycle, a car, the main floor material is neither sand nor clay nor dust. I thus get 8 binary variables, and the resulting wealth index goes from 0 to 8. The mean wealth index of mothers is equal to 2.5, the median index is equal to 2.

I also control for the mother's education, using the same variable across surveys :

- No education.
- Primary education.
- Secondary education.
- High school and above.

The last socioeconomic variable is a dummy variable which is equal to one if the place of residence of the individual is urban or rural. Urban and rural areas differ greatly in terms of income and access to health care or education. Furthermore, I find in the data that mortality rates are higher in rural areas. Garenne (2003) explains this urban advantage by the better provision of health services in cities, and by the higher socioeconomic status (measured by mothers' education for instance) of households. The height advantage in urban areas can have two explanations. Taller mothers might have lived in cities since they were children, and have benefited from better infrastructures and socioeconomic status, hence their height advantage [14]. But it might also be the case that taller women have migrated to the cities. Controlling for the place of residence allows to avoid any spurious correlation between height and mortality that would be due to urban/rural differences.

2. Vaccination rate (V_{zt})

DHS data provide information on the vaccination of every measured children. I build a dummy which is equal to 1 if the child is said to be vaccinated (with or without a justification) for 8 vaccinations. I have this information for the 4 polio injections, the 3 dpt (diphtheria, pertussis and tetanus) injections and the 1 tuberculosis injection. I then compute an individual « vaccination degree » that is the sum of these dummies. I build a regional indicator of the vaccination prevalence, which takes the following values :

- 1 : the average number of vaccinations in the region is below 3.
- 2 : the average number of vaccinations is between 3 and 5.
- 3 : the average number of vaccinations is between 5 and 6.

14. In the sample, among women living in cities, those natives from the same city they live in are around 0.5 cm taller

– 4 : the average number of vaccinations is greater than 6.

– 5 : no information on vaccinations.

This regional measure of vaccination can be used to proxy the health environment for two reasons. First, it indicates the level of health care in the region. Second, if the vaccination rate is high in the region, it lowers the prevalence of diseases.

3. Native (N_{izt})

I am afraid that migration could bias the results : if richer and taller women were selected into migration, and moved in regions where child mortality rates are lower, this could downward bias the correlation between height and mortality. As the data do not provide the place of birth, I can not control precisely for migration. However, the data tells for how long the mother has been living in the village. I use this information to control for migration, by interacting mortality with a dummy which is equal to 1 if the mother or the child is native from the surveyed village. I will find (see results) that the coefficient β_2 is positive. It confirms that there is a negative migration bias in the dataset, taller women tend to migrate to low-mortality regions.

4. Controls specific to the endogenous variable (X_{izt})

When I regress height or z-score of children on child mortality, I control for genetic inheritance, adding the height of the mother as a control variable. When using child height, I also control for growth differential between boys and girls (controlling for age, gender and age × gender). The z-score indicator already takes into account this differential. This allows me to study boys and girls together, as I checked that the results did not differ significantly by gender.

3.3 Testing the underlying assumptions of the model

Studying the link between height and child mortality is a complex task because those variables are determined by common factors. Results can not be interpreted as the causal impact of child mortality on height stature because as we saw in equation (1), mortality is not an exogenous variable for height stature. Furthermore, I already mentioned that instrumentation can not be used in this context. I thus built a statistical model to estimate the correlation between height and stature.

The specification, described in equation (4), relies on the fact that some regions have faced greater decrease in child mortality. Differences in the trend of child mortality rates are used to identify whether height decreased more in places where child mortality trends were higher than the average. Despite all the controls included, results can be biased by disease or nutritional shocks. In section 3.1, I argue that such shocks should bias negatively the estimates, making two major assumptions that I now test.

Health infrastructures are negatively correlated with mortality, positively correlated with height

I am able to provide suggestive evidence that individuals are taller and child mortality is lower when the exposition to pathogens is lowered by health infrastructures. (underlying assumptions in equations (1) and (2).

In initial waves of surveys, DHS data contained community surveys. Starting from these, I build a categorical variable that informs on health institutions. I create a dummy which is equal to one if the total number of medical institutions (hospital, clinic, maternity, community health center, dispensary, etc.) in the cluster is equal or greater than 3.

To test the hypothesis of the model, I check that the correlation between this dummy variable and height is positive, and that the correlation with mortality is negative ; controlling for urban/rural. I provide results interacted with a dummy « Native » (see section 3.2), to control for migration biases. Results can be seen in table 6. I find that mothers' heights and children's heights are higher (significantly so only for mother's height) when the number of medical institutions in the cluster of the individual is equal or greater than 3. At the regional level, I find that in regions where the average number of medical institutions per clusters in the region is equal or greater than 3, child mortality rates are significantly lower. Those results provide some suggestive evidence that the assumptions of the model regarding the impact of pathogens on height and mortality are reasonable.

Wealth is negatively correlated with mortality, positively correlated with height

Similarly than before, I want to test whether income, proxied by wealth, has a positive impact on height and a negative impact on mortality, through nutrition.

For readability purposes, I transform the wealth index variable described above into a categorical variable merging together the following values : 0, 1, 2, 3-4, 5-8. I regress height and mortality on the level of wealth, interacted with a dummy native ; results can be seen in table 7. I find that children's zscores and mothers' heights are positively correlated with the wealth index of the household at the individual level. Compared to the omitted value 0, coefficients are positive, and significant for wealth indexes greater than 3. At the regional level, I find that in regions where the mean wealth index is high, child mortality is significantly lower (no longer significant when I absorb the trend). Those results provide some suggestive evidence that the assumptions of the model regarding the impact of income, proxied here by the wealth index, are reasonable.

4 Main results

4.1 Children's height and child mortality

I do not expect to find any selection effect of mortality on child height as descriptive statistics did not provide any evidence of the existence of a paradox for children. Nonetheless, I try to estimate the model using children's heights as an endogenous variable to see whether descriptive statistics results are confirmed.

I regress child height and child z-score on child mortality, following the specification of equation (4) ; results can be seen in Table 8. In specification (2) (columns 2 and 4) only I add survey year dummies to control for the general trend [15]. Estimated coefficients are negative, going from -6 to -10 [16] for native child stature. These results mean that a 0.1 points decrease in child mortality is correlated with a 0.6 to 1 cm increase in height stature.

I include socioeconomic status of the household (education, wealth and urban/rural), the mother's height stature and the vaccination rate in the region as control variables. I do not show the estimated coefficients, but in each case I find a positive and significant effect of the wealth index, mother's education and height, and a urban place of residence.

The main result is thus that in places where child mortality decreased more (and where the health environment improved), child height stature increased significantly. This result is coherent with the usual negative correlation between child mortality and height found in developing countries other than African. Hence, regarding child stature, Sub-saharan Africa does not seem to be very specific, there is no paradox here.

4.2 Mothers' height and child mortality

I regress mothers' height on child mortality rates prevailing in the region 5 to 15 years before the survey [17]. As mentioned earlier, this identification is relevant as long as I assume long term child mortality trends (at least 15 years).

Ols regressions

Ols estimates of equation (4) can be seen in Table 9. The correlation of natives' heights with child mortality (3.379+0.909) is positive and significant. In places where child mortality decreased by 10 percentage points, mothers' height decreased by approximately 0.43 cm. The model confirms the African paradox found in descriptive statistics.

15. More precisely, I add « survey cohort » fixed effect (see section 2.2)

16. I find that the coefficient increases when the general trend is absorbed, which is not surprising as mortality decreases and child height and zscore increase over the period.

17. I checked that the results where robust when using mortality rates prevailing 15 to 20 years before the survey)

Results obtained here differ greatly from results obtained for children. At adult age only, the effect of selective mortality is strong enough to reverse the correlation between height and mortality.

Nonlinear regression : a strong selection effect at higher level of mortality

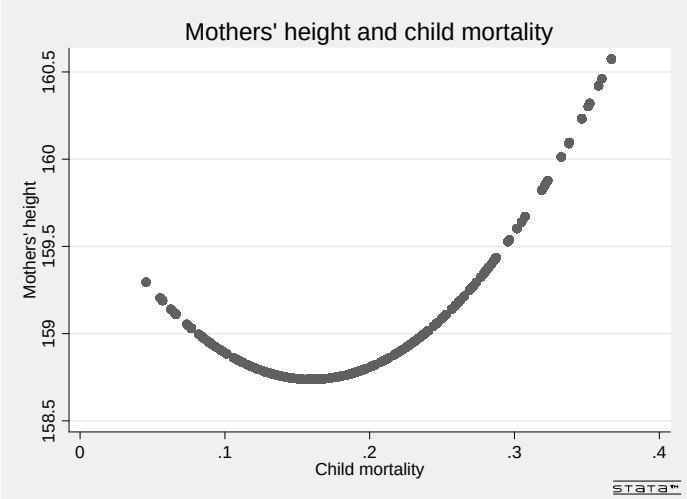
Given the purpose of this work, which is to reveal selection mechanisms, I found it relevant to go beyond ordinary least squares by using nonlinear econometrics. I implement polynomial and spline regressions. I expect the selection effect to be relatively more important for high levels of child mortality ; in which case spline and polynomial regressions are needed to describe precisely the relationship between height stature and child mortality.

I regress mothers' height on a second degree polynomial of child mortality, in order to see whether the link between height and child mortality is nonlinear. The estimated equation is the following :

$$H_{izt} = \alpha + \beta_1 M_{zt} + \beta'_1 M^2_{zt} + \beta_2 M_{zt} \times N_{izt} + \beta'_2 M^2_{zt} \times N_{izt} + \delta N_{izt} + \gamma Y_{izt} + \eta X_{izt} + \lambda V_{zt} + \mu_z + \nu_t + \epsilon_{izt} \quad (5)$$

I then compute $\widehat{H_{izt}} = \widehat{\alpha} + (\widehat{\beta_1} + \widehat{\beta_2}) \times M_{zt} + (\widehat{\beta'_1} + \widehat{\beta'_2}) \times M^2_{zt}$ and I graph this estimated height against child mortality (Figure 2).

FIGURE 2 – Regression of mothers' height on a second order polynomial of child mortality



I find that the correlation between height and mortality is even higher that what I found with OLS for child mortality rates over 17%. More precisely, I find that the correlation is negative in low mortality contexts. : At lower level of mortality, when child mortality rates fall from 15% to 10%, height increases by less than 0.5 cm. In high-mortality contexts, when child mortality rates fall from 35% to 25%, height decreases by 1 cm. It seems that the attenuation effect associated to selection increases with the level of child mortality. To measure more precisely this trend break, I implement a spline regression of mothers' height on child mortality, using 17% as a unique knot and adding the

usual controls (results in Table 10).

These results confirm what we observed in Figure 2 : the correlation between height and child mortality is negative for mortality rates below 17%, and positive above (coefficients before and after the knot are significantly different). More precisely I find that when child mortality rates decrease by 10 percentage point :

- For rates below 17%, height stature increases by 1.02 cm.
- For rates above 17%, height stature decreases by 1.07 cm.

4.3 Interpretation of the results

I now try to interpret these results, in order to give a clear view of the relationship between child mortality on the one hand, and child and adult height stature on the other hand.

The level paradox

To understand whether selective mortality can explain the height difference between Africa and Asia, I use Asian Dhs surveys. For now, I focused on two georeferenced surveys led in Bangladesh in 2004 and 2007. As for African countries, I build Gps regions, but smaller than for African countries as Bangladesh is a much denser country. I find that for a given survey year, level of education and wealth, place of residence (urban or rural), year of birth and vaccination rate, Bangladeshi mothers are 8.6 cm smaller than African mothers. It seems that this difference does not come much from a differential in child mortality rates. When I control for the regional mortality rate, and thus compare women that are exposed to the same level or mortality rates, the height differential reduces to 8.2 cm only, which is not much. I thus can not conclude that the height level difference between Asia and Africa comes from differentials in child mortality.

The trend paradox

Regarding the trend paradox, I propose in Table 2 a decomposition of the height trend based on the spline regression results.

If the correlation between height and child mortality was positive and equal to the linear correlation found in Table 9, the estimates would predict a decrease in height stature of $4.23 \times -0.0047 = -0.02$ cm. Under the assumption that the link between mortality and height is linear, I estimate that height should have decreases of -0.02 cm only. However, in the data I observe a much more significant height decrease of 0.073 cm, more than 4 times bigger. The trend paradox can be measured as the difference between the predicted and the observed height trend : 0.053 cm. Hence, if I predict height without taking into account the selective mortality specific to high mortality contexts, I over-estimate the height trend by 0.073 cm. Taking into account the nonlinearity, I differentiate the impact of child

mortality on height trends in two groups of regions : regions where initial child mortality (child mortality measured in the first cohort of survey) is below 17% or above 17%. using results from Table 10, I predict an height trend of : $0.73 \times -0.0012 \times -10.25 + 0.27 \times -0.0071 \times 10.67 = -0.052$ cm, which reduces the paradox to 0.021 cm. By taking into account the nonlinearity of the link between height and child mortality, due to selective mortality, I manage to explain more than two third of the trend paradox.

TABLE 2 – The trend paradox

	Share of pop.	**Height-mortality correlation**	**Child mort. trend**	**Predicted height trend**
Linear specification	100%	4.29***	-0.0047***	-0.02
Spline specification				
Child mortality $\leq$ 17%	27%	-10.25***	-0.0012***	-0.052
Child mortality $>$ 17%	73%	10.67***	-0.0071**	
Observed height trend :				-0.073***

A third paradox : North-South

A third paradox arises in the data : the height paradox between North and South in West Africa. I did not focus the analysis on this paradox, because it seems to me that this regional difference is a less central issue. Yet, it reveals again that the correlation between height and mortality in Africa is particularly weak, and I want to estimate how much selective mortality can give account of this phenomenon.

This North-South paradox comes from the fact that Northerners are much taller than Southerners, despite worst health and living conditions. [18] Again, this is in contradiction with the standard negative correlation between height and mortality. In the data, I identify as belonging to the north all points that are above 11 degrees of latitude [19]. The paradox is of the following magnitude :

To obtain these results, I implement the same regressions as before. Only, each time, I interact the explicative variable with a dummy north.

By regressing mortality on a dummy north, I obtain mortality levels in North and South. I also regress the mortality rate on an interaction between a dummy north and a dummy equal to one if the initial mortality rate is below 17% in the region. To obtain the correlation between mothers' height and child mortality in the four settings (north, south, low or high initial rate), I estimate height using equation (4) and adding north dummies. I do find that child mortality rates and adult heights are higher in the North, after controlling for usual explanatory variables.

18. The height differential between North and South in the dataset is about 1.5 cm, after controlling for wealth, education, and the type of place of residence.

19. North thus contains all Senegal and Mali, the major part of Burkina Faso, and the very north of Ghana, Benin and Nigeria.

TABLE 3 – The north-south paradox

		Initial mort. rate	Share of pop.	Correlation	Child mort. level	Predicted height difference
OLS	*South*		100%	1.75	0.26	0.84
	North		100%	8.13	0.31	
Spline	*South*	$\leq 17\%$	43%	-11.8***	0.12	0.95
		$> 17\%$	57%	19.3***	0.18	
	North	$\leq 17\%$	6%	-27.8***	0.18	
		$> 17\%$	94%	10.04***	0.25	
Observed height difference :						1.46***

How does the results provided before can account for this stylized fact ? In Table 3, I compare the predicted height difference between north and south obtained with a linear specification (0.84 cm), or with a spline specification (0.95 cm), with the observed difference (1.46 cm). We see that taking into account the nonlinear relationship between height and mortality does not help much to describe the north-south paradox. In any case, either with a linear or non-linear specification, I manage to explain around two third of the height differential between north and south by differences in child mortality rates. We see in the first two lines of the table that the height differential comes both from the fact that child mortality rates are higher in the north, and that the correlation is also bigger. This is not surprising as we know that selection effects are higher in high mortality contexts. This is confirmed in the bottom part of the table : the Northern advantage in terms of height is driven by the fact that a huge majority of regions in the North started with very high mortality rates (above 17%) and were thus more selected.

At the end of the day, I manage to explain partly the mysteries regarding height and child mortality within Africa with selective mortality. I now have to ask whether these results are robust and which mechanisms could bias them.

Adult heights, child heights : why do conclusions differ ?

From the beginning, I found that children did not face any paradox regarding height and child mortality rates. My main argument is that during childhood adults who are potentially taller are selected, but they are not actually taller when children. In his above-mentioned study, Moradi (2010) put forward a growth shortfall at adolescent age in sub-saharan Africa. According to him, this specific pattern partly explains why African are tall when adults, but not when children. I argue that this story can well be reconciled with my findings. In places where child mortality rates are high, selective mortality is such that only the tallest survive. As a result, if we observe the same birth cohort before and after adolescence, the height-for-age zscore is greater for the population observed after

adolescence, because this population is selected. In the data, children and mothers born during 1990-1993 are measured. Keeping these 4 birth cohorts only, I compute mean adult zscores for women aged 15 to 23, and mean child zscores for children aged 1 to 3 using the 1990 British Growth Charts as reference population, at the region level. For these cohorts, I find that mothers' zscores are 0.55 higher than children zscores. As Moradi (2010), I find that in more than 90% of the regions, mean adult zscores are above mean child zscores.

To test wether this pattern comes from selective mortality, I correlate the growth between child and adult zscores to child mortality rates. I find that in regions where child mortality rates are higher, the difference between mothers' zscores and children's zscores is higher. In those regions, where the effect of selective mortality is higher, potentially taller children were selected, so that the survival bias on observed adult heights is higher. Selective mortality thus explains the observed difference between adult and child zscores. Consequently, results found on mothers and on children are in line with a selective mortality story.

4.4 Robustness of the results

Potential biases that may affect the results

I am aware that a certain number of biases can affect the results. Theoretically, I found with the structural model that those biases may lead me to underestimate the impact of selective mortality ; so that estimates provided here are a lower bound of selective mortality effect.

One may think of a lot of shocks that may affect both child mortality and height stature, let them be at the idiosyncratic, village or even region level. It would be the case for instance of health policies, famines, climate shocks, epidemics, etc. Regional fixed-effects control for some of these shocks, but not for all. If in a given region, some households face a negative income shock that both increase the probability of death of their child and decreases their height stature [20], I might underestimate the correlation between height and mortality in such regions. In any cases, it is very likely that any of the shocks that may bias the results would affect mortality and height in opposite ways. It is indeed difficult to imagine a shock that would increase both mortality and height over time, other than through selection effects.

I am afraid that the results obtained on mothers' heights could come from the way I build the data set. When mothers' height is the endogenous variable, I partly explain height by the child mortality that mothers' children face. If there is an inheritance mechanism through which children of taller women are more likely to survive (which is the most credible pattern), it may again bias downward the correlation between height stature and child mortality at the region level. As I focus on mothers

20. In the context of Côte d'Ivoire for instance, Cogneau and Jedwab (2009) find that cocoa growers decrease investments in children's human capital when they face a negative income shock due to the decrease of cocoa prices.

aged less than 30, not all of them have children of age 5 to 15 (from which I computed child mortality). To further check that results were not biased by such a mechanism I add a dummy which is equal to 1 if the mother whose height is measured as a child aged 5 to 15 years old at the time of the survey (i.e. a child who is in the sample from which child mortality was computed) in equations 4 and 5. I also estimated those same equations but restricting the sample of mothers to those mothers whose children are not in the sample from which mortality rates were computed. Results are left unchanged using these specifications.

I can never be sure that I control for every bias. But if anything, biases should lower the selective mortality effect on height.

Results are not driven by the definition of regions

I am afraid that results could be driven by the definition of regions. As a robustness check, I test whether results varied with alternative definitions of regions.

First, in a preliminary version of this article, I built regions country per country, so that I did not have transborder regions in the sample. Results were close from those obtained in this version. I thought it was not justified to cut regions at country borders, given the subject of interest. There is no reason for the selective mortality to vary on each side of a border. I found it even more unjustified to cut regions at the country border as this study takes place in the African context, where borders were drawn almost arbitrarily.

I also test whether results change if I modify the way in which regions are created. I do the same analysis increasing or decreasing the size of the initial grid : if I initially create squared zones of side 2 degrees or 1 degree, I come to the same conclusions. Interestingly, I find that when we increase the size of regions, the correlation between height and child mortality decreases, probably because I no longer identify high mortality regions, where selection effects are higher. This is also in line with the fact that in cross country studies, authors find much lower correlation between height and child mortality in the African context [21]. I also try to aggregate zones that do not contain enough clusters starting from another point than the extreme south-west point. Again, results are not substantially different.

21. None of these studies find a positive correlation. Bozzoli, Deaton, and Quintana-Domeque (2009) find a correlation between adult height and postneonatal mortality equivalent to -4.4 in my setting (controls : GDP, country and year fixed effects. Akachi and Canning (2008) find a correlation between height and infant mortality of -15 for Sub-Saharan Africa against -50 for other developing countries (controls : nutrition, global trend).

Using a logarithm specification

I estimate equations 4 and 5 using $\ln(H_{izt})$ as an endogenous variable rather than H_{izt}. Again, results lead to the same conclusions (results available on request).

Results on mothers' height

Child mortality rates that I am able to compute for the 1980's and 1990's allow me to explain partly the African paradox by selective mortality. We do not know anything about child mortality before 1950 in Sub-Saharan Africa. The only information we have was taken from Tabutin and Choumaker (2004) and provides infant mortality estimates for 1950-2000 for each African countries (see Figure 6, last 6 columns). Looking at these trends, we can credibly assume that child mortality was even higher and selection mechanisms greater in the first half of the 20th century. I implement the same spline regression as in 10, but using infant mortality instead of child mortality as the explanatory variable, and choosing 11.5% as knot. I find that when infant mortality rates are greater than 11.5 %, the correlation with mothers' height is positive. According to Figure 6, infant mortality rates were below this threshold until the 1980's in Cote d'Ivoire, Ghana and Senegal, and until the 1990's in other countries. Women whose heights are observed were born between 1940 and 1988 and were thus exposed to very high infant mortality rates. The majority of observed GPS regions are on long-term trends for child and infant mortality. Consequently when I relate mothers' height to simultaneous infant mortality, I approximate mortality trends they actually faced.

I further check that the timing of the computation did not drive the results by modifying the definition of mortality rates. Instead of computing death probability for children born 5 to 15 years before the survey (as described in Figure 5), I compute it for children born 15 to 20 years before the survey, in order to approximate more precisely child mortality rates *actually* faced by mothers[22]. Results do not change significantly when using these modified mortality rates, indicating that conclusions regarding adult heights are not driven by the computation timing.

5 Conclusion

I study the relationship between child mortality and height in West Africa, within region. As standard instrumentation methods are not available in this context, I focus on Africa where child mortality rates are the highest in the World and build a statistical model which is estimated linearly and nonlinearly. This new setting allows me to find original results compared to the existing literature. I provide suggestive evidence of the existence of selective mortality for adult heights, that attenuates

22. This measure of child mortality could be biased. First, going back in time, I observe a censured sample of mothers, and thus of children. I only observe children who were born when their mothers were 15 to 35 years old. Also, measurement errors due to misreporting of dates is probably higher when going back in time.

and even reverses the standard negative correlation between height and child mortality. I show that in some contexts, height might have decreased in places where child mortality decreased as well. If an attenuation bias had already been underlined in the literature, such an « inversion bias » was never revealed. I also provide suggestive evidence that selective mortality select adults that are potentially taller, but not actually taller during childhood. I agree with Moradi (2010) on the fact that height-for-age zscores increase from childhood to adulthood. By showing that this growth catch-up is higher in mortality context, I suggest that it can be explained by selective mortality.

The model I propose shows that if anything nutritional or epidemiological shocks bias downward the estimates of the selection effect, so that I probably estimate a lower bound of the selection effect. The same is true for a inheritance mechanism through which taller women would give birth to children whose probability of surviving is higher. Also, the most eloquent results are obtained when I regress mothers' height on child mortality. I argue that theses results were valid if regional differentials in mortality trends were constant over a long period of time and I provide several robustness checks regarding this issue. I also argue that the African continent was characterized with even higher child mortality rates earlier in time (beginning of the second half oh the 20^{th}, and thus with higher selection effects, so that if anything I would tend to underestimate the selection effect.

I provide suggestive evidence that the major part of the trend paradox comes from selective mortality. I explain almost all of the height trend by correlating it to the evolution of mortality in the region, using the nonlinear specification. Also, I show that the height differential between North and South in West Africa can partly be explained by differences in terms of mortality. Using Dhs data on Bangladesh, I find that the height differential between Asia and Africa does not come from selective mortality in this sample.

There exists at least one other possible explanation for the African paradox, that would explain why the explicative model described here has some limitations. If I follow Akachi and Canning (2008), it seems credible that African health policies differ from health policies implemented in the rest of the World. More precisely, African policies regarding this matter have often been decided in a hurry, in case of epidemics or famines. It is also frequent that they aim at protecting from highly prevalent diseases for which efficient prevention measures exist. Such measures have a great impact on infant mortality rates, but their impact is probably null on nutrition, and thus on height. This orientation of health policies could partly explain the non significance of the correlation between child mortality and height at the regional level in Africa. More generally, the paradox could come from the fact that we try to adapt theories for height determinants which have been built for Europe but actually do not adapt to Africa. Indeed, it may be the case that health has a lower impact on height in Africa, where nutritional constraints are still an issue. This would imply that nutrition has a greater impact and pathogens a lower impact on height relatively to other continents. In that case it would not be

surprising to find that in Africa height is less correlated to child mortality.

To conclude, any analysis of height stature regarding Africa should therefore be cautious, and even more when going back in time. More precisely, the results imply that a decrease in mean heights does not inevitably reveals a deterioration of health conditions but can also be related to a decrease in infant mortality rates, which means better health conditions.

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Appendix

Figure 3 – Height and income

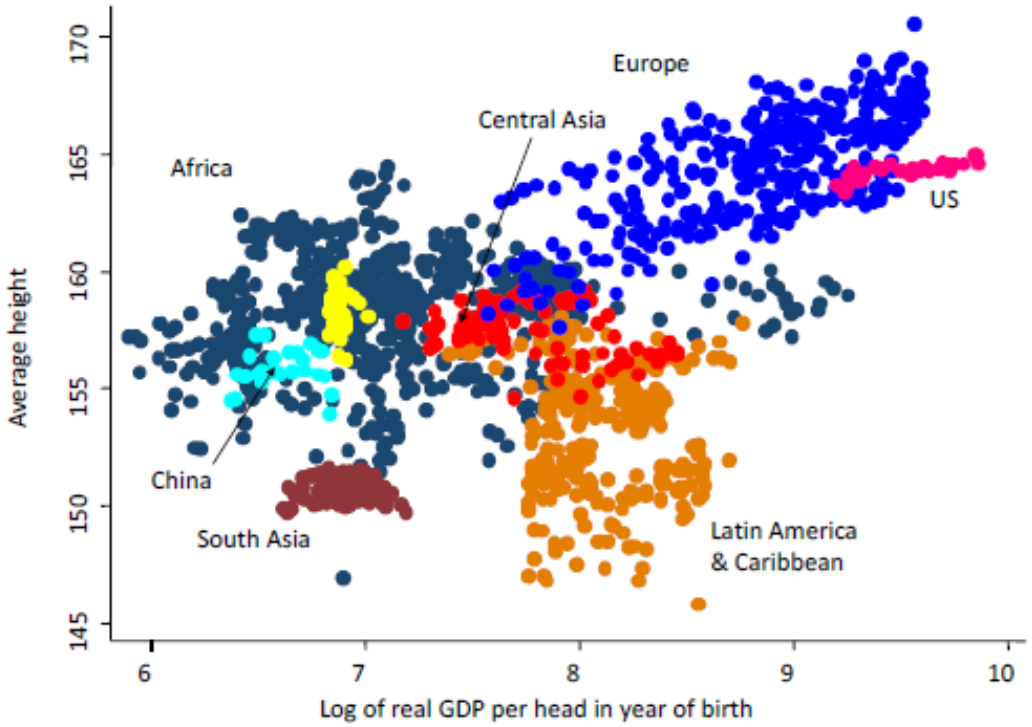


Figure taken from Deaton (2007)

TABLE 4 – Surveys, number of observations and sampling rate

Surveyed Country	Survey Year	Type of survey	Number of mothers	Population	Sampling rate
Benin	1996	DHS III	2 421	5 906 000	4.1×10^{-4}
	2001	DHS IV	4 396	6 879 000	6.4×10^{-4}
Burkina Faso	1992	DHS II	3 651	9 580 000	3.8×10^{-4}
	1998	DHS III	3 588	1 100 800	3.3×10^{-3}
	2003	DHS IV	8 863	1 285 300	6.9×10^{-3}
Cote d'Ivoire	1994	DHS II	3 026	14 502 000	2.1×10^{-4}
	1998	DHS III	1 874	16 400 000	1.1×10^{-4}
Ghana	1993	DHS II	1 792	16 316 000	1.1×10^{-4}
	1998	DHS III	2 233	18 610 000	1.2×10^{-4}
	2003	DHS IV	3 721	20 955 000	1.8×10^{-4}
	2008	DHS V	3 193	23 351 000	1.4×10^{-4}
Mali	1995	DHS III	4 458	9 549 000	4.7×10^{-4}
	2001	DHS IV	9 157	10 759 000	8.5×10^{-4}
	2006	DHS V	10 587	12 118 000	8.7×10^{-4}
Nigeria	2003	DHS IV	4 678	134 270 000	3.5×10^{-5}
	2008	DHS V	22 496	151 212 000	1.5×10^{-4}
Senegal	1992	DHS II	3 170	7 975 000	4×10^{-4}
	2005	DHS IV	2 746	11 281 000	2.4×10^{-4}

Source : Annual series of population from the World Bank.

TABLE 5 – Mothers' height and children's z-score : mean and standard errors by country and survey

Surveyed	Survey	Z-score			Mothers' height		
Country	Year	Mean.	S.d.	Obs.	Mean	S.e.	Obs.
Benin	1996	-1.8	1.5	1620	158.4	6.1	2401
	2001	-1.8	1.6	1798	158.5	6.2	4390
Burkina Faso	1993	-1.8	1.5	1744	161.8	5.9	3609
	1998	-2.1	1.7	1830	161.7	5.9	3571
	2003	-2	1.8	3260	161.6	6	8855
Cote d'Ivoire	1994	-1.7	1.4	2214	159.1	5.9	3017
	1998	-1.4	1.6	676	159.8	6.2	1871
Ghana	1993	-1.8	1.5	1231	158.7	6	1791
	1998	-1.5	1.5	1145	159	6.2	2219
	2003	-1.7	1.5	1292	159.2	6.1	3705
	2008	-1.3	1.6	963	159.3	6.5	3077
Mali	1995	-2	1.6	2962	161.6	6.1	4438
	2001	-2.0	1.8	3779	161.6	6	9118
	2006	-1.8	2	4557	161.4	6.3	10423
Nigeria	2003	-2	1.9	1770	158.5	6.3	4664
	2008	-1.8	2.3	7950	158.2	6.8	21924
Senegal	1992	-1.7	1.5	1787	162.4	6.1	3182
	2005	-1.1	1.5	1144	162.9	6.5	2731

Sample for z-scores : Children aged 12 to 35 months.
Z-scores less than -6 and more than 6 are set to missing.
Sample for mothers : aged 20 to 49.

TABLE 6 – Regression of height and child mortality on the number of medical institutions

	Zscore of children		Height of mothers		Child mortality	
Number of medical institutions in the region						
Between 0 and 2	ref.	ref.	ref.	ref.	ref.	ref.
Between 3 and 4	-0.0855	-0.0222	1.373***	1.445***	-0.0269**	-0.0268**
	(0.108)	(0.108)	(0.494)	(0.484)	(0.0125)	(0.0125)
Number of medical institutions interacted with Native						
Between 0 and 2	ref.	ref.	ref.	ref.	ref.	ref.
Between 3 and 4	0.112	0.0938	-0.176	-0.208		
	(0.118)	(0.121)	(0.281)	(0.263)		
Urban place of residence	Yes	Yes	Yes	Yes	Yes	Yes
Survey years		Yes		Yes		Yes
Observations	41,722	41,722	43,788	43,788	213	213
R-squared	0.021	0.028	0.027	0.028	0.092	0.114

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
Weights : take into account the representativity of surveys in the total population of the region studied.
Surveys : DHS Benin, Burkina Faso, Cote d'Ivoire, Ghana, Mali, Nigeria, Senegal.
Sample : Children aged 12 to 35 months, mothers aged 20 to 30 y.o.
Native : the child (or the mother) always lived in the village (we also control for a dummy « Native » but do not show the estimates).
A missing category for the number of medical institutions is added in the regression.

TABLE 7 – Regression of height and child mortality on a categorical variable for the wealth index

	Zscore of children		Height of mothers		Child mortality	
Values of the wealth index						
Equal to 0	ref.	ref.	ref.	ref.	ref.	ref.
Equal to 1	0.0815	0.0754	0.251	0.247	-0.0707***	-0.0265
	(0.247)	(0.241)	(0.266)	(0.263)	(0.0232)	(0.0323)
Equal to 2	0.285	0.292	0.278	0.265	-0.0854***	-0.0151
	(0.232)	(0.227)	(0.260)	(0.257)	(0.0311)	(0.0400)
Between 3 and 4	0.426*	0.412*	0.584**	0.576**	-0.0968***	-0.0150
	(0.232)	(0.223)	(0.258)	(0.258)	(0.0328)	(0.0431)
Between 5 and 8	1.048***	1.037***	1.774***	1.763***		
	(0.336)	(0.330)	(0.318)	(0.319)		
Wealth index interacted with Native						
Equal to 0	ref.	ref.	ref.	ref.	ref.	ref.
Equal to 1	-0.0754	-0.0679	-0.510	-0.508		
	(0.253)	(0.247)	(0.415)	(0.415)		
Equal to 2	-0.190	-0.198	0.0648	0.0586		
	(0.228)	(0.225)	(0.366)	(0.363)		
Between 3 and 4	-0.238	-0.231	-0.0694	-0.0944		
	(0.242)	(0.238)	(0.527)	(0.528)		
Between 5 and 8	-0.504	-0.502	-0.493	-0.495		
	(0.355)	(0.349)	(0.502)	(0.507)		
GPS regions	Yes	Yes	Yes	Yes	Yes	Yes
Survey years		Yes		Yes		Yes
Observations	41,722	41,722	43,788	43,788	213	213
R-squared	0.082	0.086	0.086	0.088	0.857	0.908

See Table 6.
A missing category for the wealth index is added in the regression.

TABLE 8 – Regression of children's height and z-score on child mortality

	Height of children		Z-score	
	(1)	(2)	(1)	(2)
Child mortality	-14.03**	-10.05*	-4.673**	-3.306**
	(5.946)	(5.260)	(1.893)	(1.632)
Native × Child mortality	4.204	4.317	1.501	1.545
	(3.937)	(3.994)	(1.251)	(1.269)
GPS regions	Yes	Yes	Yes	Yes
Survey years		Yes		Yes
Observations	40,454	40,454	40,454	40,454
R-squared	0.488	0.489	0.106	0.109

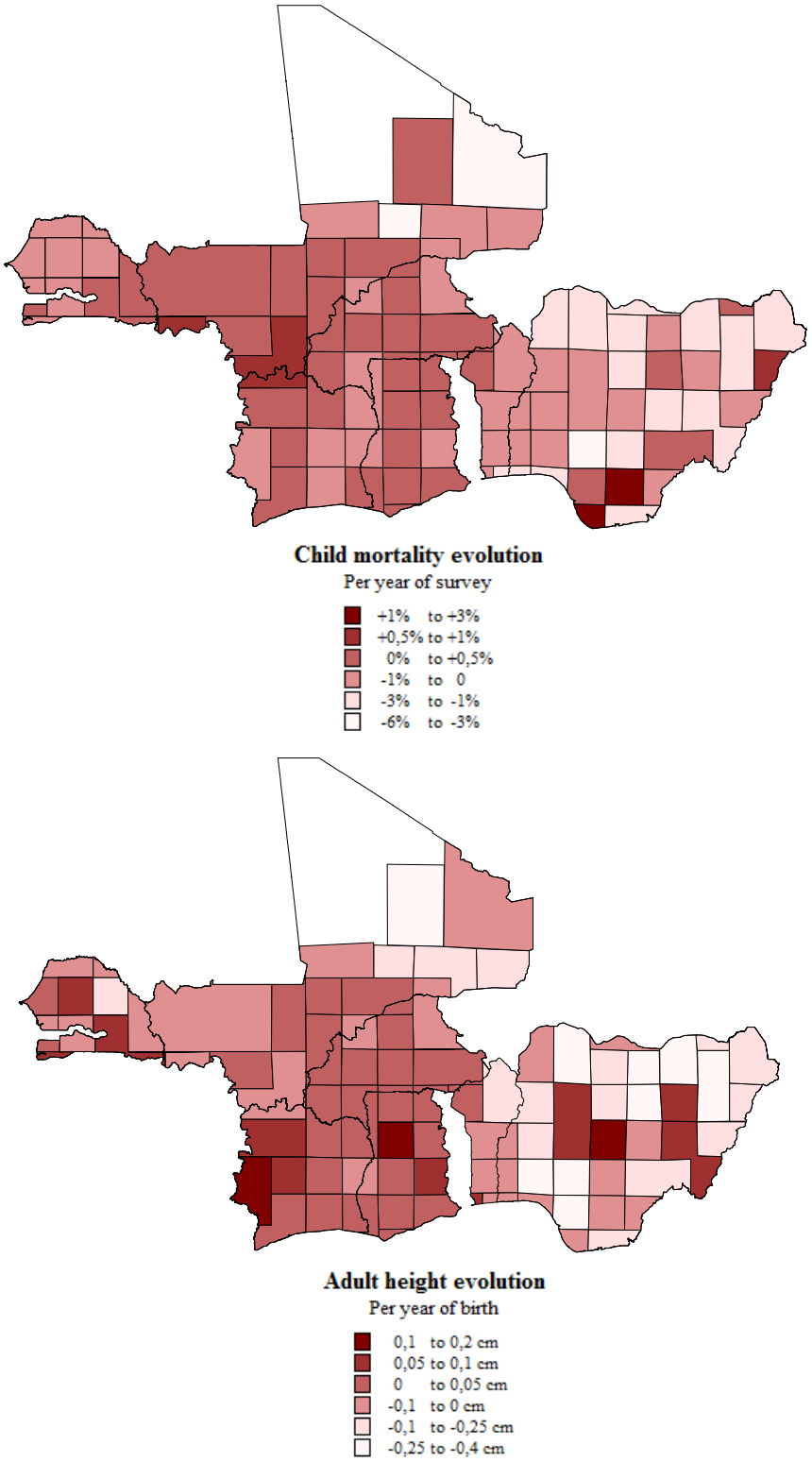
Controls : age, gender, age × gender (first 2 columns), socioeconomic status of the household, mothers' height, vaccination rate in the region.
See Table 6.

TABLE 9 – Regression of mothers' height on child mortality

	(1)	(2)
Child mortality	3.429	3.379
	(2.407)	(2.571)
Native × Child mortality	0.973	0.909
	(2.295)	(2.287)
Controls :		
GPS regions	Yes	Yes
Survey years		Yes
Observations	42,665	42,665
R-squared	0.095	0.095

Controls : socioeconomic status of the household, migration status of the mother, vaccination rate in the region.
See Table 6.

FIGURE 4 – Evolution of child mortality and stature by GPS regions



Countries on the map : Benin, Burkina Faso, Cote d'Ivoire, Ghana, Mali, Nigeria, Senegal

FIGURE 5 – The timing of computation

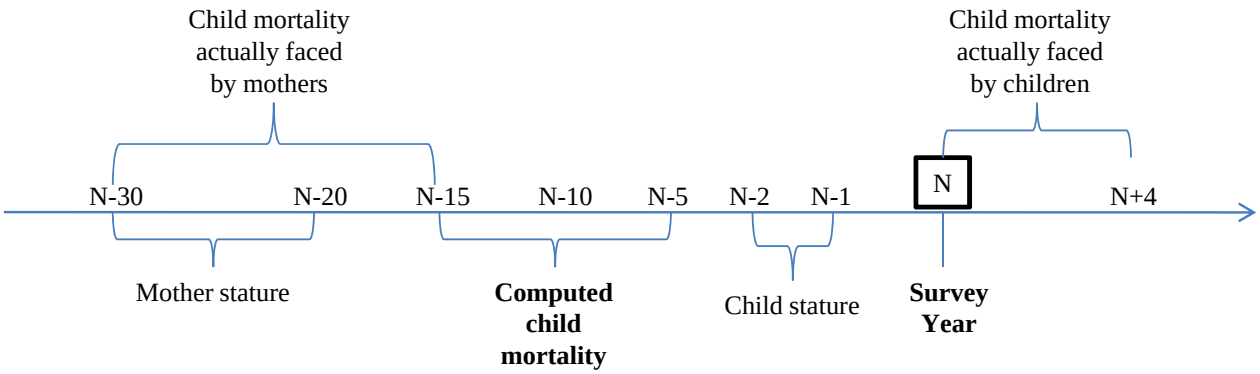


TABLE 10 – Spline regression of mothers' height on child mortality

	(1)	(2)
Child mortality $\leq$ 17%	-11.71***	-11.45***
	(2.831)	(2.870)
Child mortality $>$ 17%	11.58***	11.36***
	(3.417)	(3.496)
Native $\times$ Child mortality $\leq$ 17%	1.166	1.195
	(3.532)	(3.542)
Native $\times$ Child mortality $>$ 17%	-0.658	-0.689
	(3.954)	(3.939)
Controls :		
GPS regions	Yes	Yes
Survey years		Yes
Difference between coefficients (pvalue)	0.001	0.001
Observations	42,665	42,665
R-squared	0.096	0.096

See Table 6.

FIGURE 6 – Infant mortality rates in West Africa (1950-2000)

TABLEAU A.8. – ESPÉRANCES DE VIE ET MORTALITÉ INFANTILE DE 1950 À 2005 (48 PAYS)

Sous-régions et pays	Espérance de vie (en années)						Taux de mortalité infantile (p. mille)					
	1950-1954	1960-1964	1970-1974	1980-1984	1990-1994	2000-2004	1950-1954	1960-1964	1970-1974	1980-1984	1990-1994	2000-2004
Afrique de l'Ouest	35,5	39,1	43,0	47,1	50,0	49,6	192	168	143	120	104	90
Bénin	33,9	38,0	44,0	49,2	51,3	50,6	200	173	137	111	100	93
Burkina Faso	31,9	36,7	41,2	46,1	47,5	45,7	215	181	153	126	110	93
Cap-Vert	48,5	53,0	57,5	61,8	66,4	70,2	130	105	83	63	44	30
Côte d'Ivoire	36,0	40,4	45,4	50,0	48,3	41,0	186	158	130	106	101	101
Gambie	30,0	33,0	38,0	44,1	51,0	54,1	231	207	173	135	99	81
Ghana	42,0	46,0	49,9	53,6	56,9	57,9	149	127	108	90	72	58
Guinée	31,0	34,3	37,3	40,2	44,8	49,1	222	197	177	157	130	102
Guinée-Bissau	32,5	34,5	36,5	39,1	43,0	45,3	211	196	183	164	140	120
Liberia	38,5	40,5	42,6	44,9	39,3	41,4	194	180	165	150	191	147
Mali	32,7	35,3	38,2	44,4	47,5	48,6	240	218	196	153	131	119
Mauritanie	35,4	39,4	43,4	47,4	49,4	52,5	189	164	141	120	110	97
Niger	32,2	35,2	38,2	40,7	42,7	46,2	213	191	171	156	144	126
Nigeria	36,5	40,1	44,0	48,1	52,0	51,5	183	160	137	115	95	79
Sénégal	36,5	38,3	41,8	46,3	50,4	52,9	184	168	122	91	68	61
Sierra Leone	30,0	32,0	35,0	35,3	34,5	34,2	231	215	193	189	194	177
Togo	36,0	40,5	45,5	50,2	53,6	49,7	186	158	130	106	88	82

in Tabutin and Choumaker (2004) Life Expectancy and Infant Mortality between 1950 and 2000 in Africa.