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FIXED-EFFECT PANEL COUNTRY-SPECIFIC TRENDS IN HIV PREVALENCE, 1990 -2024 ANALYSIS OF 150 COUNTRIES

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ABSTRACT

This study examines changes in HIV prevalence among people aged 15–49 years across 150 countries over 1990–2024. The objective is to estimate country-specific annual changes and identify countries with statistically significant declining trajectories. The World Development Indicators series SH.DYN.AIDS.ZS, sourced from UNAIDS estimates, was reshaped into a country-year panel. A conventional country fixed-effects model with a common time trend was first estimated, followed by a fixed-effects specification allowing country-specific linear trends. Country-specific slopes were estimated with Newey–West heteroskedasticity and autocorrelation-consistent standard errors using three lags; false-discovery-rate adjustment was also examined as a multiple-testing sensitivity check. The common fixed-effects trend was statistically indistinguishable from zero ($\beta = 0.001$, cluster-robust SE = 0.008, $p = 0.868$), while the test for heterogeneous country slopes was highly significant ($F(149, 4{,}944) = 41.86$, $p < .001$). Twenty-four countries out of one hundred and fifty countries recorded statistically significant negative annual trends at the 5% level, and all 24 remained significant after Benjamini–Hochberg adjustment. Zimbabwe had the largest estimated decline (−0.572 percentage points per year), followed by Malawi (−0.225), Kenya (−0.190), Côte d'Ivoire (−0.180), and Uganda (−0.162). The results show that a single pooled trend masks pronounced cross-country heterogeneity. The findings support country-specific surveillance and differentiated HIV-response planning, while cautioning that prevalence is not equivalent to incidence and that a declining prevalence slope cannot by itself establish the causal effect of any intervention.

Keywords: HIV prevalence, HIV/AIDS, fixed effects, panel data, heterogeneous trends, UNAIDS.

1. INTRODUCTION

Human immunodeficiency virus (HIV) remains a major global public-health issue despite sustained advances in prevention, diagnosis and antiretroviral treatment. The epidemiological landscape has changed substantially since the 1990s, but the pace and direction of change have differed markedly across countries. The contemporary HIV response therefore requires analyses that preserve national heterogeneity rather than relying exclusively on pooled or global averages.

The World Bank's World Development Indicators (WDI) indicator SH.DYN.AIDS.ZS reports HIV prevalence among people aged 15–49 as a percentage of that population and identifies UNAIDS as the source. The values analysed here are modelled estimates, not direct counts. The dataset supplied for this study contains annual point estimates for 1990–2024; the WDI/UNAIDS series and its metadata should therefore be cited with the date on which the extract was accessed, rather than treating "World Bank, n.d." as a publication year unless a dated 2026 release is documented.

Recent UNAIDS evidence indicates substantial global progress. The 2025 Global AIDS Update reports that annual new HIV infections declined by 40% between 2010 and 2024 globally and by 56% in eastern and southern Africa. At the same time, UNAIDS stresses that progress remains uneven and that prevention gaps persist (UNAIDS, 2025). These developments make it important to examine whether long-run prevalence trajectories also differ systematically across countries.

The central question in this study is deliberately narrower than a conventional determinants-of-health analysis: how has HIV prevalence changed annually within each country, and which countries exhibit statistically significant declining trajectories? This framing does not require additional explanatory variables. Instead, it treats time as the principal regressor and estimates country-specific slopes within a fixed-effects framework.

A key methodological issue is whether a common time coefficient can adequately represent countries with different epidemic histories. A conventional country fixed-effects model allows country-specific intercepts but constrains the annual trend to be identical across countries. That restriction is unsuitable when epidemics differ in timing, scale, treatment access, surveillance systems and demographic context. Fixed-effects individual-slope approaches explicitly allow each unit to have its own trajectory and provide tests of whether a common-slope restriction is tenable (Rüttenauer & Ludwig, 2023). Here, this approach is used descriptively: it estimates country-specific linear changes rather than causal effects.

The contribution of the study is threefold. First, it provides a long-run comparative description of HIV prevalence trajectories for 150 countries. Second, it demonstrates empirically that a common panel trend is inadequate for these data. Third, it identifies

countries with statistically significant negative annual trends and quantifies the magnitude and uncertainty of those trends.

Background and Epidemiological Context

HIV prevalence is a stock measure: it captures the share of the specified population living with HIV at a given time. It should therefore be distinguished from HIV incidence, which measures new infections occurring over a period. A prevalence decline can reflect fewer new infections, changes in mortality, demographic composition, treatment-related survival, or combinations of these mechanisms. Accordingly, the present study interprets its coefficients as changes in the prevalence indicator rather than as direct estimates of changes in transmission.

The long study period spans the emergence and expansion of major HIV epidemics, the scale-up of antiretroviral therapy, large international investments in HIV prevention and treatment, and changes in testing and surveillance systems. These processes can produce nonlinear trajectories. Some countries may have experienced rapid increases during epidemic expansion followed by sustained declines, while others may have remained at relatively low prevalence or experienced different temporal patterns.

Cross-country heterogeneity is well documented. Stevens et al. (2024), for example, synthesised survey evidence on HIV prevalence and antiretroviral therapy coverage among key populations in sub-Saharan Africa and documented substantial variation across populations and settings. More recent UNAIDS methodological documentation explains that annual estimates integrate surveillance, survey and programme data within Spectrum-based models, and that estimates are accompanied by uncertainty intervals (Mahy et al., 2024; UNAIDS, 2025). These sources reinforce two points relevant to this study: national trajectories should not be assumed to be homogeneous, and the uncertainty in modelled prevalence estimates should be distinguished from regression sampling uncertainty.

Objectives and Research Questions

The general objective is to estimate annual changes in HIV prevalence and identify countries with statistically significant declining trajectories between 1990 and 2024.

1. Estimate the common annual change in HIV prevalence across the panel.
2. Test whether a common-slope fixed-effects model adequately represents the data.
3. Estimate country-specific annual changes in HIV prevalence.
4. Identify countries with statistically significant negative annual trends.
5. Quantify the magnitude and uncertainty of the strongest statistically significant declines.

The corresponding research questions concern the common annual change, the adequacy of a common country trend, the magnitude of country-specific slopes, and the identification of statistically significant declines.

2. LITERATURE REVIEW

HIV prevalence trends: interpreting a changing epidemic

HIV prevalence is the proportion of a defined population living with HIV at a particular time. It is not interchangeable with incidence, which measures new infections over a period, or with AIDS-related mortality. This distinction matters for long-run comparisons because prevalence reflects the combined influence of new infections, survival, mortality, migration and the age composition of the population. Effective antiretroviral therapy (ART) has extended life expectancy for people living with HIV. Consequently, prevalence can remain stable or rise even when incidence is falling, particularly where treatment coverage improves, and people live longer. A prevalence slope should therefore be read as a summary of the changing stock of people living with HIV, not as a direct measure of transmission or programme effectiveness.

Recent global reporting illustrates why the direction of the epidemic cannot be summarised by one worldwide trend. UNAIDS' 2025 Global AIDS Update reports that annual new HIV infections fell by about 40% between 2010 and 2024, while also estimating approximately 1.3 million new infections in 2024 and noting that the annual total had changed little from the previous year. The report describes progress alongside continuing prevention gaps and substantial differences between settings (UNAIDS, 2025). The 2024 Global AIDS Update similarly emphasises uneven regional progress, with some regions reducing new infections and others experiencing increases (UNAIDS, 2024). These are incidence findings, rather than direct estimates of prevalence, but they establish the epidemiological context in which national prevalence trajectories should be interpreted.

The distinction between regional progress and national experience is important in sub-Saharan Africa, where countries differ in the timing and intensity of their epidemics, the reach of testing and treatment, the availability of prevention services, and the quality of surveillance. Fonner et al. (2021), in a systematic review and meta-analysis of empirical evidence, documented declining HIV incidence in sub-Saharan Africa while also showing that the size and timing of declines vary across settings. Stevens et al. (2024) further demonstrate substantial variation in HIV prevalence and ART coverage among key populations across sub-Saharan African countries. Although key-population estimates cannot be substituted for general-population prevalence, the study reinforces a broader point: national averages can conceal marked differences across populations and places.

The present study contributes to this literature by analysing the general-population HIV prevalence indicator for 150 countries over 1990–2024. Its purpose is descriptive rather than causal. It estimates long-run linear changes in the percentage of people aged 15–49 living with HIV and identifies countries whose fitted slopes are statistically distinguishable from zero. This approach provides a comparable summary across countries, but the resulting coefficient compresses the full epidemic history into a single number. A country

may have experienced a sharp rise followed by a prolonged fall, or a low initial level followed by gradual growth; the same linear slope cannot describe every turning point. The country-specific estimates are therefore best understood as long-period summaries, to be read alongside the trajectory figures and the limitations of a linear specification.

Why heterogeneous country slopes are methodologically justified

A conventional country fixed-effects model allows each country to have its own intercept but imposes a common coefficient on time. In practical terms, countries may start at different prevalence levels, yet the model assumes that their fitted prevalence trajectories change at the same annual rate. This restriction is useful when a shared trend is substantively plausible, but it is difficult to defend for an outcome shaped by different epidemic onset dates, transmission patterns, demographic profiles, treatment histories and prevention systems. If country trajectories have different slopes, the pooled time coefficient can average positive and negative changes and appear close to zero even when meaningful movements occur within individual countries.

The heterogeneous-slope specification relaxes that restriction by allowing the time coefficient to vary by country. Rüttenauer and Ludwig (2023) explain the broader methodological value of fixed-effects individual-slope models: conventional fixed-effects approaches can be misleading when units have different underlying growth trajectories, while individual-slope models allow those trajectories to be represented explicitly and tested against a common-slope restriction. In this study, the approach is a natural match for the research question because the estimand of interest is not one universal HIV trend, but the annual change within each country. The nested-model test evaluates whether allowing country-specific slopes improves the model sufficiently to reject the common-slope restriction.

The method also improves the transparency of cross-country comparison. Country-specific coefficients make it possible to distinguish estimated declines, near-flat trajectories and increases, while confidence intervals and adjusted p-values help communicate uncertainty and the consequences of testing many countries. However, heterogeneous slopes do not automatically solve every modelling problem. A linear slope may be sensitive to epidemic turning points, serial correlation, outlying years, data revisions and changes in the underlying estimation process. Country-specific regression standard errors describe uncertainty conditional on the supplied series; they do not by themselves include the full uncertainty in the epidemiological estimates produced by UNAIDS' Spectrum framework.

Modelled estimates, uncertainty and interpretation

The World Bank's World Development Indicators series used here is sourced from UNAIDS estimates. UNAIDS country estimates are produced using epidemiological models that combine available surveillance, survey, programme and demographic

information. UNAIDS documentation explains that uncertainty intervals depend on the amount and quality of evidence and on assumptions required by the model. It also notes that annual estimation rounds may revise historical values when new data or methods become available (UNAIDS, 2024, 2025). As a result, the annual observations in a downloaded series should not be treated as error-free measurements.

This issue is especially relevant when classifying a country as having a statistically significant trend. The regression tests in this paper quantify sampling and time-series uncertainty under the fitted model, but the input series contains point estimates rather than the full set of annual uncertainty draws. If the underlying prevalence estimates were perturbed within their plausible uncertainty ranges, the slope and its standard error could change. Countries with large slopes and confidence intervals far from zero are likely to be less sensitive to modest revisions than countries whose estimates lie close to the significance threshold; this is a methodological expectation, not a sensitivity result established by the present data. A full uncertainty-propagation analysis would require the corresponding UNAIDS uncertainty bounds or model draws for each country-year, followed by repeated slope estimation and comparison of how often each country retains its direction and significance classification.

The study therefore uses Benjamini–Hochberg false-discovery-rate adjustment to address the fact that 150 country-level hypotheses are tested, and it treats the resulting list as evidence of statistically distinguishable linear trends rather than as a ranking of national programme performance. The adjustment addresses multiplicity among the regression tests; it does not account for the separate uncertainty in UNAIDS modelled estimates. These are different sources of uncertainty and should remain distinct in the interpretation.

Research gap and contribution

Global and regional reports provide essential summaries of HIV progress, while methodological studies explain why panel models may need to accommodate unit-specific trajectories. The gap addressed here is the combination of these two perspectives in a transparent, long-run cross-country analysis of adult HIV prevalence. By estimating both a common-slope benchmark and country-specific linear trends, the study shows whether a pooled coefficient adequately represents the observed data and identifies countries with statistically significant declines or increases. It does not attempt to explain why a country's slope takes a particular value. Explaining those differences would require a further design incorporating country-level information on prevention, ART coverage, mortality, demographic change, surveillance quality and other relevant factors.

3. METHODOLOGY

Research design and data

The study uses the World Development Indicators extract, containing 174 entities. Aggregate regional, income-group and other non-country entities were excluded, leaving 150 countries. The 1990–2024 period provides 5,250 possible country-year observations; 5,244 observations are usable, so the panel is very lightly unbalanced.

The dependent variable is HIV prevalence (% of population ages 15–49), indicator code SH.DYN.AIDS.ZS. After Data selection and restructuring, the prepared dataset in csv contains Country, ISO3, Year, Trend (Year − 1990), and HIV. The analysis uses the reported HIV point estimates without replacing missing values or inventing observations. The World Bank attributes the indicator to UNAIDS and UNAIDS updates the historical series as new evidence and methods become available.

Variables

Variable	Definition	Role
HIV	Prevalence of HIV, % of population ages 15–49	Outcome
Trend	Year – 1990	Time regressor
Country	Country identifier	Fixed effect / heterogeneous slope

Table 1. Definition of variables and model roles.

Econometric specification

The restricted fixed-effects model is:

$$HIV_{it} = \alpha_i + \beta Trend_t + \varepsilon_{it}$$

The unrestricted heterogeneous-trend model is:

$$HIV_{it} = \alpha_i + \beta_i Trend_t + \varepsilon_{it}$$

Here β_i is the country-specific annual change in prevalence, expressed in percentage points per year. A negative coefficient indicates a declining fitted linear trajectory; a positive coefficient indicates an increasing trajectory. Country-specific slopes are estimated by ordinary least squares with Newey–West heteroskedasticity- and autocorrelation-consistent (HAC) standard errors using three lags. Benjamini–Hochberg adjusted p-values are reported to address the 150 simultaneous country-level tests. These regression standard errors quantify uncertainty conditional on the point estimates; they do not include the full uncertainty in the underlying UNAIDS modelled series.

Model comparison

The restricted and unrestricted specifications were compared using a nested-model F test. The test evaluates whether country-specific slope terms jointly add explanatory power beyond the common trend.

Data Availability and Reproducibility

The analysis uses the country-year extract restricted to 1990–2024 and individual countries. The data source is World Bank and the Indicator code is: SH.DYN.AIDS.ZS· HIV prevalence, ages 15–49 · 1990–2024, it is therefore retrieved from World Bank indicator page and UNAIDS uncertainty-bound documentation.

Limitations

The analysis is descriptive rather than causal; time is the only explanatory dimension. The linear trend assumption compresses potentially nonlinear epidemic histories into a single slope. Prevalence is not incidence, so declining prevalence cannot be interpreted as a one-for-one decline in new HIV infections. The HIV prevalence values are modelled estimates. The regression standard errors do not incorporate UNAIDS' model uncertainty, and annual historical estimates may be revised when new data or methods are introduced. The Benjamini–Hochberg procedure controls the expected false-discovery proportion under its assumptions, but classifications may still change if the underlying prevalence estimates or their uncertainty are propagated through the trend estimation. This limitation is especially relevant for countries whose slope p-values lie near 0.05 or whose estimates have wide UNAIDS uncertainty bounds.

Twenty-four World Bank aggregate entities were excluded so that the analysis represents countries rather than regions or income groups.

4. RESULTS AND DISCUSSION

4.1 Results

Descriptive statistics

Year	Mean (%)	Median (%)	SD (%)	N
1990	0.923	0.100	2.348	150
2000	2.017	0.200	4.633	150
2010	1.828	0.300	4.392	150
2020	1.581	0.400	3.896	150
2024	1.432	0.400	3.384	146

Table 2. Selected annual descriptive statistics for HIV prevalence.

Across the 5,244 usable country-year observations, the mean HIV prevalence was 1.714%, the median was 0.300%, and the standard deviation was 4.119 percentage points. The maximum was 29.6%. The unweighted country mean rose from 0.923% in 1990 to 2.017% in 2000, before declining to 1.432% in 2024.

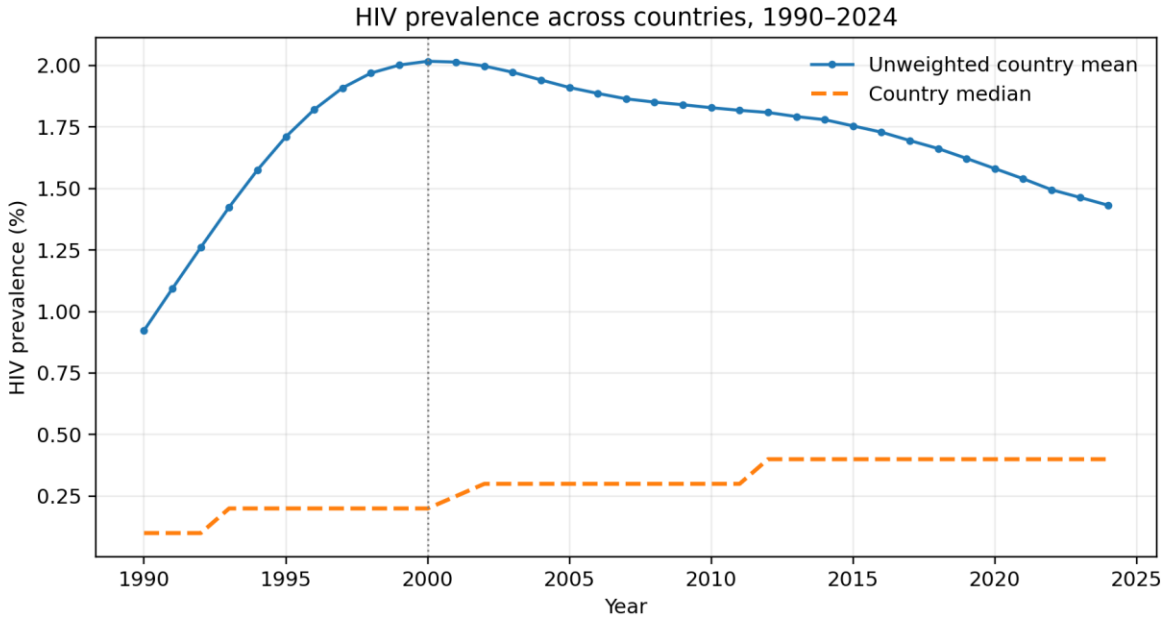


Figure 1. Unweighted mean and median HIV prevalence across the 150-country analytical sample, 1990–2024.

The panel-wide trajectory is not a simple monotonic decline. The initial increase followed by a long decline means that the full-period common linear coefficient should not be interpreted as a complete description of the epidemic history.

Common fixed-effects trend

Specification	Annual trend β	Cluster-robust SE	p-value	R^2
Country FE + common trend	0.0013	0.0080	0.868	0.900

Table 3. Common-slope fixed-effects trend model.

The common-slope coefficient is 0.0013 percentage points per year, with a country-clustered standard error of 0.0080 and p = 0.868. It is not statistically distinguishable from zero. This is an average linear summary, not evidence that prevalence was unchanged in every country; the country-specific estimates include substantial increases and declines.

Test for heterogeneous country trends

The heterogeneous-slope model raises R^2 from 0.900 to 0.956. The nested-model test gives $F(149, 4{,}944) = 41.86$, $p < .001$, rejecting the common-slope restriction. This supports reporting country-specific trajectories rather than relying on one pooled annual coefficient.

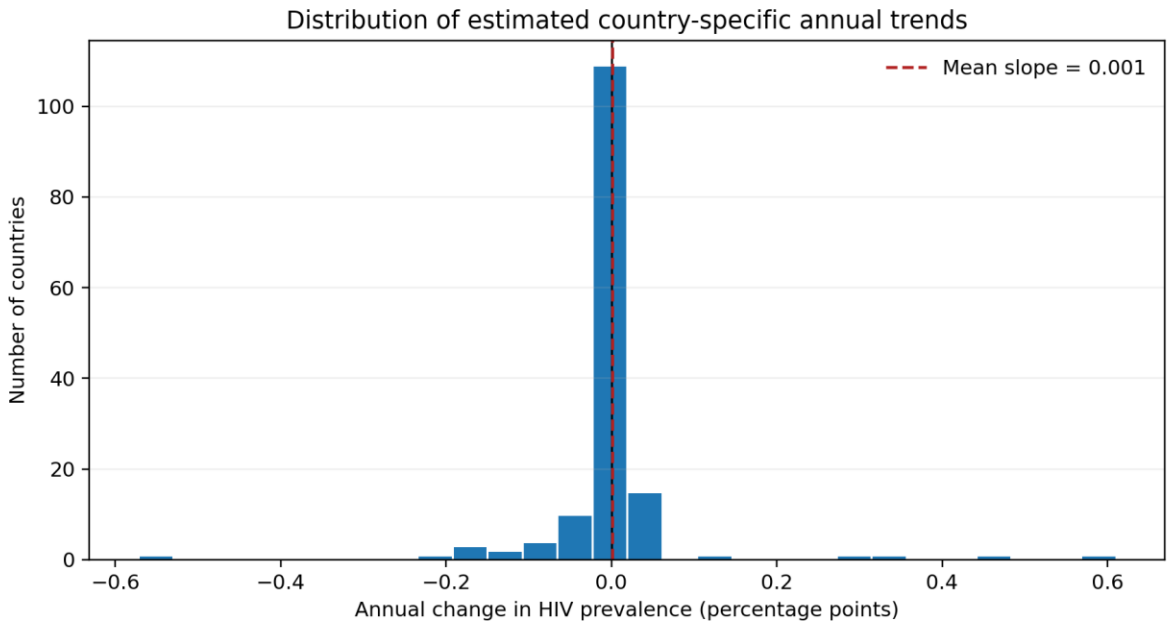


Figure 2. Distribution of estimated country-specific annual changes in HIV prevalence.

Countries with statistically significant declines

Twenty-four of the 150 countries have negative and statistically significant annual trends at the 5% level. In the supplied analysis, all 24 remain significant after Benjamini–Hochberg adjustment. This multiplicity adjustment does not account for uncertainty in the modelled HIV estimates themselves.

Country	Annual change	HAC SE	95% CI	p-value	BH q-value
Zimbabwe	-0.572	0.081	[-0.730, -0.414]	< .001	< .001
Malawi	-0.225	0.064	[-0.351, -0.099]	< .001	0.001
Kenya	-0.190	0.037	[-0.262, -0.118]	< .001	< .001
Côte d'Ivoire	-0.180	0.026	[-0.230, -0.130]	< .001	< .001
Uganda	-0.162	0.010	[-0.182, -0.142]	< .001	< .001
Central African Republic	-0.148	0.034	[-0.214, -0.082]	< .001	< .001
Burundi	-0.138	0.012	[-0.162, -0.113]	< .001	< .001
Ethiopia	-0.084	0.011	[-0.105, -0.063]	< .001	< .001
Tanzania	-0.077	0.014	[-0.105, -0.048]	< .001	< .001
Republic of the Congo	-0.074	0.009	[-0.090, -0.057]	< .001	< .001

Table 4. Ten largest statistically significant declining annual trends.

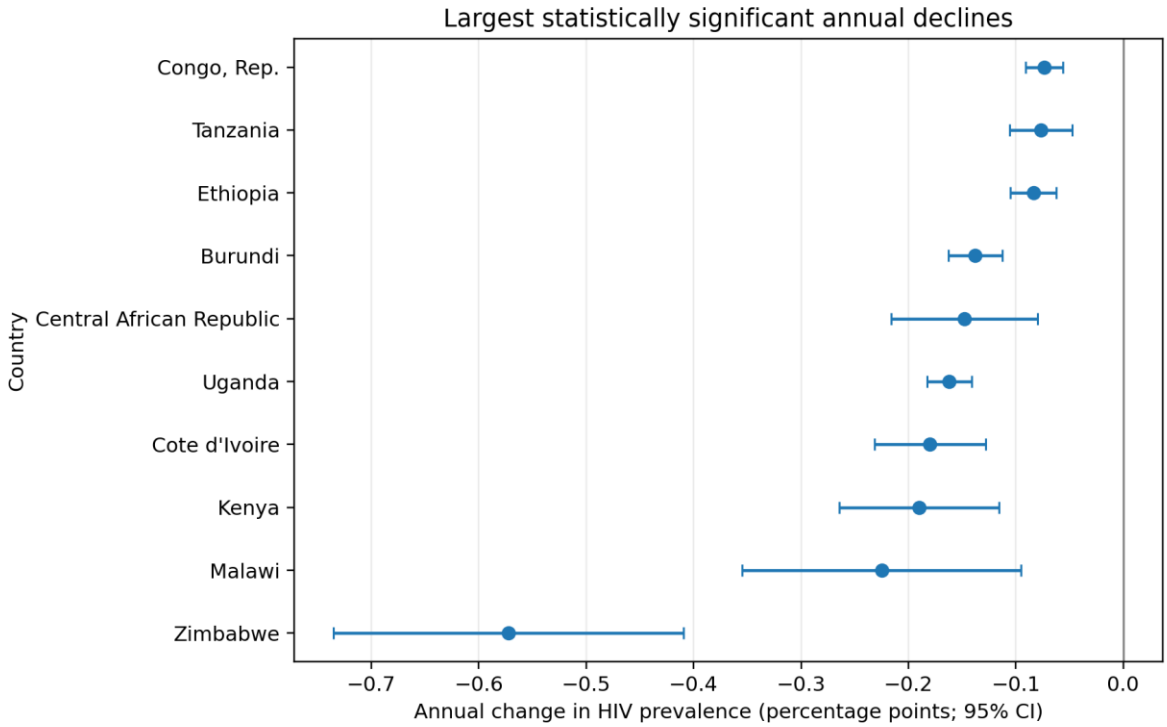


Figure 3. Estimated annual decline and 95% confidence intervals for the ten strongest statistically significant declining countries.

Full set of statistically significant declining countries

Rank	Country	Annual change	HAC SE	p-value	BH q-value
1	Zimbabwe	-0.572	0.081	< .001	< .001
2	Malawi	-0.225	0.064	< .001	0.001
3	Kenya	-0.190	0.037	< .001	< .001
4	Côte d'Ivoire	-0.180	0.026	< .001	< .001
5	Uganda	-0.162	0.010	< .001	< .001
6	Central African Republic	-0.148	0.034	< .001	< .001
7	Burundi	-0.138	0.012	< .001	< .001
8	Ethiopia	-0.084	0.011	< .001	< .001
9	Tanzania	-0.077	0.014	< .001	< .001
10	Republic of the Congo	-0.074	0.009	< .001	< .001
11	Burkina Faso	-0.073	0.006	< .001	< .001
12	Eritrea	-0.064	0.010	< .001	< .001
13	Rwanda	-0.063	0.022	0.004	0.008
14	Liberia	-0.058	0.010	< .001	< .001
15	Democratic Republic of the Congo	-0.054	0.005	< .001	< .001
16	Haiti	-0.035	0.005	< .001	< .001
17	Chad	-0.033	0.012	0.007	0.015
18	Thailand	-0.033	0.013	0.009	0.019
19	Bahamas, The	-0.024	0.008	0.001	0.003
20	Mali	-0.023	0.007	0.002	0.005
21	Honduras	-0.018	0.004	< .001	< .001
22	Niger	-0.013	0.005	0.006	0.012
23	Somalia	-0.008	0.001	< .001	< .001
24	Spain	-0.006	0.002	< .001	< .001

Table 5. Complete list of statistically significant declining countries.

Strongest declining trajectories

Zimbabwe has the largest estimated decline, at -0.572 percentage points per year (95% CI -0.730 to -0.414; $p < .001$). Malawi follows at -0.225, Kenya at -0.190, Côte d'Ivoire at -0.180, and Uganda at -0.162 percentage points per year.

Conversely, the estimated slopes are significantly positive for Mozambique (about 0.304 percentage points per year), South Africa (0.446) and Eswatini (0.610). These results should not automatically be read as evidence of worsening recent transmission or programme failure. Across 1990–2024, a positive linear slope can reflect the timing and scale of epidemic expansion, the persistence of a high-prevalence epidemic, improved diagnosis and case ascertainment, and longer survival as antiretroviral treatment expands. Treatment-related survival can sustain or raise prevalence even when incidence is falling. These are plausible explanations, not mechanisms tested by this model; country-specific incidence, mortality, treatment coverage and age-structured estimates would be needed to distinguish them.

UNAIDS model uncertainty may alter the precision and, for borderline cases, the classification of a trend. The published regression p-values condition on a single set of annual point estimates and therefore omit uncertainty intervals around those estimates.

Countries with narrow uncertainty bounds and large, persistent slopes may be less likely to change classification than countries with wide bounds or slopes close to zero, although this cannot be established from the point-estimate file alone. A formal sensitivity analysis would refit the country-specific models to repeated annual series sampled from UNAIDS uncertainty distributions, where compatible country-year draws are available, and report the share of replications in which each slope remains negative or positive and statistically distinguishable from zero. Because the dataset contains point estimates only, this study treats model uncertainty as a limitation rather than claiming to have completed that simulation.

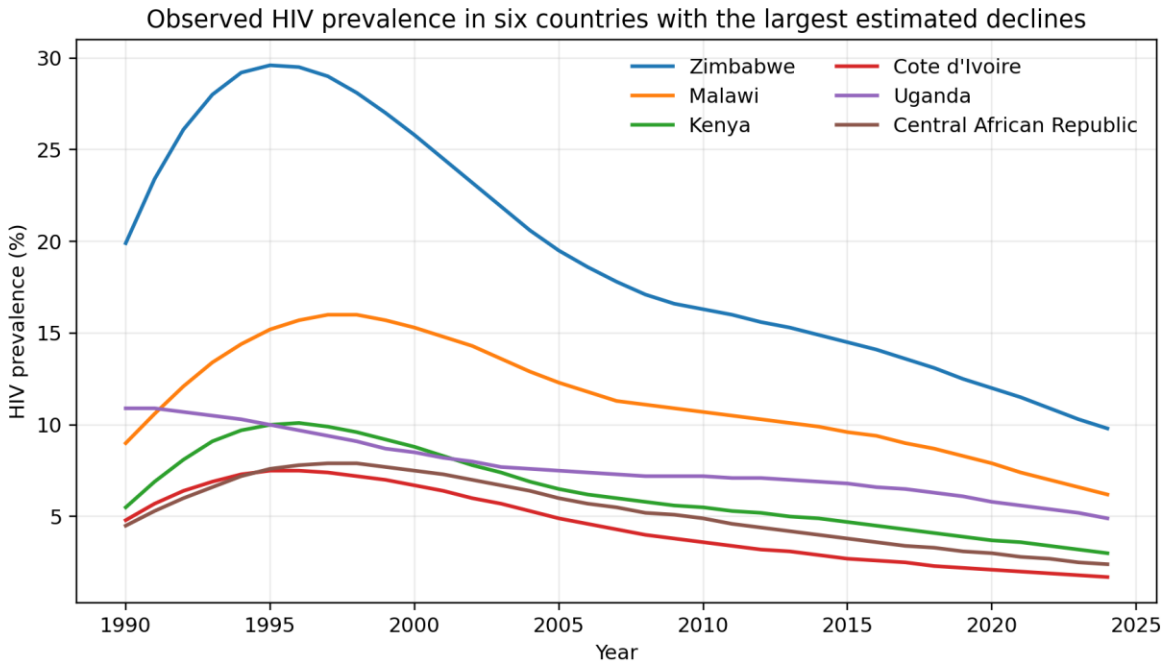


Figure 4. Observed HIV prevalence trajectories for the six countries with the largest statistically significant estimated declines.

These fitted slopes summarize long-run linear change; they do not imply that prevalence declined by exactly the same amount in every year.

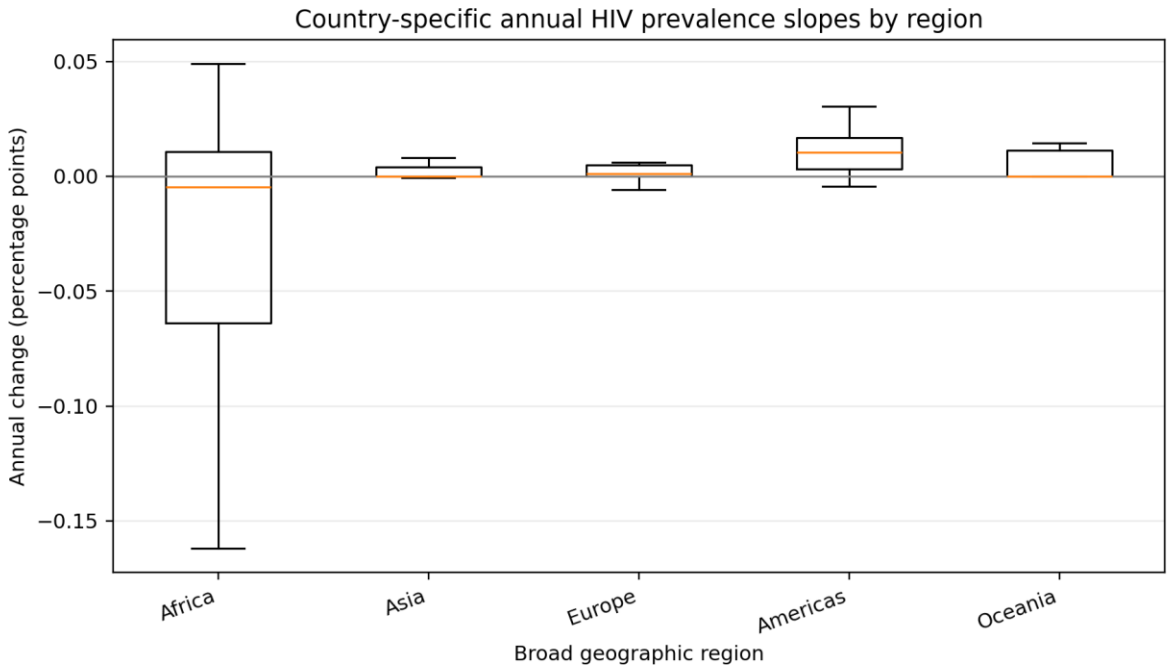


Figure 5. Distribution of country-specific annual HIV prevalence slopes by broad geographic region, 1990–2024. Boxplots summarise the distribution of point-estimate slopes; overlaid points represent countries. Region assignment is geographic and intended for descriptive comparison.

The regional distributions are descriptive rather than population-weighted. Africa has the most negative median slope among the broad regions, while the Americas has a positive median slope; substantial within-region variation remains in every region. The figure is therefore interpreted as evidence of geographic patterning alongside considerable country-level heterogeneity, not as a causal regional comparison.

4.2 Discussion

The principal result is the contrast between the common fixed-effects coefficient and the country-specific estimates. The common annual coefficient is near zero and statistically insignificant, whereas 24 countries have significant negative slopes. The formal heterogeneity test rejects the common-slope restriction. This is consistent with methodological work showing that unit-specific slopes can be important when trajectories differ across panel units (Rüttenauer & Ludwig, 2023).

Several of the largest negative slopes occur in sub-Saharan Africa, a region that has carried a substantial share of the global HIV burden. UNAIDS reports large declines in new infections in eastern and southern Africa and western and central Africa since 2010 (UNAIDS, 2025). However, the present outcome is prevalence, not incidence, so the measures should not be treated as interchangeable.

Zimbabwe has the largest estimated decline, at approximately 0.572 percentage points per year. This coefficient summarises a fitted linear trajectory across 1990–2024; it does not imply an identical decline in every year or establish that a particular intervention caused the change. Prevalence is shaped by incidence, survival, mortality, demographic change and the estimation process.

The multiple-testing check indicates that all 24 negative slopes classified as significant at $p < .05$ also remain significant after Benjamini–Hochberg adjustment. This reduces concern that the list is driven solely by multiple testing under the regression model. It does not, however, eliminate uncertainty arising from the underlying UNAIDS estimates.

The results are descriptive and should not be used to infer that one country's HIV programme is more effective than another's. Causal explanations require additional data on incidence, treatment coverage, prevention, mortality, demographic change and health-system characteristics. In addition, UNAIDS model uncertainty may affect both the estimated magnitude and statistical classification of country trends.

5. CONCLUSION AND POLICY IMPLICATIONS

5.1 Conclusion

This study estimated HIV prevalence trends for 150 countries over 1990–2024. The conventional country fixed-effects model with a common annual slope produced an insignificant coefficient of 0.0013 percentage points per year (cluster-robust $p = 0.868$), while the hypothesis of a common trend was strongly rejected ($F(149, 4{,}944) = 41.86$, $p < .001$).

The country-specific analysis identified 24 statistically significant declining trajectories, all of which remained significant after false-discovery-rate adjustment. Zimbabwe had the largest estimated decline at -0.572 percentage points per year, followed by Malawi, Kenya, Côte d'Ivoire and Uganda.

The principal implication is methodological and epidemiological: HIV surveillance benefits from country-specific longitudinal analysis. The results provide a transparent way to identify statistically distinguishable long-term declines without making causal claims that the data cannot support.

5.2 Policy and Public-Health Implications

Country-specific surveillance should complement aggregate reporting because the lack of a common trend coexists with substantial national declines.

Countries with large long-term declines can be studied comparatively to understand combinations of prevention, testing, treatment and demographic changes associated with epidemiological improvement. Such studies should incorporate incidence, treatment and mortality indicators.

Countries without statistically significant negative slopes should not automatically be classified as unsuccessful. A non-significant linear trend can reflect low prevalence, nonlinear trajectories or offsetting periods of increase and decline.

Continued monitoring is necessary even where prevalence is falling. Prevalence does not equal incidence, and treatment-related survival can change the relationship between the two indicators.

International HIV monitoring should preserve information about model uncertainty and surveillance quality. UNAIDS explains that the width of uncertainty intervals depends partly on the amount and source of available data and on the assumptions required by the estimation model; historical estimates can also be revised when new evidence or methods are introduced (UNAIDS, n.d.; Mahy et al., 2024).

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Appendix A. Full Country-Specific Trend Estimates (Re-estimated from the Supplied CSV)

Country	Code	N	Annual change	HAC SE	t	p	BH q
Zimbabwe	ZWE	35	-0.5722	0.0831	-6.88	< .001	< .001
Malawi	MWI	35	-0.2250	0.0662	-3.40	0.002	0.004
Kenya	KEN	35	-0.1903	0.0379	-5.02	< .001	< .001
Côte d'Ivoire	CIV	35	-0.1798	0.0263	-6.83	< .001	< .001
Uganda	UGA	35	-0.1619	0.0105	-15.41	< .001	< .001
Central African Republic	CAF	35	-0.1478	0.0347	-4.25	< .001	< .001
Burundi	BDI	35	-0.1377	0.0128	-10.79	< .001	< .001
Ethiopia	ETH	35	-0.0838	0.0110	-7.63	< .001	< .001
Tanzania	TZA	35	-0.0768	0.0149	-5.15	< .001	< .001
Republic of the Congo	COG	35	-0.0736	0.0088	-8.38	< .001	< .001
Burkina Faso	BFA	35	-0.0733	0.0061	-11.97	< .001	< .001
Zambia	ZMB	35	-0.0647	0.0376	-1.72	0.094	0.159
Eritrea	ERI	35	-0.0642	0.0107	-5.98	< .001	< .001
Rwanda	RWA	35	-0.0627	0.0225	-2.79	0.009	0.018
Liberia	LBR	35	-0.0576	0.0104	-5.53	< .001	< .001
Democratic Republic of the Congo	COD	35	-0.0541	0.0055	-9.76	< .001	< .001
Djibouti	DJI	35	-0.0451	0.0285	-1.59	0.122	0.202
Haiti	HTI	35	-0.0354	0.0051	-6.87	< .001	< .001
Chad	TCD	35	-0.0335	0.0128	-2.61	0.014	0.028
Thailand	THA	35	-0.0331	0.0131	-2.52	0.017	0.033
Bahamas, The	BHS	35	-0.0241	0.0078	-3.10	0.004	0.009
Mali	MLI	35	-0.0226	0.0076	-2.98	0.005	0.011
Ghana	GHA	35	-0.0207	0.0110	-1.88	0.069	0.124
Honduras	HND	35	-0.0183	0.0043	-4.27	< .001	< .001
Togo	TGO	35	-0.0155	0.0271	-0.57	0.571	0.625
Niger	NER	35	-0.0128	0.0048	-2.68	0.011	0.023
Mauritania	MRT	35	-0.0095	0.0060	-1.59	0.121	0.202
Nigeria	NGA	35	-0.0089	0.0131	-0.68	0.501	0.552
Somalia	SOM	35	-0.0076	0.0010	-7.77	< .001	< .001
Spain	ESP	35	-0.0057	0.0016	-3.55	0.001	0.003
Guatemala	GTM	35	-0.0044	0.0023	-1.90	0.067	0.122
Benin	BEN	35	-0.0019	0.0112	-0.17	0.868	0.892
Senegal	SEN	35	-0.0014	0.0056	-0.25	0.803	0.843
Canada	CAN	33	-0.0010	0.0008	-1.35	0.186	0.212
Dominican Republic	DOM	35	-0.0006	0.0081	-0.08	0.937	0.948
Malaysia	MYS	35	-0.0004	0.0019	-0.24	0.815	0.849
Sweden	SWE	33	-0.0000	0.0000	-0.03	0.975	0.975
Solomon Islands	SLB	35	0.0000	0.0000	1.36	0.184	0.211
North Macedonia	MKD	35	0.0000	0.0000	1.36	0.184	0.211
New Zealand	NZL	35	0.0000	0.0000	1.36	0.184	0.211
Serbia	SRB	35	0.0000	0.0000	1.36	0.184	0.211
Kuwait	KWT	35	0.0000	0.0000	1.36	0.184	0.211
Libya	LBY	35	0.0000	0.0000	1.36	0.184	0.211
Lebanon	LBN	35	0.0000	0.0000	1.36	0.184	0.211
Maldives	MDV	35	0.0000	0.0000	1.36	0.184	0.211
Morocco	MAR	35	0.0000	0.0000	1.36	0.184	0.211
Qatar	QAT	35	0.0000	0.0000	1.36	0.184	0.211
Sri Lanka	LKA	35	0.0000	0.0000	1.36	0.184	0.211
Iraq	IRQ	35	0.0000	0.0000	1.36	0.184	0.211
Jordan	JOR	35	0.0000	0.0000	1.36	0.184	0.211
Mongolia	MNG	35	0.0000	0.0000	1.36	0.184	0.211
Montenegro	MNE	35	0.0000	0.0000	1.36	0.184	0.211
Iceland	ISL	35	0.0000	0.0000	1.36	0.184	0.211
Denmark	DNK	35	0.0000	0.0000	1.36	0.184	0.211
Croatia	HRV	35	0.0000	0.0000	1.36	0.184	0.211

Afghanistan	AFG	35	0.0000	0.0000	1.36	0.184	0.211
Azerbaijan	AZE	35	0.0000	0.0000	1.36	0.184	0.211
Saudi Arabia	SAU	35	0.0000	0.0000	1.36	0.184	0.211
Singapore	SGP	35	0.0000	0.0000	1.36	0.184	0.211
Slovak Republic	SVK	35	0.0000	0.0000	1.36	0.184	0.211
Norway	NOR	35	0.0000	0.0000	1.36	0.184	0.211
Oman	OMN	35	0.0000	0.0000	1.36	0.184	0.211
Bangladesh	BGD	35	0.0000	0.0000	1.36	0.184	0.211
Egypt, Arab Rep.	EGY	35	0.0000	0.0000	1.36	0.184	0.211
Syrian Arab Republic	SYR	35	0.0000	0.0000	1.36	0.184	0.211
Bulgaria	BGR	35	0.0000	0.0000	1.36	0.184	0.211
Comoros	COM	35	0.0000	0.0000	1.36	0.184	0.211
Albania	ALB	35	0.0000	0.0000	1.36	0.184	0.211
United Arab Emirates	ARE	35	0.0000	0.0000	1.36	0.184	0.211
Tunisia	TUN	35	0.0000	0.0000	1.36	0.184	0.211
Vanuatu	VUT	35	0.0000	0.0000	1.36	0.184	0.211
Yemen, Rep.	YEM	35	0.0000	0.0000	1.36	0.184	0.211
Algeria	DZA	35	0.0000	0.0000	1.36	0.184	0.211
Bahrain	BHR	35	0.0000	0.0000	1.36	0.184	0.211
Australia	AUS	35	0.0000	0.0000	1.36	0.184	0.211
Slovenia	SVN	35	0.0000	0.0000	1.36	0.184	0.211
Switzerland	CHE	35	0.0001	0.0008	0.07	0.942	0.948
Peru	PER	35	0.0003	0.0007	0.39	0.698	0.759
Sudan	SDN	35	0.0017	0.0010	1.79	0.083	0.141
Bhutan	BTN	35	0.0017	0.0010	1.79	0.083	0.141
Nepal	NPL	35	0.0018	0.0020	0.87	0.392	0.435
Romania	ROU	35	0.0024	0.0010	2.50	0.017	0.034
Pakistan	PAK	35	0.0027	0.0009	2.96	0.006	0.012
Dominica	DMA	35	0.0030	0.0009	3.49	0.001	0.003
Cambodia	KHM	35	0.0034	0.0108	0.32	0.751	0.799
Lithuania	LTU	35	0.0037	0.0007	5.55	< .001	< .001
Jamaica	JAM	35	0.0037	0.0110	0.34	0.738	0.790
South Sudan	SSD	35	0.0038	0.0150	0.25	0.803	0.843
Cameroon	CMR	35	0.0038	0.0464	0.08	0.935	0.948
Netherlands	NLD	34	0.0039	0.0008	5.14	< .001	< .001
Philippines	PHL	35	0.0041	0.0016	2.56	0.015	0.031
Timor-Leste	TLS	35	0.0041	0.0005	7.88	< .001	< .001
Tajikistan	TJK	35	0.0043	0.0005	8.92	< .001	< .001
Ireland	IRL	35	0.0043	0.0005	8.92	< .001	< .001
Italy	ITA	35	0.0043	0.0005	8.92	< .001	< .001
Belgium	BEL	35	0.0043	0.0005	9.14	< .001	< .001
Luxembourg	LUX	35	0.0046	0.0007	6.68	< .001	< .001
Portugal	PRT	35	0.0055	0.0030	1.82	0.077	0.136
Greece	GRC	35	0.0055	0.0009	6.11	< .001	< .001
France	FRA	34	0.0058	0.0009	6.64	< .001	< .001
Bolivia	BOL	35	0.0059	0.0015	3.92	< .001	0.001
Malta	MLT	35	0.0060	0.0009	6.36	< .001	< .001
Kyrgyz Republic	KGZ	35	0.0061	0.0012	5.14	< .001	< .001
El Salvador	SLV	35	0.0061	0.0044	1.38	0.178	0.211
Armenia	ARM	35	0.0074	0.0018	4.14	< .001	< .001
Kazakhstan	KAZ	35	0.0074	0.0011	6.55	< .001	< .001
Tuvalu	TUV	35	0.0080	0.0007	11.64	< .001	< .001
Argentina	ARG	35	0.0082	0.0013	6.33	< .001	< .001
Georgia	GEO	35	0.0082	0.0018	4.55	< .001	< .001
Ecuador	ECU	35	0.0083	0.0020	4.10	< .001	< .001
St. Lucia	LCA	35	0.0096	0.0008	11.72	< .001	< .001
Madagascar	MDG	35	0.0102	0.0015	6.89	< .001	< .001
St. Vincent and the Grenadines	VCT	35	0.0103	0.0050	2.04	0.049	0.091
Cabo Verde	CPV	35	0.0108	0.0008	13.19	< .001	< .001

Mexico	MEX	35	0.0108	0.0006	18.73	< .001	< .001
Lao PDR	LAO	35	0.0111	0.0010	11.30	< .001	< .001
Gabon	GAB	35	0.0114	0.0336	0.34	0.736	0.790
Colombia	COL	35	0.0119	0.0021	5.58	< .001	< .001
Indonesia	IDN	35	0.0122	0.0012	10.36	< .001	< .001
Viet Nam	VNM	35	0.0128	0.0014	9.00	< .001	< .001
Paraguay	PRY	35	0.0142	0.0008	17.39	< .001	< .001
Venezuela, RB	VEN	35	0.0143	0.0028	5.05	< .001	< .001
Fiji	FJI	35	0.0144	0.0060	2.42	0.021	0.040
Sierra Leone	SLE	35	0.0151	0.0083	1.81	0.080	0.139
St. Kitts and Nevis	KNA	35	0.0158	0.0010	16.34	< .001	< .001
Brazil	BRA	35	0.0161	0.0013	11.94	< .001	< .001
Chile	CHL	35	0.0165	0.0013	13.22	< .001	< .001
Costa Rica	CRI	35	0.0170	0.0013	12.67	< .001	< .001
Latvia	LVA	35	0.0179	0.0024	7.43	< .001	< .001
Cuba	CUB	35	0.0181	0.0017	10.57	< .001	< .001
Panama	PAN	35	0.0216	0.0019	11.22	< .001	< .001
Myanmar	MMR	35	0.0219	0.0040	5.51	< .001	< .001
Barbados	BRB	35	0.0222	0.0071	3.11	0.004	0.009
Antigua and Barbuda	ATG	35	0.0254	0.0005	52.89	< .001	< .001
Guinea	GIN	35	0.0268	0.0110	2.44	0.020	0.039
Estonia	EST	35	0.0275	0.0035	7.81	< .001	< .001
Botswana	BWA	35	0.0282	0.1644	0.17	0.865	0.892
Moldova	MDA	35	0.0288	0.0035	8.26	< .001	< .001
Belize	BLZ	35	0.0304	0.0092	3.30	0.002	0.005
Angola	AGO	35	0.0308	0.0075	4.09	< .001	< .001
Gambia, The	GMB	35	0.0330	0.0154	2.14	0.040	0.074
Papua New Guinea	PNG	35	0.0347	0.0010	33.79	< .001	< .001
Suriname	SUR	35	0.0376	0.0062	6.11	< .001	< .001
Guyana	GUY	35	0.0407	0.0046	8.78	< .001	< .001
Guinea-Bissau	GNB	35	0.0489	0.0400	1.22	0.230	0.259
Namibia	NAM	35	0.1284	0.1061	1.21	0.235	0.263
Mozambique	MOZ	35	0.3039	0.0579	5.25	< .001	< .001
Lesotho	LSO	35	0.3567	0.1891	1.89	0.068	0.123
South Africa	ZAF	35	0.4459	0.0943	4.73	< .001	< .001
Eswatini	SWZ	35	0.6101	0.2041	2.99	0.005	0.011

Appendix Table A1. Country-specific annual trend estimates with HAC standard errors and Benjamini–Hochberg adjusted p-values.

Appendix B. Interpretation and Reproducibility Notes

- Annual change is measured in percentage points of HIV prevalence per year, not per cent growth relative to the previous year's prevalence.
- A negative and statistically significant annual change identifies a country with evidence of a declining linear prevalence trajectory over 1990–2024.
- Country-specific HAC standard errors use three lags to allow for short-run serial dependence in annual observations.
- Benjamini–Hochberg q-values are included because 150 country-level hypotheses are tested. All 24 countries significant at $p < .05$ also remain significant at $q < .05$.
- The study is not a causal evaluation of national HIV policy. No country should be described as having a superior HIV programme solely because its prevalence slope is more negative.
- The World Bank series is based on UNAIDS estimates produced using the Spectrum modelling framework; the regression standard errors do not incorporate the full model uncertainty of the underlying epidemiological estimates.