Equity Implications of Kenya's Dual HIV/Syphilis Antenatal Testing Strategy: A Distributional Cost-Effectiveness Analysis

Zaw Wai Yan Bo

A thesis

submitted in partial fulfillment of the

requirements for the degree of

Master of Public Health

University of Washington

2026

Committee:

Monisha Sharma

David Watkins

Ferdinand Mukumbang

Program Authorized to Offer Degree:

Global Health

@Copyright 2026

Zaw Wai Yan Bo

University of Washington

Abstract

Equity Implications of Kenya's Dual HIV/Syphilis Antenatal Testing Strategy:

A Distributional Cost-Effectiveness Analysis

Zaw Wai Yan Bo

Chair of the Supervisory Committee:

Monisha Sharma

Global Health

Background: Dual HIV/syphilis rapid diagnostic testing at antenatal care (ANC) has been shown to be cost-saving at the national level in Kenya. Whether health gains from this strategy are distributed proportionally between rural and urban pregnant women is unknown. Rural women account for approximately 69% of Kenya's modeled annual pregnancy population but may face weaker ANC cascade performance, including later ANC initiation, lower testing completion, and weaker treatment linkage.

Methods: We adapted a published Excel-based Markov decision analytic model of antenatal HIV/syphilis testing in Kenya to examine rural-urban distributional implications. Rural and urban model runs used subgroup-specific service delivery parameters. The analysis was conducted from a healthcare system perspective, with a cost-effectiveness threshold of US$596 per disability-adjusted life year (DALY) averted. Distributional outcomes included DALYs averted per 1,000 pregnant women, health-gain shares relative to population shares, exploratory

health opportunity-cost-based net health benefit, and an ANC cascade equalization analysis. One-way sensitivity analyses assessed robustness of efficiency and equity findings.

Results: Dual testing at first ANC was cost-saving in both rural and urban model scenarios. Adding late ANC dual retesting generated additional health gains below the selected threshold in both subgroups, with ICERs of US$215 per DALY averted in rural populations and US$226 per DALY averted in urban populations; the combined Kenya estimate was US$219 per DALY averted. Assuming only first-ANC-only dual testing, rural women received 58.9% of total health gains despite comprising 69% of the modeled annual pregnancy population, with a per-capita urban-rural benefit gap of 2.49 DALYs averted per 1,000 pregnant women. Adding late ANC retesting narrowed this gap to 0.57 and moved the rural share of health gains to 67.4%, close to the rural population share. The cascade equalization analysis identified treatment uptake as the cascade stage most strongly associated with modeled rural-urban differences, followed by testing uptake; ANC contact alone had a smaller effect. Efficiency conclusions were robust across all one-way sensitivity ranges; equity results were most sensitive to ANC timing and first ANC attendance.

Conclusions: Dual HIV/syphilis testing is cost-saving at first ANC and remained cost-effective with late ANC retesting in both urban and rural subgroups, supporting prior national cost-effectiveness evidence from Kenya. Strengthened late ANC retesting narrowed the urban-rural per-capita benefit gap and moved rural and urban health-gain shares closer to their shares of the modeled pregnancy population. The equity impact of dual testing depends on completion of the ANC pathway, particularly testing completion and timely treatment, after diagnosis.

Contents

List of Tables

List of Figures

Abbreviations and Acronyms

ANC = antenatal care

ART = antiretroviral therapy

CEA = cost-effectiveness analysis

CHEERS = Consolidated Health Economic Evaluation Reporting Standards

DALY = disability-adjusted life year

DCEA = distributional cost-effectiveness analysis

EMTCT = elimination of mother-to-child transmission

HIV = human immunodeficiency virus

HOC = health opportunity cost

ICER = incremental cost-effectiveness ratio

NHB = net health benefit

OWSA = one-way sensitivity analysis

PMTCT = prevention of mother-to-child transmission

PrEP = pre-exposure prophylaxis

RDT = rapid diagnostic test

RPR = rapid plasma reagin

TPHA = *Treponema pallidum* haemagglutination assay

WHO = World Health Organization

YLD = years lived with disability

YLL = years of life lost

1. Introduction

Mother-to-child transmission of HIV and syphilis is preventable when infections are detected during pregnancy and followed by timely treatment. Antenatal care (ANC) is therefore a central platform for delivering strategies for elimination of mother-to-child transmission, linking pregnant women to testing, diagnosis, treatment, and follow-up within a single care pathway.[1,2] Kenya has made substantial progress in prevention of mother-to-child transmission, including integration of HIV testing into routine maternal health services and expansion of antiretroviral coverage among pregnant women living with HIV.[3,4] Yet, progress has not been uniform, and national averages may obscure persistent gaps in pediatric HIV prevention, syphilis screening, and service delivery across populations and regions.[4,5]

Syphilis prevention has received less consistent attention than HIV prevention within antenatal services, despite the risk of congenital syphilis, stillbirth, neonatal death, and other adverse birth outcomes when maternal infection is untreated.[2,6] This gap may reflect lower visibility of congenital syphilis, weaker routine monitoring, and reliance on separate syphilis testing pathways that require additional commodities, laboratory or confirmatory testing, result return, and treatment follow-up. Dual HIV/syphilis rapid diagnostic testing addresses these barriers by allowing both infections to be screened in one clinical encounter, potentially increasing syphilis testing coverage through integration with the more established HIV testing pathway.[2,7] A published cost-effectiveness analysis found dual HIV/syphilis testing to be cost-saving in Kenya compared with separate HIV rapid diagnostic testing and laboratory-based syphilis testing at first ANC.[2]

Late ANC retesting is also important because HIV and syphilis can be acquired after the first antenatal visit.[8] Retesting creates another opportunity for diagnosis and treatment before

delivery, particularly for women who enter care late, miss testing at first contact, or acquire infection after an earlier negative test.[2,7] For syphilis, timing is especially consequential because treatment must occur early enough in pregnancy to prevent congenital outcomes.[2,6] Kenya's HIV testing guidance recommends HIV testing in the first trimester or at first contact, with retesting in the third trimester and during labour and delivery. The guidance also recommends HIV/syphilis dual testing for pregnant women presenting for initial ANC testing in any trimester, including labour and delivery, and for pregnant women presenting in the third trimester after a negative HIV/syphilis test earlier in pregnancy. However, implementation evidence from Kenya suggests that maternal HIV retesting has been inconsistently conducted in PMTCT programs, with lower retesting during pregnancy and delivery than postpartum. Retesting therefore represents both a recommended pathway and an implementation gap. In this study, late ANC dual retesting is treated as strengthened implementation of the recommended antenatal testing pathway, rather than as a new service platform.[9]

While a previous cost-effectiveness analysis (CEA) found that dual HIV/syphilis testing was cost-effective nationally in Kenya,[2] it did not provide evidence about rural-urban differences in who receives health gains, or whether benefits and value for money differ between rural and urban pregnant women. [10,11] This is important in Kenya because rural residence is closely linked to ANC access and cascade performance, including timely ANC attendance, completion of syphilis testing, receipt of results, and initiation of treatment after diagnosis. Kenya's Universal Health Coverage Policy 2020-2030 also emphasizes equity and expands access for underserved, poor, rural, and marginalized populations.[12] Rural populations often face longer travel distances, fewer facility options, and greater barriers to referral and follow-up which can appear directly in

the ANC cascade through later ANC initiation, lower testing completion, and weaker treatment linkage.[13,14]

Distributional cost-effectiveness analysis (DCEA) provides a framework for assessing who receives health gains, whose health opportunity costs are borne, and whether an intervention narrows or widens health inequality.[10,11] This study applies DCEA principles to extend a published Kenya cost-effectiveness model of antenatal HIV/syphilis testing. We sought to move beyond national average cost-effectiveness results and evaluate whether a guideline-aligned testing strategy, dual testing at first ANC and strengthened late ANC retesting,[9] remain efficient in rural and urban model runs, whether health gains are distributed proportionally across rural and urban pregnant women, and which ANC cascade stages are most associated with modeled rural-urban differences in health gains.

2. Methods

2.1 Study design, population and setting

We adapted a published Excel-based state-transition cost-effectiveness model to examine the efficiency and rural-urban distributional implications of antenatal HIV/syphilis testing strategies in Kenya.[2] The adaptation extended the original analysis by running separate model estimates for rural and urban pregnant women, using subgroup-specific service delivery parameters where data were available. The analysis was conducted from a healthcare system perspective and was guided by CHEERS 2022 reporting recommendations.[15] Health outcomes were measured in disability-adjusted life years (DALYs) averted, and economic outcomes included total costs, incremental costs, incremental cost-effectiveness ratios (ICERs), and net health benefit (NHB).

Cost-effectiveness was assessed using a threshold of US$596 per DALY averted, based on a health opportunity-cost framework for Kenya informed by Woods et al.[16]

The model followed the estimated number of pregnancies occurring in Kenya over one year. Pregnancies were modeled through antenatal care (ANC), delivery, and the postpartum period using weekly cycles, and infant outcomes were projected over a 20-year time horizon after birth. Outcomes included infant HIV infection, congenital syphilis, stillbirth, neonatal death, infant mortality, and longer-term disability. Costs and health outcomes were discounted at 3% annually to remain consistent with the published source model and guidelines.[2]

For the distributional analysis, the modeled annual pregnancy population from the source model was divided into rural and urban subgroups. Directly comparable rural-urban pregnancy counts were not available for all model inputs; therefore, the rural-urban female population distribution from the Kenya Demographic and Health Survey 2022 was used as a proxy for the rural-urban distribution of pregnancies.[3] Using this approach, rural women accounted for approximately 69% of the modeled annual pregnancy population and urban women for approximately 31%. This subgroup allocation was not a pregnancy-specific demographic model and did not adjust for rural-urban differences in maternal age structure, parity, age-specific fertility, adolescent pregnancy share, birth spacing, or recurrent pregnancies.

2.2 Model structure, testing strategies, model inputs, and assumptions

The same disease model structure was used for rural and urban subgroups. HIV and syphilis were modeled using separate but linked Markov modules that shared ANC attendance and testing inputs. Maternal infection, diagnosis, and treatment histories determined infant outcomes, including infant HIV infection, congenital syphilis, stillbirth, neonatal death, infant mortality, and longer-term disability. Infant co-infection was calculated assuming independence between

HIV and syphilis infection, consistent with the source model.[2] A key timing assumption was retained from the published model: maternal syphilis treatment was considered effective for preventing congenital outcomes only if completed by 32 weeks of gestation. Treatment after this point was modeled as equivalent to no treatment for congenital syphilis outcomes.[2,6] Health outcomes were expressed as DALYs, calculated from years of life lost and years lived with disability using disability weights from the published model and its cited sources.[2] Costs were estimated from a healthcare system perspective and included testing, confirmatory testing, maternal treatment, infant prophylaxis, and pediatric HIV or congenital syphilis care. Start-up and distribution costs were excluded, consistent with the published analysis.[2]

We evaluated three antenatal HIV/syphilis testing strategies (Table 1.).[2] In Kenya, antenatal HIV testing is recommended at first trimester or first contact, with retesting in the third trimester and during labour and delivery. The comparator was individual HIV and syphilis testing at first ANC only. In this strategy, syphilis testing used rapid plasma reagin (RPR) screening with Treponema pallidum haemagglutination assay (TPHA) confirmation for reactive results, and HIV testing used a rapid diagnostic test with confirmatory HIV rapid testing after a reactive result. The first intervention strategy was dual HIV/syphilis rapid diagnostic testing at first ANC only, replacing separate HIV and syphilis testing at first ANC with one integrated dual test without strengthened late ANC retesting implementation. The second strategy was dual HIV/syphilis rapid diagnostic testing at both first ANC and late ANC, representing strengthened implementation of the recommended antenatal retesting, consistent with the Kenyan recommendation to retest pregnant women later in pregnancy. The same testing strategies and comparator structure were applied in rural and urban model runs. Individual HIV and syphilis

testing at both first and late ANC was included only as a supplementary strategy because it was dominated in the published Kenya model.[2]

Table 1. Antenatal HIV and syphilis testing scenarios

Scenario	First ANC visit		Late ANC visit		Remark
	Syphilis	HIV	Syphilis	HIV	
Individual HIV/syphilis tests at first ANC only	RPR + TPHA	Rapid test	No test	No test	Separate-testing comparator from the published source model
Dual HIV/syphilis test at first ANC only	Dual test	Dual test	No test	No test	First-ANC dual testing strategy
Individual HIV/syphilis tests at first and late ANC	RPR + TPHA	Rapid test	RPR + TPHA	Rapid test	Supplementary strategy; dominated in the published Kenya model
Dual HIV/syphilis tests at first and late ANC	Dual test	Dual test	Dual test	Dual test	Strengthened implementation of antenatal retesting using the dual test

For the rural-urban extension, the same disease model structure and testing strategies were used for both subgroups. Population size and selected ANC cascade/service-delivery parameters were stratified by rural-urban subgroup where supporting data were available. Stratified parameters included ANC attendance and timing, facility delivery, HIV and syphilis testing coverage, ART initiation and retention, viral suppression, and syphilis treatment coverage. Test performance, disease biology, disability weights, and most unit costs were held constant across subgroups. National disease-burden estimates were applied to both subgroups in the base case because directly comparable rural-urban estimates for all required HIV and syphilis parameters were

unavailable; county-level estimates were used in sensitivity analysis to explore this assumption.[17,18] Full values and ranges are provided in Appendix A.

Most cost inputs were retained from the source model and reflect 2017 US dollars; the dual HIV/syphilis test kit cost was updated separately for this adaptation and applied equally in rural and urban model runs. Costs were not comprehensively inflated to a more recent common price year. ANC visit costs were excluded because testing was modeled as occurring within ANC, delivery, or postnatal contacts that would otherwise take place; therefore, only incremental costs associated with testing, diagnosis, and treatment were included. Consistent with the source model, each modeled pregnancy was assumed to be singleton, meaning one fetus per pregnancy rather than multiple gestation. The model followed a modeled annual pregnancy population and infant outcomes; it did not follow individual women across their reproductive lifetimes or model recurrent pregnancies. Base-case outputs were cross-checked against the published Kenya estimates from Rodriguez et al. to confirm directional alignment of the adapted model.[2]

2.3 Cost-effectiveness analysis

Cost-effectiveness was assessed by comparing incremental costs and incremental DALYs averted between each strategy and its comparator. The ICER was calculated as:

ICER = Incremental cost / Incremental DALYs averted

Dual HIV/syphilis testing at first ANC was compared with individual HIV and syphilis testing at first ANC, and dual testing at first plus late ANC was compared with dual testing at first ANC only.[2]

A strategy was considered cost-saving if it produced greater health benefit at lower cost, and cost-effective if its ICER fell below the threshold of US$596 per DALY averted.[16] To support

comparison across parameter ranges in sensitivity analyses, results were also expressed as net health benefit (NHB):

NHB = Incremental DALYs averted − (Incremental cost / λ)

where λ = US$596 per DALY averted. A positive NHB indicates that health gains exceed the health displaced elsewhere in the system at the selected threshold. Subgroup ICERs were reported descriptively, but the primary equity interpretation was based on population-adjusted health gains, health-gain shares relative to population shares, and exploratory HOC-based NHB.[11]

2.4 Urban-Rural distributional analysis

The urban-rural distributional analysis focused on whether health gains from dual testing were proportional to subgroup population size. Incremental DALYs averted were estimated separately for rural and urban populations using the subgroup model runs. Three metrics were calculated: total DALYs averted, each subgroup's share of total health gains relative to its share of the modeled annual pregnancy population, and DALYs averted per 1,000 pregnant women.[10,11] Rural women represented approximately 69% of the modeled pregnancy population and urban women approximately 31%. These population shares were used as the reference for interpreting the distribution of health gains. If a subgroup's share of total health gains was similar to its population share, benefits were interpreted as approximately proportional to population size. The urban-rural per-capita benefit gap was calculated as urban minus rural DALYs averted per 1,000 pregnant women; positive values indicate an urban per-capita advantage and negative values indicate a rural advantage.

An exploratory health opportunity-cost-based NHB analysis examined whether distributional conclusions changed after accounting for displaced or released health from cost differences.

Because data were not available on where these displaced or released health effects would occur in Kenya, this thesis explored two simple allocation assumptions.

First, incremental costs for each testing strategy were converted into DALY-equivalent health opportunity costs by dividing incremental cost by the cost-effectiveness threshold.[16]

Total HOC DALYs = Total incremental cost / λ

where λ is the cost-effectiveness threshold (US$596 per DALY averted). A positive value represents health potentially displaced elsewhere in the health system, while a negative value occurs when a strategy is cost-saving and represents health potentially gained through released resources. Total HOC DALYs were allocated to rural and urban subgroups under two assumptions: allocation proportional to subgroup population share and equal 50/50 allocation. Subgroup HOC-based NHB was calculated as:

$\text{HOC-based NHB}_i = \text{DALYs averted}_i - \text{Subgroup HOC DALYs}_i$

where *i* denotes the rural or urban subgroup. Under this formula, subtracting a positive HOC value reduces subgroup NHB, while subtracting negative HOC value increases subgroup NHB. This distinction reflects the difference between health displaced by additional spending and health potentially released through cost savings.

2.5 ANC cascade equalization analysis

An ANC cascade equalization analysis was conducted to examine where modeled rural-urban differences were most sensitive along the antenatal testing pathway. The analysis was exploratory and model-based; it was conceptually informed by causal decomposition and cascade analysis frameworks, but was not designed to estimate causal effects of real-world interventions.[19,20]

The primary analysis used one-factor-at-a-time substitution. For each scenario, selected rural cascade parameters were replaced with corresponding urban values while all other rural inputs were held constant. The model was then rerun, and the change in rural DALYs was recorded. Larger reductions in modeled rural DALYs indicated greater sensitivity to that cascade domain. Three cascade domains were examined: ANC contact, testing uptake, and treatment uptake. ANC contact was represented by first ANC attendance. Testing uptake included testing completion parameters and ANC timing, because timing determines whether testing and treatment can occur early enough to prevent infant outcomes, particularly for syphilis. Treatment uptake included HIV and syphilis treatment-related parameters after diagnosis.

A sequential substitution analysis was also conducted as a supplementary robustness check by progressively replacing rural cascade parameters with urban values. Because sequential results depend on the order of substitution, they were interpreted as supporting evidence rather than independent causal contributions.

2.6 Sensitivity analyses

Deterministic one-way sensitivity analyses were conducted to assess the robustness of the efficiency and rural-urban distributional findings. Parameters were varied one at a time across low and high values while all other inputs were held constant. Ranges were based on published or model-derived uncertainty bounds where available; otherwise, a ±20% range was used, with probability parameters constrained between 0 and 1. Full parameter ranges are provided in Appendix E.

The efficiency sensitivity analysis compared dual testing at first plus late ANC with dual testing at first ANC only, using incremental NHB as the outcome. The equity sensitivity analysis used the urban-rural difference in incremental DALYs averted per 1,000 pregnant women for the

same strategy comparison. For HIV prevalence, national values were used in the base case, while county-level estimates were used to define exploratory low and high values. Probabilistic sensitivity analysis was not conducted because subgroup-specific probability distributions were unavailable for several rural and urban inputs.

3. Results

3.1 Base-case results

In the combined Kenya estimate, dual testing at first ANC was cost-saving compared with individual HIV and syphilis testing at first ANC, saving US$2.46 million and averting 8,560 DALYs (Table 2). Dual testing at both first and late ANC averted 12,542 additional DALYs compared with dual testing at first ANC only, with an ICER of US$219 per DALY averted. This was below the cost-effectiveness threshold of US$596 per DALY averted. Individual testing at both first and late ANC was dominated by the corresponding dual-testing strategy.

The rural and urban model runs followed the same pattern. In rural populations, dual testing reduced costs by US$1.60 million and averted 5,038 DALYs. In urban populations, it reduced costs by US$0.86 million and averted 3,523 DALYs. Adding late ANC dual retesting generated additional health gains at additional cost in both subgroups. Compared with dual testing at first ANC only, dual testing at first plus late ANC averted an additional 8,456 DALYs in rural populations at an ICER of US$215 per DALY averted, and 4,086 DALYs in urban populations at an ICER of US$226 per DALY averted. Both ICERs were below the cost-effectiveness threshold of US$596 per DALY averted.

Table 2. Base-case health effects and costs of antenatal HIV/syphilis testing strategies by population group

Population	Strategy	Total costs (US$)	Total DALYs	Incr. costs (US$)	Incr. DALYs averted	ICER/status	Comparator
Rural	Individual, first ANC	$35M	697,000	—	—	-	-
Rural	Dual, first ANC	$33M	692,000	−$1.6M	5,000	Cost-saving	Individual, first ANC
Rural	Individual, first + late ANC	$38M	689,000	$4.9M	3,400	Dominated	Dual, first ANC
Rural	Dual, first + late ANC	$35M	684,000	$1.8M	8,500	215	Dual, first ANC
Urban	Individual, first ANC	$16M	311,000	—	—	-	-
Urban	Dual, first ANC	$15M	308,000	−$860K	3,500	Cost-saving	Individual, first ANC
Urban	Individual, first + late ANC	$18M	307,000	$2.6M	560	Dominated	Dual, first ANC
Urban	Dual, first + late ANC	$16M	304,000	$920K	4,100	226	Dual, first ANC
Kenya overall	Individual, first ANC	$51M	1,010,000	—	—	—	
Kenya overall	Dual, first ANC	$48M	1,000,000	−$2.5M	8,600	Cost-saving	
Kenya overall	Individual, first + late ANC	$56M	996,000	$7.5M	4,000	Dominated	
Kenya overall	Dual, first + late ANC	$51M	987,000	$2.7M	13,000	US$220	

Note. ANC = antenatal care; DALY = disability-adjusted life year; ICER = incremental cost-effectiveness ratio. Individual tests refer to separate HIV and syphilis testing. Dual test refers to an integrated HIV/syphilis rapid diagnostic test. Negative incremental costs indicate cost savings. “Cost-saving” indicates that the strategy was less costly and more effective than its comparator. “Dominated” indicates that the strategy was more costly and less effective than an available alternative and was excluded from ICER-based decision-making. Cost-effectiveness was assessed using a threshold of US$596 per DALY averted. Most cost inputs reflect 2017 US dollars from the source model; the dual HIV/syphilis test kit cost was updated separately. Values are rounded.

3.2 Distribution of health gains

Table 3 presents the rural-urban distribution of DALYs averted from dual HIV/syphilis testing. Under dual testing at first ANC only, rural populations accounted for 5,038 DALYs averted and urban populations for 3,523 DALYs averted. Although the absolute rural gain was larger, rural women received 58.9% of total health gains despite comprising approximately 69% of the modeled pregnancy population. This means that rural women received a smaller share of health gains than would be expected if benefits were distributed in proportion to population size. The corresponding gain-share/population-share ratio was 0.85, where 1.00 would indicate proportional gains. Urban women received 41.1% of total health gains despite representing approximately 31% of the modeled pregnancy population, corresponding to a ratio of 1.33 and indicating more-than-proportional gains.

Adding late ANC dual retesting moved the distribution closer to proportional gains. Rural DALYs averted increased to 8,456 and urban DALYs averted increased to 4,086. Rural populations then received 67.4% of total health gains, closer to their 69% of the modeled pregnancy population. The rural gain-share/population-share ratio increased from 0.85 to 0.98, indicating that rural health gains moved much closer to proportional gains. Urban populations received 32.6% of total health gains, with a ratio of 1.05, compared with 1.33 under first-ANC-only dual testing. Thus, late ANC dual retesting reduced the imbalance in health-gain shares between rural and urban populations.

Table 3. Distribution of DALYs averted from dual HIV/syphilis testing by rural-urban subgroup

Strategy	Population	Incremental DALYs averted	Share of modeled pregnancy population	Share of total health gains	Gain-share / population-share ratio	DALYs averted per 1,000
Dual test, first ANC	Rural	5,038	69%	58.9%	0.85	4.48

Strategy	Population	Incremental DALYs averted	Share of modeled pregnancy population	Share of total health gains	Gain-share / population-share ratio	DALYs averted per 1,000
only						
Dual test, first ANC only	Urban	3,523	31%	41.1%	1.33	6.96
Dual test, first + late ANC	Rural	8,456	69%	67.4%	0.98	7.51
Dual test, first + late ANC	Urban	4,086	31%	32.6%	1.05	8.08

Note. The gain-share/population-share ratio is calculated as each subgroup's share of total health gains divided by its share of the modeled pregnancy population. A value of 1.00 indicates that health gains are proportional to population share. Values below 1.00 indicate less-than-proportional gains, and values above 1.00 indicate more-than-proportional gains.

3.3 Per-capita urban-rural benefit gap

Figure 1 shows DALYs averted per 1,000 pregnant women by subgroup and testing strategy. Under dual testing at first ANC only, rural women gained 4.48 DALYs averted per 1,000 pregnant women, compared with 6.96 among urban women. The urban-rural benefit gap was therefore 2.49 DALYs averted per 1,000 pregnant women.

With dual testing at both first and late ANC, per-capita gains increased in both groups. Rural gains increased to 7.51 DALYs averted per 1,000 pregnant women, while urban gains increased to 8.08. The urban-rural benefit gap narrowed to 0.57 DALYs averted per 1,000 pregnant women.

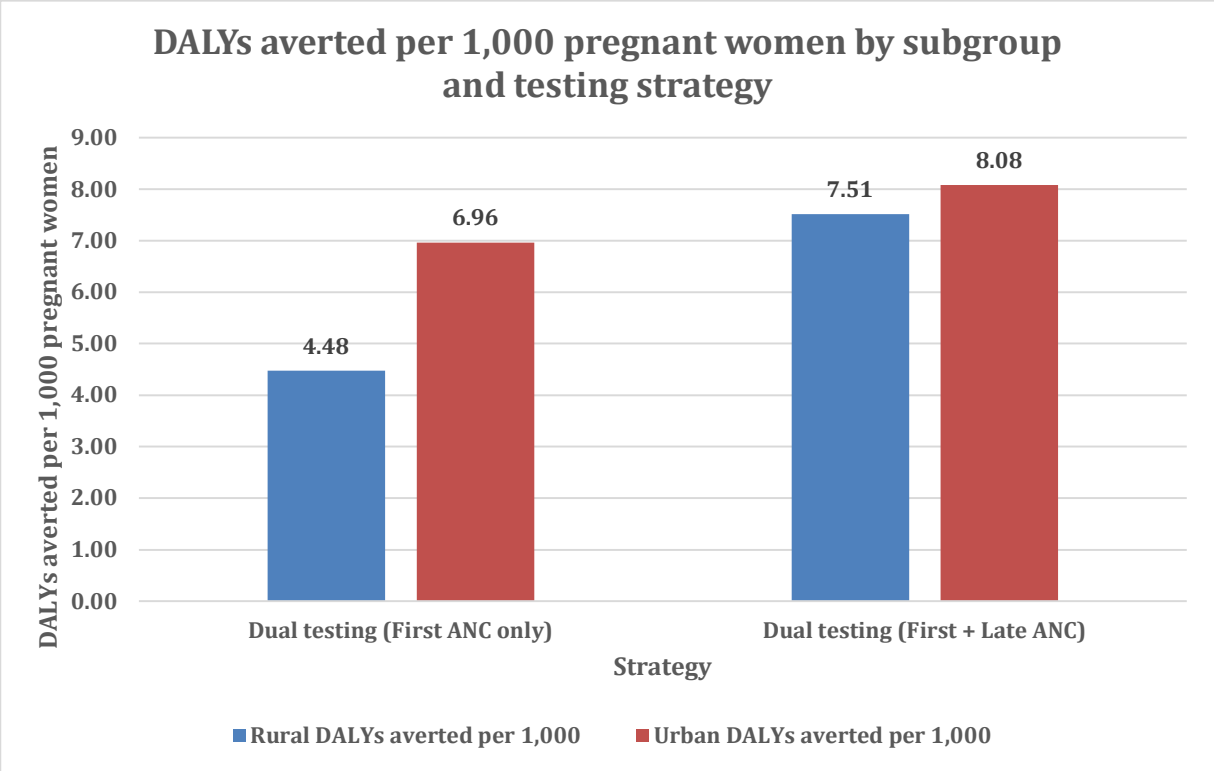

Figure 1. DALYs averted per 1,000 pregnant women by subgroup and testing strategy

Note: Bars show DALYs averted per 1,000 pregnant women. The benefit gap is defined as urban minus rural; positive values indicate higher per-capita gains among urban women. The first-ANC-only gap is 2.49 DALYs averted per 1,000 pregnant women, and the first plus late ANC gap is 0.57.

3.4 Exploratory HOC-based NHB

Figure 2 presents exploratory HOC-based NHB under two assumptions about the distribution of health opportunity costs. Under population-share allocation, HOC-based NHB followed the same rural-urban pattern as the DALY-only results. For dual testing at first ANC only, the urban-rural HOC-based NHB gap was 2.49 per 1,000 pregnant women. For dual testing at first plus late ANC, the gap narrowed to 0.57 per 1,000.

Under equal 50/50 allocation, results were more sensitive to the allocation assumption. For dual testing at first ANC only, the urban-rural HOC-based NHB gap widened to 4.73 per 1,000. For dual testing at first plus late ANC, equal allocation reversed the direction of the HOC-based gap, producing an urban-rural gap of −1.94 per 1,000.

These findings indicate that DALY-based results consistently showed narrowing of the per-capita benefit gap with late ANC retesting, while cost-inclusive HOC-based NHB depended on assumptions about where displaced or released health would fall.

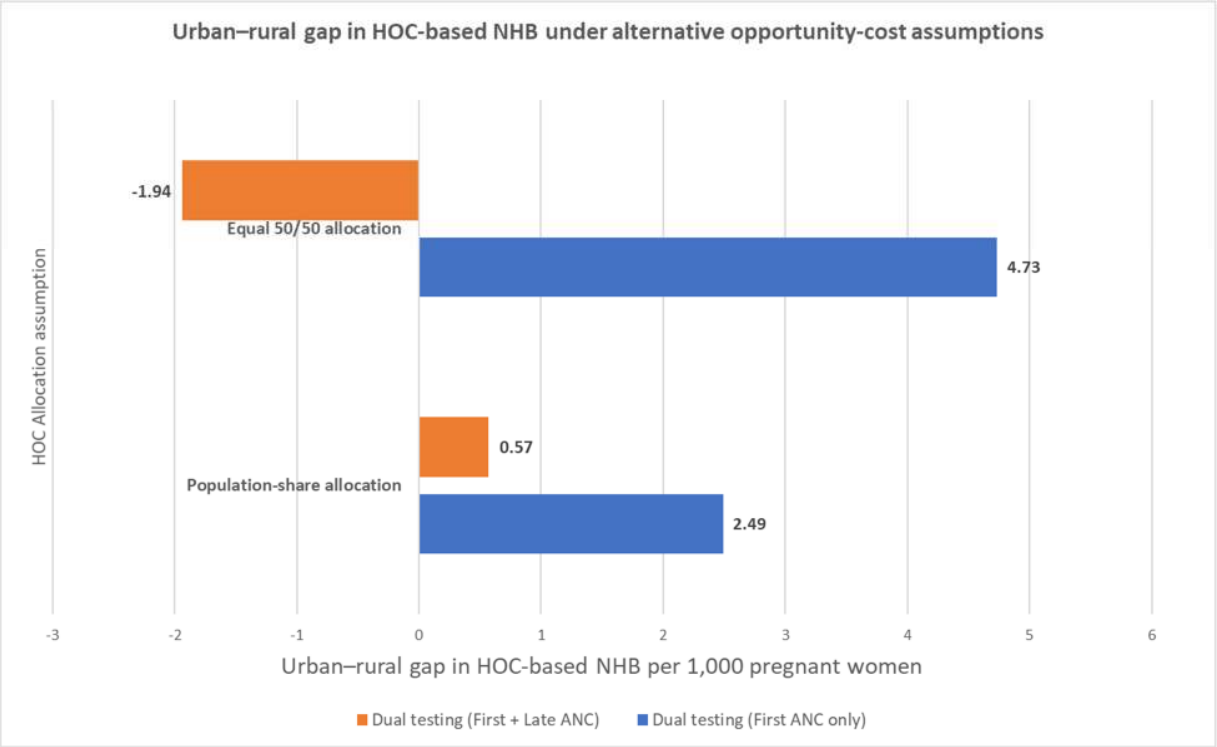

Figure 2. Urban-rural gap in HOC-based NHB under alternative opportunity-cost allocation assumptions

3.5 What drives rural-urban differences along the ANC cascade

Table 4 shows how modeled rural DALYs changed when selected rural cascade values were replaced with the corresponding urban values. This was not intended to represent a real-world

intervention. Instead, it shows which parts of the modeled ANC pathway had the largest influence on rural health gains. Baseline rural and urban cascade values used in this analysis are shown in Appendix Table D1.

Across both dual-testing strategies, treatment uptake made the largest difference, followed by testing uptake. ANC contact alone made the smallest difference. For dual testing at first ANC only, equalizing ANC contact reduced modeled rural DALYs by 500, compared with reductions of 1,894 for testing uptake and 2,947 for treatment uptake. Simultaneous equalization of all three domains reduced rural DALYs by 4,961. The same pattern was observed for dual testing at both first and late ANC: equalizing ANC contact reduced rural DALYs by 283, compared with reductions of 1,894 for testing uptake and 3,266 for treatment uptake. Simultaneous equalization of all three domains reduced rural DALYs by 5,455.

Sequential substitution results were consistent with the one-factor findings. In both strategies, treatment uptake accounted for the largest share of the cumulative sequential reduction, followed by testing uptake; ANC contact contributed relatively little.

Table 4. One-factor-at-a-time ANC cascade equalization results among rural pregnant women

Strategy	Equalized domain	Modeled rural DALYs after substitution	Absolute DALY reduction	Relative reduction vs rural baseline
Dual test, first ANC only	ANC contact	691,577	500	0.07%
Dual test, first ANC only	Testing uptake	690,183	1,894	0.27%
Dual test, first ANC only	Treatment uptake	689,130	2,947	0.43%
Dual test, first ANC only	All linked stages	687,116	4,961	0.72%
Dual test, first + late ANC	ANC contact	683,338	283	0.04%
Dual test, first + late ANC	Testing uptake	681,727	1,894	0.28%
Dual test, first + late ANC	Treatment uptake	680,355	3,266	0.48%
Dual test, first + late ANC	All linked stages	678,166	5,455	0.80%

Note. Values show reductions in modeled rural DALYs after substituting selected rural cascade parameters with corresponding urban values while holding other inputs constant. “All linked stages” represents simultaneous equalization of ANC contact, testing uptake, and treatment uptake, and is not the sum of isolated rows. Larger reductions indicate greater model sensitivity to that cascade domain.

3.6 Sensitivity analyses

Incremental NHB remained positive across all one-way deterministic sensitivity ranges. The largest reductions in incremental NHB occurred when HIV test acceptance was set to its high value, followed by variation in first ANC attendance, late ANC timing, HIV prevalence, first ANC timing, and dual test cost. ART initiation, viral suppression, HIV test specificity, and late ANC attendance had smaller effects.

For equity, the base-case urban-rural incremental DALY gap was most sensitive to rural first ANC timing, first ANC attendance in both subgroups, rural HIV prevalence, and urban first ANC timing. Rural first ANC timing produced the widest range: varying it between 18 and 26 weeks shifted the gap from −0.68 to 3.72 DALYs averted per 1,000 pregnant women. Earlier rural ANC timing shifted the gap toward greater rural per-capita benefit, while later rural ANC timing widened the urban advantage.

Overall, the efficiency advantage of dual testing at first plus late ANC was robust across tested parameter ranges, while equity results were more sensitive to assumptions about ANC timing, first ANC attendance, and subgroup HIV prevalence.

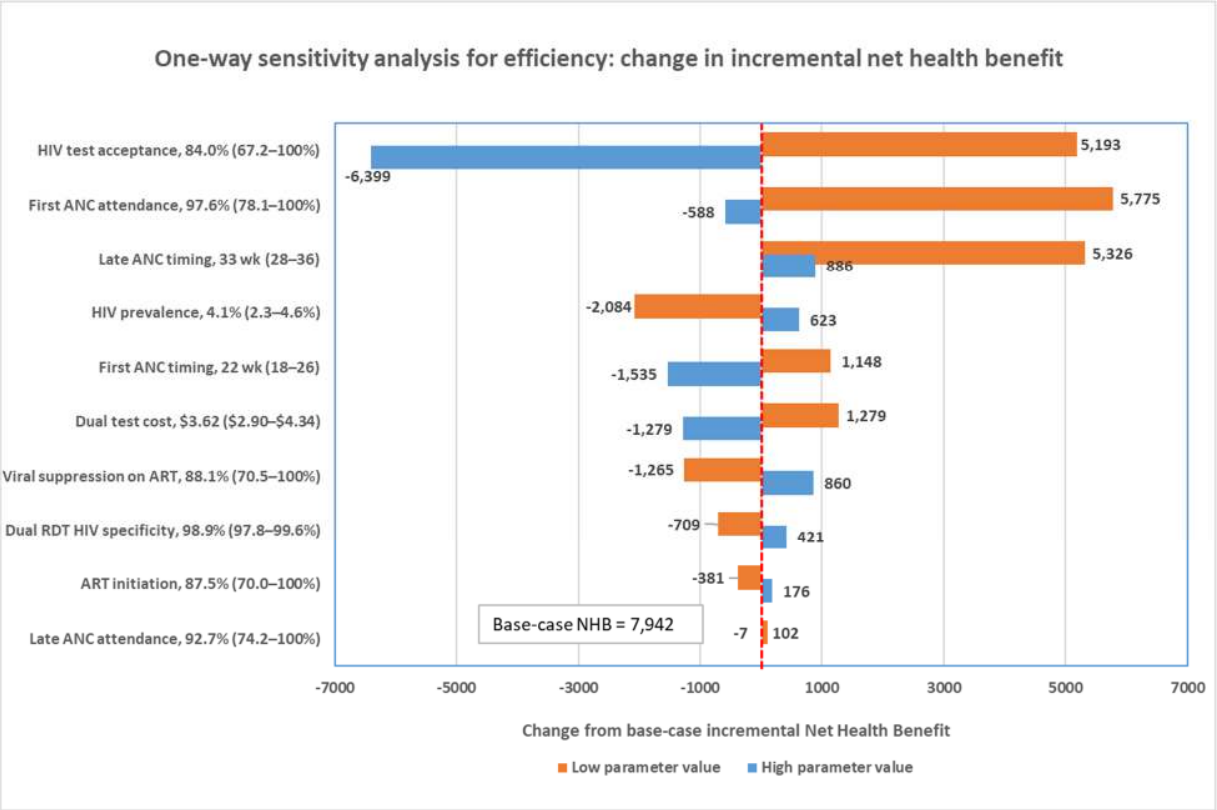

Figure 3. One-way sensitivity analysis for efficiency: change in incremental net health benefit

Figure note. Bars show the change from base-case incremental NHB for dual testing at first plus late ANC compared with dual testing at first ANC only. Positive values indicate increased NHB relative to the base case; negative values indicate reduced NHB. Base-case incremental NHB was 7,942 DALYs for the modeled Kenya annual pregnancy population.

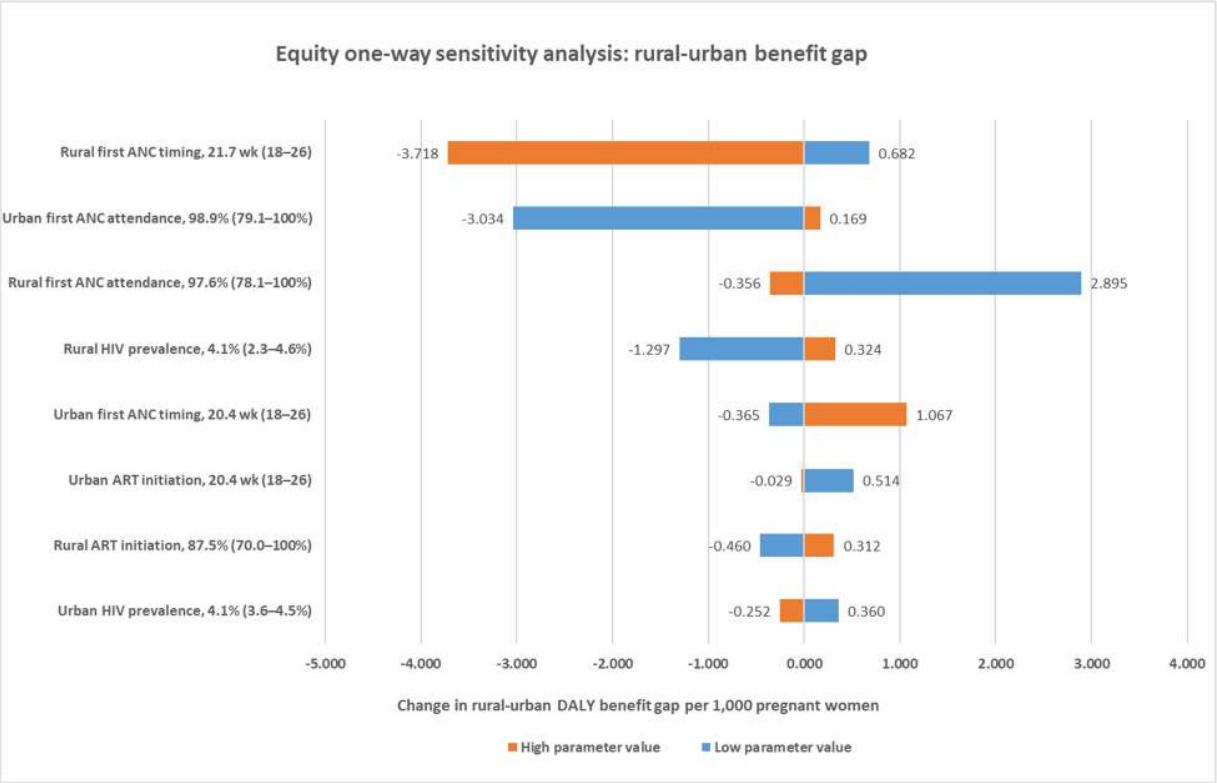

Figure 4. One-way sensitivity analysis for equity: change in urban-rural incremental DALY benefit gap

Figure note. Bars show the change from the base-case urban-rural benefit gap, defined as urban minus rural incremental DALYs averted per 1,000 pregnant women. Positive values indicate an increase in the urban advantage; negative values indicate a shift toward greater rural per-capita benefit.

4. Discussion

Dual HIV/syphilis testing at first ANC was cost-saving in both rural and urban model runs, consistent with prior national cost-effectiveness evidence from Kenya.[2] Dual testing at both first and late ANC generated additional health gains at a cost below the selected threshold. These findings support the efficiency case for integrated antenatal testing. The main new finding is

distributional: under first-ANC-only dual testing, rural women received a smaller share of total health gains than their share of the modeled annual pregnancy population, while urban women received a larger share relative to their population size. When late ANC dual retesting was added, the rural share of health gains moved much closer to the rural population share, and the urban-rural per-capita benefit gap narrowed from 2.49 to 0.57 DALYs averted per 1,000 pregnant women.

This narrowing appears to be driven by the ANC cascade parameters rather than by the testing technology alone. In the rural model runs, later ANC timing and weaker testing and treatment uptake created more missed opportunities under first-ANC-only testing. Adding late ANC retesting recovered some of these missed opportunities, narrowing the urban-rural per-capita benefit gap. The cascade equalization analysis supported this interpretation: replacing rural treatment uptake and testing uptake values with urban values reduced modeled rural DALYs more than replacing ANC contact alone. In practical terms, dual testing can only produce equitable benefits if women complete the pathway from ANC contact to testing, diagnosis, and timely treatment.

These findings show why distributional analysis adds value beyond national average cost-effectiveness results. First-ANC-only implementation produced less-than-proportional rural gains, while strengthened late ANC retesting moved the distribution of benefits closer to population shares. The analysis does not suggest that dual testing is inequitable. Rather, it shows that implementation strength matters. A nationally cost-saving strategy can still generate uneven per-capita benefits if access, testing completion, and treatment linkage differ across settings.

The main policy implication is that late ANC retesting should be strengthened as an implementation priority within the antenatal HIV/syphilis testing pathway. Kenya's HTS

guidance recommends HIV testing in the first trimester or at first contact, with retesting in the third trimester and during labour and delivery. The guidance also recommends HIV/syphilis dual testing for pregnant women presenting for initial ANC testing in any trimester, including labour and delivery, and for pregnant women in the third trimester who had a negative HIV/syphilis test earlier in pregnancy.[9] However, implementation evidence from Kenya shows that maternal HIV retesting has been inconsistently conducted in PMTCT programs, with lower retesting during pregnancy and delivery than postpartum. In this analysis, adding late ANC dual retesting was cost-effective and moved rural and urban health-gain shares closer to their shares of the modeled pregnancy population. Retesting will have limited equity value if rural women still face barriers to testing completion, result receipt, syphilis treatment, ART initiation, or follow-up. Rural ANC strengthening should therefore prioritize the full testing-to-treatment pathway, not attendance alone. For rural-urban equity, the findings suggest that national testing coverage alone is not enough to monitor whether the benefits of dual testing are reaching pregnant women proportionally. Programs should also track whether women attend ANC early enough, complete HIV and syphilis testing, receive results, and start treatment in time to prevent infant outcomes. Because the distributional results were sensitive to ANC timing, testing completion and treatment uptake, these indicators should be measured and updated as implementation data improve. Rural-urban monitoring of first ANC timing, testing completion, late retesting coverage, syphilis treatment timing, ART initiation, and DALYs averted per 1,000 pregnant women would help identify where implementation gaps remain and whether strengthened late ANC retesting is reducing rural-urban gaps in health gains.

This study has several strengths. We use a previously established model which allowed the analysis to focus on rural-urban distributional implications rather than developing a new model

structure.[2] The contribution of this analysis is therefore pragmatic and policy-oriented. Instead of using subgroup ICERs as the primary equity conclusion, it uses subgroup model runs, population-adjusted health-gain metrics, exploratory health opportunity-cost allocation, and ANC cascade equalization to make distributional implications visible. This approach addresses CHEERS 2022 Items 18 and 19, which call for reporting subgroup heterogeneity and distributional effects where relevant.

This analysis has several limitations. First, this was not a full welfare-based DCEA. The analysis did not estimate baseline lifetime health distributions, formal inequality indices, equally distributed equivalent health, or inequality-aversion parameters. Such analysis would require additional population health and social-preference data from Kenya and was outside the scope of this thesis. Second, national disease-burden estimates were applied to both rural and urban groups in the base case because comparable subgroup-specific estimates were unavailable for all required parameters. This made the distributional interpretation more directly linked to cascade performance but may not fully capture true epidemiological variation. Third, the rural-urban allocation used female population shares from KDHS 2022 as a proxy for pregnancy shares and did not stratify maternal age structure, parity, age-specific fertility, adolescent pregnancy share, birth spacing, or recurrent pregnancies.

Fourth, most costs were retained from the published source model and reflect 2017 US dollars, while the dual HIV/syphilis test kit cost was updated separately. This may limit direct interpretation for current decision-making, particularly if prices have changed since the source model was developed. ANC visit costs were also excluded because testing was modeled as occurring within existing ANC, delivery, or postnatal contacts; if strengthened retesting requires

additional visits, outreach, staff time, or service-delivery resources, implementation costs may be underestimated.

Fifth, the cascade equalization analysis was diagnostic rather than identifying causal association. Replacing rural parameters with urban values identifies model sensitivity but does not represent a fully specified intervention. Sixth, probabilistic sensitivity analysis was not conducted because subgroup-specific probability distributions were unavailable for several rural and urban inputs. Finally, rural-urban residence captures only one equity dimension; wealth, county, education, adolescent status, facility readiness, and distance to care may also shape antenatal testing outcomes.[13,14]

Future research could extend this work into a full welfare-based DCEA by estimating baseline rural-urban health distributions, formal inequality measures, equally distributed equivalent health, and inequality-aversion scenarios for Kenya.[10,11] Improved data on rural-urban HIV and syphilis burden, ANC timing, testing completion, syphilis treatment, and ART linkage among pregnant women would strengthen subgroup parameterization. Future analyses stratified by wealth, education, adolescent status, distance to facility, or county could reveal inequities that a binary rural-urban classification cannot capture. Qualitative or mixed-methods research with Kenyan ANC providers, pregnant women, and program managers could also help explain why specific cascade stages fail and which implementation strategies are most feasible.

5. Conclusion

Dual HIV/syphilis testing at first ANC was cost-saving in both rural and urban model runs, and strengthened late ANC dual retesting generated additional health gains at ICERs below the selected threshold. This analysis extends prior national cost-effectiveness evidence by showing

that the distribution of health gains may differ between rural and urban pregnant women. Under first-ANC-only dual testing, rural women received substantial health gains but a smaller share of total benefits than their share of the modeled annual pregnancy population. Adding late ANC retesting narrowed the urban-rural per-capita benefit gap and moved rural and urban health-gain shares closer to their shares of the modeled pregnancy population. The equity impact of dual testing depends on more than test availability. Testing completion and treatment uptake after diagnosis were more strongly associated with modeled rural-urban differences than ANC contact alone. Realizing the equity potential of dual antenatal testing in Kenya will therefore require maintaining integrated testing while strengthening the rural ANC testing-to-treatment cascade.

References

1. World Health Organization. Country guidance for planning triple elimination of mother-to-child transmission of HIV, syphilis and hepatitis B virus programmes. 2022. Accessed January 7, 2026. https://www.who.int/publications/i/item/9789240112490

2. Rodriguez PJ, Roberts DA, Meisner J, et al. Cost-effectiveness of dual maternal HIV and syphilis testing strategies in high and low HIV prevalence countries: a modelling study. *Lancet Glob Health*. 2021;9(1):e61-e71. doi:10.1016/S2214-109X(20)30395-8

3. Kenya National Bureau of Statistics M of H. Kenya Demographic and Health Survey - 2022 - Kenya National Bureau of Statistics. 2023. Accessed May 24, 2026. https://www.knbs.or.ke/reports/kdhs-2022/

4. Maina RM, Mwalili SM, Gathungu DK, Orwa TO, Mbogo RW. Assessing the Impact of Optimized Prevention Strategies for Mother-To-Child HIV Transmission Dynamics in Kenya: A Mathematical Modeling Study. *Int J Math Math Sci*. 2026;2026(1):6632361. doi:10.1155/ijmm/6632361

5. Elizabeth Glaser Pediatric AIDS Foundation. Innovations and Impact Toward the Elimination of Mother-to-Child Transmission in Kenya. Published online 2021. https://www.pedaids.org/wp-content/uploads/2021/12/PMTCT-kenya-brief-v4.pdf

6. World Health Organization. *WHO Guideline on Syphilis Screening and Treatment for Pregnant Women*. World Health Organization; 2017. Accessed February 4, 2025. https://iris.who.int/handle/10665/259003

7. Dual HIV/syphilis rapid diagnostic tests can be used as the first test in antenatal care. Accessed March 18, 2026. https://www.who.int/publications/i/item/WHO-CDS-HIV-19.38

8. Penumetsa M, Neary J, Farid S, et al. Implementation of HIV Retesting During Pregnancy and Postpartum in Kenya: A Cross-Sectional Study. *Glob Health Sci Pract*. 2022;10(1):e2100451. doi:10.9745/GHSP-D-21-00451

9. National AIDS and STI Control Programme. *Kenya HIV Testing Services Operational Manual. Ministry of Health, Kenya; 2022*. 2022. https://www.prepwatch.org/wp-content/uploads/2023/04/Kenya-HTS-Manual.pdf

10. Asaria M, Griffin S, Cookson R, Whyte S, Tappenden P. Distributional Cost-Effectiveness Analysis of Health Care Programmes - A Methodological Case Study of the UK Bowel Cancer Screening Programme. *Health Econ*. 2015;24(6):742-754. doi:10.1002/hec.3058

11. Cookson R, Griffin S, Norheim OF, Culyer AJ, eds. *Distributional Cost-Effectiveness Analysis: Quantifying Health Equity Impacts and Trade-Offs*. Oxford University Press; 2020. doi:10.1093/med/9780198838197.001.0001

12. Ministry of Health K. *Kenya Universal Health Coverage Policy 2020-2030: Accelerating Attainment of Universal Health Coverage*. Ministry of Health, Kenya; 2020. https://repository.kippra.or.ke/handle/123456789/3566

13. Macharia PM, Joseph NK, Nalwadda GK, et al. Spatial variation and inequities in antenatal care coverage in Kenya, Uganda and mainland Tanzania using model-based geostatistics: a socioeconomic and geographical accessibility lens. *BMC Pregnancy Childbirth*. 2022;22:908. doi:10.1186/s12884-022-05238-1

14. Keats EC, Akseer N, Bhatti Z, et al. Assessment of Inequalities in Coverage of Essential Reproductive, Maternal, Newborn, Child, and Adolescent Health Interventions in Kenya. *JAMA Netw Open*. 2018;1(8):e185152. doi:10.1001/jamanetworkopen.2018.5152

15. Husereau D, Drummond M, Augustovski F, et al. Consolidated Health Economic Evaluation Reporting Standards 2022 (CHEERS 2022) statement: updated reporting guidance for health economic evaluations. Published online January 11, 2022. doi:10.1136/bmj-2021-067975

16. Woods B, Revill P, Sculpher M, Claxton K. Country-Level Cost-Effectiveness Thresholds: Initial Estimates and the Need for Further Research. *Value Health*. 2016;19(8):929-935. doi:10.1016/j.jval.2016.02.017

17. Onyango G. Kenya's AIDS Response Progress Report 2025. National Syndemic Disease Control Council. Accessed March 23, 2026. https://nsdcc.go.ke/documents-and-frameworks/

18. Kenya HIV Estimates 2024, A DECADE OF PROGRESS REPORT (2013-2023). National Syndemic Disease Control Council. Accessed March 23, 2026. https://analytics.nsdcc.go.ke/estimates/PROGRESS-REPORT-2024.pdf

19. Jackson JW. Meaningful causal decompositions in health equity research: definition, identification, and estimation through a weighting framework. *Epidemiol Camb Mass*. 2021;32(2):282-290. doi:10.1097/EDE.0000000000001319

20. Wagner AD, Gimbel S, Ásbjörnsdóttir KH, et al. Cascade Analysis: An Adaptable Implementation Strategy Across HIV and Non-HIV Delivery Platforms. *JAIDS J Acquir Immune Defic Syndr*. 2019;82:S322. doi:10.1097/QAI.0000000000002220

21. Cookson R, Griffin S, Norheim OF, Culyer AJ, Chalkidou K. Distributional Cost-Effectiveness Analysis Comes of Age. *Value Health*. 2021;24(1):118-120. doi:10.1016/j.jval.2020.10.001

Funding

This thesis did not receive dedicated external funding.

Conflicts of Interest

The author declares no conflicts of interest.

Appendices

Appendix A. Model Parameters Table

Category	Parameter	Variable	Rural value	Urban value	Low value	High value
STARTING STATES	Population (annual pregnancies)_rural	popsize	1,125,714	505,756	—	—
	Proportion of women at onset of pregnancy who know HIV status	hiv_status_known	57.0%	57.0%	57.0%	57.0%
	Prevalence of HIV among pregnant women	hiv_prev	4.1%	4.1%	3.28%	4.92%
	Probability of test acceptance, HIV	test_accept	84.0%	84.0%	67.2%	100.0%
	Prevalence of syphilis amoung pregnant women	syp_prev	0.95%	0.95%	0.8%	1.1%
INCIDENCE OF MATERNAL HIV	Proportional reduction in incidence due to PrEP	red_prep	70.5%	70.5%	70.5%	70.5%
	Weekly incidence of HIV in early pregnancy (before first ANC).	inc_preg_early	0.000330769	0.000330769	5.76923e-05	0.0006375
	Weekly incidence of HIV in late pregnancy (after first ANC)	inc_preg_late	0.000330769	0.000330769	5.76923e-05	0.0006375
	Weekly incidence of HIV in early post-partum period (first 6 weeks)	inc_pp_early	0	0	0	0
	Weekly incidence of HIV in mid post-partum period (6 weeks-6 months)	inc_pp_mid	0.000269231	0.000269231	0.000155769	0.000465385
	Weekly incidence of HIV in late post-partum period (6-12 months)	inc_pp_late	0.000269231	0.000269231	0.000155769	0.000465385
MATERNAL SYPHILIS INCIDENCE	Syphilis incidence (annual)	syp_inc	0.0044	0.0044	0.0044	0.0044
	Weekly probability of new syphilis infection	syp_inc_wk	8.46118e-05	8.46118e-05	8.46118e-05	8.46118e-05
	Percent of Infections Live	syp_pct_live	52.9%	52.9%	52.9%	52.9%
ANC TIMING	Mean week of first ANC, base case	weekofanc1	22	20	18	26
	Mean week of 2nd ANC, base case	weekofanc2	33	33	33	33
	Mean week of delivery	deliveryweek	39	39	39	39
TESTING PROBABILITIES	Attendance at first ANC visit	att_firstANC	97.6%	98.9%	97.6%	98.9%
	Attendance at ANC visit in late gestation	att_lategest	92.7%	92.7%	92.7%	92.7%
	Delivery at facility	att_delivery	0.831	0.97	0.831	0.831
	Attendance at 6 week post-partum visit	att_6wk	0.96	0.96	0.96	0.96
	Attendance at 14 week post-partum visit	att_14wk	0.88	0.88	0.88	0.88
	Attendance at 6 month post-partum visit	att_6mo	86.5%	86.5%	86.5%	86.5%

Category	Parameter	Variable	Rural value	Urban value	Low value	High value
	Attendance at 9 month post-partum visit	att_9mo	85.0%	85.0%	85.0%	85.0%
	Probability of stockout, HIV test kit	stockout	5.0%	5.0%	5.0%	5.0%
	Probability of receiving results, HIV	p_results	97.8%	97.8%	97.8%	97.8%
	Syphilis test coverage	testcoverage_syp	70.2%	79.3%	56.6%	83.7%
	Dual test coverage	testcoverage_dual	76.7%	86.6%	61.4%	91.9%
TEST CHARACTERISTICS - HIV	3rd gen: Sensitivity in Ag- stage	sens_Ag-	0	0	0	0
	3rd gen: Sensitivity in Ag+/Ab- stage	sens_a3	0	0	0	0
	3rd gen: Sensitivity in Ab+ stage	sens_c3	100.0%	100.0%	99.1%	100.0%
	3rd gen: Sensitivity in early infection	sens_e3	66.7%	66.7%	66.7%	66.7%
	3rd gen: Specificity	spec3	98.9%	98.9%	97.8%	99.6%
	Dual: Sensitivity in Ag+/Ab- stage	dual.sens.hiv.a	0	0	0	0
	Dual: Sensitivity in Ab+ stage	dual.sens.hiv.c	100.0%	100.0%	99.1%	100.0%
	Dual: Sensitivity in early infection	dual.sens.hiv.e	66.7%	66.7%	66.7%	66.7%
	Dual: Specificity (HIV)	hiv.spec.dual	98.9%	98.9%	97.8%	99.6%
TEST CHARACTERISTICS - SYPHILIS	RPR: Sensitivity	rpr.sens	80.0%	80.0%	77.0%	100.0%
	RPR: Specificity	rpr.spec	98.0%	98.0%	98.0%	98.0%
	TPHA: Sensitivity	tpha.sens	100.0%	100.0%	100.0%	100.0%
	TPHA: Specificity	tpha.spec	100.0%	100.0%	100.0%	100.0%
	RPR + Conf. TPHA, Combined Sensitivity	base.sens	80.0%	80.0%	80.0%	80.0%
	RPR + Conf. TPHA, Combined Specificity	base.spec	100.0%	100.0%	100.0%	100.0%
	Dual: Sensitivity (syphilis)	dual.sens.syp	93.0%	93.0%	81.5%	91.5%
	Dual: Specificity (syphilis)	dual.spec.syp	98.0%	98.0%	97.2%	100.0%
TREATMENT PARAMETERS	Probability of starting ART if test positive	p_ART	87.5%	98.8%	70%	100.0%
	Probability of being viral load suppressed if on ART	p_VL	88.1%	88.1%	88.1%	88.1%
	Retention in ART 1 year post-partum	ART_ret	73.8%	73.8%	70.0%	80.0%
	Proportion retained on ART each week (from power equation)	ART_drop_factor	0.996667	0.996667	0.996667	0.996667
	Syphilis Treatment Coverage	p.syp.tx.base	44.0%	44.0%	40.0%	55.0%
	Syphilis Treatment Coverage, Dual	p.syp.tx.dual	52.9%	59.7%	46.9%	58.9%
MISC	Duration of Ag- state	transition_ag	2.3	2.3	2.3	2.3
	Duration of Ag+/Ab- state	transition_ab	0.7	0.7	0.7	0.7
	Duration of Ab+ early infection (weeks)	transition_r	6	6	6	6
	Duration of recent infection	duration_of_recent_infection	9	9	9	9
MORTALITY	Mortality, adult females	mort_adultfemale	5.76923e-05	5.76923e-05	5.76923e-05	5.76923e-05
	Mortality, maternal/perinatal	mort_maternal	0.00057	0.00057	0.00057	0.00057
HIV INCIDENCE RATE OF INFANT	in utero per week, established infection	λutero_c	0.00186326	0.00186326	—	—
	in utero per week, recent infection	λutero_a	0.0164739	0.0164739	—	—

Category	Parameter	Variable	Rural value	Urban value	Low value	High value
TRANSMISSION	at parturition and early PP, established infection	λpart_c	0.0226	0.0226	—	—
	at parturition and early PP, recent infection	λpart_a	0.0294	0.0294	—	—
	per week of lactation, recent infection, exclusively breast fed (EBF), mid post-partum	λm_ebf_a	0.00540956	0.00540956	—	—
	per week of lactation, recent infection, exclusively breast fed (EBF), late post-partum	λl_ebf_a	0.00540956	0.00540956	—	—
	per week of lactation, established infection, exclusively breast fed (EBF), mid post-partum	λm_ebf_c	0.001998	0.001998	—	—
	per week of lactation, established infection, exclusively breast fed (EBF), late post-partum	λl_ebf_c	0.0005	0.0005	—	—
PROPORTIONAL REDUCTION IN HIV INCIDENCE RATE OF INFANT TRANSMISSION	due to infant prophylaxis with ARVs	arvred_inf	0.675	0.675	—	—
	due to viral load suppression	Vred	0.95	0.95	—	—
	due to breast feeding avoidance	nbfred	1	1	—	—
PROBABILITY OF HIV MODIFIERS	that infant receives prophylaxis	p_arvinf	0.936	0.936	—	—
	of breast feeding avoidance in early post-partum, HIV+	p_nbfepp_pos	0.025	0.025	—	—
	of breast feeding avoidance in early post-partum, HIV-	p_nbfepp_neg	0.001	0.001	—	—
	of breast feeding avoidance in mid post-partum, HIV+	p_nbfmpp_pos	0.212	0.212	—	—
	of breast feeding avoidance in mid post-partum, HIV-	p_nbfmpp_neg	0.0058	0.0058	—	—
	of breast feeding avoidance in late post-partum, HIV+	p_nbflpp_pos	0.334	0.334	—	—
	of breast feeding avoidance in late post-partum, HIV-	p_nbflpp_neg	0.009	0.009	—	—
SYPHILIS INFANT TRANSMISSION & OUTCOMES	No Syphilis, probability of Stillbirth	nosyp.p.stillbirth	0.000287	0.000287	—	—
	Treated in Pregnancy (not late), probability of Stillbirth	syp.tx.p.stillbirth	3.78%	3.78%	—	—
	Treated in Pregnancy (not late), probability of Neonatal death	syp.tx.p.death	1.8%	1.8%	—	—
	Treated in Pregnancy (not late), probability of Premature/low birth weight	syp.tx.p.lbw	2.2%	2.2%	—	—
	Treated in Pregnancy (not late), probability of Congenital syphilis	syp.tx.p.congsyp.symp	0.45%	0.45%	—	—
	Not treated/late treatment, probability of Stillbirth	syp.notx.p.stillbirth	21.0%	21.0%	—	—
	Not treated/late treatment, probability of Neonatal death	syp.notx.p.death	9.0%	9.0%	—	—

Category	Parameter	Variable	Rural value	Urban value	Low value	High value
	Not treated/late treatment, probability of Premature/low birth weight	syp.notx.p.lbw	6.0%	6.0%	—	—
	Not treated/late treatment, probability of Congenital syphilis case	syp.notx.p.congsyp.symp	15.0%	15.0%	—	—
	Third Trimester Start (cutoff for "early treatment")	early.preg.wks	32	32	—	—
INFANT MORTALITY	Weekly probability of neonatal death (up to 6 weeks), HIV- or HIV+ on ART	mort_n	0.00490112	0.00490112	0.00490112	—
	Weekly probability of infant death (remainder of model period), HIV-, HIV+ on ART, Syphilis -	mort_i	0.00030866	0.00030866	—	—
	Probability of survival to 1 year, HIV+ infants not on ART	surv_hiv	64.8%	100.0%	—	—
	Probability of survival to 1 year, HIV- infants or HIV+ infants on ART	surv_nhiv	96.4%	100.0%	—	—
DALYS	Life expectancy at birth	life_exp	66.65	66.65	—	—
	Life expectancy at 1 year	life_exp1	68.2	68.2	—	—
	Life expectancy at birth, HIV+	life_expHIV	26.2	26.2	—	—
	Disability Weight: LBW	dw_lbw	0.106	0.106	—	—
	Disability Weight: Congenital Syphilis Infection	dw_syp	0.315	0.315	—	—
	Disability weight: HIV: symptomatic, pre-AIDS	dw_HIVnotx	0.274	0.274	—	—
	Disability weight: HIV/AIDS: receiving antiretroviral treatment	dw_HIVtx	0.078	0.078	—	—
	Disability weight: AIDS: not receiving antiretroviral treatment	dw_AIDSnotx	0.582	0.582	—	—
	Disability weight: HIV + Syphilis (HIV/AIDS: receiving antiretroviral treatment)	dw_syp+HIVtx	0.368	0.368	—	—
	Disability weight: HIV + Syphilis (HIV: symptomatic, pre-AIDS)	dw_syp+HIVnotx	0.503	0.503	—	—
	Disability weight: HIV + Syphilis (HIV: symptomatic, pre-AIDS)	dw_syp+AIDSnotx	0.714	0.714	—	—
	Proportion of life with HIV, untreated	propLE_HIV_notx	90.0%	90.0%	—	—
	Years with DW from cogenital syphilis	years_congsyp	3	3	—	—
COSTS	Cost of Dual Test Kit	cost_dual	$3.62	$3.62	$2.90	$4.34
	Cost of 3rd Generation Test Kit	cost_3gen	$2.64	$2.64	$2.11	$3.17
	Additional costs for true positive screening tests, per HIV+ woman	cost_TP	$3.68	$3.68	$2.94	$4.42
	Additional costs for false positive screening tests, per HIV- woman	cost_FP	$26.39	$26.39	$21.11	$31.67
	Cost of maternal antiretroviral treatment per consenting confirmed positive woman, per week	cost_matART	$4.86	$4.86	$3.89	$5.83
	Cost of infant prophylaxis per consenting	cost_infprop	$2.32	$2.32	$1.86	$2.78

Category	Parameter	Variable	Rural value	Urban value	Low value	High value
	confirmed positive woman (overall, not per week)					
	Cost of maternal pre-exposure prophylaxis, per week	cost_prep	$6.19	$6.19	$4.95	$7.43
	Cost of infant antiretroviral treatment per week, <2 weeks	cost_infART_under2wks	$6.73	$6.73	$5.38	$8.08
	Cost of infant antiretroviral treatment per week, 2 weeks-1 year	cost_infART_over2wks	$6.73	$6.73	$5.38	$8.08
	Cost of RPR, per test	cost_rpr	$3.09	$3.09	$2.47	$3.71
	Average cost TPHA	cost_tpha	$0.59	$0.59	$0.47	$0.71
	Penicillin Cost	cost_penicillin	$0.64	$0.64	$0.51	$0.77
	Cost of 10M units of IV benzyl penicillin G treatment (2017 USD)	cost_iv_pen	$1.42	$1.42	$1.14	$1.70
	Inpatient bed-day	cost_bed_day	$8.41	$8.41	$6.73	$10.09
	Total cost of congenital syphilis treatment	cost_cong_tx	$85.52	$85.52	$68.42	$102.62
DISCOUNTED YLDs	Discount Rate	disc_rate	3.0%	3.0%	—	—
	Discounted lifetime YLDs, HIV only, on ART	disc_YLDs_HIVtx	1.4	1.4	—	—
	Discounted lifetime YLDs, HIV only, not on ART	disc_YLDs_HIVnotx	5.28	5.28	—	—
	Discounted lifetime YLDs, Congenital Syphilis Only	disc_YLDs_syp	0.891	0.891	—	—
	Discounted lifetime YLDs, LBW only	disc_YLDs_lbw	0.103	0.103	—	—
	Discounted lifetime YLDs, Coinfection, on ART	disc_YLDs_coinfectiontx	2.19	2.19	—	—
	Discounted lifetime YLDs, Coinfection, not on ART	disc_YLDs_coinfectionNotx	5.82	5.82	—	—
	Average ART adherence	prob_ART_adh	84.0%	84.0%	—	—

Appendix B. Supplementary Cost-Effectiveness Results Including Infant Outcomes

Table B1 presents the full base-case results including cumulative modeled infant HIV infections and congenital syphilis cases over the 20-year horizon. These columns were omitted from the main-text Table 3 for brevity; results for the dominated strategy (individual tests at first and late ANC) are included here for completeness.

Population	Strategy	Total costs (US$)	Total HIV infections	Total syphilis infections	Total DALYs	Incr. costs (US$)	Incr. DALYs averted	ICER/status	Comparator
Rural	Individual,	34,525,144	7,878	11,202	697,115	-	-	-	-

Population	Strategy	Total costs (US$)	Total HIV infections	Total syphilis infections	Total DALYs	Incr. costs (US$)	Incr. DALYs averted	ICER/status	Comparator
	first ANC								
Rural	Dual, first ANC	32,925,896	7,879	9,667	692,077	-1,599,248	5,038	Cost-saving	Individual, first ANC
Rural	Individual, first + late ANC	37,873,238	6,450	11,202	688,660	4,947,342	3,417	Dominated	Dual, first ANC
Rural	Dual, first + late ANC	34,745,417	6,451	9,667	683,621	1,819,520	8,456	215	Dual, first ANC
Urban	Individual, first ANC	16,053,044	3,309	4,864	311,264	-	-	-	-
Urban	Dual, first ANC	15,195,393	3,309	3,792	307,742	-857,651	3,523	Cost-saving	Individual, first ANC
Urban	Individual, first + late ANC	17,779,021	2,618	4,864	307,179	2,583,628	563	Dominated	Dual, first ANC
Urban	Dual, first + late ANC	16,117,200	2,619	3,792	303,655	921,807	4,086	226	Dual, first ANC
Kenya overall	Individual, first ANC	50,578,188	11,187	16,066	1,008,379	-	-	-	-
Kenya overall	Dual, first ANC	48,121,290	11,188	13,459	999,818	-2,456,898	8,560	Cost-saving	Individual, first ANC
Kenya overall	Individual, first + late ANC	55,652,259	9,068	16,066	995,839	7,530,969	3,979	Dominated	Dual, first ANC
Kenya overall	Dual, first + late ANC	50,862,616	9,070	13,459	987,277	2,741,327	12,542	219	Dual, first ANC

Note. ANC = antenatal care; DALY = disability-adjusted life year; ICER = incremental cost-effectiveness ratio. Infant HIV infections and congenital syphilis cases refer to cumulative modeled infant outcomes over the 20-year horizon. Individual tests refer to separate HIV and syphilis testing. Dual test refers to an integrated HIV/syphilis rapid diagnostic test. Negative incremental costs indicate cost savings. “Cost-saving” indicates that the strategy was less costly and more effective than its comparator. “Dominated” indicates that the strategy was more costly and less effective than an available alternative and was excluded from ICER-based decision-making. Cost-effectiveness was assessed using a threshold of US$596 per DALY averted. Costs are reported in 2017 US dollars. Values are rounded.

Appendix C. Distributional and HOC-based NHB Tables

Table C1. Distribution of DALYs averted from dual HIV/syphilis testing by rural-urban subgroup

Strategy	Population	Incremental DALYs averted	Share of modeled annual pregnancy population	Share of total health gains	Gains / population share	DALYs averted per 1,000
Dual test, first ANC only	Rural	5,038	69%	58.9%	0.85	4.48
Dual test, first ANC only	Urban	3,523	31%	41.1%	1.33	6.96
Dual test, first + late ANC	Rural	8,456	69%	67.4%	0.98	7.51
Dual test, first + late ANC	Urban	4,086	31%	32.6%	1.05	8.08

Note. Comparators are the same as defined in Table 3. Incremental DALYs averted are calculated relative to each strategy's comparator as defined in Section 2.4. Share of gains relative to population share is calculated as each subgroup's share of total health gains divided by its share of the modeled annual pregnancy population. Values below 1 indicate less-than-proportional gains relative to population share; values above 1 indicate more-than-proportional gains.

Table C2. Exploratory HOC-based NHB under alternative health opportunity-cost allocation assumptions

Strategy	Allocation assumption	Rural HOC-based NHB per 1,000	Urban HOC-based NHB per 1,000	Urban-rural gap
Dual test, first ANC only	Population-share allocation	7.00	9.49	2.49
Dual test, first ANC only	Equal 50/50 allocation	6.31	11.04	4.73
Dual test, first + late ANC	Population-share allocation	4.69	5.26	0.57
Dual test, first + late ANC	Equal 50/50 allocation	5.47	3.53	-1.94

Note. HOC = health opportunity cost; NHB = net health benefit. HOC-based NHB was calculated as DALYs averted minus allocated HOC DALYs. Health opportunity costs were calculated using a threshold of US$596 per

DALY averted. Positive urban-rural gaps indicate higher HOC-based NHB per 1,000 pregnant women among urban populations; negative values indicate higher HOC-based NHB among rural populations.

Appendix D. ANC Cascade Equalization Analysis

Table D1. Baseline rural and urban ANC cascade parameters used in cascade equalization analysis

Cascade domain	Parameter	Rural value	Urban value
ANC contact/timing	First ANC attendance	97.60%	98.90%
ANC contact/timing	Mean first ANC timing	21.7 weeks	20.4 weeks
Testing uptake	Syphilis test coverage	70.20%	79.30%
Testing uptake	Dual test coverage	76.70%	86.60%
Treatment uptake	ART initiation after positive test	87.50%	98.80%
Treatment uptake	Syphilis treatment coverage, dual testing	52.90%	59.70%
Delivery contact	Facility delivery	83.10%	97.00%

Table D2. One-factor-at-a-time ANC cascade equalization results among rural pregnant women

Strategy	Equalized domain	Modeled rural DALYs after substitution	Absolute DALY reduction	Relative reduction vs rural baseline (%)
Dual test, first ANC only	ANC contact	691,577	500	0.07%
Dual test, first ANC only	Testing uptake	690,183	1,894	0.27%
Dual test, first ANC only	Treatment uptake	689,130	2,947	0.43%
Dual test, first ANC only	All linked stages	687,116	4,961	0.72%

Strategy	Equalized domain	Modeled rural DALYs after substitution	Absolute DALY reduction	Relative reduction vs rural baseline (%)
Dual test, first + late ANC	ANC contact	683,338	283	0.04%
Dual test, first + late ANC	Testing uptake	681,727	1,894	0.28%
Dual test, first + late ANC	Treatment uptake	680,355	3,266	0.48%
Dual test, first + late ANC	All linked stages	678,166	5,455	0.80%

Note. Values show reductions in modeled rural DALYs after substituting selected rural cascade parameters with corresponding urban values while holding other inputs constant. “All linked stages” represents simultaneous equalization of ANC contact, testing uptake, and treatment uptake, and is not the sum of isolated rows. Larger reductions indicate greater model sensitivity to that cascade domain.

Table D2. Sequential counterfactual substitution across ANC cascade stages

Strategy	Equalized domain	Modeled rural DALYs after substitution	Absolute DALY reduction	Cumulative reduction vs rural baseline (%)
Dual test, first ANC only	Baseline rural	692,077	—	—
Dual test, first ANC only	ANC contact	691,577	500	0.07%
Dual test, first ANC only	Testing uptake	690,089	1,896	0.29%
Dual test, first ANC only	Treatment uptake	687,116	2,973	0.72%
Dual test, first + late ANC	Baseline rural	683,621	—	—
Dual test, first + late ANC	ANC contact	683,338	283	0.04%
Dual test, first + late ANC	Testing uptake	681,463	1,897	0.32%
Dual test, first + late ANC	Treatment uptake	678,166	3,297	0.80%

Note. ANC = antenatal care; DALY = disability-adjusted life year. Sequential substitutions were applied cumulatively in the following order: ANC contact, testing uptake, and treatment uptake. Stage-specific DALY reduction represents the change from the previous sequential step, not an independent causal effect. Cumulative reduction vs rural baseline is calculated as the percentage reduction in modeled rural DALYs from the baseline rural scenario to each sequential step.

Appendix E. Sensitivity Analysis Parameter Ranges

Figure E1. One-way sensitivity analysis for efficiency: change in incremental net health benefit

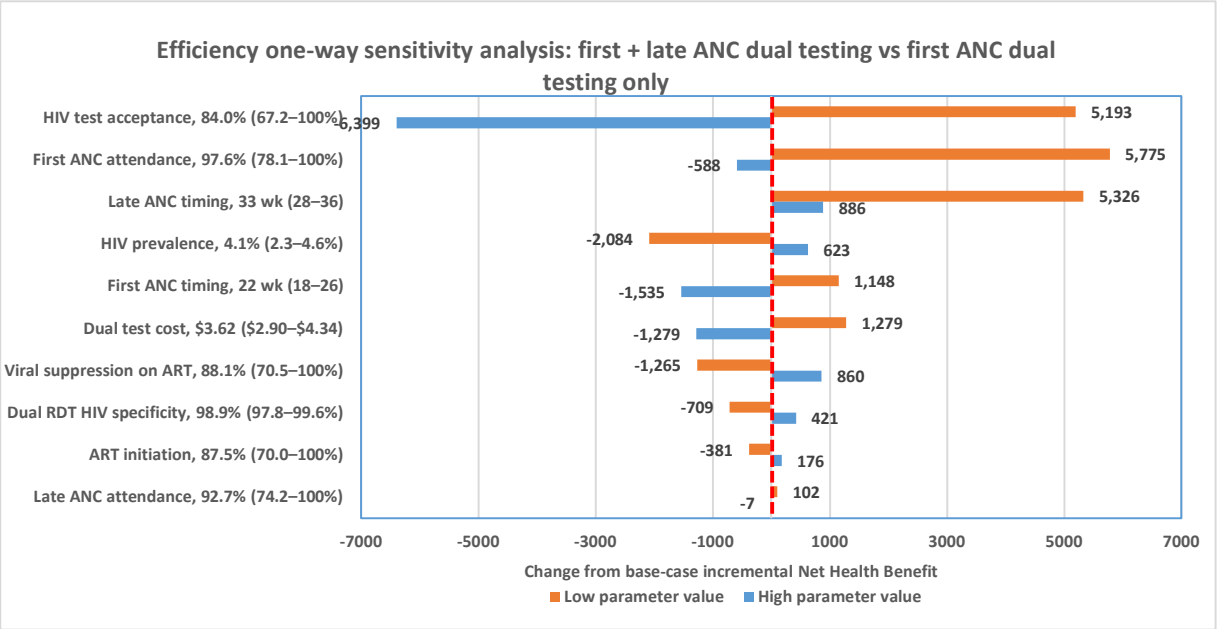

Figure note. Bars show the change from base-case incremental NHB for dual testing at first plus late ANC compared with dual testing at first ANC only. Positive values indicate increased NHB relative to the base case; negative values indicate reduced NHB. Base-case incremental NHB was 7,942 DALYs for the modeled Kenya pregnancy population.

Figure E2. One-way sensitivity analysis for equity: change in urban-rural incremental DALY benefit gap

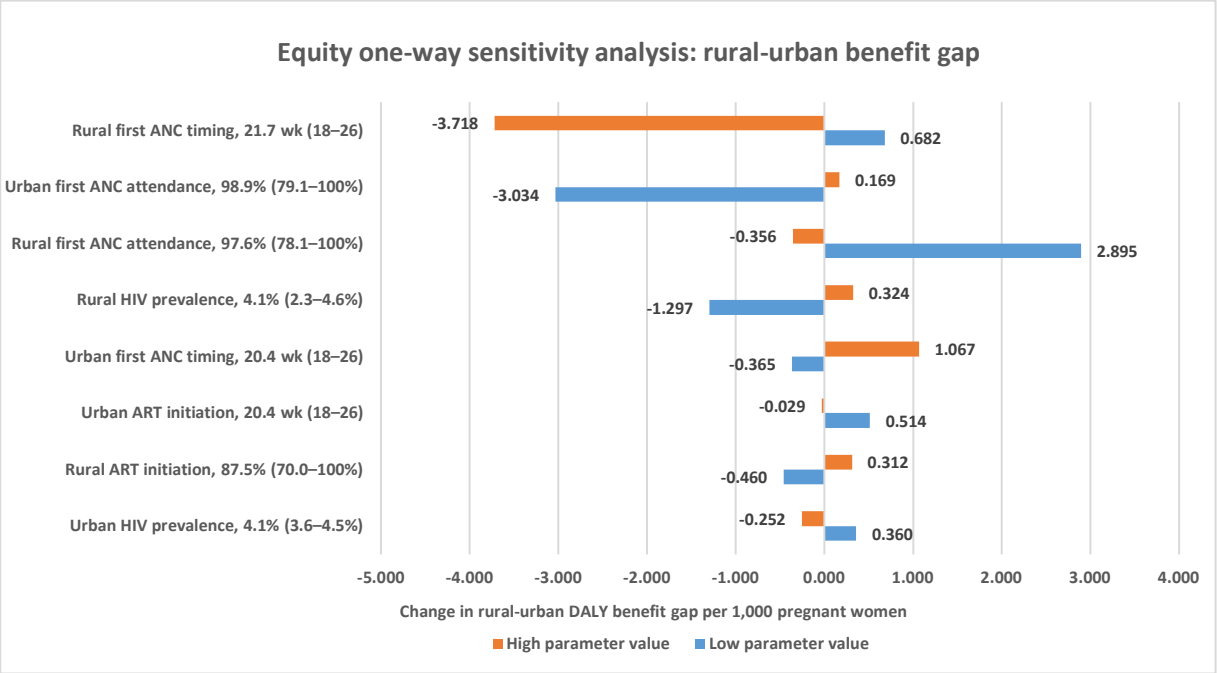

Figure note. Bars show the change from the base-case urban-rural benefit gap, defined as urban minus rural incremental DALYs averted per 1,000 pregnant women. Positive values indicate an increase in the urban advantage; negative values indicate a shift toward greater rural per-capita benefit.