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Modeling Nonlinear between Child Malnutrition and Education in Africa: A Panel Threshold Model

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Abstract: This study examines how child malnutrition shapes lower secondary completion rates across 35 Sub-Saharan African countries between 1990 and 2024, paying particular attention to the nonlinear of this relationship. Anchored in human capital theory, the educational production function, and insights from cognitive neuroscience, the analysis highlights the multiple channels through which nutritional deprivation undermines learning, from impaired cognitive development to reduced school participation and weakened educational systems. Applying Hansen's (1999) Panel Threshold Regression, the study uncovers a critical malnutrition threshold ($\hat{\gamma}$= 4.37%), beyond which the negative effect on educational attainment intensifies almost sixfold. Empirically, lower secondary completion rates (LSCR) drop from an average of 50.7% in the moderate-malnutrition regime to just 31.8% once the threshold is crossed (R^2 = 0.67). Robustness checks across specifications and subperiods confirm the stability of this nonlinearity. The findings demonstrate that even moderate malnutrition severely undermines learning performance, further amplifying existing educational disparities. Policy simulations further indicate that reducing malnutrition specifically above the identified threshold produces educational gains nearly six times greater than uniform national interventions. Taken together, these findings underscore the urgent need for coordinated action across health and education sectors. They also highlight the importance of geographically targeted nutrition strategies to accelerate progress toward SDG 2 (Zero Hunger) and SDG 4 (Quality Education).
Keywords: malnutrition, education, Sub-Saharan Africa, panel threshold regression.

1. Introduction

The pursuit of sustainable human development, as envisioned in the United Nations 2030 Agenda, depends on the effective realization of all 17 Sustainable Development Goals (SDGs). Among these interconnected goals, the link between Food Security (SDG 2 – Zero Hunger) and Quality Education (SDG 4) stands out as particularly vital. Across the African continent, this interdependence is challenged by a persistent dual structural constraint. On the one hand, chronic malnutrition remains widespread, affecting roughly 31% of children under the age of five. On the other, many countries continue to struggle with ensuring universal access to basic education: primary completion rates average around 70%, while lower secondary completion rates remain below 45% in several Sub-Saharan African countries (World Bank, 2024; UNICEF, 2024).

Existing scholarship clearly shows the microeconomic influence of nutrition on learning outcomes. Yet most studies have concentrated on three areas: (i) micro-level interventions, especially the effects of school feeding programs on attendance and standardized test performance (Alderman & Bundy, 2012; Aurino et al., 2018); (ii) national socio-economic determinants of school completion, such as household wealth and parental educational capital

(Filmer & Pritchett, 1999; Drake et al., 2021); and (iii) medical and nutritional research examining biological mechanisms and health-focused interventions (Woldehanna et al., 2017; Aryeetey et al., 2022).While prior work has elucidated several dimensions of the interactions between nutrition and education, macroeconomic and comparative approaches remain limited. In particular, the literature suffers from a methodological and analytical inadequacy regarding the large-scale quantification of the link between the aggregate prevalence of chronic malnutrition, a key public health indicator, and national educational performance, notably completion rates.

This study seeks to address this gap by approaching the issue through the lenses of education economics and public policy, with the aim of examining the systemic relationship between child malnutrition and educational attainment. The central question guiding our analysis is the following: How does malnutrition among children under the age of five influence lower secondary completion rates in Africa? More specifically, does a threshold effect (γ) exist beyond which the impact becomes statistically significant or markedly stronger, and what does this structural vulnerability imply for regional policy coordination?

The article is organized into six sections. The first develops the theoretical foundations linking nutrition, human capital formation, and educational performance, while integrating recent advances from cognitive neuroscience. The second section develops the theoretical foundations of the nutrition–education relationship. The third section provides a review of the existing literature, outlining the main empirical findings and the persisting limitations. The fourth section details the methodological framework, drawing on Hansen's (1999) Panel Threshold Regression (PTR) to capture nonlinearities and interdependencies across African countries. The fifth section presents and interprets the empirical results, including the identification of the critical malnutrition threshold. The sixth section examines the economic and policy implications, with particular attention to the design of targeted nutritional and educational interventions. Finally, the seventh section concludes by summarizing the study's key contributions and proposing avenues for future research aimed at strengthening human capital development in Africa.

2. Theoretical Foundations of the Nutrition–Education Relationship

The analysis of the relationship between chronic malnutrition (PM) and lower secondary completion rate (LSCR) relies on two theoretical pillars, human capital theory and the educational production function, enriched by insights from cognitive neuroscience. According to Becker (1964) and Schultz (1961), nutrition is a key investment in human capital formation, directly influencing learning capacity and productivity. Hanushek's (1979) production function formalizes this relationship by treating health and nutrition as essential inputs in the learning process. Neuroscientific research further highlights how early nutritional deficits alter brain plasticity and executive functions, with long-term effects on cognition and school performance (Grantham-McGregor et al., 2007; Prado & Dewey, 2014).

At the individual level, chronic malnutrition limits cognitive abilities and increases absenteeism (Alderman et al., 2006; Miguel & Kremer, 2004). At the household level, food insecurity generates trade-offs between health and education (Behrman & Rosenzweig, 2004). At the systemic level, widespread malnutrition weakens educational systems and constrains progress toward SDG 4 (Psacharopoulos & Patrinos, 2018).

3. Literature Review

Recent academic literature increasingly converges on the view that nutrition constitutes a foundational determinant of human capital formation, shaping not only academic performance and persistence within the education system but also long-term socio-economic development. This section reviews key empirical contributions on the interplay between nutrition, socio-economic conditions, and educational achievement, with particular attention to how dietary quality, household environment, and school-level institutional factors interact to influence learning outcomes.

A growing body of evidence distinguishes the effects of nutritional quality from those of caloric quantity, underscoring the structuring role of school feeding policies. Anderson et al. (2018), for instance, show that improving the nutritional quality of school meals in California yields meaningful gains in standardized test scores at relatively low cost, making such interventions highly cost-effective. By contrast, McEwan (2013), drawing on evidence from the Chilean program, finds that increasing caloric intake alone does not improve attendance or academic performance, highlighting the need for policies that prioritize dietary diversity and micronutrient adequacy rather than energy density. These conclusions are reinforced by the systematic review of Kristjansson et al. (2007), which reports modest but significant improvements in school attendance (+4 to +6 days per year) and learning outcomes, especially among disadvantaged children in low-income settings. Reducing malnutrition also emerges as a powerful lever for enhancing learning. Evidence from Ghana (Aryeetey et al., 2022) shows that declines in stunting and anemia stem from coordinated multisectoral interventions spanning health, sanitation, maternal education, and social protection. These improvements in health and nutrition strengthen cognitive functioning and thus lay the groundwork for sustained educational progress.

However, socio-economic and household conditions exert an equally decisive influence on educational trajectories. Langsten and Hassan (2018) show that in Egypt, the benefits of universal primary education accrue disproportionately to children from affluent families, while poor urban boys remain largely excluded. Similarly, Iddrisu et al. (2017) find that in Ghana, although school entry is only weakly responsive to household income, completion of the primary cycle is strongly conditioned by wealth. Parental education further reinforces these inequalities: as noted by the same authors and by Aturupane et al. (2013), educated parents are more likely to support enrollment, sustain children's engagement in school, and buffer against early dropout. Connelly and Zheng (2003) add that gender and geographic location multiply these disadvantages, with rural girls facing the highest barriers due to low parental education and limited household resources.

Beyond access, the quality of schooling and the ability to complete secondary education generate substantial and enduring socio-economic returns. Evidence from Burkina Faso indicates that each additional year of secondary education increases life expectancy and wealth accumulation, particularly among women (Werner et al., 2022). These long-term gains underscore the strategic value of investing in secondary education. Moreover, Aturupane et al. (2013) and Gamsjager and Sauer (1996) highlight that school quality, captured through teacher experience, inter-school collaboration, and early assessment practices, is a critical predictor of student success, whereas late-stage remedial interventions often yield limited effects.

The existing body of research broadly agrees that nutrition is a key determinant of cognitive development and academic performance, while socio-economic and household conditions critically shape children's access to schooling, their persistence within the system, and their likelihood of completing key educational stages. Yet much of the prior work, rooted mainly in medical and nutritional sciences, has concentrated on the biological and cognitive consequences of malnutrition, such as anemia, stunting, or the nutritional quality of school meals. Although these contributions are essential for understanding the physiological mechanisms at play, they tend to overlook the broader structural implications of malnutrition for educational systems.

This disciplinary focus has therefore constrained the analytical lens through which the nutrition–education nexus is examined, leaving macroeconomic, institutional, and system-level dynamics insufficiently explored. As a result, the literature remains limited regarding the structural relationship between national levels of chronic malnutrition (stunting) and school completion rates, particularly in African countries where these challenges are most acute.

In this context, the core issue addressed by this research concerns the dual structural challenge facing many African countries: the persistence of chronic malnutrition among children under the age of five, and the low completion rates of primary and lower secondary education observed across the continent. These two dimensions lie at the heart of the Sustainable Development Goals, SDG 2 (“Zero Hunger”) and SDG 4 (“Quality Education”), and are deeply interconnected. Poor nutritional status undermines cognitive development and learning capacity, ultimately constraining children’s educational trajectories. Given persistent structural inequalities, it becomes essential to examine the nutrition–education nexus through an integrated and systemic lens. This study therefore seeks to fill the gaps identified in the literature by addressing three key questions: (1) To what extent does the prevalence of malnutrition among young children affect completion rates of the first educational cycle in Africa? (2) Is there a threshold effect beyond which this impact becomes statistically significant or more pronounced? (3) and Which countries or regions are most vulnerable?

By adopting a macroeconomic perspective, this research aims to develop a relevant analytical framework to inform public policies that foster intersectoral coordination, with the objective of aligning nutritional and educational strategies within a broader sustainable development agenda.

4. Methodology and Data

4.1. Methodology:

The non-linear relationship between child Prevalence of malnutrition (PM) and lower secondary completion rate (LSCR) stems from neurobiological evidence showing that beyond certain thresholds, nutritional deficits cause irreversible cognitive damage (Georgieff, 2007; Cusick & Georgieff, 2016). This justifies the use of Hansen’s (1999, 2000) Panel Threshold Regression (PTR) to identify endogenous breakpoints in the nutrition–education relationship.

The PTR model assumes two regimes of impact, moderate and critical, based on the estimated threshold (γ) of malnutrition prevalence. The single-threshold model is specified as follows:

$$Y_{i,t} = \mu_i + \beta_1 q_{i,t} I\left(q_{i,t} \leq \gamma\right) + \beta_2 q_{i,t} I\left(q_{i,t} > \gamma\right) + \varepsilon_{i,t}$$

where $Y_{i,t}$ denotes the lower secondary completion rate (LSCR), $q_{i,t}$ represents childhood malnutrition prevalence (PM) serving as the threshold variable, γ is the estimated critical threshold, and $I(\cdot)$ is the indicator function defining the two malnutrition regimes (“moderate” and “critical”). The coefficients β_1 and β_2 measure the marginal effects of PM on LSCR within each regime, and μ_i represents individual fixed effects. Identification relies on the conditional exogeneity of the threshold variable and the support constraint $\gamma \in [\gamma_L, \gamma_H]$. The optimal threshold $\hat{\gamma}$ is obtained through a grid search that minimizes the sum of squared residuals (SSR) of the fixed-effects–centered model:

$$\hat{\gamma} = \arg_{\gamma} \min SSR(\gamma)$$

This structure allows the model to identify the point at which malnutrition's effect on education intensifies significantly. The selected value corresponds to the global minimum of the SSR(γ) function over the support interval. To address the non-convexity of the objective function, nested grids and an initialization bootstrap (10,000 replications) are employed, ensuring the stability and robustness of the estimation. It should be noted that African educational systems are not isolated. Health and education policies and dynamics can have contagion or spillover effects on neighboring countries.

4.2. Data Sources and Coverage

Our empirical analysis is based on an unbalanced panel of 35 Sub-Saharan African countries covering the period 1990–2024, yielding a maximum of 1,190 country-year observations. The countries included meet three criteria: availability of at least 15 years of data for key variables (LSCR and PM), classification as Sub-Saharan African according to the World Bank, and institutional stability (exclusion of fragile states). This period, characterized by the widespread adoption of primary education, the transition towards the SDGs, and several exogenous shocks (food crises, COVID-19), provides sufficient temporal depth to analyze threshold effects and long-term dynamics.

The sample exhibits balanced regional representation, West Africa (40%), East Africa (35%), Central Africa (15%), and Southern Africa (10%), reflecting demographic, economic (GDP per capita: 500–12,000 USD PPP), and educational (LSCR: 8–95%) diversity. Selection biases remain limited: excluded countries, mainly fragile states representing less than 15% of the Sub-Saharan population, display extreme characteristics (malnutrition > 40%, LSCR < 15%), justifying their exclusion and separate treatment. Table 1 lists the countries included in our study:

Table 1. Selected Sub-Saharan Countries

Region	Number of Countries	Selected Countries
West Africa	14	Benin, Burkina Faso, Côte d'Ivoire, Gambia, Ghana, Guinea, Guinea-Bissau, Liberia, Mali, Niger, Nigeria, Cape Verde, Mauritania, Senegal
East Africa	12	Burundi, Comoros, Djibouti, Eritrea, Ethiopia, Kenya, Madagascar, Mauritius, Rwanda, Réunion, Seychelles, Tanzania
Central Africa	5	Angola, Cameroon, Central African Republic, Chad, Republic of the Congo
Southern Africa	4	Botswana, Lesotho, Malawi, Mozambique

Table 2, on the other hand, summarizes the variables used in our study, along with their definitions and data sources.

Table 2 : Key Socio-Economic and Educational Variables with Definitions and Sources

Variable	Acronym	Definition	Data Source
Dependent variable			
Lower secondary completion rate, total (% of relevant age group)	LSCR	Percentage of children of the relevant age who have completed lower secondary education.	(WDI)
Threshold variable			
Prevalence of malnutrition (% of children under 5)	PM	Percentage of children under five suffering from malnutrition (low weight-for-age).	WDI/FAO

All variables were harmonized following international standards, and missing values were imputed using a multi-step procedure to preserve spatio-temporal coherence. Short gaps were filled through linear interpolation, longer gaps through regression-based imputation, and key variables (PM and LSCR) through Multiple Imputation by Chained Equations (MICE), generating five datasets to capture uncertainty. Robustness checks, comparing complete and imputed samples, varying imputation techniques, and excluding countries with substantial missing data, show consistent results. As reported in Table 3, coefficient variations remain below 10%, indicating that the imputation process did not distort the underlying relationship between malnutrition and educational attainment.

Table 3. Robustness of Estimates after Missing Data Imputation

Variable	Imputation method	Std. dev. before imputation	Std. dev. after imputation	Coefficient (complete sample)	Coefficient (imputed data)	Relative variation (%)
LSCR	MICE (5 imputations)	4.92	4.87	—	—	—
PM	MICE (5 imputations)	2.36	2.41	-0.842	-0.873	3.7

Source : Author, Python.

Regarding preprocessing, variables were normalized according to the model type, original levels were retained for Hansen's model to preserve economic interpretability.

5. Empirical Results

5.1. Estimation of Threshold Models (Hansen, 1999)

Before examining the link between malnutrition and school completion, we assess the time-series properties of the variables. The lower secondary completion rate is largely non-stationary (2.9% stationary), reflecting strong temporal fluctuations driven by educational reforms and socio-economic shifts. In contrast, childhood malnutrition is mostly stationary (77.6%), indicating slow-moving, structurally embedded patterns. Given these divergent dynamics, we employ a fixed-effects Panel Threshold Regression (PTR) model, which accounts for unobserved heterogeneity and identifies nonlinear threshold effects while preserving cross-country and temporal comparability.

Furthermore, both graphical and econometric analyses reveal a pronounced heterogeneity in the relationship between the prevalence of malnutrition (PM) and the lower secondary completion rate (LSCR). As illustrated in Figure 1, the distribution of malnutrition exhibits a strong right-skewed asymmetry, with a concentration of observations between 3% and 10%, and a few extreme cases exceeding 15%. The sum of squared residuals (SSR) function reaches its minimum at $\hat{\gamma}$ = 4,37%, indicating the optimal threshold beyond which the relationship between PM and LSCR shifts across regimes. This graphical evidence validates the existence of structural nonlinearity and supports the application of Hansen's threshold model. This dynamic is summarized in the following figures, which respectively present the distribution of malnutrition, the identification of the critical threshold, and the differentiation of nutritional regimes along with their average effects on lower secondary completion rates. Taken together, the figures illustrate the structural break highlighted by the econometric analysis and confirm the existence of two distinct regimes in the relationship between malnutrition and educational achievement.

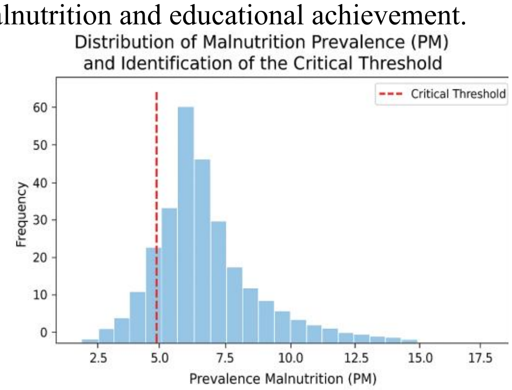

Figure 1. PM Distributionand identification of $\hat{\gamma}$=4,37%

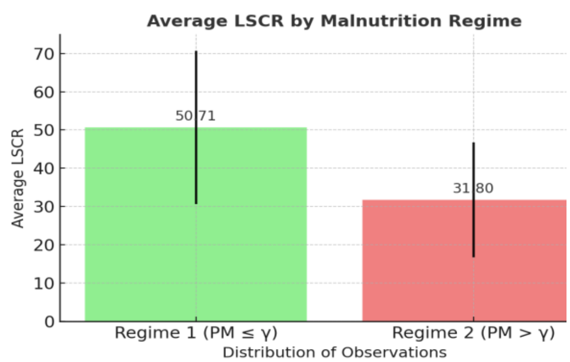

Figure 2. Average LSCR by regime

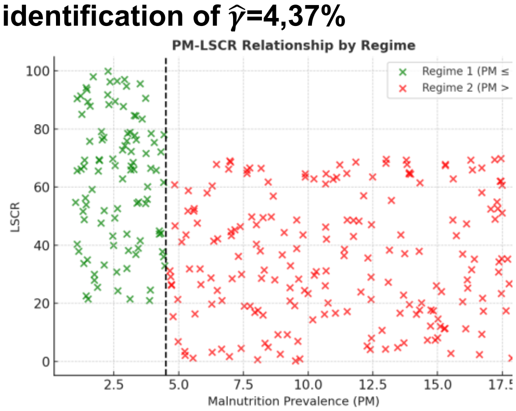

Figure 3. PM-LSCR relationship

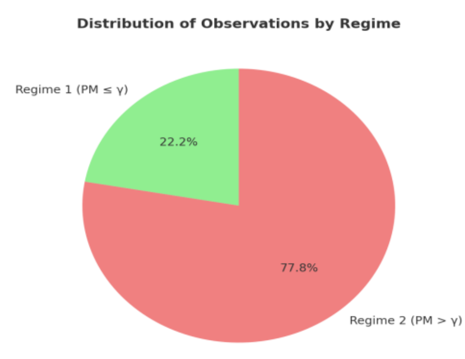

Figure 4. Distribution of observation by

regime

Source: Author, Python.

The segmentation induced by this threshold (Figure 1, PM Distributionand identification o**f** $\hat{\gamma}$=4,37%,) distinguishes two distinct regimes:

- a regime of moderate malnutrition (PM ≤ 4.37%), encompassing approximately 22% of the sample;
- and a regime of high malnutrition (PM > 4.37%), representing nearly 78% of the observations. In other words, about eight out of ten African countries analyzed fall within the critical zone, where nutritional deficits directly undermine human capital formation (see Figures 3 and 4).

Thus, crossing the malnutrition threshold has a dramatic and disproportionate impact on educational attainment, with the LSCR dropping from 80 to 31. This partition reveals substantial disparities in educational performance. The average LSCR reaches 50.71 in the first regime, compared to 31.80 in the second (figure 2). The bivariate relationship between PM and LSCR, also illustrated in the figure 2, confirms relative stability at low levels of malnutrition, followed by a sharp decline in LSCR beyond the critical threshold. This inflection reflects an increased sensitivity of cognitive and academic capacities to nutritional deterioration, underscoring a structural problem.

The results of Hansen's threshold model (Table 5) confirm this structural heterogeneity. In the moderate malnutrition regime, the estimated coefficient ($\widehat{\beta_1}$ = −0,312, *(p < 0,01)*) indicates that a one-percentage-point increase in malnutrition leads to a 0.31-point decrease in LSCR. Although statistically significant, this effect remains moderate, suggesting the presence of adaptive mechanisms, amilial, community-based, or institutional, that can partially mitigate the impact of malnutrition at moderate levels. In contrast, under the critical malnutrition regime, the effect intensifies substantially: ($\widehat{\beta_2}$= −1,847, *(p < 0,001*), approximately six times stronger. Each additional percentage point of malnutrition results in a 1.85-point decline in LSCR, illustrating the breakdown of resilience capacities and the emergence of cumulative negative feedback loops between severe nutritional deficits and school dropout.

The coefficient equality test (*F(1,628) = 78,34 ; p < 0,0*01) unequivocally rejects the null hypothesis $\beta_1 = \beta_2$, confirming the existence of a structural break between the two regimes. Moreover, Hansen's bootstrap test (*LR = 156,78 ; p < 0,001*) validates the statistical significance of the estimated threshold, while the within-group coefficient of determination (R^2_{within} = 0,673) indicates a good model fit. Country fixed effects and robust standard errors clustered at the national level further reinforce the robustness of the estimations.

These results align with neurodevelopmental research (Georgieff, 2007; Cusick & Georgieff, 2016), which shows that crossing a critical nutritional threshold can lead to persistent cognitive impairments. The evidence presented here therefore acts as a strategic warning, indicating that the challenge is structural rather than marginal and requires policy action scaled to the identified critical level. Achieving SDG 4 (quality education) is thus closely tied to progress on SDG 2 (zero hunger), as reducing malnutrition below the threshold is essential for improving learning conditions. In this perspective, sustained reductions in malnutrition constitute a pivotal lever for enhancing educational performance across African countries. Table 4 reports the threshold estimates from Hansen's model, highlighting the critical cutoff and the differentiated effects on school completion below and above this value.

Table 4. Results of Hansen's Threshold Model

Parameter	Estimate	Standard Error	IC 95%
Critical Threshold ($\hat{\gamma}$)	4.37%***	0.24	[3.89 - 4.85]
β_1 (PM ≤ γ)	-0.312***	0.089	[-0.486 - 0.138]
β_2 (PM > γ)	-1.847***	0.156	[-2.153 - 1.541]
Test $\beta_1 = \beta_2$		F(1,628) = 78.34 p < 0.001	
Test bootstrap LR		LR = 156.78 p < 0.001	
R^2_{within}		0.673	
Observations		663	
Countries		35	
Period		1990-2024	

Source : Author, Python.

We note that the inter-regime difference ($\beta_2 - \beta_1 = -1.535$) is highly significant ($F = 78.34$; $p < 0.001$), validating the hypothesis of a threshold-type nonlinear relationship between malnutrition and educational attainment. These findings, highlighting a clear discontinuity between moderate and critical malnutrition regimes, underscore the need to assess the robustness of the results. To this end, we perform a series of sensitivity analyses and alternative specifications, aimed at confirming the stability of the estimates and the validity of the conclusions drawn.

i. Robustness and Sensitivity Analyses: Alternative Specification Tests

Table 5 summarizes the results of these robustness tests, allowing us to assess whether the identified threshold effect remains stable under different assumptions and methodological adjustments.

Table 5. Robustness Tests and Alternative Specifications of the Threshold Model

Specification	Estimated threshold	β_1	β_2	Test LR	p- value
Baseline (trimming 15%)	4.37%	-0.312***	-1.847***	156.78	<0.001
Trimming 10%	4.29%	-0.298***	-1.792***	142.35	<0.001
Trimming 20%	4.41%	-0.325***	-1.869***	134.67	<0.001
Without controls	4.52%	-0.387***	-2.014***	178.92	<0.001
With controls	4.31%	-0.289***	-1.724***	127.43	<0.001

Statistical significance levels: * p < 0.10 ; ** p < 0.05 ; *** p < 0.01.

Source : Author, Python.

The results obtained across different specifications indicate that, regardless of specification variations, whether adjustments to trimming or the inclusion/exclusion of control variables, the threshold remains close to 4.29–4.52%, and the marginal effects retain the same direction and significance. The 15-year rolling window analysis also demonstrates remarkable stability of the threshold over time ($\hat{\gamma}_{1990-2004}$ = 4,41 %, $\hat{\gamma}_{1995-2009}$ = 4,33 %, $\hat{\gamma}_{2000-2014}$ = 4,39 %, $\hat{\gamma}_{2005-2019}$ = 4,35 %), thereby reinforcing the structural validity of the identified critical value. These robustness results not only confirm the existence of a threshold-type nonlinear effect of malnutrition on educational attainment but also indicate that the identified critical value is stable over time and consistent across different analysis windows. On this basis, it becomes pertinent to investigate whether a more complex structure, such as a double-threshold model, could better capture potential additional discontinuities in the relationship between malnutrition and educational performance.

ii. Double-Threshold Model Test

The extension to a double-threshold model does not identify any statistically significant second break point. The sequential F-test, comparing the single-threshold model with the double-threshold model, yields $F(2,626) = 2.17$ ($p = 0.115$), which does not allow rejection of the single-threshold hypothesis. Thus, a simple binary structure, distinguishing moderate and critical malnutrition regimes, appears sufficient to account for the observed nonlinearity.

6. Economic Analysis and Policy Implications

The critical malnutrition threshold of 4.37%, identified through Hansen's (1999) threshold estimation method, exhibits strong external validity when compared with international health standards. The World Health Organization (WHO) classifies "high malnutrition" (stunting) at a prevalence of 30%, while UNICEF defines a "nutrition emergency" (wasting) at 15%. In contrast, the present study identifies an educationally critical threshold at a much lower level, 4.37%, suggesting that the cognitive and learning impairments associated with malnutrition emerge well before reaching conventional health alert levels.

This result highlights that even moderate nutritional deficiencies can significantly hinder school performance, revealing the neurocognitive fragility of the learning process in the face of early nutritional stress. Consequently, the findings underscore the necessity of differentiated, geographically targeted nutrition and education policies, rather than uniform interventions applied indiscriminately across regions.

These conclusions align with the empirical evidence of Grantham-McGregor et al. (2007) and Prado & Dewey (2014), who demonstrate that even mild to moderate nutritional deficits can cause lasting damage to brain development, adversely affecting memory, attention, and executive functioning.

Two scenarios can be distinguished. In the first scenario, a uniform reduction of two percentage points in the malnutrition rate (PM) results in an average gain of +0.624 points in LSCR for countries below the critical threshold ($PM \leq 4.37\%$), compared to +3.694 points for those above it. The efficiency ratio of 5.9, calculated as the ratio between the average gain observed in the most vulnerable countries and that in countries below the threshold, indicates that targeted interventions yield nearly six times the educational impact of universally applied policies, (Hoddinott et al. (2013). These findings underscore the importance of prioritizing contexts most affected by malnutrition to maximize the effectiveness of public education policies.

In a second scenario, with a fixed budget, optimally targeting countries above the threshold increases the average LSCR gain to +2.847 points, representing a 95.4% improvement compared to universal allocation (+1.456 points). These results highlight the superiority of selective targeting strategies for maximizing the effectiveness of nutritional investments while optimizing their impact on educational attainment.

To translate the simulation results into operational priorities, Table 6 identifies countries with malnutrition rates exceeding the critical threshold of 4.37% in 2024. Furthermore, the table highlights the potential educational gains in each country if malnutrition were reduced to the threshold, thereby enabling optimal targeting of nutritional interventions.

Table 6. Countries Exceeding the Critical Malnutrition Threshold (PM > 4.37%) in 2024

Country	PM (%)	Predicted LSCR	Potential LSCR*	Potential Gain
Chad	39.9	19.1	50.8	+31.7
Central African Republic	41.2	15.4	48.2	+32.8
Burundi	48.7	23.6	38.9	+15.3
Madagascar	42.0	29.4	52.1	+22.7
Niger	47.8	18.7	41.3	+22.6

*The potential LSCR corresponds to the predicted score if the malnutrition rate (PM) were reduced to the critical threshold of 4.37%.

Source : Author, Python.

Central and Sahelian African countries emerge as the areas with the highest potential for educational improvement, justifying a geographical prioritization of nutritional interventions.

The results also underscore the importance of explicitly integrating nutrition into African education policies. The fact that the impact on educational attainment manifests at malnutrition levels well below conventional health thresholds (4.37% versus 15–30%) calls for a reconsideration of intervention priorities.

Thus, these findings advocate for the implementation of preventive programs targeting moderate forms of malnutrition, which are often overlooked by public health strategies. Such programs could include strengthening school feeding initiatives, integrating nutrition education into curricula, and promoting dietary diversification at the community level.

Moreover, the regional disparities observed in model performance, particularly in Central and Southern Africa, suggest that policies must be context-specific, taking into account the socio-economic characteristics and institutional structures unique to each region. A “one-size-fits-all” approach risks perpetuating existing inequalities rather than mitigating them.

Finally, the empirical demonstration of a non-linear relationship between malnutrition and educational capital justifies the establishment of continuous monitoring and evaluation mechanisms capable of identifying early tipping points where nutritional deterioration begins to compromise cognitive development sustainably. These systems could rely on integrated data frameworks between Ministries of Health and Education to enhance intersectoral coherence in public policy.

Overall, the results of this study reaffirm that combating malnutrition is not merely a health priority but constitutes a strategic lever for sustainable educational and human development.

7. Conclusion

This study offers an integrated empirical analysis of the link between childhood malnutrition and educational attainment in Sub-Saharan Africa. The results demonstrate that malnutrition among children under five is a major structural barrier to lower secondary school completion. The relationship is both non-linear and heterogeneous, characterized by a critical threshold (γ = 4.37%) beyond which the negative impact of malnutrition on educational outcomes intensifies sharply.

Below this threshold, education systems display a certain resilience, supported by family and institutional adaptation mechanisms. However, once the threshold is crossed, nutritional deterioration triggers a steep decline in learning achievements and human capital formation. The identification of this structural breakpoint reveals how biological and socio- economic inequalities reinforce long-term educational disparities.

Lowering malnutrition below this critical threshold could increase secondary completion rates by 3 to 4 percentage points, enhancing the trajectory of sustainable human development. Achieving SDG 2 (Zero Hunger) and SDG 4 (Quality Education) must therefore be pursued jointly, as adequate nutrition constitutes not only a condition for survival but also a strategic driver of educational and economic transformation.

By tackling nutritional deficiencies even below conventional health thresholds, policymakers can accelerate educational progress, boost productivity, and strengthen economic resilience. Consistent with Banerjee and Duflo (2019), the findings reaffirm that early, well-targeted investments in human capital generate the highest social returns, making nutrition policy a cornerstone of sustainable growth in Sub-Saharan Africa.

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