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A longitudinal macro analysis of social determinants of health and their impacts on HIV prevalence and nutritional deficiencies in Sub-Saharan Africa

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ABSTRACT

Sub-Saharan Africa faces a dual public health crisis of HIV and nutritional deficiencies driven by profound socio-economic disparities. Despite significant micro-study research, macro-level, longitudinal patterns and causal dynamics remain underexplored. This study employs Panel Auto-regressive distributed lags, Panel Granger causality, and Vector auto-correction model to examine the influence of social determinants on HIV prevalence and nutritional deficiencies across Sub-Saharan Africa. The study further carried out robustness diagnostics using Driscoll – Kraay standard error regression to confirm the reliability of the results. For HIV prevalence, income, education, and employment reduce rates over the long term, while healthcare access and housing quality show positive associations. Short-term effects show the benefits of income and healthcare access, with other factors showing limited impact. For nutritional deficiencies, income, education, employment, and housing quality significantly reduce malnutrition in the long term, while healthcare access correlates positively. Short-term effects show the immediate role of income and housing quality. The causal results show unidirectional links between income, education, employment, and housing quality to HIV. Housing quality and income exhibit bidirectional causality. No causal link exists between HIV and nutritional deficiencies. The study recommends the need for income support programs, expanded educational access, skill development, and strengthened healthcare systems.

1. Introduction

Sub-Saharan Africa has diverse socio-economic and significant public health challenges (Alkhatib et al., 2021; Cook et al., 2024; Odugbose et al., 2024). Among these challenges, the dual burden of Human Immunodeficiency Virus (HIV) and nutritional deficiency presents a critical concern for the well-being and development of its populations (Beck et al., 2024). Socioeconomic determinants, including poverty, education, employment, and access to healthcare, play an essential role in determining health outcomes. Economic instability and low educational attainment can limit individuals' access to preventive measures, healthcare services, and adequate nutrition, thus increasing vulnerability to HIV and nutritional deficiencies. Furthermore, structural factors such as inequality, gender disparities, and lack of infrastructure can compound these challenges (Akinwale, 2023; Marire & Iqbal, 2024; Olawade, 2024).

Social determinants of health (SDH) have been envisaged to affect Human Immunodeficiency Virus (HIV) and Nutritional Deficiency. SDH plays a role in influencing the course and impact of HIV infection. Individuals from disadvantaged socioeconomic backgrounds often face greater challenges in accessing HIV prevention, testing, treatment, and care services. Studies have shown that lower income and education levels are associated with delayed diagnosis of HIV, leading to late initiation of antiretroviral therapy (ART) and poorer clinical outcomes (Bloom et al., 2022). For instance, individuals with limited financial resources may struggle to afford transportation to healthcare facilities or may face barriers in accessing comprehensive healthcare due to a lack of health insurance or high out-of-pocket costs (Aidala et al., 2016; Rahman et al., 2022). HIV/AIDS has long been a major public health issue in Sub-Saharan Africa, with the region accounting for a substantial proportion of the global HIV burden. Despite significant progress in treatment and prevention, HIV remains a leading cause of morbidity and mortality. Concurrently, nutritional deficiency—often characterised by inadequate intake of essential nutrients and associated with conditions

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such as stunting and anaemia—further worsens the health challenges faced by individuals living with HIV.

In the presence of global efforts to combat these issues, they remain pervasive with socio-economic factors in Sub Saharan Africa. The region's socio-economic environment—including poverty, education, employment, and healthcare access—is crucial in influencing health. However, the precise mechanisms through which these socioeconomic determinants impact HIV prevalence and nutritional deficiencies are not fully understood. Unstable housing and homelessness are prevalent among economically disadvantaged populations, which can disrupt consistent access to HIV care and adherence to treatment regimens, thereby increasing the risk of disease progression and transmission (Filippone et al., 2023; Pellowski et al., 2013). More so, social determinants such as stigma and discrimination also significantly impact HIV. Most of these stigmas may result from a low income and poor educational background. Marginalised populations, including racial and ethnic minorities, often experience higher levels of stigma and discrimination, which can deter them from seeking HIV testing and care services (Boakye et al., 2024; Fauk et al., 2021; Tesfay et al., 2020). Moreover, discriminatory practices in healthcare can result in suboptimal care and treatment adherence among affected individuals (Kerrigan et al., 2019).

Regarding the prevalence and severity of nutritional deficiencies among populations, SDH significantly influences the prevalence and severity of nutritional deficiencies among populations. Access to adequate nutrition is linked to socioeconomic status, with lower-income individuals and families often facing barriers that limit their ability to obtain nutritious food. Food insecurity, defined as limited or uncertain access to sufficient, safe, and nutritious food, is a key consequence of economic disadvantage (Drewnowski, 2022). Food-insecure households may rely on low-cost, energy-dense foods that are high in fats and sugars but low in essential vitamins and minerals, contributing to a higher risk of nutritional deficiencies such as iron deficiency anaemia, vitamin D deficiency, and inadequate intake of fruits and vegetables (Eicher-Miller et al., 2023).

Existing studies often focus on localised studies, which may not capture the long-term trends and macro-level influences; this lack of longitudinal perspective limits the ability to identify sustained patterns and causal relationships between socio-economic conditions and health. Additionally, the interactions between socioeconomic factors and health issues are frequently compounded by structural and systemic factors, such as inequality and inadequate infrastructure, which require comprehensive analysis. The focus and goal of this study is to add to empirical literature through the estimation of longitudinal macro-analysis that systematically investigates how socio-economic determinants influence HIV prevalence and nutritional deficiencies over time in Sub-Saharan Africa.

The study is justified on two grounds, among others. Firstly, existing empirical literature predominantly focuses on micro-level analyses and other factors rather than examining the impact of socio-economic determinants of health on HIV and malnutrition in Sub-Saharan Africa. This study aims to fill this gap by investigating how socio-economic factors influence both HIV and malnutrition, given their significant prevalence and impact in the region. Secondly, the United Nations Sustainable Development Goals (SDGs) underline the importance of addressing issues such as zero hunger, quality education, good health and well-being, inequality reduction, and gender equity. This study aligns with these SDGs, aiming to contribute towards sustainable development in Africa by exploring the interplay between socio-economic determinants, HIV, and malnutrition.

This study aims to investigate social determinants of health on HIV and nutritional deficiencies across Sub-Saharan Africa. Utilising a macro-level analysis across multiple countries, this research will offer new insights into how regional trends in socioeconomic factors influence health outcomes on a larger scale, paving the way for targeted policy interventions to mitigate the burden of HIV and malnutrition. The primary aim of this study is to evaluate the influence of social determinants of health (SDH) on HIV and nutritional deficiencies in Sub-Saharan Africa. The specific objectives are as follows:

i. To assess the impact of social determinants of health on HIV prevalence in Sub-Saharan Africa.
ii. To investigate how social determinants of health affect nutritional deficiencies within the region.
iii. To analyse the causal relationships among social determinants of health, HIV, and nutritional deficiencies in Sub-Saharan Africa.
iv. To examine the effects of variations or impulse response of social determinants of health on HIV and nutritional deficiencies over time, with the aim to forecast.

2. Literature review and gap identified in the empirical literature

2.1. Brief review and gap identified in the empirical literature review

The literature on the relationship between socioeconomic determinants and health, particularly HIV and nutritional deficiencies, emphasises the substantial impact of factors such as income, education, employment, social status, and access to healthcare services. Numerous studies have confirmed that these determinants influence human health across various populations ((Angulo-Arreola et al., 2017; Ginsburg et al., 2016; Mosha et al., 2021). Income disparities significantly influence access to nutritious food and healthcare services, with wealthier individuals typically experiencing better health (Angulo-Arreola et al., 2017). Education, particularly maternal education, plays a crucial role in improving health outcomes by enhancing health literacy, which helps in reducing HIV prevalence and improving nutritional status (Ginsburg et al., 2016). Employment stability is another key factor, as regular income can ensure access to adequate nutrition and healthcare (Gupta et al., 2008). Furthermore, marginalised groups, particularly in rural or underdeveloped areas, are more susceptible to malnutrition and HIV infection due to systemic barriers, discrimination, and social exclusion (Lillie-Blanton & Hoffman, 2005).

Theoretical perspectives have consistently shown the importance of income in improving nutrition (Cheteni et al., 2020; Kassie et al., 2015; Mosha et al., 2021; Taruvinga et al., 2013) and the linkage between HIV and social determinants such as education, income, and employment (Glanz et al., 2015). However, empirical studies predominantly focus on micro-level analyses, such as food security and specific health outcomes (Egah et al., 2023; Seenivasan et al., 2023; Purushotham et al., 2023; Bonis-Profumo et al., 2022; Ingutia & Sumelius, 2022; Rahaman et al., 2021), or micro-level investigations of HIV and social determinants, such as family economic empowerment and maternal health (Masiano et al., 2023; Murewanhema et al., 2022; Toska et al., 2017; Tutlam et al., 2023; Zgambo et al., 2018; Zuma et al., 2022).

The relationship between social determinants of health (SDH) and the prevalence of HIV and nutritional deficiencies has been widely examined through many theoretical frameworks, accentuating the importance of their critical role in health. SDH incorporates the conditions in which individuals are born, grow, live, work, and age, fundamentally influenced by the distribution of power, resources, and opportunities. These determinants significantly impact disease vulnerability and healthcare access, serving as the root causes of health inequities. Central to this understanding is the Social Determinants of Health Framework, as defined by the World Health Organization (WHO), which identifies non-medical factors such as income, education, gender, and healthcare accessibility as pivotal contributors to health disparities, including those related to HIV and nutritional deficiencies (Freudenberg, 2023; Mbanga et al., 2023). Low socio-economic status limits access to nutritious food, healthcare, and HIV prevention information, exacerbating vulnerability to malnutrition and disease progression (Fuseini et al., 2021).

Other theories include the Ecological Systems Theory showing the multi-level influences, from household food insecurity to macro-level policies, on health outcomes in HIV-affected populations (Bronfenbrenner, 1979; Woodland et al., 2024). The Syndemic Theory explains how epidemics, such as HIV and malnutrition, are amplified by social inequities, creating cycles of poor health (Singer & Mendenhall, 2022). The Health Belief Model (HBM) emphasises the role of perceived risks and barriers in health behaviours while recognising how social factors constrain access to care (Maiman & Becker, 1974; Tesfay et al., 2020). Life Course Theory links early-life conditions with long-term health vulnerabilities, illustrating how childhood malnutrition and HIV may have lifelong impacts (Adair, 2014; Elder et al., 2003). Structural Violence Theory further contextualises these issues, emphasising the role of systemic inequalities in perpetuating health disparities (Farmer, 2004). Collectively, these frameworks describe the need for comprehensive interventions targeting poverty, food insecurity, and access to healthcare to disrupt cycles of inequity and improve consequences for populations affected by HIV and malnutrition.

Recently empirical literature regarding socioeconomic determinants and HIV reaffirms the role of income as a critical socio-economic determinant of HIV. Tutlam et al. (2023) found that while family economic empowerment interventions improved psychological well-being among adolescents orphaned by AIDS, their impact on risky sexual behaviours was limited. Masiano et al. (2023) explored the cost-effectiveness of conditional cash transfers for preventing mother-to-child HIV transmission in the Democratic Republic of Congo, concluding that these interventions are affordable and effective in reducing transmission rates. Similarly, Cavazos-Rehg et al. (2021) documented that integrating family assets, employment opportunities, and financial security into interventions is crucial for addressing the mental health needs of HIV-positive youth, especially in areas with limited mental health services.

Education remains a cornerstone in mitigating HIV risks. Murewanhema et al. (2022) linked insufficient education and economic marginalisation among adolescent girls to high HIV prevalence in sub-Saharan Africa (SSA), pointing to the need for culturally sensitive sexual health interventions. Zuma et al. (2022) made known how unequal access to education perpetuates gender disparities, emphasising the importance of gender-sensitive approaches in addressing HIV transmission. Haley and Marsh (2021) demonstrated that while beneficial in improving family decision-making, women's empowerment programs often fall short without structural reforms addressing poverty and gender biases. Kahonge (2023) demonstrated that poverty and lack of health insurance remain significant barriers to early HIV treatment in Kenya, worsening health disparities. Integrating socio-economic interventions with healthcare services is vital for improving treatment uptake, particularly in rural and underserved areas.

Subsequently, recent empirical literature regarding socio-economic determinants and nutritional deficiency has established the connection. For example, Seenivasan et al. (2023) established a link between national economic indicators and malnutrition, investigating the relationship between GDP per capita and the double burden of malnutrition and reported that improved income tends to reduce malnutrition. Purushotham et al. (2023) identified socio-economic disparities in dietary patterns, noting that lower-income groups faced higher risks of obesity due to reliance on semi-processed foods, while higher-income groups were susceptible to over-nutrition. Narayanan et al. (2019) found a strong correlation between women's empowerment and improved nutrition in rural South Asia, emphasising the role of maternal education in addressing malnutrition. Heckert et al. (2019) demonstrated that nutrition-sensitive agricultural programs improved child nutrition in Burkina Faso by enhancing better household decision-making.

Ingutia and Sumelius (2022) revealed that cooperative participation among farmers improved food security and nutrition in rural Kenya, underlining the need for employment opportunities that enhance resource access. However, the lack of irrigation and inadequate support systems remained barriers to achieving food security. Rahaman et al. (2021) focused on the importance of sustainable food systems in addressing hunger and malnutrition in developing economies, advocating for global cooperation to ensure food affordability. Fuseini et al. (2021) linked food insecurity to poor antiretroviral therapy adherence, emphasising the necessity of integrated HIV and food security interventions. Cairncross et al. (2010) highlighted the critical impact of poor sanitation on nutrition, particularly among children. Chronic exposure to pathogens due to inadequate sanitation infrastructure perpetuates stunting and other nutritional deficiencies in low-income settings.

The consensus from these empirical studies suggests that social determinants have significant developmental benefits and are critical goals in public health initiatives. For instance, children's education correlates with improved health and nutrition (Dadras et al., 2024). Additionally, Raj et al. (2018) reported that lack of empowerment and financial inclusion heightens the risk of intimate partner violence. However, while micro-level analyses provide essential insights into localised growth and development, they often fall short in promoting broader, aggregate outcomes. Studies like those by Haley and Marsh (2021) indicate that while inclusive participation in income-generating activities (IGAs) is crucial for poverty management, it may not fundamentally transform household economic status. Similarly, Stark et al. (2018) concluded that standalone social determinants programs may not sufficiently address economic vulnerability among adolescent females without simultaneous economic empowerment strategies or structural reforms.

Thus, there remains a growing need for macro-level studies exploring the impact of social determinants of health on nutrition and HIV. While Seenivasan et al. (2023) examined macroeconomic variables and malnutrition, more comprehensive macro-level investigations are necessary to improve public health challenges. Despite the breadth of studies, much of the existing literature focuses on micro-level analyses (De Waal & Whiteside, 2003; Mishra et al., 2007). These studies typically examine individual or household data, shedding light on the effects of socioeconomic factors at a local level. While valuable, these micro-level studies often do not comprehensively show how broader macroeconomic trends across Sub-Saharan Africa influence health.

2.2. Development of hypotheses

This study is underpinned by the Social Determinants of Health (SDH) framework, which posits that health implications are influenced and can be determined by economic, social, and environmental factors rather than only biological determinants (Karatekin et al., 2024; WHO, 2024). This framework aligns with the fundamental principles of structural violence theory (Davis & Lindell, 2024), which suggests that factors such as poverty, education, and access to healthcare contribute to health issues. The ecological systems theory also points out that interactions between individuals and socio-environmental may influence human health (Lätsch, 2018).

Guided by these theoretical perspectives, the hypotheses for this study were formulated. The first hypothesis is that social determinants of health (SDH) impact HIV prevalence in Sub-Saharan Africa. This statement is supported by literature indicating that poverty, education levels, inequality, and healthcare access are drivers of HIV prevalence in developing economies (Chipanta et al., 2022; Dadzie et al., 2024; Harsono et al., 2024; Sullivan et al., 2021). The second hypothesis (ii), which links SDH to nutritional deficiencies, is similarly rooted in the SDH framework, as economic instability, food insecurity, and poor healthcare directly affect nutritional status (Patel & Pandey, 2024).

Furthermore, the third hypothesis (iii), which posits causal relationships among SDH, HIV prevalence, and nutritional deficiencies, is justified through both the SDH and structural violence theories. The two theories suggest that structural inequalities create interdependent health challenges, with HIV infection worsening malnutrition due to increased metabolic demands and compromised immune function (Ali et al., 2024; Mohammadi et al., 2024). Finally, the fourth hypothesis (iv), which examines variations in SDH over time and their predictive power, aligns with the approach within public health, emphasising the nature of social determinants and their long-term impact on disease patterns (Fanfan et al., 2024).

3. Methodology

3.1. Theoretical framework of the study

The theoretical framework of this study is grounded in the Social Determinants of Health (SDH), which posits that economic conditions play a crucial role in influencing health issues. Specifically, this study explores how nutritional deficiency and Human Immunodeficiency Virus (HIV) are affected by these social determinants, aiming to achieve its research objectives.

$$\mathrm{HEO} = \mathrm{f}\ (\mathrm{SDT}) \tag{1}$$

In this study, Health Outcomes (HEO) are nutritional deficiency and HIV. Social Determinants (SDT) include income, education, occupation, healthcare access, housing quality, and sanitation (World Health Organization (WHO), 2021a,b). The robust social networks variable was not included due to data unavailability. Given the significance of the variables discussed, Eq. (1) has been revised to incorporate the following variables:

$$HEO = f(INC, EDU, OCC, HEC, HQS) \tag{2}$$

In Eq. (2), INC is income, EDU is education, OCC is occupation, HEC is health care, and HQS is housing quality sanitation.

3.2. Statistical models

The statistical model designed to meet the objectives of this study is presented below, incorporating control variables such as income per capita, food production and population growth:

$$NMD = f(INC, EDU, OCC, HEC, HQS, PPG, FPP, IPC) \tag{3}$$

$$HIV = f(INC, EDU, OCC, HEC, HQS, PPG, FPP, IPC) \tag{4}$$

The variables from Eqs. (3) and (4) retain their definitions as outlined in Eqs. (1) and (2). The nutritional deficiency (NMD) and HIV equations are given in (3), (4). It is crucial to note that these determinants should not be considered in isolation to achieve desired results (WHO, 2021a,b). The framework also emphasises the role of historical and structural factors in health, many of which are included as control variables in empirical models. Variables such as population growth, food production, and income per capita are incorporated, as improvements in these factors are expected to enhance health (Liu et al., 2024; Nasreen et al., 2024; Nordhaus, 2002; Strauss & Thomas, 1998; Weil, 2014). Other variables are defined as PPG is population growth, FPP is food production, and IPC is income per capita.

The hypotheses to be tested in this study are as follows:

i. Social determinants of health have a significant impact on HIV prevalence in Sub-Saharan Africa.
ii. Social determinants of health significantly influence nutritional deficiencies within the region.
iii. There exist causal relationships among social determinants of health, HIV prevalence, and nutritional deficiencies in Sub-Saharan Africa.
iv. Variations or impulse responses in social determinants of health significantly affect HIV prevalence and nutritional deficiencies over time, with potential for accurate forecasting.

Explicitly, the test of the hypotheses will be achieved using the following model specification as follows:

3.3. For hypotheses one and two

This study employs a Panel Autoregressive Distributed Lag (ARDL) model to investigate the relationship between social determinants of health and HIV prevalence and nutritional deficiencies (NMD) in Sub-Saharan Africa. The following dynamic panel ARDL models are specified for HIV and NMD equations:

3.4. Model for HIV prevalence

$$HIV_{it} = \alpha_i + \sum_{p=1}^{P} \lambda_p HIV_{i,t-p} + \sum_{q=0}^{Q} \beta_q X_{i,t-q} + \varepsilon_{it} \tag{5}$$

Eq. (5), the panel ARDL for HIV, where: HIV_{it}represents the HIV prevalence in country 'i' at time 't', $X_{i,t}$is a vector of independent variables consisting of income (INC), education (EDU), occupation (OCC), healthcare (HEC), housing quality and sanitation (HQS), population growth (PPG), food production (FPP) and income per capita (IPC), $\alpha_i$captures country-specific fixed effects, and $\varepsilon_{it}$is the error term. Then, 'p' and 'q' represent the lag orders of the dependent and independent variables, respectively. The formulation allows for a dynamic understanding of how past levels of HIV prevalence (via the lagged dependent variable) and lagged determinants influence current levels of HIV prevalence. Such a specification is important given the persistence of HIV and the time-varying impact of social, economic and institutional factors.

3.5. Long-run model for HIV prevalence

The following equation represents the long-run relationship between the social determinants and HIV prevalence:

$$\begin{aligned} HIV_{it} = {} & b_i + \beta_1 INC_{it} + \beta_2 EDU_{it} + \beta_3 OCC_{it} + \beta_4 HEC_{it} + \beta_5 HQS_{it} + \beta_6 PPG_{it} \\ & + \beta_7 FPP_{it} + \beta_8 IPC_{it} + \varepsilon_{it} \end{aligned} \tag{6}$$

In this equation, that is (6), the coefficients β_1 toβ_8 represent the long-run elasticities of the respective social determinants and other variables on HIV prevalence. These coefficients capture the extent to which each factor influences HIV prevalence in the long run, while $b_i$is the intercept. In the short run, the model introduces dynamic adjustments through lagged changes in dependent and independent variables. The long-run relationship assumes that, after adjusting for short-term fluctuations, the system will reach an equilibrium state where changes in social determinants of health have a persistent and stable influence on HIV prevalence. Given the nature of the HIV epidemic in Sub-Saharan Africa, which has both short-term fluctuations and long-term structural drivers (such as income inequality, education access, and healthcare infrastructure), capturing this long-run relationship is crucial for policy formulation.

3.6. Short-run model for HIV prevalence

The short-run dynamics are captured by introducing the first differences of the variables and lagged error correction terms. The short-run model for HIV prevalence is specified as:

$$\Delta HIV_{it} = \gamma_0 + \sum_{p=1}^{P} \lambda_p \Delta HIV_{i,t-p} + \sum_{q=0}^{Q} \beta_q \Delta X_{i,t-q} + \phi EC_{i,t-1} + \varepsilon_{it} \tag{7}$$

where: Δ denotes the first difference operator, representing the changes in the variables from one period to the next. $EC_{i,t-1}$ is the error correction term, which captures the speed of adjustment towards the long-run equilibrium after short-term deviations. The parameter ϕ is the coefficient on the error correction term and is expected to be negative and significant, indicating a stable long-run relationship. The model allows for identifying both short-term effects (though the lagged difference of the explanatory variables) and the adjustment that corrects deviations from the long-run equilibrium. For example, short-run increases in income or healthcare access may have an immediate impact on HIV prevalence. However, the error correction mechanism ensures that the long-run equilibrium forces eventually balance these deviations.

3.7. Model for nutritional deficiencies

To test the hypothesis of the impact of social determinants on nutritional deficiencies, a similar ARDL structure is employed. The model is specified as:

$$NMD_{it} = \alpha_i + \sum_{p=1}^{P} \lambda_p NMD_{i,t-p} + \sum_{q=0}^{Q} \beta_q X_{i,t-q} + \varepsilon_{it} \tag{8}$$

where: NMD_{it}represents nutritional deficiencies in country 'i' at time 't'. The explanatory variables, $X_{i,t}$, consist of the same set of social determinants of health (SD1 to SD5), population growth (PPG), food production (FPP), and income per capita (IPC).

3.8. Long-run model for nutritional deficiencies

The long-run relationship equilibrium relationship for nutritional deficiencies is expressed as:

$$\begin{aligned} NMD_{it} = {} & a_i + \alpha_1 INC_{it} + \alpha_2 EDU_{it} + \alpha_3 OCC_{it} + \alpha_4 HEC_{it} + \alpha_5 HQS_{it} \\ & + \alpha_6 PPG_{it} + \alpha_7 FPP_{it} + \alpha_8 IPC_{it} + \varepsilon_{it} \end{aligned} \tag{9}$$

Eq. (9) expresses the long-term relationship between the independent variables and nutritional deficiencies. The coefficients α_1 to α_8 capture the long-term impact of the social determinants and additional factors on nutritional deficiencies. The relationship is important for understanding how structural and persistent factors, such as healthcare access or income inequality, affect the nutrition of the population in Sub-Saharan Africa.

3.9. Short-run models for nutritional deficiencies

The short-run dynamics for nutritional deficiencies are modelled similarly to HIV prevalence:

$$\Delta NMD_{it} = \gamma_0 + \sum_{p=1}^{P} \lambda_p \Delta NMD_{i,t-p} + \sum_{q=0}^{Q} \beta_q \Delta X_{i,t-q} + \phi EC_{i,t-1} + \varepsilon_{it} \tag{10}$$

As in the case of the HIV model, the error correction term $EC_{i,t-1}$in the NMD also measures how quickly the system returns to equilibrium after short-term fluctuations in the social determinants and other variables.

The optimal lag length for the Panel ARDL model was determined using the Akaike Information Criterion (AIC), which balances model fit and parsimony. The final selection was based on the lag length that minimized the AIC, this is to ensure that the dynamic relationships were effectively captured while avoiding overfitting.

3.10. For hypothesis three

To address Objective 3, which aims to analyse the causal relationships among social determinants of health, HIV prevalence, and nutritional deficiencies in Sub-Saharan Africa, a Panel Granger Causality framework is employed. Panel Granger Causality tests allow us to examine the direction of causality between variables in a panel setting, meaning we can determine whether changes in one variable (e.g., social determinants of health) help predict future changes in another variable (e.g., HIV prevalence or nutritional deficiencies). The Panel Granger Causality test can be specified as follows:

$$HIV_{it} = \alpha_i + \sum_{p=1}^{P} \lambda_p HIV_{i,t-p} + \sum_{q=0}^{Q} \beta_q X_{i,t-q} + \varepsilon_{it} \tag{11}$$

and

$$INC_{it}, EDU_{it}, \dots, IPC_{it} = \alpha_i + \sum_{p=1}^{P} \lambda_p SD_{i,t-p} + \sum_{q=0}^{Q} \beta_q HIV_{i,t-q} + \varepsilon_{it} \tag{12}$$

where $HIV_{it}$is the HIV prevalence rate in country 'i' at time 't'. INC_{it}, EDU_{it}, OCC_{it}, HEC_{it} and HQS_{it} represent the social determinants of health ($SD_{i,t-p}$) for income, education, occupation, healthcare, housing quality/sanitation in Eqs. (11) and (12). $\alpha_i$represents country-specific fixed effects. $\lambda_p$captures the lagged impact of the dependent variable (HIV or social determinants) on itself. $\beta_q$measures the Granger causality between the independent variables and the dependent variable. To assess whether the social determinants Granger-cause HIV prevalence, we estimate the following null hypothesis for each determinant:

H0. INC does not Granger-cause HIV

Similarly, to check if HIV prevalence Granger-causes social determinants, we test:

H0. HIV does not Granger-cause INC

If the null hypothesis is rejected, we conclude that there is Granger causality from one variable to the other. The same framework applies to investigate the Granger causality between social determinants of health and nutritional deficiencies. Specifically, the Granger causality test will determine whether lagged values of social determinants, population growth, food production, and income per capita predict future changes in nutritional deficiencies (NMD) and vice versa.

3.11. For hypothesis four

To test the effects of variations or impulse responses of social determinants of health on HIV prevalence and nutritional deficiencies over time, a Panel Vector Error Correction Model (VECM) was employed. A Panel VECM captures the short-term adjustments to deviations from the long-run equilibrium, making it ideal for this objective. Moreover, the model's output, specifically the Variance Decomposition, is used to interpret the dynamic interactions among the variables. Following empirical and theoretical justification, the variables are ordered in the VECM: PPG, FPP, INC, EDU, OCC, HEC, HQS and HIV/NMD.

The Panel VECM consists of a long-run cointegration equation and a short-run error correction model. The long-run equilibrium equation is given by:

$$\Pi Y_{i,t-1} = \alpha + \lambda' Y_{i,t-1} + \varepsilon_{it} \tag{13}$$

In Eq. (13), Π is the cointegration matrix that captures long-run relationships. λ is the cointegrating vector, defining equilibrium relationships among variables. $\alpha$is a vector of deterministic components, that is, the constant and $\varepsilon_{it}$is the vector of error terms.

Taking first differences to capture short-run dynamics, the model is presented as follows:

$$\Delta Y_{it} = \phi \varepsilon_{i,t-1} + \sum_{j=1}^{\rho-1} \tau_j \Delta Y_{i,t-j} + \mu_i + \nu_t + \varepsilon_{it} \tag{14}$$

In Eq. (14), ΔY_{it} represents the first-differenced vector of endogenous variables, ϕ is the speed of adjustment matrix, indicating how deviations from equilibrium are corrected. Likewise, $\varepsilon_{i,t-1}$is the vector of error correction terms and $\tau_j$are short-run coefficient matrices capturing lagged effects. While $\mu_i$captures country-specific fixed effects and $\nu_t$represents time effects. Finally, $\varepsilon_{it}$is the stochastic disturbance term.

Table 1
Information about the variables.

No	Variables	Definition of variable	Source
1	HIV	The prevalence of HIV is the percentage of males and females infected with HIV.	UNAIDS estimates.
2	NMD	Prevalence of Undernourishment is the percentage of the population whose habitual food consumption is insufficient to provide the dietary energy levels required to maintain a normally active and healthy life.	Food and Agriculture Organization
3	INC- Income	Wage and salaried workers, total (% of employment) (modelled ILO estimate)	International Labour Organization. "ILO modelled estimates database" ILOSTAT
4	EDU – Education	School enrolment, secondary, total (% gross)	UNESCO Institute for Statistics (UIS).
5	OCC - Aggregate employment	Employers, total (% of female employment) (modelled ILO estimate)	International Labour Organization. "ILO modelled estimates database" ILOSTAT
6	HEC – Healthcare facilities	Current health expenditure (% of GDP)	World Health Organization Global Health Expenditure database
7	HQS – Housing Quality Sanitation	Sanitation services used for house-quality sanitation	World Bank Development Indicator
8	PPG – Population growth	Population growth (annual %)	United Nations Population Division. World Population
9	FPP – Food Production	Food production index (2014–2016 = 100)	Food and Agriculture Organization, electronic files and website.
10	IPC – Income per capita	Adjusted net national income per capita (annual % growth)	World Bank

(Source: Authors' computation.)

3.12. Robustness checks

In addition of using the Panel Autoregressive Distributed Lag (ARDL) model to test the first two hypotheses, this study implements Driscoll-Kraay standard errors as a robustness check to account for potential heteroskedasticity, autocorrelation, and cross-sectional dependence. Panel ARDL is widely recognised for its effectiveness in analysing long-run relationships among variables in panel data, particularly when dealing with non-stationary series that may exhibit co-integration. However, to further validate the findings and enhance robustness, this study also conducts second-generation unit root tests, specifically the Cross-Sectionally Augmented IPS (CIPS) test and the Cross-Sectionally Augmented Dickey-Fuller (CADF) test, to account for potential cross-sectional dependencies in stationarity assessments. Additionally, a heterogeneity test is performed to evaluate the extent of variation across cross-sections.

Table 1 provides information about the series; income is reflected in INC and IPC. However, we emphasise that these variables capture different economic dimensions to clarify the distinction between INC (wage and salaried workers, % of employment) and IPC (adjusted net national income per capita, % growth). INC reflects labour market composition by measuring the proportion of formally employed individuals, while IPC represents macroeconomic income trends and overall economic well-being. Given these distinctions, multicollinearity is unlikely. Additionally, a correlation analysis confirms that any relationship between INC and IPC remains within an acceptable statistical range, ensuring the robustness of our model.

3.13. Information about the series

4. Result presentation and discussion of the study

Table 2 shows the correlation analysis result. For NMD, income (−0.40267), education (−0.33517), and housing quality (−0.39846) showed moderate negative correlations, indicating their mitigating effects on nutritional deficiencies through improved access to resources

Table 2
Correlation analysis.

Correlation analysis for NMD

	NMD	INC	EDC	OCC	HEC	HQS	PPG	FPP	IPC
NMD	1								
INC	−0.40267[a]	1							
EDU	−0.33517[a]	0.69322[c]	1						
OCC	0.31650[a]	−0.65397[c]	−0.44375[a]	1					
HEC	0.13246[a]	0.12330[a]	0.09245[b]	−0.13569a	1				
SD5	−0.39846[a]	0.71885[b]	0.56898[c]	−0.58083[c]	0.08434[a]	1			
HQS	−0.00493[b]	−0.40505[a]	−0.25209[c]	0.57502[c]	−0.25595[a]	−0.28796[a]	1		
FPP	−0.16995[a]	0.30486[b]	0.38097[a]	−0.28241[a]	0.14977[a]	0.43488[a]	−0.13650[a]	1	
IPC	0.10880[a]	−0.04077[c]	−0.02294[b]	0.08765[c]	0.01573[c]	−0.04619[a]	0.07411[a]	−0.03298[a]	1

Correlation analysis for HIV

	HIV	INC	EDU	OCC	HEC	HQS	PPG	FPP	IPC
HIV	1								
INC	0.28374[a]	1							
EDU	0.08757[b]	0.69015[c]	1						
OCC	−0.04230[a]	−0.62461[c]	−0.39129[a]	1					
HEC	0.16583[a]	0.12221[b]	0.13291[b]	−0.07828[a]	1				
HQS	0.23282[a]	0.62624[a]	0.46839[a]	−0.54465[b]	0.05393[a]	1			
PPG	−0.03367[a]	−0.34973[b]	−0.18613[c]	0.51411[b]	−0.17936[a]	−0.28149[a]	1		
FPP	−0.06531[a]	0.31554[b]	0.36921[a]	−0.30826[a]	0.139872[a]	0.41283[a]	−0.11869[a]	1	
IPC	0.07885[a]	−0.04360[c]	−0.03828[b]	0.03161[c]	−0.04570[c]	−0.01640[a]	0.02221[a]	−0.01414[a]	1

a, b and c show significance levels @ 1 %, 5 % and 10 % respectively.
(Source: Authors' computation.)

Table 3
Descriptive statistics.

Descriptive statistics For NMD									
	NMD	INC	EDU	OCC	HEC	HQS	PPG	FPP	IPC
Mean	1.24553	1.38414	1.54667	1.76699	0.68338	1.41723	6.92986	1.94296	0.32097
Median	1.26481	1.38429	1.58076	1.77749	0.67012	1.45946	7.07594	1.97963	0.43171
Maximum	1.83123	1.91482	2.11443	1.93382	1.30991	1.98623	8.33953	2.25847	1.56558
Minimum	0.53147	0.70406	0.17486	1.55389	0.15841	0.49070	5.16512	1.43456	−2.61924
Std. Dev.	0.26462	0.30994	0.31930	0.09384	0.17632	0.29294	0.65517	0.11564	0.51866
Skewness	−0.49330	−0.09690	−0.94836	−0.32988	0.16768	−0.31248	−0.37626	−1.08337	−1.51913
Kurtosis	2.66726	2.09251	4.26614	2.25286	2.94593	2.58653	2.66430	4.25518	7.34987
Jarque-Bera	40.2479	31.9679	193.075	36.8839	4.28404	20.8474	25.2075	232.785	1045.16
Sum	1109.77	1233.27	1378.09	1574.39	608.894	1262.75	6174.50	1731.17	285.989
Sum Sq. Dev.	62.3241	85.4960	90.7407	7.83869	27.6718	76.3757	382.030	11.9026	239.424
Observations	891	891	891	891	891	891	891	891	891

Descriptive statistics For HIV									
	HIV	INC	EDU	OCC	HEC	HQS	PPG	FPP	IPC
Mean	0.36065	1.37963	1.52715	1.76605	0.67536	1.41767	6.89413	1.94023	0.33080
Median	0.27875	1.38310	1.57154	1.77533	0.66728	1.46399	7.01874	1.97651	0.43547
Maximum	1.47421	1.91482	2.11443	1.93382	1.30991	1.98623	8.33953	2.25847	1.74499
Minimum	−1.00000	0.69041	0.17486	1.55389	−0.53264	0.44621	5.15749	1.43456	−2.61924
Std. Dev.	0.57106	0.30562	0.32475	0.09387	0.18819	0.30242	0.65144	0.11961	0.52434
Skewness	−0.18647	−0.08470	−0.83666	−0.30050	−0.23523	−0.36959	−0.28395	−1.04786	−1.40421
Kurtosis	2.92190	2.14531	3.80286	2.18952	4.51939	2.53433	2.58957	4.27148	6.89697
Jarque-Bera	5.97698	31.2529	141.804	41.9109	104.146	31.4202	20.2116	247.359	949.867
Sum	356.324	1363.07	1508.83	1744.86	667.261	1400.66	6811.40	1916.94	326.836
Observations	988	988	988	988	988	988	988	988	988

(Source: Authors' computation.)

and healthier living environments. Employment (0.31650) and healthcare access (0.13246) displayed unexpected or weak positive correlations, suggesting that insecure or low-paying jobs and limited healthcare scope might not adequately address nutritional needs. Food production (−0.16995) and income per capita (0.10880) had weak correlations, indicating the need for equitable distribution and access to resources. Strong positive correlations between income and education (0.69322) and income and housing (0.71885) show their collective role in improving socio-economic conditions and public health. However, the weak associations of population growth and food production with NMD suggest that structural factors like equitable access remain critical for addressing nutritional deficiencies.

For HIV prevalence, income (0.28374), healthcare access (0.16583), and housing quality (0.23282) exhibited moderate positive correlations, possibly reflecting better detection rates and socio-behavioural factors linked to economic activity. Education (0.08757) and food production (−0.06531) had weak correlations, indicating a limited direct impact on HIV outcomes. Employment (−0.04230) and population growth (−0.03367) showed negligible associations, highlighting that employment quality and other socio-economic contexts are more influential in shaping HIV risks. Inter-variable correlations further revealed significant socio-economic linkages. For example, income correlated strongly with education (0.69015) and housing quality (0.62624), reinforcing their interconnected impact on health. The negative correlation between employment and housing quality (−0.54465) indicated disparities in living standards in regions with high but precarious employment.

Table 3 shows the descriptive analysis result. The descriptive analysis shows a mean NMD value of 1.2455, indicating moderate nutritional deficiency across the population. Socioeconomic determinants such as income, education, employment, healthcare, and housing quality exhibit varying mean values, with employment (1.7669) and healthcare (0.6834) representing the extremes. These findings suggest disparities in resource availability that likely contribute to nutritional deficiencies. Standard deviations for key variables, including income (0.3099), education (0.3193), and housing quality (0.29294), reflect variability in socio-economic inequalities in access to resources critical for nutrition. The data suggest that higher income, education, and housing quality variability correlates with unequal resource distribution, exacerbating NMD. Meanwhile, the relatively low variability in healthcare access (0.17632) points to consistency, though its adequacy remains unclear. Population growth (6.9299) and food production (1.9429) reflect demographic and economic trends, highlighting the pressure on resources and the importance of equitable distribution.

The mean HIV prevalence of 0.3607 reflects a moderate level across the studied population, pointing to a significant public health concern. Socioeconomic determinants, including income, education, and housing quality, display notable variability, with housing quality (1.7661) having the highest mean and healthcare access (0.6754) the lowest. Standard deviations indicate moderate spread, with income (0.3056) and education (0.3248) showing considerable variability, suggesting socioeconomic inequalities that may influence HIV vulnerability. Variability in housing quality and sanitation (SD 0.29294) shows the disparities that could exacerbate HIV transmission through poor living conditions. While healthcare access shows lower variability (SD 0.1882), its adequacy in addressing HIV prevention and treatment remains a critical question. The observed demographic pressures from population growth (6.8941) further underline the need for equitable health service distribution.

4.1. Cross-sectional dependence and heterogeneity

In the appendix section, the result of the cross-sectional dependence of HIV and NMD were presented. In the HIV equation, it is revealed that Breusch-Pagan LM have statistic of 763.456 with a probability value of 0.063, indicating marginal dependence. Similarly, the Pesaran Scaled LM test reports a statistic of 15.7448 with a probability value of 0.052, while the Pesaran CD test shows a statistic of 1.70705 with a probability value of 0.082, suggesting weak cross-sectional dependence. Likewise, in the NMD equation, the Breusch-Pagan LM statistic is 521.27, with a probability value of 0.072, while the Pesaran Scaled LM test shows a statistic of 10.9539 with a probability value of 0.045. Furthermore, the Pesaran CD test report a statistic of 1.81806, with a probability value of

Table 4
Panel ARDL mean group result for HIV equation.

Dependent variable: HIV				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
Long-run behaviour				
INC	−0.90451	0.09182	−9.85006	0.0000
EDU	−0.36635	0.07129	−5.13840	0.0000
OCC	−1.43968	0.25136	−5.72758	0.0000
HEC	0.54349	0.08886	6.11568	0.0000
HQS	0.45003	0.07381	6.09676	0.0000
PPG	0.04421	0.02952	1.49727	0.1346
FPP	−0.87999	0.15469	−5.68872	0.0000
IPC	−0.10115	0.03096	−3.26722	0.0011
C	−2.50624	0.56927	−4.40251	0.0000
Short run behaviour				
ECM (−1)	−0.00445	0.00159	−2.79680	0.0053
D(INC)	−0.32351	0.07128	−4.53802	0.0000
D(EDU)	−0.01102	0.00859	−1.28268	0.1999
D(OCC)	−0.04956	0.12346	−0.40143	0.6882
D(HEC)	−0.52467	0.08959	−5.85617	0.0000
D(HQS)	0.06561	0.05555	1.18114	0.2378
D(PPG)	−0.85597	0.09569	−8.94496	0.0000
D(FPP)	−0.00841	0.02149	−0.39145	0.6955
D(IPC)	0.00198	0.00125	1.58025	0.1144
Number of groups			44	
Number of observations			988	

Diagnostic checks		
Test type	Value	Prob.
Heteroskedasticity LR Test	125.032	0.5014
Jarque-Bera Normality Test	34.7805	0.1085

(Source: Authors' computation.)

Table 5
Panel ARDL mean group result for NMD equation.

Dependent variable: NMD				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
Long-run behaviour				
INC	−0.18226	0.04489	−4.05985	0.0001
EDU	−0.06545	0.03429	−1.90856	0.0566
OCC	−0.55899	0.12405	−4.50603	0.0000
HEC	0.21506	0.04511	4.76755	0.0000
HQS	−0.14705	0.04060	−3.62165	0.0003
PPG	0.09776	0.01468	6.65787	0.0000
FPP	0.00098	0.07564	0.01296	0.9897
IPC	0.04545	0.01475	3.07993	0.0021
C	1.33375	0.27084	4.92438	0.0000
Short run behaviour				
ECM (−1)	−0.27773	0.09787	−2.83762	0.0047
D(INC)	−0.28365	0.07627	−3.71874	0.0002
D(EDU)	−0.00388	0.01396	−0.27792	0.7811
D(OCC)	−0.26307	0.19561	−1.34490	0.1790
D(HEC)	−0.02320	0.02007	−1.15641	0.2478
D(HQS)	−0.25698	0.09776	−2.62863	0.0087
D(PPG)	0.15038	0.17190	0.87484	0.3819
D(FPP)	−0.10757	0.03671	−2.92958	0.0035
D(IPC)	−0.00097	0.00210	−0.46226	0.6440
Number of groups			44	
Number of observations			891	

Diagnostic checks		
Test type	Value	Prob.
Heteroskedasticity LR Test	150.524	0.7544
Jarque-Bera Normality Test	76.7826	0.6761

(Source: Authors' computation.)

0.069. Since these results indicate weak cross-sectional dependence, the standard panel ARDL was estimated. However, to further ensure robustness, Driscoll-Kraay standard errors are employed to account for potential heteroskedasticity, autocorrelation, and residual cross-sectional dependence. The results of the heterogeneity and CIPS and CADF unit root tests are presented in Tables A7 and A8 in the appendix section.

Other preliminary results are presented in the appendix section; Tables A1, A2, A3, and A3 show mix integration, that is, stationarity at level I (0) and integrated of order one I (1). Tables A5 and A6 present the Kao Residual Cointegration and Johansen Fisher Panel Cointegration test, confirming cointegration. The outcome of the preliminary analysis motivates this study to use Panel ARDL.

The long-run analysis in Table 4 reveals the significant role of socio-economic factors in influencing HIV prevalence. Income (−0.90451), education (−0.36635), and employment (−1.43968) show strong negative relationships with HIV prevalence, emphasising the protective effects of socio-economic stability. Increased income enables access to healthcare, education, and preventive resources, reducing susceptibility to HIV. Masiano et al. (2023) corroborated those economic interventions like cash transfers effectively lower HIV transmission rates. Similarly, education improves awareness and safer health behaviours, aligning with studies like Zuma et al. (2022), which emphasise the role of gender-sensitive education in HIV prevention. Employment stability reduces economic vulnerability, which often drives risky behaviours linked to HIV, as highlighted by Bärnighausen et al. (2007), who documented higher HIV prevalence in lower-income groups due to such factors.

Conversely, healthcare access (0.54349) and housing quality (0.45003) are positively associated with HIV prevalence in the long run. This reflects the dual role of improved healthcare in increasing detection rates and the potential urbanization-linked risks tied to better housing conditions. These findings align with Kranzer et al. (2010), who noted that healthcare expansion in rural Malawi revealed higher HIV mortality due to previously undetected cases. Similarly, urbanization can elevate HIV transmission risks due to increased population density and mobility, requiring targeted urban health interventions.

In the short run, income (−0.32351) and healthcare access (−0.52467) demonstrate immediate protective effects on HIV prevalence, underlining the importance of economic stability and timely healthcare interventions. These findings are consistent with Murewanhema et al. (2022), who emphasised the immediate benefits of economic and healthcare improvements in reducing HIV risks. However, variables such as education, employment, and housing quality show no significant short-term effects, suggesting their impact requires sustained investment and time. The Error Correction Model (ECM) coefficient of −0.00445 indicates a slow adjustment to equilibrium, reflecting the persistence of HIV-related challenges. Diagnostic tests confirm the model's reliability, with no evidence of heteroskedasticity or non-normal residuals.

4.1.1. Implications for public health policy

The findings emphasise the need for multi-sectoral strategies to combat HIV effectively. Long-term investments in poverty reduction, education, and job creation are crucial to reducing HIV prevalence, as stable socio-economic conditions promote health literacy and access to preventive resources. Expanding healthcare services to integrate HIV education, testing, and treatment is essential, especially in urban and high-density areas, where transmission risks are elevated due to mobility and lifestyle factors. Urban planning should incorporate public health considerations to mitigate these risks. Short-term interventions, such as economic support programs and rapid healthcare expansion, can yield immediate benefits in reducing HIV prevalence.

The result of the Panel ARDL of NMD is presented in the Table 5. The long-run analysis reveals that socio-economic factors such as income (−0.18226), education (−0.06545), employment (−0.55899), and housing quality and sanitation (−0.14705) have significant negative

Table 6
Causality test result.

Null hypothesis:	Obs	F-statistic	Prob.	Decision
INC does not Granger Cause HIV	966	3.51995	0.0300	Unidirectional Relationship from INC to HIV
HIV does not Granger Cause INC		1.31289	0.2695	
EDU does not Granger Cause HIV	945	2.43691	0.0880	No causality
HIV does not Granger Cause EDU		0.14464	0.8653	
OCC does not Granger Cause HIV	966	3.16519	0.0426	Unidirectional Relationship from OCC to HIV
HIV does not Granger Cause OCC		0.00883	0.9912	
HEC does not Granger Cause HIV	934	1.71904	0.1798	No causality
HIV does not Granger Cause HEC		2.06253	0.1277	
HQS does not Granger Cause HIV	947	7.92492	0.0004	Unidirectional Relationship from HQS to HIV
HIV does not Granger Cause HQS		0.90196	0.4061	
NMD does not Granger Cause HIV	829	0.88341	0.4138	No causality
HIV does not Granger Cause NMD		1.69561	0.1841	
NMD does not Granger Cause INC	849	2.72457	0.0662	Unidirectional Relationship from NMD to INC
INC does not Granger Cause NMD		0.75628	0.4697	
NMD does not Granger Cause EDU	849	2.86129	0.0577	Unidirectional Relationship from NMD to EDU
EDU does not Granger Cause NMD		1.57834	0.2069	
NMD does not Granger Cause OCC	849	3.43746	0.0326	Unidirectional Relationship from NMD to OCC
OCC does not Granger Cause NMD		0.69684	0.4984	
NMD does not Granger Cause HEC	849	0.21892	0.8034	Unidirectional Relationship from HEC to NMD
HEC does not Granger Cause NMD		2.46884	0.0853	
NMD does not Granger Cause HQS	867	2.39725	0.0916	Unidirectional Relationship from NMD to EDU
HQS does not Granger Cause NMD		1.15556	0.3154	

(Source: Authors' computation.)

effects on NMD, emphasising their protective roles in reducing nutritional deficiencies over time. Increased income enables access to nutritious food and healthcare, echoing findings by Seenivasan et al. (2023), who demonstrated that higher GDP per capita correlates with reduced malnutrition. Housing and sanitation improvements mitigate exposure to foodborne illnesses, supporting findings by Cairncross et al. (2010) that poor sanitation contributes to malnutrition through increased disease risk.

Conversely, healthcare access (0.21506) shows a positive relationship with NMD, suggesting that healthcare systems may focus more on treatment than prevention in areas with high nutritional deficiencies. This aligns with Cairncross et al. (2010) observation that interventions addressing underlying causes, such as environmental risks, are critical to reducing long-term deficiencies. Population growth (0.09776) also exhibits a positive long-run relationship with NMD, indicating that demographic pressures may strain resources and exacerbate nutritional deficiencies without adequate investment in resource allocation. While essential for overall food availability, food production is insignificant in influencing long-term NMD, showing the importance of equitable distribution and access over mere production levels. This finding shows the need for infrastructural and policy support to ensure that increased food production translates to improved nutrition.

In the short run, income (−0.28365) and housing quality and sanitation (−0.25698) emerge as key factors reducing NMD. Immediate income improvements enable households to access nutrient-dense foods, while better housing and sanitation lower exposure to health risks, supporting findings by Sheldon and Kaminaga (2023). Food production (−0.10759) also shows a short-term effect, reflecting the immediate benefits of food availability on nutrition. However, variables such as education, employment, and healthcare access do not show significant short-term effects, suggesting their influence requires sustained efforts and longer time horizons. The Error Correction Model (ECM) coefficient (−0.2773) confirms a stable adjustment towards equilibrium, with approximately 27.73 % of deviations corrected each period. Diagnostic tests confirm the model's reliability, with no significant heteroskedasticity and normally distributed residuals.

4.1.2. *Implications for public health policy*

The findings emphasise integrating socio-economic strategies with public health interventions to address nutritional deficiencies in Sub-Saharan Africa. Long-term investments in poverty reduction, education, stable employment, and infrastructure improvement are critical for developing sustainable nutrition security. Policies must also prioritise healthcare systems that balance treatment with proactive nutritional interventions, such as community-level education and preventive healthcare services. Short-term measures, such as cash transfers and investments in housing and sanitation, can provide immediate relief from nutritional risks. These interventions reduce exposure to environmental health hazards and enable better access to food, addressing the urgent needs of vulnerable populations.

Table 6 presents the causality result. The causality analysis reveals unidirectional relationships among social determinants of health (SDH), nutritional deficiency (NMD), and HIV prevalence. A notable finding is the direct influence of income (INC), education (EDU), employment (OCC), and house quality and sanitation (HQS) on HIV prevalence. These determinants show the structural barriers influencing vulnerability to HIV, such as limited access to healthcare, lack of health literacy, and exposure to unsafe living conditions; these findings aligned with previous studies that have stressed their importance in reducing HIV (Abdulai et al., 2024; Perazzo et al., 2024). Income inequality, unemployment, and poor educational attainment are particularly significant in perpetuating risk behaviours and reducing healthcare engagement, thereby fuelling HIV prevalence. The study also shows the reciprocal influence of nutritional deficiency on social determinants. NMD drives economic exclusion by diminishing income (INC) and reducing employability (OCC) and education (EDU) due to poor physical and cognitive health, which affects educational standards. It also impacts housing quality and sanitation (HQS), perpetuating cycles of poverty. Additionally, the relationship between healthcare facilities (HEC) and NMD suggests that insufficient healthcare infrastructure exacerbates nutritional challenges, particularly in resource-limited environments. Interestingly, no direct causality exists between NMD and HIV; this finding implies that while both are significant health issues, their relationship operates indirectly through shared determinants such as income and healthcare access; this implicates the necessity of addressing these health challenges through multisectoral strategies. Studies have shown that food-insecure households are more likely to engage in risky behaviours, increasing their risk of HIV infection (Beyene, 2023; Khatri et al., 2023; Kimeng, 2024; Oklikah et al., 2024; Okoye, 2024).

4.1.3. *Implication of result*

The findings emphasise the need for integrated public health policies

Table 7
HIV variance decomposition.

Variance decomposition of SD1:

Period	S.E.	PPG	FPP	IPC	INC	EDU	OCC	HEC	HQS	HIV
1	0.01352	0.01349	0.18213	0.17335	99.63102	0.00000	0.00000	0.00000	0.00000	0.00000
5	0.05251	0.02932	0.01623	1.04684	97.45757	0.01967	0.46150	0.38147	0.01289	0.57447
10	0.08311	0.05926	0.00657	2.46614	94.79598	0.02201	0.49685	0.53663	0.00961	1.60691

Variance decomposition of SD2:

Period	S.E.	PPG	FPP	IPC	INC	EDU	OCC	HEC	HQS	HIV
1	0.08538	0.00322	0.07272	0.00213	0.02364	99.89826	0.00000	0.00000	0.00000	0.00000
5	0.15805	0.06250	0.07782	3.04601	0.15005	96.10026	0.12248	0.33781	0.00254	0.10048
10	0.22127	0.05635	0.06588	5.81767	0.21238	93.09992	0.12206	0.41213	0.00285	0.21072

Variance decomposition of SD3:

Period	S.E.	PPG	FPP	IPC	INC	EDU	OCC	HEC	HQS	HIV
1	0.00663	9.43E-05	0.24934	0.01053	0.08766	4.26E-05	99.65231	0.00000	0.00000	0.00000
5	0.01466	0.11935	0.06438	0.69185	0.60481	0.00395	98.01893	0.06776	0.41492	0.01402
10	0.02096	0.18645	0.04019	1.96129	1.15868	0.00355	95.49505	0.03877	1.10666	0.00932

Variance decomposition of SD4:

Period	S.E.	PPG	FPP	IPC	INC	EDU	OCC	HEC	HQS	HIV
1	0.06520	0.23561	0.01178	0.07530	0.44195	0.09418	0.25849	98.88261	0.00000	0.00000
5	0.14154	0.08836	0.03667	0.47258	1.05688	0.55687	0.06813	97.57268	0.13920	0.00859
10	0.19721	0.23523	0.01996	0.69257	1.26558	0.66399	0.03559	96.95332	0.10875	0.02496

Variance decomposition of SD5:

Period	S.E.	PPG	FPP	IPC	INC	EDU	OCC	HEC	HQS	HIV
1	0.00414	0.03940	0.12115	0.41225	0.00366	0.00244	0.00409	0.00071	99.41628	0.00000
5	0.02613	0.02932	0.04189	0.77627	0.00849	0.00320	0.15769	0.52908	98.26278	0.19124
10	0.05869	0.14924	0.00936	1.44111	0.05979	0.00365	0.23030	0.83892	96.84901	0.41859

(Source: Authors' computation.)

targeting social determinants of health to combat both nutritional deficiencies and HIV prevalence. Income inequality can be addressed through economic empowerment programs, such as income supplementation and job creation, reducing vulnerability to both conditions. Economic stability enables better access to healthcare and improved living conditions, directly mitigating health risks. Education emerges as a vital lever for change. Health literacy programs focusing on sexual health and nutritional awareness can empower individuals to adopt preventive measures against HIV and address malnutrition. Investing in education, particularly for marginalised communities, is critical to breaking cycles of health inequities. Healthcare infrastructure requires urgent strengthening, particularly in underserved regions where limited access to healthcare exacerbates malnutrition and indirectly fuels health vulnerabilities. Expanding healthcare facilities and improving their quality can provide better management of NMD and support HIV prevention strategies. Improving housing quality and sanitation can have profound health benefits. Poor living conditions worsen environmental stressors linked to malnutrition and HIV vulnerability. Integrated programs that combine housing improvement with health services can simultaneously address structural inequities and health challenges.

Table 7 presents HIV variance decomposition. In the HIV equation, the variance decomposition results reveal that housing quality and sanitation have the most substantial impact on HIV prevalence by the 10-period horizon. Krieger and Higgins (2002) stated that housing quality and sanitation are critical determinants, particularly in low-income environments. Followed sequentially by other SDH indicators as follows: income, education, healthcare access, and employment. The leading influence of housing quality and sanitation suggests that improving living conditions and sanitation significantly reduce HIV risk. This relationship may be due to the critical role that sanitation and housing quality play in mitigating health risks in high-density, urban areas where HIV transmission rates are often elevated. Furthermore, the role of income and education as the next most influential determinants shows the importance of economic stability and health literacy in HIV prevention. Income enables individuals to access healthcare and preventive resources, while education promotes health literacy, encouraging behaviours that reduce HIV risk. These results imply that public health interventions should prioritise housing improvements, poverty reduction, and educational advancement to achieve meaningful reductions in HIV prevalence over the long term. The impulse response function for the HIV equation is presented at the appendix section in Fig. A1.

4.1.4. *Implications for public health policy and practice*

The findings provide clear implications for public health policy and planning in Sub-Saharan Africa. The long-term influence of housing quality and sanitation on HIV prevalence suggests that public health strategies should prioritise infrastructure development and housing quality improvements to reduce transmission risks in densely populated or high-risk areas. Policies targeting safe and sanitary living environments could significantly reduce HIV exposure by addressing the environmental conditions that exacerbate transmission rates. Additionally, the importance of income and education on HIV suggests that policies aimed at economic empowerment and educational opportunities can

Table 8
NMD variance decomposition.

Variance decomposition of SD1:										
Period	S.E.	PPG	FPP	IPC	INC	EDU	OCC	HEC	HQS	NMD
1	0.01357	0.07328	0.38478	0.09474	99.44718	0.00000	0.00000	0.00000	0.00000	0.00000
5	0.05007	0.03278	0.13311	0.59405	96.68239	0.08689	0.78886	0.57091	0.00439	1.10658
10	0.07792	0.29830	0.11230	1.57335	94.53677	0.13860	1.00806	0.89274	0.04618	1.39366

Variance decomposition of SD2:										
Period	S.E.	PPG	FPP	IPC	INC	EDU	OCC	HEC	HQS	NMD
1	0.08874	0.18787	0.12916	0.09899	0.02781	99.55615	0.00000	0.00000	0.00000	0.00000
5	0.16143	0.06909	0.12522	1.22815	0.19310	97.05471	0.07702	0.68632	0.03028	0.53608
10	0.22398	0.14776	0.10809	1.94104	0.26440	95.77121	0.09584	0.93339	0.10836	0.62987

Variance decomposition of SD3:										
Period	S.E.	PPG	FPP	IPC	INC	EDU	OCC	HEC	HQS	NMD
1	0.00675	0.04442	0.31402	0.02438	0.04990	5.00E-05	99.56721	0.00000	0.00000	0.00000
5	0.01490	0.15195	0.07307	0.47860	0.50053	0.00584	98.02273	0.06213	0.51036	0.19476
10	0.02118	0.23528	0.04187	1.20013	0.92753	0.00832	95.98341	0.03139	1.40467	0.16736

Variance decomposition of SD4:										
Period	S.E.	PPG	FPP	IPC	INC	EDU	OCC	HEC	HQS	NMD
1	0.06257	0.40313	0.00038	0.01237	0.28401	0.06087	0.22643	99.01279	0.00000	0.00000
5	0.13625	0.18442	0.06514	0.02048	0.86144	0.42280	0.06127	98.33438	0.03813	0.01190
10	0.18976	0.40970	0.03674	0.01258	0.88769	0.51427	0.03425	98.00590	0.07972	0.01911

Variance decomposition of SD5:										
Period	S.E.	PPG	FPP	IPC	INC	EDU	OCC	HEC	HQS	NMD
1	0.00415	0.03239	0.16633	0.38184	0.07004	0.01550	0.00104	0.02801	99.30482	0.00000
5	0.02626	0.19196	0.09133	0.35685	0.03824	0.03038	0.19375	0.62927	98.46777	0.00042
10	0.05975	0.71117	0.02822	0.55615	0.06215	0.03497	0.34637	0.97907	97.26717	0.01469

(Source: Authors' computation.)

create sustained health benefits by enhancing access to preventive resources and promoting health literacy.

Table 8 presents the variance decomposition for nutritional deficiency. For nutritional deficiencies, SDH indicators such as income emerge as the most influential determinant by the 10-period horizon, followed by other SDH indicators such as education, employment, healthcare, and housing quality. Income's leading role in affecting nutritional outcomes reflects the importance of financial resources in accessing nutritious food, healthcare, and essential living conditions that support healthy growth and development. Seenivasan et al. (2023) reported that income reduced malnutrition rates. The influence of education as the second most significant factor suggests that health literacy and nutrition knowledge are essential for preventing malnutrition. Employment's contribution further emphasises the importance of stable income sources in reducing nutritional deficiencies, as secure employment provides the financial means for households to access and maintain a healthy diet. The sequential influence of healthcare and housing highlights the importance of supporting services and safe living conditions in preventing malnutrition, particularly in high-risk and low-income populations. The impulse response function for the NMD equation is presented at the appendix section in Fig. A2.

4.1.5. Implications for public health policy and practice

The findings on nutritional deficiencies highlight the importance of economic stability and educational advancement as foundational strategies for reducing malnutrition. Income is shown to be crucial for securing access to nutrient-rich food and healthcare, suggesting that poverty reduction and economic support programs are essential components of nutrition-focused public health strategies. Given the impact of education, incorporating nutrition education into school curricula and community health programs can help to improve health literacy and dietary practices, particularly in vulnerable populations.

4.2. Robustness checks

The robustness check using Driscoll-Kraay standard error supports the validity of the ARDL findings while showing some variations in significance for specific variables. The result is presented in Table A9 in the appendix section. For both the HIV and NMD equations, the long-run relationships result with income, education, healthcare, and population growth remain consistent across models, except education in the NMD equation, which was negative but insignificant. Minor discrepancies in the significance of population growth in the HIV equation. Likewise, population growth and food production are not the same in the NMD equation. The outcome of the changes suggests these variables may be more context-dependent, depending on the estimation technique. This robustness analysis confirms that the primary predictors in the ARDL model are reliable, underlining the importance of income stability, education, healthcare access, and other control variables used in influencing HIV and NMD.

The findings derived in this study align with Sustainable Development Goals (SDGs), emphasising the need for integrated policies to improve health in Sub-Saharan Africa. Improve attempts to reduce HIV prevalence and nutritional deficiencies support SDG 3 (Good Health and

Well-being) through better healthcare systems and education programs. Socioeconomic measures like income support and education contribute to SDG 1 (No Poverty) and SDG 10 (Reduced Inequalities), while investments in sanitation and housing align with SDG 6 (Clean Water and Sanitation) and SDG 11 (Sustainable Cities and Communities). Likewise, improving food security through better agricultural policies supports SDG 2 (Zero Hunger), strengthening the connection of social, economic, and health policies for sustainable development.

5. Conclusion and policy recommendations

Sub-Saharan Africa faces dual public health crises of HIV and nutritional deficiencies, driven by profound socio-economic disparities. Socio-economic determinants—poverty, education, employment, and healthcare access—play critical roles in influencing health, disproportionately affecting disadvantaged populations and worsening vulnerability to HIV and malnutrition. The region bears the highest global burden of HIV/AIDS, as reported by UNAIDS, alongside pervasive nutritional deficiencies, with over 50 % of children under five and many pregnant women affected, according to WHO. Existing research often focuses on localised studies, leaving gaps in understanding macro-level, longitudinal patterns and causal dynamics. This study employs econometric models to explore the influence of social determinants on HIV prevalence and nutritional deficiencies across Sub-Saharan Africa. Using Panel ARDL for dynamic analysis, Panel Granger causality for directional pathways, and VECM for temporal variations. The Driscoll-Kraay standard error is carried out as robustness check, which confirm the result to a large extent.

The findings emphasise the role of socioeconomic stability in addressing HIV prevalence and nutritional deficiencies in Sub-Saharan Africa. Policies must prioritise income support programs, educational access, and skill development initiatives targeting vulnerable populations. Strengthening healthcare systems is vital to integrate HIV prevention through routine screenings, education, and culturally sensitive counselling services. Investments in housing quality and sanitation infrastructure, coupled with community-driven initiatives, can reduce environmental health risks. Nutritional support programs, improved food access, and agriculture-focused policies are essential to combat malnutrition and enhance food security.

This study advances the understanding of how social determinants influence health through dynamic econometric models. Identifying the long-term and causal impacts of income, education, employment, housing, and healthcare on HIV and nutritional deficiencies provides evidence-based insights for public health policy. Integrating panel ARDL and Granger causality models offers a methodological innovation, enabling a deeper exploration of bidirectional and unidirectional relationships. This research bridges socio-economic theory with applied public health, contributing to a comprehensive framework for tackling systemic health disparities in Sub-Saharan Africa. The study acknowledges several limitations. Data on social exclusion, an important determinant of health, was unavailable, restricting its inclusion in the analysis. The focus on HIV prevalence rather than incidence limits insights into new infections and disease progression. Additionally, the lack of gender-disaggregated analysis overlooks critical of how social determinants impact men and women differently.

Future research should incorporate social exclusion indicators to understand marginalised populations' health better. Investigating HIV incidence and disease progression alongside prevalence can provide more insights. More so, gender-specific analyses are necessary to address unique vulnerabilities. Likewise, while this study provides insights into the relationships among social determinants of health, HIV prevalence, and nutritional deficiencies, potential omitted variable bias remains a limitation. Future research could incorporate government health policies, cultural influences, healthcare accessibility, and environmental conditions.

CRediT authorship contribution statement

Mzolisi Abednigo Payi: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Dominic Abaver:** Writing – review & editing, Supervision, Project administration, Funding acquisition, Conceptualization. **Teke Apalata:** Writing – review & editing, Supervision, Project administration, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare no competing interests related to this article's conceptualisation, methodology, analysis, or findings. No financial, professional, or personal relationships with other individuals or organisations have influenced the development or interpretation of this work.

Furthermore, the research and writing of this article were conducted independently and without any sponsorship or funding from external entities that could result in a potential conflict of interest.

Appendix A. Appendices

Level unit root results

Table A1
Level unit root results (with individual intercept).

Individual intercept					
Series	LLC	IPS	ADF	PP	Decision
HIV	−5.15519	2.75083	221.519	175.716	I (0)
Prob	0.0000	0.9970	0.0000	0.0000	
NMD	0.92086	4.23976	62.5916	62.5094	NS
Prob	0.8214	1.0000	0.9816	0.9819	
INC	−8.11550	2.24706	132.053	106.067	Mixture
Prob	0.0000	0.9877	0.0059	0.1859	
EDU	−6.50124	−1.05616	114.607	141.503	Mixture
Prob	0.0000	0.1454	0.0411	0.0004	
OCC	−1.61707	2.26727	71.0076	73.3983	Mixture

(*continued on next page*)

Table A1 (*continued*)

Individual intercept					
Series	LLC	IPS	ADF	PP	Decision
Prob	0.0529	0.9883	0.9631	0.9429	
HEC	−3.34376	−0.91254	130.535	130.529	Mixture
Prob	0.0004	0.1807	0.0076	0.0076	
HQS	−143.054	−117.333	3734.43	2813.06	I (0)
Prob	0.0000	0.0000	0.0000	0.0000	
PPG	−16.0167	−4.46962	668.876	322.966	I (0)
Prob	0.0000	0.0000	0.0000	0.0000	
FPP	−4.05837	0.45636	96.7670	122.445	Mixture
Prob	0.0000	0.6759	0.4589	0.0356	
IPC	−18.4285	−17.8363	478.813	493.242	I (0)
Prob	0.0000	0.0000	0.0000	0.0000	

(Source: Authors' computation.)

Table A2
Level unit root results (individual intercept and trend).

Individual intercept and trend					
Series	LLC	IPS	ADF	PP	Decision
HIV	−8.23224	−5.18597	220.899	292.985	I (0)
Prob	0.0000	0.0000	0.0000	0.0000	
NMD	2.85664	6.40479	25.2528	32.9475	NS
Prob	0.9979	1.0000	1.0000	1.0000	
INC	2.34937	7.60597	58.5484	57.0757	NS
Prob	0.9906	1.0000	0.9985	0.9991	
EDU	0.01208	1.01512	120.195	135.536	Mixture
Prob	0.5048	0.8450	0.0184	0.0014	
OCC	0.36902	1.28894	87.0938	86.6013	NS
Prob	0.6439	0.9013	0.6800	0.6934	
HEC	−2.72120	−0.48332	129.721	130.735	Mixture
Prob	0.0033	0.3144	0.0086	0.0073	
HQS	−31.3792	−14.2468	1302.10	1606.48	I (0)
Prob	0.0000	0.0000	0.0000	0.0000	
PPG	4.68173	11.7184	132.531	115.645	Mixture
Prob	1.0000	1.0000	0.0080	0.0840	
FPP	−5.44128	−4.57352	187.573	189.253	I (0)
Prob	0.0000	0.0000	0.0000	0.0000	
IPC	−17.9465	−15.5505	414.895	750.728	I (0)
Prob	0.0000	0.0000	0.0000	0.0000	

(Source: Authors' computation.)

First difference unit root results

Table A3
Level unit root results (with individual intercept).

Individual intercept					
Series	LLC	IPS	ADF	PP	Decision
D(HIV)	−15.8339	−23.3882	636.408	1219.29	I (1)
Prob	0.0000	0.0000	0.0000	0.0000	
D(NMD)	−0.87524	−4.65968	144.712	153.360	I (1)
Prob	0.1907	0.0000	0.0001	0.0000	
D(INC)	−8.33390	−10.1212	283.644	299.441	I (1)
Prob	0.0000	0.0000	0.0000	0.0000	
D(EDU)	−26.5884	−25.8993	682.413	980.323	I (1)
Prob	0.0000	0.0000	0.0000	0.0000	
D(OCC)	−10.2374	−12.4399	345.479	315.197	I (1)
Prob	0.0000	0.0000	0.0000	0.0000	
D(HEC)	−27.6523	−25.6182	690.754	846.661	I (1)
Prob	0.0000	0.0000	0.0000	0.0000	
D(HQS)	−23.0416	−15.8209	728.824	789.883	I (1)
Prob	0.0000	0.0000	0.0000	0.0000	
D(PPG)	−8.25529	−9.15456	265.237	287.644	I (1)
Prob	0.0000	0.0000	0.0000	0.0000	
D(FPP)	−35.2240	−32.7566	900.713	1404.72	I (1)
Prob	0.0000	0.0000	0.0000	0.0000	
D(IPC)	−44.2523	−41.8160	1163.43	3824.13	I (1)
Prob	0.0000	0.0000	0.0000	0.0000	

(Source: Authors' computation.)

Table A4
Level unit root results (individual intercept and trend).

Individual intercept and trend					
Series	LLC	IPS	ADF	PP	Decision
D(HIV)	−20.1571	−24.1354	605.513	1543.73	I (1)
Prob	0.0000	0.0000	0.0000	0.0000	
D(NMD)	2.80922	−6.13522	193.2573	293.0186	I (1)
Prob	0.0000	0.0000	0.0000	0.0000	
D(INC)	−8.81931	−8.65765	245.299	263.389	I (1)
Prob	0.0000	0.0000	0.0000	0.0000	
D(EDU)	−26.1963	−25.0876	597.650	1798.69	I (1)
Prob	0.0000	0.0000	0.0000	0.0000	
D(OCC)	−7.13763	−7.62705	247.362	224.521	I (1)
Prob	0.0000	0.0000	0.0000	0.0000	
D(HEC)	−25.7697	−23.3215	573.383	1081.84	I (1)
Prob	0.0000	0.0000	0.0000	0.0000	
D(HQS)	−21.0830	−27.6365	1033.12	1025.57	I (1)
Prob	0.0000	0.0000	0.0000	0.0000	
D(PPG)	−7.98614	−6.27637	196.167	246.699	I (1)
Prob	0.0000	0.0000	0.0000	0.0000	
D(FPP)	−31.8669	−30.1090	741.121	1784.37	I (1)
Prob	0.0000	0.0000	0.0000	0.0000	
D(IPC)	−39.2070	−34.9221	938.782	4949.36	I (1)
Prob	0.0000	0.0000	0.0000	0.0000	

(Source: Authors' computation.)

Table A5
Kao Residual Cointegration test.

HIV equation		
Series: HIV INC EDU OCC HEC HQS PPG FPP IPC		
	t-Statistic	Prob.
ADF	−3.188622	0.0007

NMD equation		
Series: NMD INC EDU OCC HEC HQS PPG FPP IPC		
	t-Statistic	Prob.
ADF	−2.097003	0.0180

(Source: Authors' computation.)

Table A6
Johansen Fisher Panel Cointegration test.

Unrestricted cointegration rank test (trace and maximum eigenvalue)				
Hypothesised No. of CE(s)	Fisher Stat. (From trace test)	Prob.	Fisher Stat. (From max-eigen test)	Prob.
HIV equation				
None	52.68	0.9809	52.68	0.9809
At most 1	52.68	0.9809	52.68	0.9809
At most 2	52.68	0.9809	52.68	0.9809
At most 3	36.04	1.0000	257.1	0.0000
At most 4	8.318	1.0000	597.8	0.0000
At most 5	110.5	0.0060	700.0	0.0000
At most 6	10,009	0.0000	10,009	0.0000
At most 7	1082.	0.0000	755.6	0.0000
At most 8	548.2	0.0000	548.2	0.0000
NMD equation				
None	2952.	0.0000	981.1	0.0000
At most 1	3244.	0.0000	1325.	0.0000
At most 2	1518.	0.0000	745.9	0.0000
At most 3	955.6	0.0000	407.6	0.0000
At most 4	615.1	0.0000	257.5	0.0000
At most 5	419.7	0.0000	186.8	0.0000
At most 6	304.9	0.0000	160.1	0.0000
At most 7	237.3	0.0000	163.8	0.0000
At most 8	196.7	0.0000	196.7	0.0000
Trend assumption: No deterministic trend				

(Source: Authors' computation.)

Table A7
Cross-sectional dependence unit root test.

Method		CIPS		CADF	
Series		CO	C & T	CO	C & T
PPG	Stat	−2.08275	−2.89200	−1.52476	−7.40674
	Prob.	<0.10	>0.10	>0.10	<0.01
D(PPG)	Stat	−1.88655	−2.30125	−4.62304	−2.66545
	Prob.	<0.01	<0.05	<0.01	<0.05
FPP	Stat	−2.69024	−2.93285	−2.83994	−3.1160
	Prob.	<0.01	<0.01	>0.10	>0.10
D(FPP)	Stat	−4.40024	−4.30097	−4.92245	−4.79349
	Prob.	<0.01	<0.01	<0.01	<0.05
INC	Stat	−2.61444	−2.26432	−1.87473	−2.07987
	Prob.	<0.01	>0.10	>0.10	>0.10
D(INC)	Stat	−2.58640	−3.09627	−1.98226	−6.35798
	Prob.	<0.01	<0.01	<0.10	<0.01
EDU	Stat	−2.13828	−2.50046	−1.84121	−1.89602
	Prob.	<0.05	>0.10	>0.10	>0.10
D(EDU)	Stat	−3.69972	−4.00385	−3.45099	−3.32305
	Prob.	<0.01	<0.01	<0.05	<0.05
OCC	Stat	−2.09473	−2.30770	−1.78129	−1.46953
	Prob.	<0.10	>0.10	>0.10	>0.10
D(OCC)	Stat	−2.84208	−3.15975	−3.96333	−3.98954
	Prob.	<0.01	<0.01	<0.05	<0.05
HEC	Stat	−0.83340	−1.60693	−4.05037	−6.61431
	Prob.	>0.10	>0.10	<0.05	<0.05
D(HEC)	Stat	−2.85774	−14.15656	−12.25969	−14.47842
	Prob.	<0.01	<0.01	<0.01	<0.01
HQS	Stat	1.92424	0.76801	−2.02820	1.0561
	Prob.	>0.10	>0.10	>0.10	>0.10
D(HQS)	Stat	−3.96855	−2.32721	−6.88245	−8.20501
	Prob.	<0.01	<0.01	<0.01	<0.05
HIV	Stat	1.58652	1.90891	−2.19963	−1.27457
	Prob.	>0.10	<0.05	>0.10	<0.01
D(HIV)	Stat	−3.47232	−2.07416	−2.94661	−3.02781
	Prob.	<0.01	<0.01	<0.01	<0.01
NMD	Stat	−1.40630	−1.23071	−1.17320	−1.19871
	Prob.	<0.10	<0.10	<0.10	>0.10
D(NMD)	Stat	−3.21084	−4.03299	−4.69549	−8.0028
	Prob.	<0.01	<0.01	<0.01	<0.01
Note: CO means constant only, and C & T means constant and trend.					

(Source: Authors' computation.)

Table A8
Cross-sectional dependence and heterogeneity result.

Cross-sectional dependence (CD) result

HIV Equation: CD Test			NMD Equation: CD Test		
Method	Statistics	Prob.	Method	Statistics	Prob.
Breusch-Pagan LM	763.456	0.063	Breusch-Pagan LM	521.27	0.072
Pesaran scaled LM	15.7448	0.052	Pesaran scaled LM	10.9539	0.045
Pesaran CD	1.70705	0.082	Pesaran CD	1.81806	0.069

Heterogeneity test result

Test	HIV equation	NMD equation
Swamy's Slope Homogeneity Test	Chi-square	Chi-square
	7.8891	6.9205
	Prob.	Prob.
	0.007	0.0074

(Source: Authors' computation.)

Robustness checks

Table A9
Driscoll – Kraay standard errors regression results.

Variable	Coefficient	Dri. Kraay Std. Error	t-Statistic	Prob.
Dependent variable: HIV				
INC	−0.799933	0.087062	−9.188113	0.0000
EDU	−0.335049	0.073029	−4.5879	0.0000
OCC	−0.444513	0.158018	−2.813049	0.0049
HEC	0.537395	0.09178	5.855222	0.0000
HQS	0.336762	0.075619	4.45341	0.0000
PPG	−0.036518	0.03051	−1.196889	0.2313
FPP	−1.086031	0.136653	−7.947366	0.0000
IPC	−0.085385	0.032007	−2.667665	0.0076
R-squared	0.7801	Root MSE		0.3560
Dependent variable: NMD				
INC	−0.141988	0.042681	−3.326705	0.0009
EDU	−0.053775	0.035291	−1.523769	0.1276
OCC	−1.047671	0.081344	−12.87947	0.0000
HEC	0.229395	0.046392	4.944672	0.0000
HQS	−0.091201	0.041812	−2.181212	0.0292
PPG	−0.099473	0.015173	−6.555709	0.0000
FPP	−0.169336	0.067995	−2.490435	0.0128
IPC	0.04306	0.015241	2.825221	0.0047
R-square	0.6094	Root MSE		0.1070

(Source: Authors' computation.)

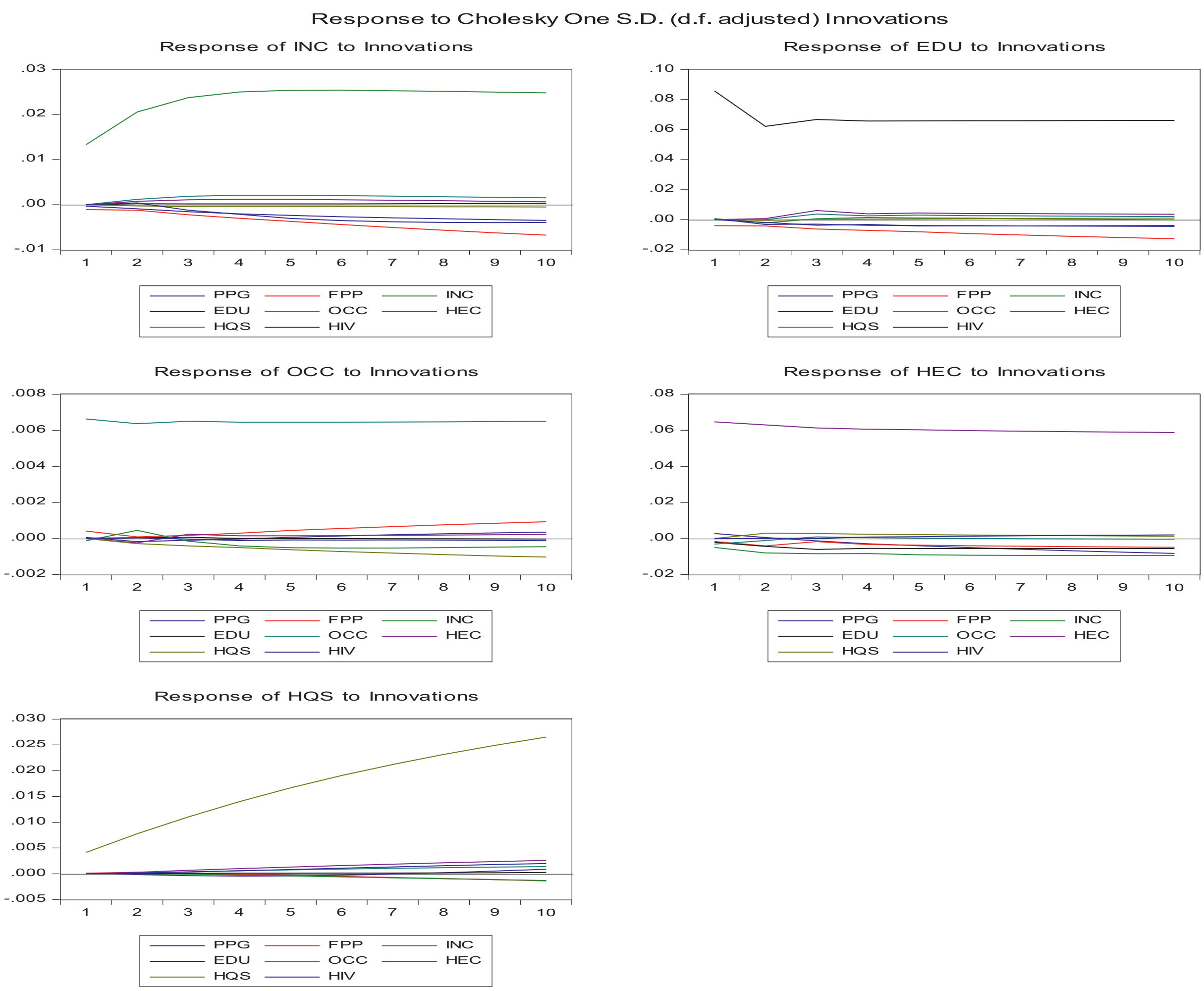

Fig. A1. Impulse response function for HIV equation.

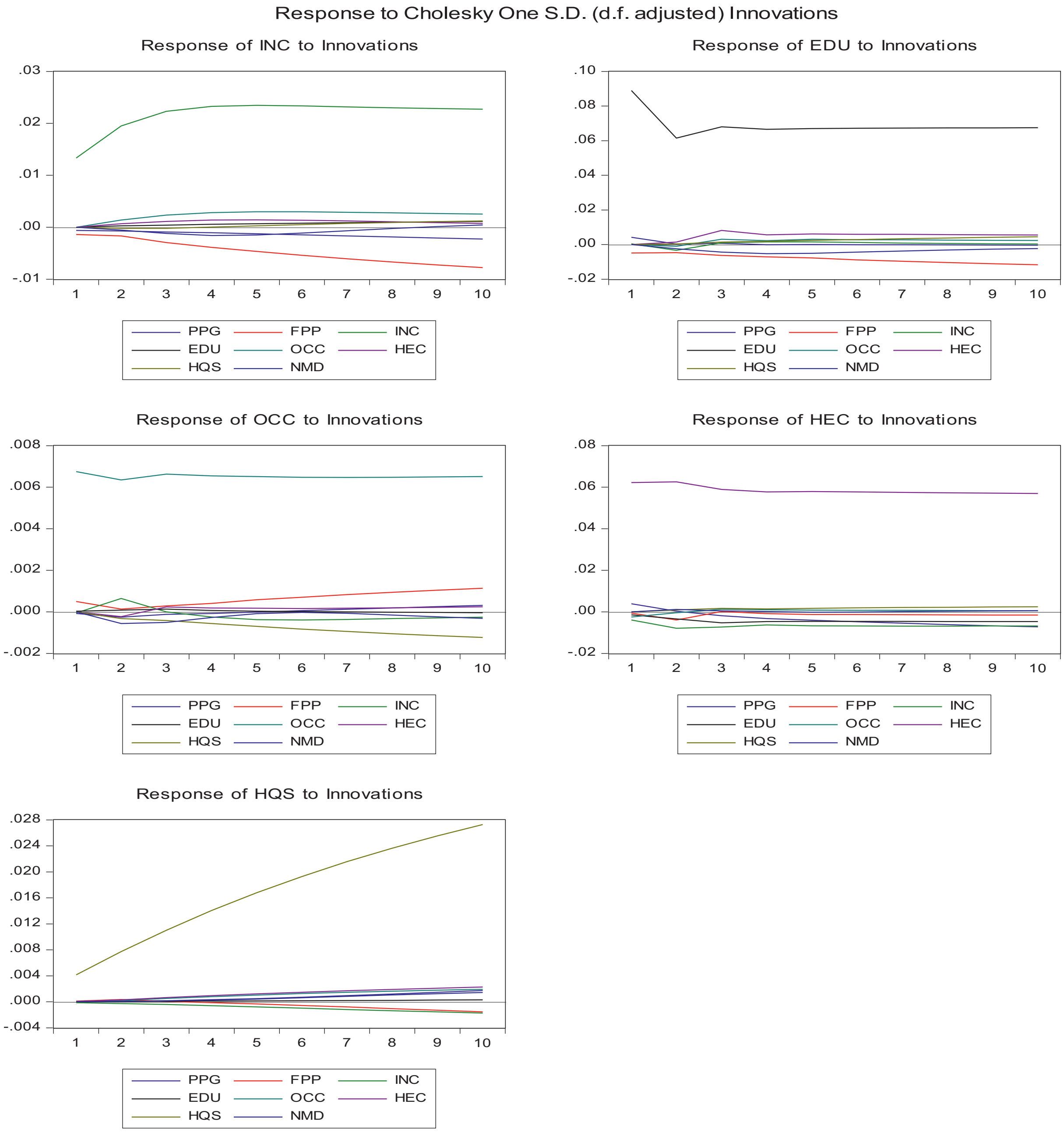

Fig. A2. Impulse response function for NMD.

Data availability

Data will be made available on request.

References

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