PROMOTING HIV TESTING BY MEN IN UGANDA: ALIGNING PREFERENCES AND POLICY

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ABSTRACT

Elisabeth M. Schaffer: Promoting HIV Testing by Men in Uganda: Aligning Preferences and Policy
(Under the direction of Harsha Thirumurthy)

Background: Men in sub-Saharan Africa are less likely than women to test for HIV. The gap in male testing coverage leads to increased morbidity and mortality for HIV-positive men compared to HIV-positive women and to missed opportunities to prevent transmission. One approach that has demonstrated potential to increase male testing is community-based testing.

Objective: The objective of this dissertation was to provide evidence-based guidance to optimize the delivery of community-based HIV testing to promote uptake by men in sub-Saharan Africa.

Methods: I administered a discrete choice experiment (DCE) to a random sample of 203 adult male residents of rural Uganda. The DCE elicited stated preferences for attributes of community-based testing that can be modified to promote testing. I used a random parameters logit model to estimate preferences and simulate uptake under alternative service delivery models. I estimated additional random utility models and conducted covariate analyses to investigate preference heterogeneity. I incorporated predictions of testing uptake into a decision analytic model to evaluate the cost-effectiveness of alternative service delivery models to increase HIV testing and diagnosis.

Key Findings: Participants stated strong preferences for access to antiretroviral therapy (ART) at the time of testing. The predicted uptake of testing under alternative service delivery models increased 26-44 percentage points when immediate access to ART for HIV-positive persons was provided. Incentives of US $0.85 also influenced participants' choices and increased the predicted testing uptake 6-12 percentage points. It was unclear whether preference heterogeneity could be attributed to participants' characteristics. The most cost-effective service delivery models to increase HIV testing were not necessarily most cost-effective at increasing diagnosis. Changes of only a few percentage points in the probability that men who access a given service delivery model would test positive greatly increased the likelihood that the service delivery model was cost-effective at increasing diagnosis.

Conclusion: The stated preference methods used in this dissertation reveal opportunities to improve community-based HIV testing to encourage uptake by men. Further research is warranted to corroborate the external validity of stated preferences to predict revealed preferences and to determine how community-based service delivery models can effectively reach undiagnosed HIV-positive men.

To my parents, for your love and support.

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PREFACE

This dissertation is organized in a non-traditional format. The first chapter provides an overview of the topic and presents the specific aims of the dissertation. Chapters 2, 3, and 4 are research papers for the three dissertation aims, intended to stand alone as publishable manuscripts and thus have redundancies with other chapters. Chapter 5 concludes with a summary of findings, implications for policy and practice, and plans for future research.

Chapter 2 of this dissertation is under review for publication at the time of submitting this dissertation as part of my doctoral degree requirements to the faculty of the University of North Carolina at Chapel Hill. Copyright will be transferred to the publisher upon acceptance for publication.

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LIST OF ABBREVIATIONS

AIC	Akaike information criterion
AIDS	Acquired immune deficiency syndrome
ART	Antiretroviral therapy/treatment
BIC	Bayesian information criterion
CD4	Cluster differentiation four
CEA	Cost-effectiveness analysis
CEAC	Cost-effectiveness acceptability curve
CHC	Community health campaign
CI	Confidence interval
DCE	Discrete choice experiment
HBT	Counselor-administered home-based testing
HIV	Human immunodeficiency virus
HIVST	HIV self-testing
ICER	Incremental cost-effectiveness ratio
LCL	Latent class logit
MDT	Multi-disease testing
OR	Odds ratio
PEPFAR	United States President’s Emergency Plan for AIDS Relief
PPV	Positive predictive value
PSA	Probabilistic sensitivity analysis
RPL	Random parameters logit
SD	Standard deviation
SE	Standard error

UGX	Ugandan shillings
UNAIDS	Joint United Nations Program on HIV/AIDS
US $	United States dollars
WHO	World Health Organization
WTP	Willingness-to-pay

CHAPTER 1. INTRODUCTION

1.1. Overview and Specific Aims

Increasing HIV awareness among HIV-positive persons is the first objective in a global strategy to end HIV/AIDS. To significantly reduce viral transmission by 2030, the Joint United Nations Program on HIV/AIDS (UNAIDS) has proposed the "90-90-90 targets" which urge countries to ensure that 90% of HIV-positive persons know they have HIV, 90% of persons diagnosed with HIV are receiving antiretroviral therapy (ART), and 90% of persons receiving ART are virally suppressed by 2020 (1). While considerable progress has been made to expand access to HIV testing, there are a number of important gaps in testing coverage including low coverage among men in sub-Saharan Africa. Men are less likely than women to have ever tested, to have tested recently, and to know when they are HIV-positive (2,3).

HIV testing is an essential step to access treatment and care for HIV/AIDS, and low testing coverage among men in sub-Saharan Africa translates into missed opportunities to link HIV-positive men to services that are essential to promote and sustain their health. Consequences of the male testing gap include missed and late HIV diagnosis, delayed start of ART, and ultimately increased morbidity and mortality for HIV-positive men compared to HIV-positive women (4–9). HIV testing is also critical to prevent HIV transmission. Knowledge of one's serostatus leads to safer sexual decision making. Individuals who learn that they are HIV-positive following voluntary counseling and testing have fewer sexual partners and increased condom use than individuals who test HIV-negative (10,11). Additionally, ART has become fundamental to HIV prevention since the landmark HPTN 052 trial demonstrated that adherence to ART reduces sexual transmission in serodiscordant couples by 96% (12). It is therefore critical that HIV-positive men know their status and enroll in treatment not only for their own health but to prevent HIV transmission to their sexual partners. Men who test HIV-negative also stand to benefit from learning their status. HIV testing provides an opportunity to link HIV-negative men to voluntary medical male circumcision which reduces female-to-male HIV transmission by 50-60% (13–15) and to pre-exposure prophylaxis which reduces HIV acquisition from an HIV-positive partner by as much as 90% when taken daily with high adherence (16,17).

One approach that has considerable potential to increase HIV testing by men and curtail consequences associated with the gap in male testing coverage is community-based HIV testing (18–20). Community-based testing takes HIV testing outside of health facilities to "reach people where they are". Various community-based service delivery models have been implemented in sub-Saharan Africa including mobile, home, workplace, event, and self-testing programs (18,21). Compared to facility-based testing, community-based testing has achieved higher coverage among men (18), and it is likely that the convenience and accessibility of community-based HIV testing appeal to men and reduce barriers related to travel, costs, and stigma (22,23). Other advantages of community-based HIV testing include increased proportions of first-time testers and individuals who have high CD4 counts compared to facility-based testing (18,21). Additionally, community-based HIV testing achieves high enrollment in care and ART initiation when facilitated linkage support is provided (18).

For these reasons, community-based HIV testing is a compelling approach to increase male testing coverage in sub-Saharan Africa, yet a number of important knowledge gaps must be addressed for decision makers to optimize the delivery of community-based HIV testing to promote uptake by men. The overall objective of this dissertation was to provide evidence-based guidance for decision makers who seek to harness community-based HIV testing to promote testing by men in sub-Saharan Africa. I achieved this objective by pursuing three analytical aims. Specifically, my aims were to:

Aim 1: Elicit men's preferences for attributes of community-based HIV testing and predict uptake of HIV testing under alternative service delivery models;

Aim 2: Describe heterogeneity in men's preferences for attributes of community-based HIV testing;

Aim 3: Evaluate the cost-effectiveness of alternative community-based service delivery models to increase HIV testing and HIV diagnosis among men.

1.2. Methods

My analytical approach involved a synthesis of methods from the fields of health economics and decision sciences. Each of these fields contributes unique strengths to decision making. Health economics provides a strong theoretical foundation and rigorous microeconomic modeling methods to investigate individual preferences and behavioral responses to health policies and interventions. Decision sciences, in turn, offers a range of mathematical modeling methods to incorporate what we know about diseases, people, and the impact of health policies and interventions to make population-level projections of effectiveness and cost-effectiveness under alternative scenarios.

Given the need to promote HIV testing by men in sub-Saharan Africa, I first turned to the field of health economics and began my dissertation research with a stated preference study. Economists have long studied choices and, when choices are made in the real world, we can observe and analyze choices as revealed preferences. Stated preference research is similar to revealed preference research except that the choices individuals make are hypothetical (24). Although a potential pitfall of stated preference research is that hypothetical choices might not reflect real world choices, evidence upholds the external validity of stated preferences to predict revealed preferences (25).

The most well known type of stated preference research study and the type of study I conducted for my dissertation is a discrete choice experiment (DCE). A DCE is a survey that elicits individuals' preferences for attributes of a product or service (26). Participants are presented with a series of hypothetical choices in which two or more product or service alternatives are compared. Each alternative is described by its attributes and participants are prompted to evaluate the attributes to choose their preferred alternatives (27,28). Responses are used to estimate preferences, which reveal the relative importance of the attributes for participants' choices (29). A unique advantage of a DCE and the primary reason I employed a DCE for this dissertation is that preference estimates can also be used to predict uptake of alternatives (30–32). Uptake predictions provide a valuable link to the realm of mathematical modeling (33). By understanding how likely it is that individuals are to use a health product or, in this context of this dissertation, health service, we can model how engagement with health services translates into population health outcomes.

This dissertation proceeds in two methodological phases. In Aims 1 and 2, I employ econometric modeling techniques to investigate men's stated preferences and heterogeneity in men's preferences for attributes of community-based service delivery models for HIV testing. I also use preference estimates to predict uptake of HIV testing under alternative service delivery models. In Aim 3, I incorporate uptake predictions into a mathematical model to predict the impact and cost-effectiveness of alternative community-based service delivery models to promote HIV testing and HIV diagnosis among men.

1.3. Research Setting

The setting for my dissertation research was Uganda. An estimated 1.35 million people live with HIV in Uganda (34). As of 2017, 1.05 million (77%) have been diagnosed, and 950,000 (68%) are receiving ART (34). While over 90% of HIV-positive women and children have been diagnosed, only 61% of HIV-positive men have been diagnosed (34). Diagnosis of HIV among men is therefore critical to attain the first 90-90-90 target in Uganda.

The HIV epidemic in Uganda is generalized and bears similarities to other HIV epidemics in Eastern and Southern Africa (35). Uganda began offering HIV testing in 1990 and the testing landscape has evolved dramatically since then (36). Voluntary counseling and testing is offered at health facilities, and a range of community-based service delivery models for HIV testing have been implemented including counselor-administered home-based testing, workplace testing, mobile testing, and HIV testing at community health campaigns (35). Since the end of 2016, pilot demonstrations and randomized trials have been launched to investigate the use of oral fluid-based HIV self-tests to promote testing among target populations of fishermen, female sex workers, and male partners of women attending antenatal care (37–39). However, oral fluid-based HIV self-tests are not yet widely available.

1.4. Data

The DCE was integrated into data collection for a large randomized trial (NCT02890459). The randomized trial enrolled adult (≥18 years) male residents from four neighboring parishes of Mbarara District, a rural district in southwestern Uganda, and investigated the comparative effectiveness of novel behavioral economic strategies to incentivize participants to test for HIV at a local community health campaign (40). Participants were identified for recruitment into the study by way of a household census. Eligible men who agreed and provided their informed consent to participate in the trial were administered an enrollment questionnaire. The questionnaire asked participants about their socio-demographic characteristics, health, and history of HIV testing. The questionnaire also included the DCE, and the DCE was administered to a random subsample of trial participants. The questionnaire was administered before participants were randomized to different incentive interventions. Data collected by way of the enrollment questionnaire formed the principal data source for my dissertation. Aims 1 and 2 rely on these data. Aim 3 incorporates results from Aim 1 as input estimates for parameters of a mathematical model, along with additional parameter estimates that I collected from peer-reviewed literature and published sources.

1.5. Significance and Innovation

The research papers that here follow are significant because they provide timely evidence and strategic guidance for decision makers who seek to respond to a pressing challenge confronting the successful scale-up of HIV/AIDS services and attainment of the UNAIDS 90-90-90 targets in sub-Saharan Africa. Others have realized and demonstrated how DCEs can be applied to generate uptake predictions that can be incorporated into mathematical models (33,41). I, however, am the first to apply these methods to determine how decision makers can promote HIV testing by men in sub-Saharan Africa. I apply a close awareness of the HIV testing landscape in sub-Saharan Africa and the policy frontier in Uganda to investigate service delivery models and interventions to promote male testing that have become policy relevant only recently. I thus deliver some of the first findings regarding the impact that such service delivery models and interventions are likely to have on uptake of HIV testing by men. Additionally, I advance the methods base for the use of DCEs to furnish estimates that can be incorporated into mathematical models by demonstrating how uptake predictions can be calibrated to match revealed preference data to enhance the external validity of DCE-based predictions.

CHAPTER 2. PROMOTING HIV TESTING BY MEN: A DISCRETE CHOICE EXPERIMENT TO ELICIT PREFERENCES AND PREDICT UPTAKE UNDER ALTERNATIVE SERVICE DELIVERY MODELS IN UGANDA

2.1. Introduction

The Joint United Nations Program on HIV and AIDS (UNAIDS) has proposed a set of ambitious objectives known as the "90-90-90 targets" that countries should attain by 2020 in order to end the AIDS epidemic as a major global health threat by 2030. Increasing awareness of HIV status such that 90% of HIV-positive persons know their status constitutes the first target and sets the standard for progress toward the remaining two targets (1). While considerable progress has been made to expand access to HIV testing, there are a number of important gaps in testing coverage including low uptake by men in sub-Saharan Africa. Men are less likely than women to have ever tested and to have tested recently for HIV (2,3). Consequences of the testing disparity include missed or late diagnosis of HIV, delayed initiation of antiretroviral therapy (ART), and increased mortality for HIV-positive men (4–9). Low rates of male testing also constitute missed opportunities to prevent transmission as HIV testing provides not only an entry point for linking individuals to a health system for their own care but for providing treatment, counseling, and additional interventions for HIV prevention (12,42).

Community-based HIV testing achieves higher coverage among men than standard facility-based testing and is a strategic approach to expand male testing (18,19). Various community-based service delivery models can be harnessed to deliver HIV testing. Mobile, home, and event-based service delivery models have been widely implemented in sub-Saharan Africa, and the World Health Organization (WHO) has recently called for the expansion of novel service delivery models that use oral fluid-based HIV self-tests to promote testing, particularly among hard-to-reach and at-risk populations (43). Community-based service delivery models also provide flexible platforms to improve how HIV testing is delivered to encourage men to test for HIV. To the extent that certain attributes of how testing is delivered appeal to men and can be modified to motivate more men to test for HIV, such improvements can be considered interventions to increase male testing. For decision makers who seek to optimize the delivery of HIV testing to expand coverage among men, there is a vital need to identify attributes of HIV testing that men prefer and to prioritize service delivery models that increase uptake of HIV testing by men.

A discrete choice experiment (DCE) is a useful survey tool for eliciting preferences for attributes of a health service and can also be used to predict uptake under alternative service delivery models (28,31). DCEs have grown increasingly popular in health economics, and a few studies have investigated preferences for HIV testing among diverse populations in sub-Saharan Africa (44–46). Yet, none have used a DCE to predict uptake of HIV testing under alternative service delivery models. Predictions are particularly useful when observed estimates of testing uptake are unavailable, as is the case for novel service delivery models and interventions to promote testing that have not yet been implemented. Moreover, predictions of testing uptake can be incorporated as parameters in mathematical models to assess the health outcomes and cost-effectiveness of providing HIV testing to men under alternative service delivery models (33,41).

To our knowledge, our study is the first to use a DCE to elicit preferences and predict uptake of HIV testing by men under alternative service delivery models in sub-Saharan Africa. We estimate preferences for community-based service delivery models that hold strong potential to appeal to men and for policy-relevant attributes of these service delivery models that represent timely interventions that could be undertaken to increase male testing in sub-Saharan Africa. We then simulate uptake of HIV testing under different scenarios relevant to decision makers who seek to expand male testing coverage. Our findings are important as they reveal the comparative potential of promising service delivery models to promote male testing and indicate the impact that several interventions are likely to have on uptake of HIV testing by men in sub-Saharan Africa.

2.2. Methods

Study Setting and Population

The DCE was conducted during the enrollment phase (April – June 2016) of a randomized trial investigating the comparative effectiveness of novel incentive strategies to encourage men to test for HIV at a local, multi-disease community health campaign (NCT02890459). The trial was conducted in Mbarara District, a rural region of southwestern Uganda where HIV prevalence among adult males is 7.0 - 8.0% (47).

Prior to enrollment for the trial, we conducted a census of households in four neighboring parishes within Mbarara District. Male residents who were ≥18 years of age were eligible to participate in the trial if they had been living in the community for at least six months in the past year and were not planning to move away in the next three months. All eligible men present at the time of the census were invited to participate in the trial.[1] Men who accepted to participate were administered an enrollment questionnaire. The DCE formed one section of the questionnaire.[2]

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[1]If eligible men were not available when research assistants visited their homes, two additional attempts were made to reach the men.

[2]Following administration of the enrollment questionnaire, participants were offered incentives to take an HIV test at a community health campaign that would be visiting their community in roughly 4-6 weeks. The incentives were material prizes, and participants were randomized to incentives that varied by type and cost.

The Discrete Choice Experiment

Community-based service delivery models and attributes of HIV testing that can be leveraged to promote male testing were developed based on a literature review and expert confirmation. We first reviewed the literature to identify service delivery models that have been implemented or are under active consideration in sub-Saharan Africa and selected three based on their potential to increase HIV testing by men in Uganda: 1) HIV testing at a community health campaign; 2) counselor-administered home-based testing; and 3) HIV self-testing (HIVST) using an oral fluid-based test obtained at a local pharmacy. We then added attributes to the DCE to represent changes to how each service delivery model is implemented that could promote male testing. We included three binary attributes that indicated whether: 1) multi-disease testing; 2) immediate access to ART for HIV-positive persons; and 3) a financial incentive were available. These service delivery models and attributes are described below, and the levels used to describe the service delivery models and attributes to participants are presented in **Table 1**.

Community-based service delivery models for HIV testing

HIV testing at a community health campaign: Community health campaigns are a form of mobile testing that have achieved high population-level coverage of testing in several parts of sub-Saharan Africa (20,23,48,49). Community health campaigns are held at convenient locations and typically offer HIV testing with other health services. Uptake of HIV testing by men at prior community health campaigns is high relative to facility-based testing (20).

Counselor-administered home-based testing: Through home-based testing, a health counselor makes door-to-door visits to households in a community and offers to test household members for HIV. Home-based testing has been implemented in Uganda and found to be effective at reaching population groups with low rates of prior testing (36,50). Previous findings suggest men prefer home-based testing to facility-based testing (51,52).

HIVST using an oral fluid-based test obtained at a local pharmacy: Oral fluid-based HIV self-tests allow individuals to take their own sample, perform a simple test, and interpret the result on their own. HIVST has been shown to have high acceptability for diverse populations, including groups that are less likely to access facility-based testing (53–55). HIVST is not yet widely available in Uganda, and we included the distribution of self-tests at local pharmacies as a service delivery model that could be introduced.[3]

Attributes of HIV testing

Access to ART for HIV-positive persons: Ensuring immediate access to ART for individuals who test positive could be reassuring to men who are uncertain of their status. Further, many countries including Uganda have recently adopted WHO's "Treat All" guideline recommendation that all individuals who are diagnosed with HIV should start ART, regardless of disease stage or CD4 count (42,56). Greater efforts are being made to ensure that ART is available at the time of HIV testing, and it is timely to assess the impact that providing immediate access to ART for HIV-positive persons could have on uptake of HIV testing by men.

Availability of multi-disease testing: Providing testing for multiple diseases at the time of HIV testing could reduce barriers due to HIV-related stigma and appeal to men who perceive their risk of being HIV-positive to be low. Integration of testing services has recently been shown to be feasible in several countries, including Uganda, and is receiving growing attention

[3]We focused on distribution of self-tests at local pharmacies as pharmacies have considerable reach across Uganda. Moreover, a national campaign has been launched in neighboring Kenya to make self-tests available in pharmacies and there is therefore precedent for the distribution of self-tests at local pharmacies. Other distribution channels are, however, possible and under investigation elsewhere.

(20,57). We included the ability to test for tuberculosis, malaria, hypertension, and diabetes at the time of HIV testing as an attribute in the DCE.[4]

Financial incentive for HIV testing: Offering incentives has been proposed as an intervention to increase male testing and could help offset financial or psychosocial costs that men associate with testing (58–61). A systematic review found that incentives are effective at increasing HIV testing for diverse populations, especially when testing is provided outside of health facilities (58). We included the provision of a fixed incentive of 3,000 Ugandan shillings (about US $0.85) for HIV testing as an attribute in the DCE.[5]

Choice Sets and Experimental Design

Choice sets were constructed to display two alternatives for HIV testing and an opt-out alternative so that participants could choose not to test if neither testing alternative appealed to them. Each testing alternative was defined by a specific service delivery model and set of attribute levels. In cases where pairing an attribute level with a specific service delivery model would result in combinations that policymakers would not consider implementing, we defined constraints such that the attribute and service delivery model levels were not paired.[6]

In total, ten testing alternatives were possible and we generated an experimental design from the 45 unique pairwise combinations of alternatives that could be presented in choice sets. We selected a fraction of the total possible choice sets to ease participant burden. The natural preference ordering of the levels for the binary attributes increased the design efficiency and

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[4]These diseases are endemic to the region and, in the case of non-communicable diseases, on the rise in sub-Saharan Africa. Screening for all of these diseases can be performed using rapid test technologies and is thus amenable to community-based delivery (see, for instance, Chamie et al, 2012).

[5]This amount approximates the cost of transportation to a community-based venue.

[6] Four constraints total were included in the experimental design and are presented in Appendix A.

yielded several choice sets that allowed little information to be gained from the trade-offs made by a given choice; we excluded these choice sets. We evaluated the remaining choice sets and selected 10 to maximize the range of trade-offs that participants could make when choosing between testing alternatives. We blocked the experimental design into 2 versions of 5 choice sets and evaluated the design efficiency using Sawtooth Software (Orem, UT, USA). The steps taken to construct the experimental design are presented in **Figure 1**.

Survey Administration

Twenty-four enumerators were trained to enroll participants and administer a questionnaire using handheld tablets. The DCE section was programmed for random delivery to 1 in 10 participants. Along with the handheld tablets, the enumerators were provided booklets that contained illustrations to describe the choice sets to participants. A sample choice set is presented in **Figure 2**. All questionnaire items were translated from English into Runyankole, the local language, and read aloud. During the first two weeks of enrollment, we field-tested a version of the DCE to assess participant understanding of the choice sets. We revised the wording of the levels and adjusted the formatting of the choice sets to enhance comprehension.

2.3. ECONOMETRIC ANALYSIS

Conceptual Framework and Random Parameters Logit Model Specification

Random utility theory provides the conceptual framework for discrete choice analysis (62,63). According to random utility theory, the utility U_{nit} an individual *n* derives from alternative i in choice set *t* consists of a deterministic component V_{nit} that is a function of observed variables and an unobservable random component ε_{nit} such that:

$$U_{nit} = V_{nit} + \varepsilon_{nit} = \beta' x_{it} + \varepsilon_{nit}$$

where x_{it} is a vector of observed variables that define alternative *i* and β' is a vector of marginal utility (i.e. preference) parameters associated with the variables. Different assumptions regarding the distribution of ε_{nit} lead to different random utility models (64).

We employed a random parameters logit (RPL) model to estimate men's preferences for HIV testing service delivery models and their attributes. The RPL model allows the parameters of observed variables to vary over individuals (64,65). The vector of parameter estimates β'_n for an individual *n* can be expressed as the sum of the population mean b' and the individual deviation $\eta_n{}'$, which represents the individual's preferences relative to the average preferences of the population (66):

$$U_{nit} = \beta'_n x_{it} + \varepsilon_{nit} = (b' + \sigma'\eta_n)x_{it} + \varepsilon_{nit}$$

In this specification, $\boldsymbol{b'}$ and $\boldsymbol{\sigma'}$ are estimated by the model, while $\boldsymbol{\eta_n \sim N(0,1)}$ and is correlated over alternatives and choices for individuals. The remaining term, $\boldsymbol{\varepsilon_{nit}}$, represents the unobserved portion of utility assumed to be independent and identically distributed extreme value. The RPL model is an appealing specification, as it allows for correlation across choices and heterogeneity in participant preferences.[7] The RPL model also allows for flexible substitution patterns across choice alternatives. This flexibility is essential for generating accurate predictions of testing uptake.

Substituting variables for the levels associated with the alternatives participants viewed in the DCE yields the following empirical specification that we estimated:[8]

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[7]For the choice context investigated here, it is likely that choices made by the same individual are correlated and that there is heterogeneity in preferences across our broad-based sample.

[8]Model parameters were estimated using 500 Halton draws and standard errors clustered at the individual level.

$$V_{nit} = \beta_{nCHC} Community\ health\ campaign_{it} + \beta_{nHBT} Home\_based\ testing_{it} + \beta_{nHIVST} HIV\ self\_testing_{it} + \beta_{nMDT} Multi\_disease\ testing_{it} + \beta_{nART} Immediate\ ART_{it} + \beta_{nInc} Incentive_{it} + \beta_{nWNT} Would\ not\ test_{it}$$

where $Community\ health\ campaign_{it}$, $Home\_based\ testing_{it}$, $HIV\ self\_testing_{it}$, $Multi\_disease\ testing_{it}$, $Immediate\ ART_{it}$, and $Incentive_{it}$ represent the levels that defined the testing alternatives and $Would\ not\ test_{it}$ is an alternative-specific constant that accounts for the fact that a participant could always choose to opt-out of HIV testing. We employed effects coding to ensure that the level parameters were not correlated with the constant for the opt-out alternative (67). We tested for interactions between the service delivery model and attribute levels. Additionally, we estimated a specification that allowed for correlation between coefficients.[9]

Prediction and Calibration of HIV Testing Uptake

Results from a RPL model are typically reported as mean coefficients, yet coefficients can also be simulated for each individual in the sample and we harnessed this capability to make predictions of testing uptake. We used the individual coefficients to calculate the utility that each individual associated with the testing alternatives presented in the DCE and the alternative to opt-out of HIV testing. We then applied a utility maximization rule that an individual would test for HIV under a given service delivery model if his utility for that alternative exceeded his utility for all other alternatives in a given choice scenario. Finally, we compared our predictions to observed estimates of testing uptake reported in peer-reviewed literature and calibrated our predictions to achieve concordance with reference values for service delivery models that have

[9]The inclusion of constraints in the experimental design made it possible that coefficients were correlated. We estimated a RPL model that allows coefficients to be correlated to account for this possibility.

been implemented in the study context.[10] All analyses were conducted using Stata 14.1 (StataCorp, College Station, TX, USA).

2.4. Results

Sample Characteristics

In total, 203 men (88% of those who were eligible to participate in the randomized trial and who were randomly selected to receive the DCE) participated in the DCE. Nine participants self-reported an HIV-positive status at enrollment and were excluded from analysis. Characteristics of participants who comprised the analytical sample are presented in **Table 2**. Most participants had a primary education or less (70%), were employed in agriculture or manual labor (74%), and were married (63%). One-third (34%) were less than 30 years of age and over half (53%) reported that they tested for HIV in the past 12 months. Eighteen percent of participants perceived their risk of HIV to be moderate or high, and 23% had two or more sexual partners in the past 12 months.

Estimated Preferences

Table 3 presents results from the RPL model. The results were largely similar across specifications. The large negative coefficient for the alternative-specific constant for the opt-out alternative reveals that, on average, participants preferred to test for HIV using the testing alternatives presented in the DCE rather than to opt-out of HIV testing. Counselor-administered home-based testing and HIV testing at a community health campaign were generally preferred over obtaining an oral fluid-based self-test at a local pharmacy. Ensuring immediate access to ART for HIV-positive persons and the provision of a US $0.85 incentive for HIV testing

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[10]We followed a calibration procedure described by Kenneth Train in *Discrete Choice Methods with Simulation* (2009). Further information regarding the calibration procedure and the reference values used to achieve concordance between predicted and observed estimates of testing uptake is presented in Appendix B.

increased the probability that an alternative was chosen. The availability of multi-disease testing was found to increase the probability that an alternative was chosen only in the specification that included interaction terms. Likelihood ratio tests revealed that the specifications with interaction terms and correlated coefficients considerably improved model fit. We selected the model that allowed for correlation between coefficients as our final specification as it best captures the uncertainty around model parameters. We discuss the remainder of our results with respect to this specification.

To facilitate interpretation of the relative importance of the attributes (including the service delivery model) on participants' choices, we plotted the coefficients in **Figure 3**. Immediate access to ART for HIV-positive persons was the strongest driver of choices, followed by the service delivery model and the provision of a US $0.85 incentive. The coefficient plots for the availability of multi-disease testing suggest a positive effect on choices, yet the overlapping standard error bars for the coefficients reveal that this effect was not significant ($p = 0.10$).

Predicted Uptake of HIV Testing

Figure 4 displays the predicted uptake of HIV testing by adult men when a single community-based service delivery model is implemented in rural Uganda.[11] HIVST using an oral fluid-based test obtained at a local pharmacy yielded the smallest yet still considerable predicted uptake of 32% of adult men. Counselor-administered home-based testing and HIV testing at a community health campaign garnered 47% and 64% predicted uptake by adult men, respectively. The predicted uptake of HIV testing under the different service delivery models was augmented

[11]Predictions of testing uptake have been calibrated to match uptake by 64% of adult men of HIV testing at a community health campaign as reported by Chamie et al., 2016. The community health campaign was a base case service delivery model where multi-disease testing was provided but incentives and immediate access to ART for HIV-positive persons were not (68). Further details are provided in Appendix B.

by modifying attributes of how testing is delivered. Offering incentives of US $0.85 increased the predicted uptake by 6-12 percentage points. Providing immediate access to ART for HIV-positive persons increased the predicted uptake by 26-44 percentage points. Providing multi-disease testing increased the predicted uptake by 28 percentage points, an effect that was specific to uptake of counselor-administered home-based testing.[12]

Figure 5 displays the predicted uptake of HIV testing by adult men when two community-based service delivery models for HIV are implemented concurrently.[13] The cumulative predicted uptake of HIV testing under different combinations of two service delivery models ranged from 84-92%. The highest predicted uptake (91-92%) was achieved when one of the service delivery models provided immediate access to ART for HIV-positive persons.

2.5. Discussion

This DCE found that men in Uganda state that they are willing to use community-based service delivery models to test for HIV. We predicted that implementing community-based service delivery models for HIV testing singly and in tandem can result in uptake of HIV testing by over 90% of adult men. These findings are important in light of the strong interest and priority given to identifying low-cost HIV testing service delivery models that can help countries attain the UNAIDS 90-90-90 targets to significantly reduce viral transmission (34).

Of the service delivery models investigated, HIV testing at a community health campaign and counselor-administered home-based testing demonstrated the greatest potential to appeal

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[12]The impact of providing multi-disease testing on testing uptake is only estimated for the home-based testing service delivery model due to constraints included in the experimental design.

[13]To attain the ambitious 90-90-90 targets, decision makers might consider implementing not just a single community-based service delivery model but two service delivery models in tandem. The predicted uptake of HIV testing under two community-based service delivery models has been calibrated to match uptake by 86% of adult men who tested for HIV at either a community health campaign or by way of counselor-administered home-based testing as reported in Chamie et al., 2016. Further details are provided in Appendix B.

broadly to men residing in rural Uganda. Both of these service delivery models have been implemented and enhanced uptake of HIV testing in Uganda (36,50). It is therefore not surprising that men are willing to use these service delivery models. It is, however, unexpected that men preferred the previously implemented service delivery models for HIV testing over HIVST given that high levels of acceptability with HIVST have been reported elsewhere (53,54,69–71) . That HIVST was the least preferred service delivery model could suggest that HIVST holds limited appeal for men residing in rural Uganda. It is also possible that a lack of familiarity with HIVST diminished appreciation for it. During the DCE, participants were provided basic information regarding the service delivery models, and it is likely that additional education and marketing is needed to increase demand for HIVST.

We also found that attributes of how HIV testing is delivered are important and influence men's choices. Above all, men preferred that ART be immediately available for HIV-positive persons at the time of HIV testing. Many community-based service delivery models for HIV testing do not currently offer ART. Rather, the standard of care is to link individuals who test positive to a health facility to undergo confirmatory testing and begin ART. That men prioritized immediate access to ART for HIV-positive persons so strongly is illuminating and indicates one way that community-based testing can be improved to enhance uptake of HIV testing. Providing confirmatory testing and a starter antiretroviral regimen for individuals who test positive at community-based venues could be an effective intervention to increase male testing. This finding is momentous given that many countries have recently adopted WHO's "Treat All" guideline recommendation (42). Recent studies have found that ART initiation on the same day of HIV diagnosis is feasible and improves uptake of ART in clinical settings (72,73). Our results indicate that providing immediate access to ART through community-based service delivery models for

HIV testing is likely to have another important benefit to increase uptake of HIV testing. Further research is needed to investigate the feasibility of providing ART through community-based service delivery models for HIV testing and to identify effective strategies for linking HIV-positive persons to long-term treatment and care.

The provision of a US $0.85 incentive also influenced men's choices. Recent experiments have demonstrated that incentives are effective at increasing HIV testing for adolescents and families in sub-Saharan Africa (74,75), and our results add evidence that financial incentives are likely to be an effective intervention to increase HIV testing for men. Although the predicted increase in uptake associated with offering an incentive for HIV testing in the DCE was not as large as the predicted change associated with providing immediate access to ART, the cost of the incentive was only US $0.85. It is therefore possible that a relatively small payment is a cost-effective intervention to promote male testing, and further research is needed to investigate the elasticity of testing behaviors in response to changes in the level of payment.

We acknowledge several limitations of the study. The DCE elicited men's preferences for attributes of HIV testing that are highly relevant from a policy perspective, yet we did not conduct formative research prior to the DCE to establish attributes that are important to the study population. It is possible that additional attributes influence men's decisions to test for HIV. Any attributes that were not defined in the DCE were assumed to be constant across testing alternatives or indicated by the service delivery model. We acknowledge our results could have been affected if participants mistakenly associated influential attributes that were not defined in the DCE with particular service delivery models. Second, we employed an experimental design that included constraints between service delivery model and attribute level combinations, and it is possible that we did not fully isolate the effects of highly constrained attributes. The availability of multi-disease testing, in particular, was highly constrained and was not found to significantly influence men's choices on average, yet our predictions of testing uptake suggest that offering multi-disease testing can increase testing under counselor-administered home-based testing. We therefore recommend that the results regarding multi-disease testing be interpreted in context. Third, our exclusion criteria and sampling strategy might have resulted in underrepresentation of residents who were highly mobile or absent from the community for extended duration, and the generalizability of our results could be limited for certain subpopulations. Lastly, we investigated preferences among a broad sample to respond to the challenge of low population-level uptake of HIV testing by men, yet another approach to ensure that 90% of men who are living with HIV know their HIV status is to target subgroups of men who are at high risk of acquiring HIV. Both approaches are important for the health of men and for HIV prevention. We do not distinguish the preferences of high-risk subgroups in this study yet encourage further research to do so.

Despite its limitations, this study provides useful guidance for decision makers who seek to expand HIV testing coverage among men in sub-Saharan Africa. Decision makers should consider providing immediate access to ART for HIV-positive persons and offering financial incentives to increase uptake of community-based HIV testing by men. Our work compels further investigation of the costs associated with providing ART and financial incentives through community-based service delivery models for HIV testing in order to evaluate the cost-effectiveness of these interventions to increase male testing. Additionally, our work demonstrates the importance of sensitizing communities to the use and benefits of HIVST prior to its introduction. Finally, further research to understand individual, interpersonal or societal characteristics that influence men's decisions to test for HIV is warranted. Such findings could help target the delivery of HIV testing to subgroups of men and address other barriers that men face when accessing HIV testing. Collectively, these actions will improve the responsiveness of testing services to promote male testing and aid progress toward the 90-90-90 targets.

2.6. Acknowledgements

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2.7. Compliance with Ethical Standards

Ethics Approval

The study received approval from the Makerere University School of Medicine Research and Ethics Committee, the Ugandan National Council on Science and Technology, the University of California at San Francisco Committee on Human Research, and the institutional review board of the University of North Carolina at Chapel Hill. Informed consent was obtained from all study participants.

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Conflicts of Interest

The authors declare no conflicts of interest.

Table 1. Attributes and Levels Included in the DCE

Attribute	Levels
Service delivery model	- You attend a community health event in your village - A health counselor comes to your home and offers to test you for HIV - You pick up a self-test kit at a nearby pharmacy
Availability of multi-disease testing services	- You can test for tuberculosis, malaria, pressure and diabetes when you test for HIV [a] - Only HIV testing is available
Access to ART for HIV-positive persons	- Medications to treat HIV are *immediately* available - Medications to treat HIV are *not* immediately available
Provision of an incentive for HIV testing	- You receive 3,000 Shillings when you test for HIV - You do not receive compensation

[a] "Pressure" was used to refer to hypertension/diabetes. ART, antiretroviral therapy

Table 2. Participant Characteristics

	N (%)
Total participants [a]	194
Age (years)	
18-29	65 (34)
30-49	82 (42)
50+	47 (24)
Highest level of education attained	
Primary or less	136 (70)
Secondary	44 (23)
Beyond secondary	14 (7)
Occupation	
Agriculture/farming	100 (52)
Manual labor	42 (22)
Professional or business	33 (17)
Other	19 (10)
Marital status	
Married or cohabitating	122 (63)
Never married	51 (26)
Separated/divorced/widowed	21 (11)
Tested for HIV in the past 12 months	
No	91 (47)
Yes	103 (53)
Self-perceived risk of having HIV	
No risk	66 (34)
Low risk	88 (45)
Moderate to high risk	35 (18)
Unknown risk	5 (3)
Number of sexual partners in the past 12 months	
No partners	32 (17)
1 partner	117 (61)
2 or more partners	44 (23)

[a] Excludes 9 participants who self-reported a seropositive status at enrollment.

Table 3. Estimation of Men's Preferences for Service Delivery Models and Attributes of HIV Testing under Random Parameter Logit Model Specifications with and without Interaction Terms and Correlation between Model Coefficients

	Model 1		Model 2		Model 3	
	Base RPL specification		RPL with interaction terms		RPL with correlated coefficients	
Variables	β	SE	β	SE	β	SE
HIV testing at a community health campaign (CHC)	0.64**	(0.25)	0.13	(0.38)	0.22	(0.32)
Home-based testing (HBT)	0.21	(0.13)	0.57*	(0.22)	0.53*	(0.21)
HIV self-testing (HIVST)	-0.86***	(0.20)	-0.70**	(0.25)	-0.75**	(0.25)
Multi-disease testing is available	0.17	(0.20)	0.63*	(0.30)	0.55	(0.34)
ART is immediately available (ART)	1.09***	(0.18)	1.51***	(0.33)	1.38***	(0.32)
An incentive of US $0.85 is provided	0.25*	(0.11)	0.39*	(0.18)	0.33*	(0.15)
Would not test for HIV	-7.46***	(1.36)	-9.59***	(2.62)	-8.60***	(1.72)
Interaction terms						
CHC*ART			0.58	(0.31)		
HBT*ART			-0.58	(0.31)		
CHC*Incentive			0.04	(0.35)		
HIVST*Incentive			-0.04	(0.35)		
Goodness of fit						
Log-likelihood	-535.02		-523.96		-518.97	
AIC / BIC	1094.05 / 1165.76		1079.92 / 1175.53		1091.94 / 1253.29	
Likelihood ratio test			Model 2 vs. Model 1		Model 3 vs. Model 1	
Likelihood ratio test statistic			22.13		32.11	
Likelihood ratio p-value			0.0002		0.0062	
Observations	2,910		2,910		2,910	

Results are reported as mean coefficients with robust standard errors in parentheses; *** p<0.001, ** p<0.01, * p<0.05. RPL, random parameters logit; ART, antiretroviral therapy; AIC, Akaike information criterion; BIC, Bayesian information criterion.

Figure 1. Construction of the Experimental Design

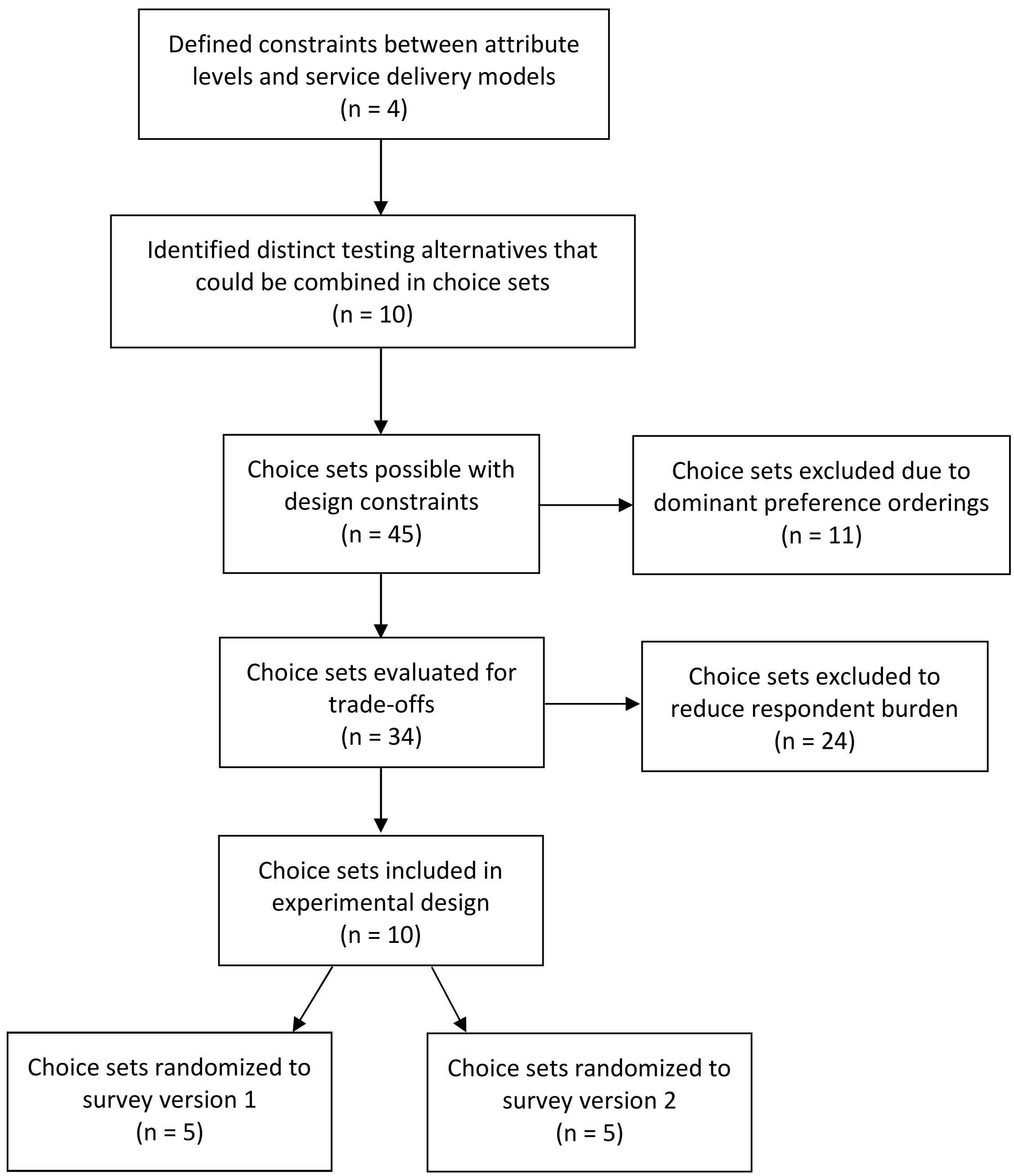


Figure 2. Example Choice Set

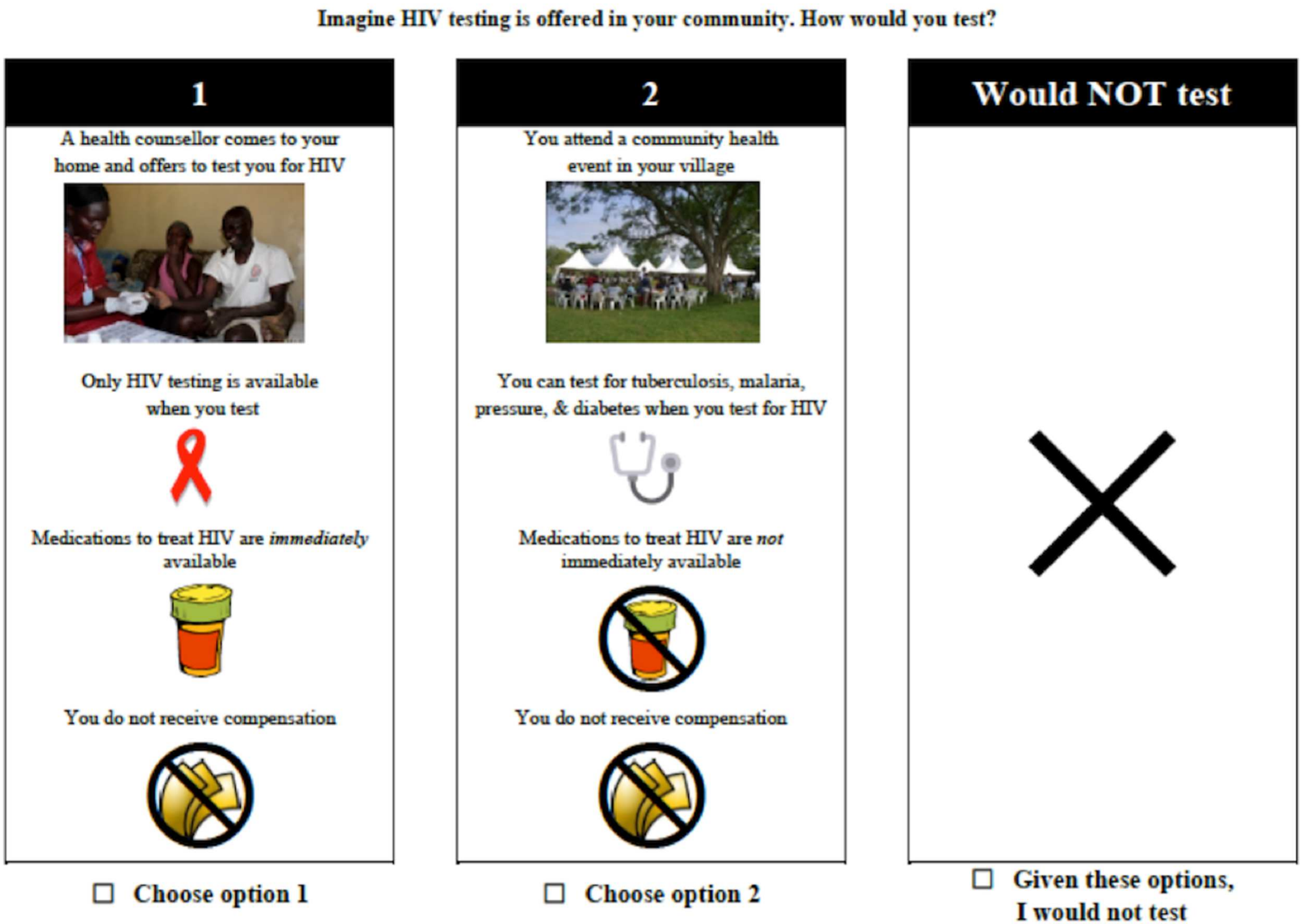
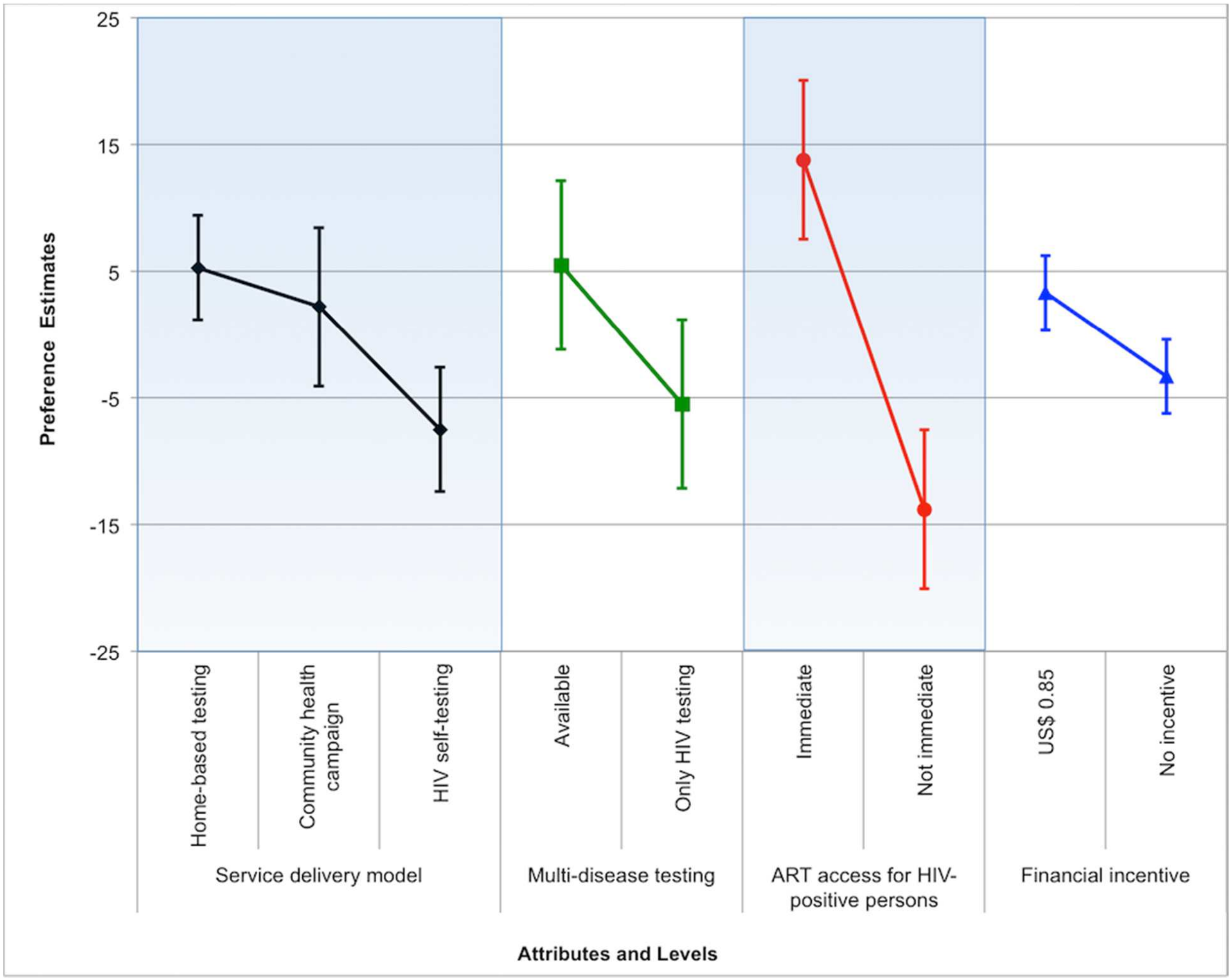
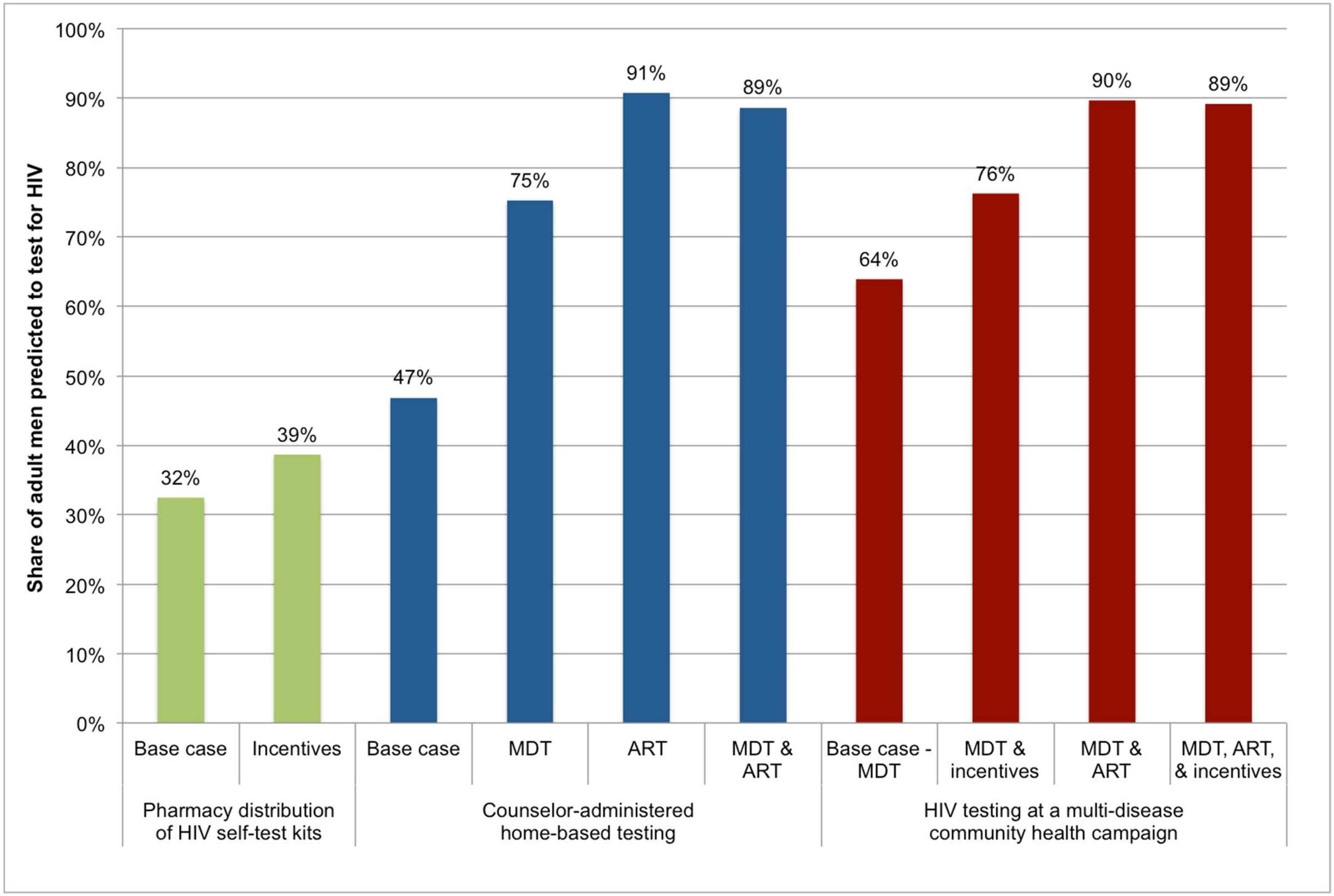


Figure 3. Relative Importance of Attributes on Men's Choices



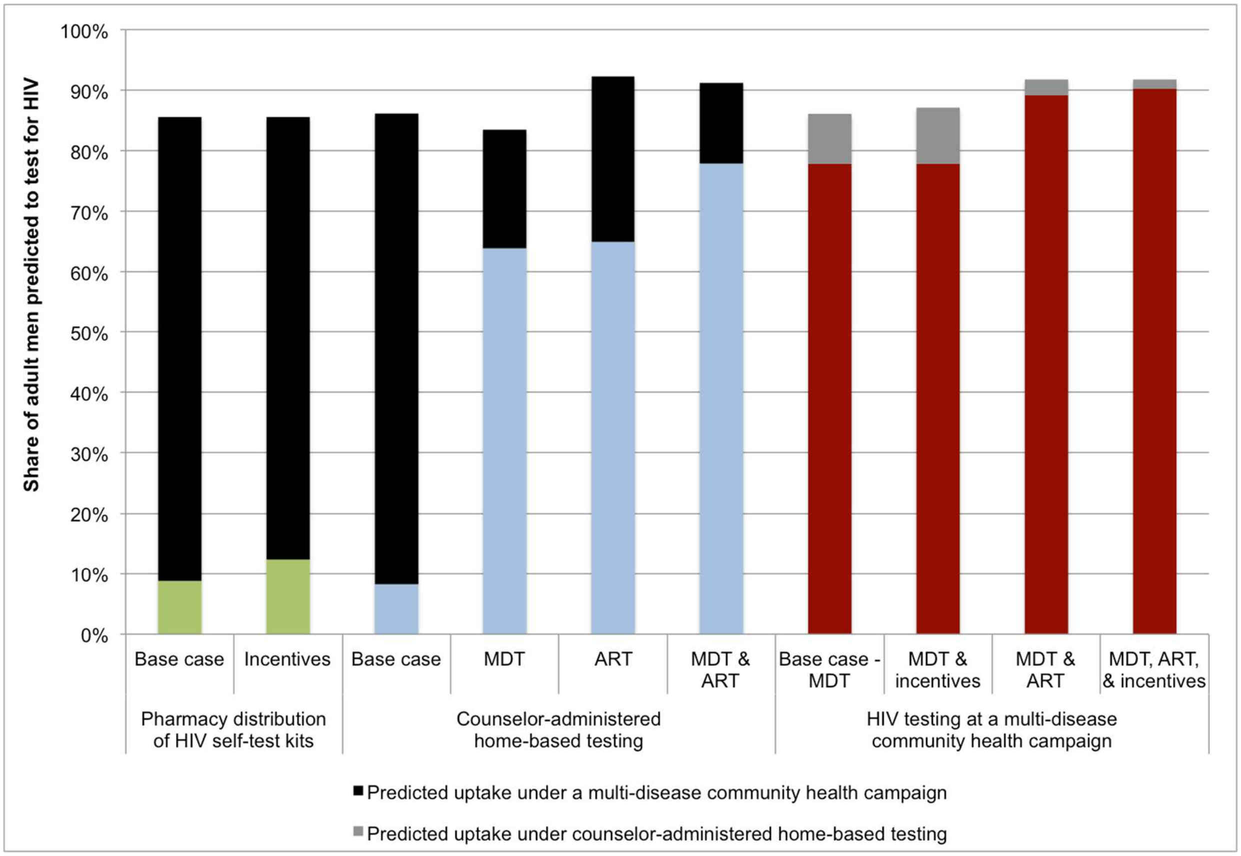
Mean preference estimates have been rescaled by a factor of ten. The vertical distance between coefficients for the levels of a given attribute indicates the relative importance of the attribute on participants' choices. ART, antiretroviral therapy

Figure 4. Predicted Uptake of HIV Testing under a Single Community-Based Service Delivery Model



MDT, multi-disease testing; ART, immediate access to antiretroviral therapy for HIV-positive persons.

Figure 5. Predicted Uptake of HIV Testing when Two Community-Based Service Delivery Models are Implemented in Tandem



For the sake of comparison, one service delivery models has been set to a base case community health campaign when the alternative service delivery model is either HIVST or home-based testing. The comparison service delivery model is switched to a base case version of counselor-administered home-based testing when the alternative service delivery model is HIV testing at a community health campaign. MDT, multi-disease testing; ART, immediate access to antiretroviral therapy for HIV-positive persons.

CHAPTER 3. UNDERSTANDING PREFERENCE HETEROGENEITY TO INCREASE HIV TESTING BY MEN IN UGANDA

3.1. Introduction

Increasing HIV awareness so that 90% of HIV-positive persons know that they have HIV is the first objective in a global strategy to significantly reduce viral transmission and bring the HIV/AIDS epidemic to an end (1). In order to attain this ambitious target, it is important for HIV testing to be widely accessible and acceptable to diverse populations. Although remarkable progress has been made to expand access to HIV testing, key gaps in testing coverage remain. A strong body of evidence indicates that across sub-Saharan Africa, men are less likely than women to test for HIV and be aware of their status when they are HIV-positive (2,3,76). Various hypotheses point to structural, cultural, and social factors that underlie the male testing gap (22,77–79). While these factors are complex, interrelated, and challenging to address, what is evident is that standard facility-based testing holds limited appeal for men. One way to try to increase uptake of HIV testing by men is to elicit men's preferences for HIV testing and identify ways that testing services can be improved to encourage more men to learn their HIV status.

A discrete choice experiment (DCE) is a useful survey tool for eliciting user's preferences for health services (26). A DCE consists of a series of hypothetical choice scenarios in which two or more health services are described by their attributes, and participants are asked to evaluate the attributes and choose the service they prefer to use in each scenario (27,30). The primary outputs from a DCE are quantitative estimates of participants' preferences for attributes of the health service (29). These estimates can be compared to assess the relative importance of the attributes for participants' choices. Results from a DCE are typically reported as mean preference estimates for the sample, and DCEs often yield useful findings regarding population preferences for attributes of health services that can be modified to increase health service utilization. Population preferences are policymakers' primary interest in many cases; however, mean preference estimates alone do not reveal the heterogeneity in preferences that can be a rich source of information regarding the distribution of preferences within a diverse sample and the variation in preferences within a population at large. Fortunately, rigorous methods can be applied to analyze and describe preference heterogeneity using data collected from a DCE.

This paper presents the results of an in-depth investigation of heterogeneity in men's preferences for attributes of community-based HIV testing. Community-based delivery of HIV testing in which HIV testing is provided outside of health facilities has achieved higher uptake by men, compared to facility-based testing alone, and is a strategic approach to expand male testing (18,22). We previously reported the findings of a DCE regarding preferences and the predicted uptake of HIV testing under community-based service delivery models for a broad sample of men who are representative of the adult male population of rural Uganda (80). We extended our investigation for this paper to analyze preference heterogeneity, as it is likely that not all men have the same preferences for HIV testing and it is beneficial to determine to what extent and how preferences vary in order to enhance testing uptake. Moreover, HIV testing is particularly important for certain subgroups of men, such as those who are at heightened risk of acquiring HIV and those who have not tested recently, and we sought to discover ways that HIV testing can be enhanced to increase uptake by these subgroups.

DCEs have grown increasingly popular in health economics, and two studies have reported findings regarding heterogeneity in men's preferences for attributes of HIV testing in sub-Saharan Africa (44,45). Ostermann and colleagues (2014) investigated preferences among adults in urban Tanzania and found that the most important attribute to male participants was distance to the testing site, followed by the method of sample collection, and the degree of confidentiality.[1] The authors estimated preferences using a random parameters logit model that allows preferences to vary across individuals and found significant heterogeneity in preferences. Subgroup analyses revealed that compared to men who had previously tested, men who had never tested for HIV were more likely to prefer oral HIV tests and less likely to prefer venipuncture. Compared to men who had tested in the past year, men who had not tested recently were more likely to prefer venipuncture, weekend testing, and that no one know they tested for HIV. Ostermann and colleagues (2015) also discovered significant differences in the preferences of a high-risk population of male mountain porters in a subsequent study. Mountain porters were less averse to traveling longer distances to testing sites and were more likely to prefer having access to treatment at the testing site than their urban counterparts. These findings suggest that men's preferences for HIV testing vary and beckon further analyses of preference heterogeneity in population-based DCEs.

Our work builds on these previous studies to investigate heterogeneity in preferences for attributes of HIV testing among a representative sample of adult men from rural Uganda. We advance the literature by employing advanced modeling methods and present a systematic approach for investigating unobserved and observed preference heterogeneity. Similar to Ostermann and colleagues, we employ a random parameters logit model. We also estimate a standard conditional logit model and a latent class logit model. Each model specification makes different assumptions about preference heterogeneity, and we compare the results to demonstrate

[1]Collectively, men preferred shorter distances to the testing site (yet preferred testing 1 km away from their homes over testing at home), finger prick tests over venipuncture or an oral swab, and that their spouses know that they tested for HIV over no one or many people knowing that they tested.

the importance of accounting for unobserved heterogeneity in men's preferences. Additionally, we conduct covariate analyses to investigate preference heterogeneity that can be attributed to observed characteristics of participants. We apply methods appropriate to each model specification and provide a framework for investigating ways to tailor HIV testing to promote uptake by subgroups.

3.2. Methods

The DCE was conducted during the enrollment phase of a randomized trial investigating the comparative effectiveness of novel incentive strategies to encourage men to test for HIV at a local, multi-disease community health campaign (NCT02890459). Adult male residents were invited to participate in the randomized trial during a census of households in four neighboring parishes within Mbarara District, a rural District in southwestern Uganda where the adult male HIV prevalence is 7 – 8% (47). Male residents who were ≥18 years of age were eligible to participate in the trial if they had been living in the community for at least six months in the past year and were not planning to move away in the next three months (40). All eligible men present at the time of the census were invited to participate in the trial. Those who agreed and provided their informed consent were administered an enrollment questionnaire. The DCE formed one section of the questionnaire and was administered to a random subsample of 203 participants. Following administration of the enrollment questionnaire, participants were offered incentives to take an HIV test at a community health campaign that would be visiting their community in roughly 4-6 weeks. The incentives were material prizes, and participants were randomized to incentives that varied by type and cost.

Each man who participated in the DCE evaluated 5 choice sets. The choice sets displayed 2 alternatives for HIV testing and an opt-out alternative so that participants could choose not to test if neither testing alternative appealed to them. Each testing alternative was characterized by four attributes (**Table 4**), the first of which was a three-level attribute indicating the community-based service delivery model for HIV testing. The service delivery models included in the DCE were: 1) HIV testing at a community health campaign; 2) counselor-administered home-based testing; and 3) HIV self-testing (HIVST) using an oral fluid-based test obtained at a local pharmacy. The additional three attributes each had two levels that indicated whether or not multi-disease testing, immediate access to antiretroviral therapy (ART), and a financial incentive of 3,000 Ugandan shillings (approximately US $0.85) were available at the time of HIV testing. These binary attributes represent ways that policymakers could seek to improve the delivery of community-based HIV testing to enhance uptake by men. The administration of the DCE has been previously described (80), so we limit our description of statistical methods to those used to investigate preference heterogeneity.

Discrete Choice Modeling of Preference Heterogeneity

A number of random utility models can be applied to analyze data from a discrete choice experiment, all of which begin with the common framework of random utility theory (62,63). According to random utility theory, the utility U_{nit} an individual *n* derives from alternative *i* in choice set *t* consists of a deterministic component V_{nit} that is a function of observed variables and an unobservable random component ε_{nit} such that:

$$\boldsymbol{U_{nit} = V_{nit} + \varepsilon_{nit} = \beta_n{}' x_{it} + \varepsilon_{nit}} \qquad (1)$$

where x_{it} is a vector of attribute levels that define alternative *i* and $\beta_n{}'$ is a vector of marginal utility (i.e. preference) parameters associated with the attribute levels. We assume that individual *n* makes choices to maximize his utility such that he will choose alternative *i* over another alternative *j* in choice set *t* if and only if $U_{nit} > U_{njt}, \forall\, j \neq i$.

As researchers, we observe attributes of the alternatives and specify V_{nit} accordingly. For the current application, specifying variables for the attribute levels associated with the alternatives participants viewed in the DCE yielded the following utility function:

$$
\begin{aligned}
U_{nit} = {} & \beta_{nCHC} Community\ health\ campaign_{it} + \beta_{nHBT} Home\_based\ testing_{it} \\
& + \beta_{nHIVST} HIV\ self\_testing_{it} + \beta_{nMDT} Multi\_disease\ testing_{it} \\
& + \beta_{nART} Immediate\ ART_{it} + \beta_{nInc} Incentive_{it} + \beta_{nWNT} Would\ not\ test_{it} \\
& + \varepsilon_{nit}
\end{aligned}
$$

where $Community\ health\ campaign_{it}$, $Home\_based\ testing_{it}$, $HIV\ self\_testing_{it}$, $Multi\_disease\ testing_{it}$, $Immediate\ ART_{it}$, and $Incentive_{it}$ represent the attribute levels that defined the testing alternatives and $Would\ not\ test_{it}$ is an alternative-specific constant that accounts for the fact that a participant could always choose to opt-out of HIV testing. We do not observe ε_{nit}, however, and therefore have to make an assumption about its distribution (64). Different assumptions about the distribution of ε_{nit} give rise to different random utility models.

Historically, McFaddon's conditional logit (CL) model has been a popular model specification (81). The CL model assumes that the random variables that compose ε_{nit} are independent and identically distributed with an extreme value distribution. Conditional on knowing β_n, the probability that individual *n* chooses alternative *i* in choice set *t* is given by (65,66,82):

$$L_{nit}(\beta_n) = \frac{e^{\beta_n{}' x_{it}}}{\sum_{j=1}^{J} e^{\beta_n{}' x_{jt}}} \qquad (2)$$

The probability that individual *n* makes a particular sequence of choices, conditional on knowing β_n is a product of choice probabilities:

$$S_n(\beta_n) = \prod_{t=1}^{T} L_{ni(n,t)t}(\beta_n) \qquad (3)$$

This choice probability is a closed-form expression that can be evaluated through maximum likelihood estimation, and an advantage of the CL model is its ease of computation. Yet, an important limitation of the CL model is that it assumes that preferences are the same across individuals (29,82). Another limitation of the CL model is that it assumes choices are independent (64,82). In many cases, it is likely that preferences vary across individuals and, in the context of a DCE, it is highly likely that choices made by the same individual are correlated.

Two models that relax the assumptions of the CL model are the random parameters logit (RPL) and latent class logit (LCL) models (83,84). The probability that individual *n* makes a particular sequence of choices for both the RPL and LCL models is given by (65,66,82):

$$P_n(\theta) = \int S_n(\beta) f(\beta|\theta) d\beta \qquad (4)$$

This choice probability is the unconditional probability of a particular sequence of choices and is the conditional probability integrated over the distribution of β. Preferences vary with a density $f(\beta|\theta)$ where θ are the parameters of the distribution.[2] The distribution of β is assumed to be continuous in a RPL model, whereas the LCL model assumes the distribution of β is discrete and takes on a finite number of values.

The continuous distribution of β in the case of the RPL leads to a log-likelihood function that cannot be solved analytically but can be approximated through maximum likelihood simulation, provided that the distribution of β is specified in advance. The log-likelihood function of LCL model, on the other hand, can be solved using maximum likelihood estimation, provided that the number of discrete preference classes is specified in advance.

[2]It can be seen that if it is assumed that all individuals have the same preferences, the distribution is discrete and takes a single value. In this case, equation 4 collapses to equation 3.

To investigate whether the more advanced RPL and LCL model specifications that accommodate preference heterogeneity are preferred specifications relative to the standard CL model specification, we first estimated each model. We simulated the RPL model assuming a normal distribution for β. We estimated multiple LCL models that allowed for 1 – 7 latent classes and compared their estimation properties and goodness-of-fit measures to select a 3-class model as the preferred LCL specification.

We then examined the results of the RPL and LCL models for signs of preference heterogeneity and compared goodness-of-fit measures across the CL, RPL, and LCL model specifications to evaluate the performance of each specification to estimate men's preferences for attributes of HIV testing. We examined Akaike and Bayesian information criteria (AIC/BIC) and log-likelihood values. Additionally, we performed likelihood ratio (LR) tests to determine whether the RPL and LCL model specifications significantly improved model fit relative to the CL logit model. We also performed a LR test to compare the LCL to the RPL model specification.

Covariate Analyses

The RPL and LCL models account for and yield valuable information about preference heterogeneity, yet the heterogeneity is unobserved in that it is not attributable to individual characteristics of participants. Decision makers who seek to promote HIV testing among priority subgroups of high-risk and hard-to-reach men are likely interested to know whether the preferences of these subgroups are distinct from the preferences of men-at-large. The ability to detect heterogeneity according to characteristics of participants is therefore also valuable. Before the DCE was administered, participants responded to questionnaire items that assessed their demographic characteristics, history of HIV testing, and health and sexual behavior; we used these data to conduct covariate analyses to investigate whether heterogeneity in men's preferences for attributes of HIV testing was associated with observed characteristics of participants.

Estimating preferences using the CL and RPL models, we conducted subgroup analyses in which we interacted each attribute level variable and the constant for the alternative to opt-out of HIV testing with a dichotomous variable that defined participant subgroups. The new interaction variables were included in the model specification to evaluate the difference in the marginal utility of the attribute levels and the alternative-specific constant between those in and out of the subgroups of interest. We defined subgroups (**Table 5**) according to history of recent HIV testing (whether a participant had tested for HIV in the past 12 months or not), self-perceived risk of HIV (whether a participant perceived himself to have no or low risk as opposed to moderate to high risk of acquiring HIV), and self-reported sexual behavior (whether a participant had 0-1 nonpaid sexual partners versus 2 or more sexual partners or at least 1 paid sexual partner in the past 12 months). Additionally, we conducted subgroup analyses for select demographic characteristics, including age (whether a participant was aged less than 30 years versus 30 years or older), marital status (whether a participant was never married versus married, separated, widowed, or divorced), and highest educational level attained (whether a participant had primary education or less versus more than primary education).

As latent classes are themselves subgroups of the population, we did not conduct subgroup analyses for preferences estimated using the LCL model specification. Instead, we investigated whether the previously mentioned testing history, risk, and demographic characteristics of participants were predictors of latent class membership. We estimated unadjusted and adjusted odds ratios using a multinomial logistic regression model in which the three latent classes were treated as a categorical outcome. All analyses were conducted using Stata 14.1 (StataCorp, College Station, TX, USA).

3.3. Results

Preference Estimation and Heterogeneity

Preferences estimated using the CL, RPL, and LCL model specifications are presented in **Tables 6-8**. In the case of the CL model specification, mean coefficients for the sample along with their associated standard errors alone are reported. The RPL model specification yielded mean coefficients for the sample along with standard deviations that reveal whether there was significant heterogeneity in participants' individual preferences for the attribute levels included in the DCE. The LCL model specification produced mean coefficients for three latent classes of participants that were identified as having similar preferences. The latent classes were estimated to represent 57%, 30%, and 13% of participants. Despite differences in the presentation of results, two findings were consistent across model specifications. The relatively large negative value of the coefficient for the alternative to opt-out of HIV testing across model specifications reveals that, on average, participants assigned greater utility to the average testing alternative presented in the DCE than to the alternative to opt-out of HIV testing. Additionally, the consistently large, positive coefficient for the provision of immediate access to ART for HIV-positive persons at the time of HIV testing for all but a single latent class for whom this attribute was not significant suggests that this attribute was an important determinant of participants' choices.

Goodness-of-fit measures comparing the three random utility model specifications are provided in **Table 9**. The AIC and BIC values were smaller and the log-likelihood values were closer to zero for the RPL and LCL model specifications relative to the CL model specification. Likelihood ratio tests also indicated that the RPL (LR test statistic = 1130.91, $p < 0.01$) and LCL

(LR test statistic = 1141.57, $p < 0.01$) model specifications improved model fit relative to the CL model specification yet did not differ significantly from each other (LR test statistic = 10.66, $p = 0.22$).

Considering the RPL and LCL model specifications in turn, results from the RPL model specification indicated that access to ART for HIV-positive persons at the time of HIV testing was the most important attribute to participants (relative importance weight = 2.18, 95% confidence interval [CI]: 1.46-2.90), and participants preferred ART to be immediately available for HIV-positive persons ($p < 0.01$). The service delivery model was the second most important attribute (importance weight = 1.50, 95% CI: 0.66-2.34), and participants preferred HIV testing at a community health campaign ($p < 0.01$) and counselor-administered home-based testing ($p < 0.01$) over obtaining an oral fluid-based self-test at a local pharmacy. An incentive of US $0.85 had a relatively modest yet significant influence on participants' choices (importance weight = 0.50, 95% CI: 0.07-0.92). Statistically significant standard deviations for preference estimates revealed heterogeneity in preferences for the service delivery model, access to ART for HIV-positive persons at the time of testing, and the alternative to opt-out of HIV testing.

Results from the LCL model specification were broadly consistent with findings from the RPL model specification. To facilitate interpretation of the preference patterns for each latent class, we plotted the preference estimates for each latent class in **Figure 6**. Preference estimates for the latent class that included 57% of participants bore some similarities to the mean preferences estimates from the RPL model specification. The most important attribute to participants in this class was access to ART for HIV-positive persons at the time of testing (importance weight = 3.09, 95% CI: 2.06-4.13), followed by the availability of multi-disease testing (importance weight = 2.42, 95% CI: 0.42-4.43), and the service delivery model (importance weight = 2.04, 95% CI: 0.95-3.14). The provision of an incentive was not found to significantly influence the choices of participants in this class. However, an incentive was important to participants belonging to the second latent class that included 30% of participants (importance weight = 1.09, 95% CI: 0.37-1.80). Moreover, an incentive was the only attribute that was found to significantly influence participant choices for this latent class. The preferences of the third latent class that included 13% of participants were also distinctive. The service delivery model was the most important attribute for this latent class (importance weight = 5.17, 95% CI: 1.62-8.71) and participants in this latent class preferred HIV self-testing using an oral fluid-based test obtained at a local pharmacy over counselor-administered home-based testing ($p < 0.01$) and HIV testing at a community health campaign ($p < 0.01$). Access to ART for HIV-positive persons was also an important attribute to participants in the third latent class (importance weight = 4.50, 95% CI: 2.55-6.44), although the availability of multi-disease testing and the provision of an incentive were not. The third latent class also appeared to have a smaller disutility for the alternative to opt-out of HIV testing.

Covariate Analyses

Subgroup analyses conducted using the CL model specification indicated differences in stated preferences for attributes of HIV testing according to participants' self-perceived risk of acquiring HIV and self-reported sexual behaviors in the past 12 months (**Table 10**). Participants with a moderate to high self-perceived risk of acquiring HIV were less likely to prefer HIV testing at a community health campaign and were more likely to prefer counselor-administered home-based testing ($p = 0.02$), the availability of multi-disease testing ($p = 0.02$), and the provision of an incentive ($p = 0.02$). Participants who had 2 or more sexual partners or who had at least one paid sexual partner in the past 12 months were less likely to prefer HIV testing at a community health campaign ($p < 0.01$) and were more likely to prefer HIV self-testing using an oral fluid-based test obtained at a local pharmacy ($p = 0.05$) and the availability of multi-disease testing ($p < 0.01$). The analyses did not reveal significant differences in participants' stated preferences for attributes of HIV testing according to participants' demographic characteristics or history of HIV testing in the past 12 months.

Subgroup analyses conducted using the RPL model specification did not reveal significant differences in participants' stated preferences for attributes of HIV testing that could be attributed to participant characteristics (**Table 11**). However, participants aged 18-29 years ($p = 0.02$) and those who did not have a history of testing for HIV in the past 12 months ($p < 0.01$) demonstrated a stronger disutility for the alternative to opt-out of HIV testing, suggesting that they assigned, on average, greater value to the HIV testing alternatives presented in the DCE relative to their counterparts (i.e. older men and men who had tested for HIV in the past 12 months).

Individual characteristics of participants were not found to predict latent class membership (**Table 12**). Neither unadjusted nor adjusted odds ratios estimated from multinomial logit models were statistically significant for any of the individual characteristics that were used to define subgroups for the CL and RPL model specifications.

3.4. Discussion

This study yields several conclusions regarding heterogeneity in men's preferences for attributes of community-based HIV testing that may be useful for policymakers who seek to promote male testing. Our first and most evident finding is that men's preferences for attributes of community-based HIV testing are heterogeneous. Both the RPL and LCL model specifications revealed preference heterogeneity and considerably improved model fit by allowing preferences to vary across individual participants and participant groups, respectively. Second, we found that even though preferences were heterogeneous, our results were broadly consistent across model specifications suggesting that each model specification reliably estimates preferences at the population-level. Results from the different model specifications also suggested certain preferences that are largely homogenous. For instance, we found that men assigned a disutility to opting out of HIV testing across all model specifications. We also found that immediate access to ART for HIV-positive persons was strongly preferred across all model specifications, save for a single latent class for whom this attribute was not significant under the LCL specification. Third, our results strongly suggest that there is room for policymakers to harness preference heterogeneity to enhance the delivery of community-based HIV testing to promote uptake by men. The discovery of a latent class of participants who preferred HIV self-testing over other service delivery models for HIV testing is very compelling, particularly because the service delivery model was the most influential attribute for participants in this latent class and participants in this class had the weakest disutility for opting out of HIV testing. Although we cannot definitively say that HIV self-testing is preferred by men who have less utility for HIV testing in general, our results beg further investigation of the possibility. The discovery of a latent class for whom a financial incentive was the single influential attribute is also intriguing. This finding suggests that providing financial incentives could be an effective way to make HIV testing more appealing to certain men and issues a strong call for further resolution of individual characteristics associated with latent class membership so that policymakers might more effectively target incentivized testing interventions.

Our work contributes to broader health policy dialogues in two important ways. First, we add evidence to demonstrate that understanding preference heterogeneity is important for policy pertaining to ways to increase uptake of HIV testing. Although the importance of heterogeneity in clinical outcomes has been well recognized, the role of preference heterogeneity in response to policies and public health interventions has been less clear (85,86). Yet, just as knowledge of heterogeneity of treatment effects has led to gains in the clinical effectiveness of treatment strategies, understanding preference heterogeneity provides opportunities to enhance the effectiveness of health policies and interventions. A growing body of literature demonstrates that investigating heterogeneity in stated preferences provides great opportunity to anticipate and understand heterogeneity in revealed preferences (i.e. health behaviors), and we show how a range of econometric modeling techniques can be used to investigate heterogeneity in men's preferences for attributes of community-based HIV testing (87–90). Additionally, our work speaks to the importance of targeting in HIV program planning in sub-Saharan Africa, an issue that has received recent, high-level recognition in the HIV/AIDS literature and that holds intuitive appeal from a cost-effectiveness perspective (86,91,92). Innovative research to locate populations at high risk of acquiring HIV through geospatial analysis and to deliver geographically-targeted interventions is currently being advanced under the rationale that preventive interventions that reach populations most vulnerable to acquiring HIV are likely to be effective and cost-effective approaches to reduce HIV transmission (91,92). We show that stated preference research provides another approach to determine how to target populations who lack engagement with preventive services and who could be at risk of acquiring HIV. Moreover, a stated preference approach allows for the comparison of a range of strategies and can reveal how single or a mix of strategies might be optimal to reach vulnerable populations.

We acknowledge several limitations of our study. First, we strongly suspect the DCE was underpowered to detect differences in participants' preferences that can be attributed to participant characteristics for the RPL and LCL model specifications. Although subgroup analyses conducted using the CL model specification pointed to differences in preferences according to participants' self-perceived risk of HIV and self-reported sexual behaviors in the past 12 months, we ruled out the CL as a preferred model specification, given that it relies on assumptions that are unlikely to hold for our population and was dominated by both the RPL and LCL model specifications in measures of goodness of fit. Covariate analyses conducted using the RPL and LCL model specifications yielded few significant results and none with regard to preferences for attributes of community-based HIV testing. Our analyses to investigate heterogeneity according to observed characteristics of participants are therefore inconclusive. This limitation is major, as we cannot make links between the heterogeneity that we detected in our analyses to observed characteristics of men that could inform how HIV testing can be targeted to defined subgroups. Second, our exclusion criteria and sampling strategy could have led to underrepresentation of men who are frequently away from their home communities and the generalizability of our results could be limited for certain subpopulations. Third, our work is premised on the assumption that stated preferences are concordant with revealed preferences. Evidence upholds the external validity of DCEs to predict actual choices, yet this is an area for further research (25).

Despite these limitations, this study makes key strides to advance understanding of heterogeneity in men's preferences for attributes of community-based HIV testing. Our results add dimensionality to population-level preference patterns and indicate that there is room to harness heterogeneity to more effectively target community-based HIV testing to promote uptake by men. We provide a methodological example for investigating unobserved and observed preference heterogeneity and pave the way for further investigation of linkages between the two.

Table 4. Attributes and Levels Included in the DCE

Attribute	Levels
Service delivery model	- You attend a community health event in your village - A health counselor comes to your home and offers to test you for HIV - You pick up a self-test kit at a nearby pharmacy
Availability of multi-disease testing services	- You can test for tuberculosis, malaria, pressure and diabetes when you test for HIV [a] - Only HIV testing is available
Access to ART for HIV-positive persons	- Medications to treat HIV are *immediately* available - Medications to treat HIV are *not* immediately available
Provision of an incentive for HIV testing	- You receive 3,000 Shillings when you test for HIV - You do not receive compensation

[a] "Pressure" was used to refer to hypertension/diabetes. ART, antiretroviral therapy.

Table 5. Participant Subgroups

	N (%)
Total participants [a]	194
Age (years)	
18 - 29 years	65 (34)
≥ 30 years	129 (66)
Marital status	
Never married	51 (26)
Married/cohabitating/divorced/widowed	143 (74)
Highest level of education attained	
Primary or less	136 (70)
Beyond primary	14 (30)
Tested for HIV in the past 12 months	
No	91 (47)
Yes	103 (53)
Self-perceived risk of having HIV [b]	
No or low risk	154 (81)
Moderate to high risk	35 (19)
Self-reported sexual behavior in the past 12 months	
0-1 nonpaid partners	147 (76)
≥2 partners or at least 1 paid partner	46 (24)

[a] Excludes 9 participants who self-reported a seropositive status at enrollment.
[b] Excludes 5 participants who self-reported an unknown risk of having HIV.

Table 6. Conditional Logit Model Estimation of Preferences

Variables	β	SE
HIV testing at a community health campaign	0.96**	(0.35)
Home-based testing	0.13	(0.18)
HIV self-testing	-1.09***	(0.26)
Multi-disease testing is available	-0.08	(0.27)
ART is immediately available	1.04***	(0.12)
An incentive of US $0.85 is provided	0.25	(0.15)
Would not test for HIV	-4.17***	(0.25)
Number of choices	2,910	
Number of participants	194	

Results are reported as mean coefficients with robust standard errors in parentheses; *** $p<0.001$, ** $p<0.01$, * $p<0.05$. ART, antiretroviral therapy.

Table 7. Random Parameters Logit Model Estimation of Preferences

Variables	β	SE	Standard deviation	SE
HIV testing at a community health campaign	0.64**	(0.25)	1.13***	(0.30)
Home-based testing	0.21	(0.13)	0.49*	(0.23)
HIV self-testing	-0.86***	(0.20)	1.62***	(0.40)
Multi-disease testing is available	0.17	(0.20)	0.09	(0.25)
ART is immediately available	1.09***	(0.18)	1.12***	(0.17)
An incentive of US $0.85 is provided	0.25*	(0.11)	0.33	(0.39)
Would not test for HIV	-7.46***	(1.36)	3.63***	(0.79)
Number of choices	2,910			
Number of participants	194			

Results are reported as mean coefficients and standard deviations with robust standard errors in parentheses; *** p<0.001, ** p<0.01, * p<0.05. ART, antiretroviral therapy.

Table 8. Latent Class Logit Model Estimation of Preferences

	Class 1		Class 2		Class 3	
Variables	β	SE	β	SE	β	SE
HIV testing at a community health campaign	0.23	(0.49)	0.26	(0.29)	-2.56*	(1.00)
Home-based testing	0.91**	(0.30)	0.10	(0.14)	-0.05	(0.36)
HIV self-testing	-1.13**	(0.43)	-0.35	(0.28)	2.61**	(0.84)
Multi-disease testing is available	1.21*	(0.51)	0.18	(0.20)	0.30	(0.56)
ART is immediately available	1.55***	(0.26)	-0.10	(0.14)	2.25***	(0.50)
An incentive of US $0.85 is provided	0.23	(0.30)	0.54**	(0.18)	-0.33	(0.38)
Would not test for HIV	-4.57***	(0.67)	-4.41***	(0.73)	-1.70***	(0.46)
Constant	0.66**	(0.25)			-0.84*	(0.36)
Probability of class membership						
Class 1	0.575					
Class 2	0.297					
Class 3	0.127					
Number of choices	2,910					
Number of participants	194					

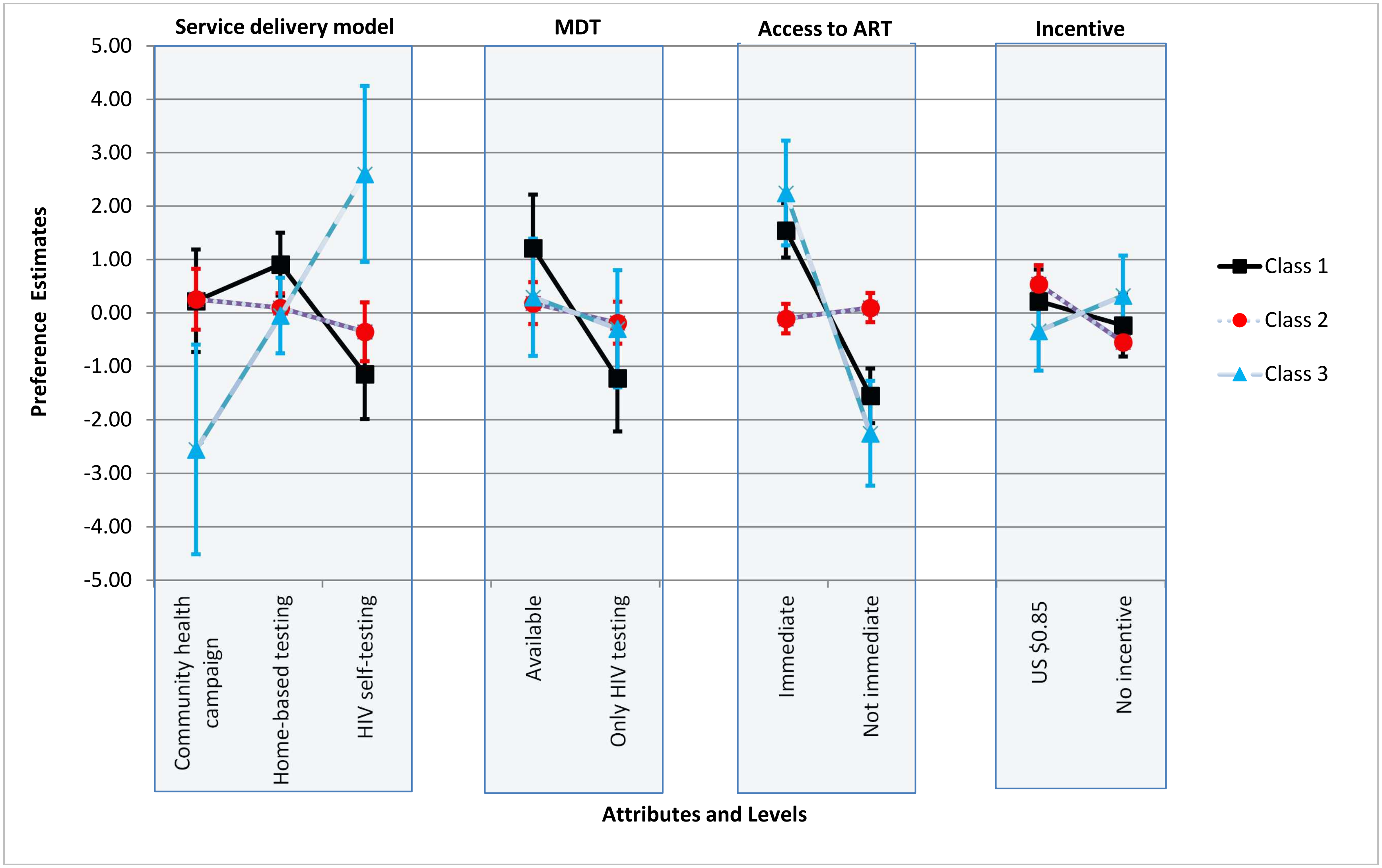
Results are reported as mean coefficients for each class with robust standard errors in parentheses; *** $p<0.001$, ** $p<0.01$, * $p<0.05$. ART, antiretroviral therapy.

Table 9. Goodness-of-Fit Measures

	AIC	BIC	Log-likelihood	Likelihood ratio test	Likelihood ratio test statistic	p-value
Conditional logit	2212.95	2248.81	-1100.48	RPL vs. CL	1130.91	<0.001
Random parameters logit	1094.05	1165.76	-535.02	LCL vs. CL	1141.57	<0.001
Latent class logit	1099.39	1218.91	-529.69	LCL vs. RPL	10.66	0.2217

AIC, Akaike information criterion; BIC, Bayesian information criterion; CL, conditional logit; RPL, random parameters logit; LCL, latent class logit.

Figure 6. Importance of Attributes on Choices Made by Men from Three Latent Classes



MDT, multi-disease testing; ART, antiretroviral therapy.

Table 10. Subgroup Analyses Conducted with the Conditional Logit Model

Covariate defining subgroup	Aged 18-29 years		Single (never married)		Primary education or less	
Variables	β	SE	β	SE	β	SE
HIV testing at a community health campaign	0.98**	(0.43)	0.96***	(0.33)	1.07***	(0.38)
Home-based testing	0.17	(0.23)	0.16	(0.18)	0.06	(0.18)
HIV self-testing	-1.16***	(0.33)	-1.12***	(0.27)	-1.13***	(0.23)
Multi-disease testing is available	-0.19	(0.33)	-0.11	(0.25)	-0.10	(0.25)
ART is immediately available for HIV-positive persons	1.15***	(0.17)	1.09***	(0.15)	1.06***	(0.15)
An incentive of US $0.85 is provided	0.26	(0.19)	0.23	(0.17)	0.09	(0.21)
Would not test for HIV	-4.07***	(0.24)	-4.07***	(0.24)	-3.55***	(0.33)
Interactions						
Community health campaign * Covariate	-0.16	(0.27)	-0.04	(0.19)	-0.10	(0.37)
Home-based testing * Covariate	-0.14	(0.14)	-0.09	(0.08)	0.03	(0.19)
HIV self-testing * Covariate	0.31	(0.38)	0.13	(0.24)	0.07	(0.54)
Multi-disease testing * Covariate	0.32	(0.18)	0.11	(0.16)	0.04	(0.17)
Immediate ART * Covariate	-0.27	(0.16)	-0.17	(0.13)	-0.02	(0.22)
Incentive * Covariate	-0.01	(0.19)	0.09	(0.13)	0.22	(0.27)
Would not test for HIV * Covariate	-0.30	(0.24)	-0.28	(0.16)	-0.40	(0.22)
Number of choices	2,910		2,910		2,910	
Number of participants	194		194		194	

Results are reported as mean coefficients with robust standard errors in parentheses; *** p<0.001, ** p<0.01, * p<0.05. ART, antiretroviral therapy.

Table 10. Subgroup Analyses Conducted with the Conditional Logit Model (continued)

Covariate defining subgroup	Has not tested for HIV in the past 12 months		Perceived risk of HIV is moderate or high		Had ≥2 sexual partners or paid for sex in the past 12 months	
Variables	β	SE	β	SE	β	SE
HIV testing at a community health campaign	0.87**	(0.35)	1.12***	(0.35)	1.15***	(0.38)
Home-based testing	0.16	(0.19)	0.00	(0.19)	0.05	(0.20)
HIV self-testing	-1.03***	(0.20)	-1.12***	(0.25)	-1.20***	(0.29)
Multi-disease testing is available	-0.00	(0.27)	-0.22	(0.27)	-0.22	(0.30)
ART is immediately available for HIV-positive persons	0.98***	(0.15)	1.11***	(0.14)	1.05***	(0.14)
An incentive of US $0.85 is provided	0.29**	(0.14)	0.21	(0.17)	0.26	(0.18)
Would not test for HIV	-4.10***	(0.47)	-3.98***	(0.25)	-4.19***	(0.21)
Interactions						
Community health campaign * Covariate	0.18	(0.23)	-0.33**	(0.14)	-0.55***	(0.20)
Home-based testing * Covariate	0.04	(0.20)	0.23***	(0.07)	-0.07	(0.13)
HIV self-testing * Covariate	-0.22	(0.42)	0.10	(0.19)	0.62*	(0.32)
Multi-disease testing * Covariate	-0.18	(0.19)	0.21**	(0.09)	0.47***	(0.16)
Immediate ART * Covariate	0.15	(0.15)	-0.21	(0.12)	0.05	(0.13)
Incentive * Covariate	-0.10	(0.08)	0.22**	(0.10)	-0.07	(0.13)
Would not test for HIV * Covariate	-0.07	(0.32)	-0.45	(0.30)	0.06	(0.16)
Number of choices	2,910		2,835		2,895	
Number of participants	194		189		193	

Results are reported as mean coefficients with robust standard errors in parentheses; *** p<0.001, ** p<0.01, * p<0.05. ART, antiretroviral therapy.

Table 11. Subgroup Analyses Conducted with the Random Parameters Logit Model

Covariate defining subgroup	Aged 18-29 years		Single (never married)		Primary education or less	
Variables	β	SE	β	SE	β	SE
HIV testing at a community health campaign	0.53	(0.31)	0.60*	(0.30)	0.90	(0.51)
Home-based testing	0.39*	(0.18)	0.32*	(0.16)	0.10	(0.24)
HIV self-testing	-0.92***	(0.24)	-0.92***	(0.25)	-1.00**	(0.39)
Multi-disease testing is available	0.24	(0.25)	0.26	(0.25)	-0.10	(0.37)
ART is immediately available for HIV-positive persons	1.34***	(0.26)	1.23***	(0.25)	1.11***	(0.29)
An incentive of US $0.85 is provided	0.33*	(0.14)	0.24	(0.14)	0.07	(0.23)
Would not test for HIV	-6.96***	(1.64)	-7.30***	(1.84)	-6.61***	(1.40)
Interactions						
Community health campaign * Covariate	-0.10	(0.97)	0.02	(0.99)	-0.55	(1.01)
Home-based testing * Covariate	-0.71	(0.41)	-0.56	(0.46)	-0.00	(0.44)
HIV self-testing * Covariate	0.82	(1.25)	0.54	(1.33)	0.55	(1.33)
Multi-disease testing * Covariate	0.26	(0.97)	-0.17	(1.00)	0.97	(0.89)
Immediate ART * Covariate	-0.57	(0.55)	-0.62	(0.61)	0.17	(0.57)
Incentive * Covariate	-0.29	(0.50)	0.01	(0.51)	0.60	(0.53)
Would not test for HIV * Covariate	-3.20*	(1.32)	-2.39	(1.23)	-0.76	(1.17)
Number of choices	2,910		2,910		2,910	
Number of participants	194		194		194	

Results are reported as mean coefficients with robust standard errors in parentheses; *** p<0.001, ** p<0.01, * p<0.05. ART, antiretroviral therapy.

Table 11. Subgroup Analyses Conducted with the Random Parameters Logit Model (continued)

Covariate defining subgroup	Has not tested for HIV in the past 12 months		Perceived risk of HIV is moderate or high		Had ≥2 sexual partners or paid for sex in the past 12 months	
Variables	β	SE	β	SE	β	SE
HIV testing at a community health campaign	0.48	(0.34)	0.79**	(0.30)	0.95**	(0.31)
Home-based testing	0.21	(0.16)	0.14	(0.16)	0.12	(0.15)
HIV self-testing	-0.70*	(0.28)	-0.93***	(0.24)	1.07***	(0.25)
Multi-disease testing is available	0.33	(0.30)	0.11	(0.24)	0.01	(0.22)
ART is immediately available for HIV-positive persons	0.98***	(0.25)	1.21***	(0.24)	1.15***	(0.22)
An incentive of US $0.85 is provided	0.29	(0.17)	0.23	(0.13)	0.28*	(0.13)
Would not test for HIV	-4.88***	(0.95)	-6.65***	(1.35)	-7.44***	(1.59)
Interactions						
Community health campaign * Covariate	1.19	(1.04)	-0.93	(1.64)	-2.02	(1.23)
Home-based testing * Covariate	0.60	(0.54)	0.35	(0.57)	-0.46	(0.49)
HIV self-testing * Covariate	-1.78	(1.43)	0.58	(2.05)	2.48	(1.59)
Multi-disease testing * Covariate	-0.37	(0.91)	2.52	(3.23)	1.96	(1.74)
Immediate ART * Covariate	1.77	(1.27)	0.51	(2.15)	0.32	(0.81)
Incentive * Covariate	-0.20	(0.63)	0.26	(1.44)	-0.39	(0.58)
Would not test for HIV * Covariate	-31.69**	(9.72)	-3.13	(6.78)	-0.56	(1.37)
Number of choices	2,910		2,835		2,895	
Number of participants	194		189		193	

Results are reported as mean coefficients with robust standard errors in parentheses; *** p<0.001, ** p<0.01, * p<0.05. ART, antiretroviral therapy.

Table 12. Unadjusted and Adjusted Odds Ratios (aOR) and 95% Confidence Intervals (CI) for Characteristics Associated with Class Membership [a]

	Total participants	Latent classes			
		Class 2 (n = 48)		Class 3 (n = 21)	
Characteristic	n (%)	OR (95% CI)	aOR (95% CI)	OR (95% CI)	aOR (95% CI)
Age					
18 - 29 years	65 (34)	Ref.	Ref.	Ref.	Ref.
≥ 30 years	129 (66)	0.57 (0.28 – 1.13)	0.70 (0.25 - 1.94)	0.54 (0.21 – 1.39)	0.48 (0.13 - 1.73)
Marital status					
Married/divorced/separated	143 (74)	Ref.	Ref.	Ref.	Ref.
Never married	51 (26)	1.90 (0.92 – 3.93)	1.73 (0.61 - 4.93)	1.39 (0.49 – 3.92)	0.86 (0.21 - 3.53)
Educational level					
Primary or less	136 (70)	Ref.	Ref.	Ref.	Ref.
Beyond primary	58 (30)	0.85 (0.40 – 1.79)	0.70 (0.32 - 1.52)	1.14 (0.43 – 3.07)	0.95 (0.35 - 2.61)
Tested for HIV in past 12 months					
Yes	103 (53)	Ref.	Ref.	Ref.	Ref.
No	91 (47)	0.75 (0.38 – 1.47)	0.69 (0.34 - 1.41)	0.95 (0.38 – 2.41)	1.04 (0.40 - 2.69)
Perceived risk of HIV [b]					
No or low risk	154 (81)	Ref.	Ref.	Ref.	Ref.
Moderate or high risk	35 (19)	1.96 (0.86 – 4.49)	2.08 (0.84 - 5.12)	1.79 (0.58 – 5.51)	1.85 (0.48 - 7.19)
Sexual behavior in past 12 months [c]					
0-1 nonpaid partners	147 (76)	Ref.	Ref.	Ref.	Ref.
2 or more partners or paid for sex	46 (24)	0.82 (0.36 – 1.84)	0.50 (0.22 - 1.12)	0.95 (0.32 – 2.81)	0.68 (0.20 - 2.36)
Number of participants	194	-	189	-	189

[a] The likelihood of membership in classes 2 and 3 is compared to the likelihood of membership in class 1 (n = 125); *p<0.05.
[b] Excludes 5 participants who reported an unknown risk of HIV.
[c] Excludes 1 participant with missing data.

CHAPTER 4. THE COST-EFFECTIVENESS OF COMMUNITY-BASED SERVICE DELIVERY MODELS TO INCREASE HIV TESTING AND DIAGNOSIS AMONG MEN IN UGANDA

4.1. Introduction

Increasing HIV awareness is the first objective in a global strategy to halt HIV transmission. In order to end the AIDS epidemic by 2030, the Joint United Nations Program on HIV/AIDS (UNAIDS) has proposed the "90-90-90 targets" which urge countries to ensure that 90% of HIV-positive persons know their status, 90% of those diagnosed with HIV are receiving treatment, and 90% of those receiving treatment are virally suppressed by 2020 (1). While considerable progress has been made to expand access to HIV testing, a number of important gaps in testing coverage remain including low coverage among men in sub-Saharan Africa. It is well recognized that men are less likely than women to test for HIV, and that HIV-positive men are less likely to be aware of their status and to be receiving antiretroviral treatment than HIV-positive women (2,5,7). These disparities lead to increased morbidity and mortality for HIV-positive men and to missed opportunities to prevent HIV transmission (4,6,8,93).

In Uganda, the most recent update on the country's progress toward the 90-90-90 targets reveals that 77% of HIV-positive persons are aware of their status (34). While over 90% of HIV-positive women and children have been diagnosed, only 61% of HIV-positive men have been diagnosed (34). Men are therefore a critical population to engage in HIV testing, and national and bilateral actors involved in the HIV/AIDS response are actively seeking ways to enhance the effectiveness of testing services to increase uptake of HIV testing and HIV diagnosis among men. At the same time, the annual per capita expenditure on health in Uganda is $46, and interest in the effectiveness of testing services to reach men must be balanced with consideration of the resources required to achieve improvements (94). The United States President's Emergency Plan for AIDS Relief (PEPFAR), for instance, is a major source of funding for HIV/AIDS activities in Uganda and has made targeting men with the most efficient service delivery models for HIV testing a strategic priority for 2018 (95).

A recent systematic review and meta-analysis revealed that community-based delivery of HIV testing—which includes approaches such as home-based testing, community health campaigns, and HIV self-test provision—achieves higher uptake of HIV testing by men than standard facility-based testing (18). The accessibility and convenience of community-based service delivery models for HIV testing likely appeal to men and reduce barriers related to travel, costs, and stigma (22,23). Community-based service delivery models are also more effective at diagnosing individuals with high CD4 counts and thus hold great potential to avert large health decrements for HIV-positive men and to prevent HIV transmission (18,21). For these reasons, community-based service delivery models are a compelling approach to expand male testing. For policymakers who seek to optimize the allocation of resources to increase HIV awareness among men and achieve the 90-90-90 targets, there is a vital need to evaluate the cost-effectiveness of community-based service delivery models to increase HIV testing and diagnosis among men.

Previous studies have investigated the effectiveness and costs of various community-based service delivery models to promote HIV testing in sub-Saharan Africa (18,21,36,96–101). However, differences in the populations targeted with HIV testing and the methods used to assess uptake and costs associated with service delivery models implemented across diverse contexts have made it challenging to evaluate the cost-effectiveness of community-based service delivery models to promote HIV testing and HIV diagnosis among men in sub-Saharan Africa.

Additionally, high-level modeling studies have been conducted that investigate the cost-effectiveness of increasing HIV testing coverage relative to other interventions that could be conducted to enhance the delivery of services and promote patient engagement along the cascade of HIV/AIDS treatment and care (102,103). Yet these studies make broad assumptions about increases in testing coverage without considering the operational capacities and variation in demand that are associated with specific service delivery models for HIV testing.

In this study, we investigate the cost-effectiveness of three community-based service delivery models to increase HIV testing and diagnosis among men in rural Uganda. Each of the service delivery models has strong potential to appeal to men in rural Uganda, and we predicted uptake of HIV testing using results from a discrete choice experiment (DCE) that we previously conducted. A DCE is a choice-based survey to elicit preferences for attributes of a service or product; results from a DCE can be used to predict uptake of the service or product (27,30,33,41). Using uptake predictions from a DCE ensured that we have consistent measures of testing uptake across different service delivery models for a representative sample of men in Uganda.[1] Additionally, we applied a comparative framework to consistently assess the costs associated with each service delivery at a steady operational state.

To our knowledge, our analysis is the first to evaluate the cost-effectiveness of multiple community-based service delivery models to increase HIV testing and diagnosis among men in sub-Saharan Africa, and our work advances the literature in two important ways. First, our use of a DCE to generate uptake parameters is innovative and allowed us to estimate uptake for existing service delivery models as well as predict uptake for a service delivery model that is new to the

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[1]We estimated uptake of HIV testing for a sample of men who are representative of the adult male population in rural Uganda, and the DCE provided an environment, albeit an artificial environment, in which all participants made choices between alternatives from a consistent range of possibilities. Our estimates of HIV testing uptake are therefore equivalent to estimates of testing coverage.

testing landscape. Oral fluid-based HIV self-tests are not yet widely available in Uganda. However, the World Health Organization (WHO) has recently called for the expanded use of HIV self-tests as novel tools to promote HIV testing (43), and we deliver the first evidence of men's demand for an innovative service delivery model that makes use of HIV self-tests to promote testing in Uganda. Second, we investigated the cost-effectiveness of community-based service delivery models to not only increase HIV testing by men but to also diagnose HIV among men previously unaware of their HIV status. Many efforts to attain the first 90-90-90 target have focused on expanding testing coverage among the population at large with the rationale that as testing coverage expands so too will HIV awareness (104,105). Yet, it is essential to evaluate the effectiveness of alternative service delivery models to not only increase HIV testing but to also increase HIV diagnosis. We incorporated variation in the probabilities that men would test positive and be newly diagnosed with HIV under each service delivery model and reveal how important differences emerge when evaluating the cost-effectiveness of alternative service delivery models according to each outcome. Our results hold important implications for the design and delivery of community-based service delivery models for HIV testing.

4.2. Methods

Model Structure

We constructed a decision analytic model to compare the costs and testing outcomes associated with three community-based service delivery models that have strong potential to increase HIV testing by men in sub-Saharan Africa (**Figure 7**). We compared: 1) HIV testing at multi-disease community health campaigns (CHC); 2) home-based testing (HBT) in which health counselors make door-to-door visits to homes in a community and offer to test household members for HIV; and 3) the distribution of oral fluid-based HIV self-tests at local pharmacies (HIVST). We evaluated outcomes over a one-year horizon when a single community-based service delivery model for HIV testing is made available relative to a status quo scenario in which no community-based service delivery model for HIV testing is provided. The analytical cohort consisted of adult (≥18 years) male residents of rural Uganda. We excluded urban residents from the analytical cohort as they have greater access to health facilities and different livelihoods than rural residents.

Our outcomes of interest were uptake of HIV testing and new HIV diagnoses. We modeled the proportion of our cohort that tested for HIV and that tested HIV-positive under each service delivery model. We accounted for the sensitivity and specificity of the diagnostics used by each service delivery model to detect HIV. Additionally, we estimated the proportion of HIV-positive test results that constituted new HIV diagnoses as some service delivery models could attract individuals who already know their HIV status. For instance, HIV testing is integrated with testing for other diseases at community health campaigns. Integration of testing services can help reduce HIV-related stigma, and individuals who already know that they are HIV-positive have been found to use CHC (23,40,100).

Model Parameters

Costs

We estimated the costs to deliver HIV testing under each service delivery model from a programmatic perspective. To ensure comparability across service delivery models, we accounted for the total costs essential to implement each service delivery model at a steady state of operation. We excluded start-up and quality control costs that are important in practice yet are not steady-state operational costs. We assumed that each service delivery model operated within an existing organizational infrastructure and included costs specific to each service delivery model associated with personnel, transportation, equipment, building rentals, overhead, and community mobilization to inform residents of the availability of HIV testing.

CHC and HBT are service delivery models that have been implemented in Uganda. We obtained estimates of the costs of providing HIV testing under these service delivery models from peer-reviewed literature. We searched for studies that investigated the implementation of these service delivery models at scale (at or above the parish-level) and that provided sufficient detail to ensure the quality of the costing methods employed. We used random-effects meta-analysis to pool estimates when estimates were available from multiple studies that met these criteria.

HIVST is a novel service delivery model that has not yet been implemented widely in Uganda, and we employed a micro-costing approach to estimate the costs of implementing this service delivery model for a representative rural district. We assumed that a public sector organization (e.g. a governmental or non-governmental organization) would oversee implementation and partner with local pharmacies to distribute self-tests free-of-charge to rural residents. We consulted the National Drug Authority of Uganda for a list of licensed pharmacies in the district and obtained a price quote for the cost to procure a bulk order of OraQuick HIV self-tests (OraSure Technologies, Inc.) under a low-cost charitable support agreement with the Bill and Melinda Gates Foundation (106). We consulted program expenditure records for existing community-based HIV testing programs to estimate fuel and vehicle costs to deliver HIV self-tests to pharmacies and to estimate personnel, overhead, and building rental costs. A breakdown of the total costs for HIVST is presented in **Appendix C**.

We reported all costs in 2016 USD. Costs that were reported in prior years were converted to Ugandan shillings using the exchange rate that the authors reported, inflated using Ugandan consumer price indices to their 2016 value, then converted to USD at the 2016 official exchange rate. We did not use a purchasing power parity index for cost conversion as all costs were specific to Uganda and reporting of costs at the official exchange rate allows our results to be more readily compared to costs previously reported in peer-reviewed literature.[2] We did not apply a discount factor as the analytical time horizon was limited to one year.

Population parameters and probabilities of HIV testing and diagnosis

We estimated the size of the adult male population of rural Uganda using national population projections (107). The probabilities that men would test for HIV under each service delivery model were estimated from a DCE (80). The DCE investigated men's preferences for attributes of community-based service delivery models for HIV testing and was administered to a random sample of 203 adult male residents from four parishes of Mbarara District, a rural district in southwestern Uganda. We used the results of the DCE to predict uptake of HIV testing under each of the service delivery models investigated in this analysis. To strengthen confidence in our uptake predictions, we calibrated the uptake predictions from the DCE to match reference values of uptake of HIV testing by men under existing service delivery models that have been reported in the peer-reviewed literature (64).[3]

The probabilities that men tested HIV-positive and were newly diagnosed with HIV were obtained from peer-reviewed literature for CHC and HBT. We focused our search of the literature on studies that investigated the implementation of these service delivery models at scale in Uganda and provided sex-disaggregated estimates. We pooled estimates using random effects meta-analysis when multiple estimates were available for a single parameter.

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[2]Additionally, one important cost component for HIVST was the procurement of OraQuick self-tests from OraSure Technologies under a charitable support agreement with the Bill and Melinda Gates Foundation. This agreement allows for low-cost procurement of self-tests in developing countries. Using a purchasing power index to convert this cost to international dollars would not have the effect that it is intended to have.

[3]Prediction and calibration of testing uptake have been previously described in greater detail in Chapter 2 and Appendix B.

The probabilities that men who use HIVST would test HIV-positive and be newly diagnosed with HIV are unknown, and we had to make assumptions about the base case values for these parameters. We estimated the probability that men would test HIV-positive under HIVST as a function of the HIV prevalence among testers and the sensitivity and specificity of OraQuick HIV self-tests (108).[4] We assumed that the HIV prevalence among men who use HIVST would be the same as the adult male HIV prevalence. We further assumed that all men who test HIV-positive under HIVST would not already know that they were HIV-positive and would thus be newly diagnosed with HIV. Base case parameter inputs are presented for each service delivery model in **Table 13**.

4.3. Analyses

Base Case Analyses

We used the decision analytic model to estimate the total costs, number of men who tested for HIV, and number of men newly diagnosed with HIV under each service delivery model. We then calculated incremental cost-effectiveness ratios (ICERs) to compare the cost-effectiveness of the service delivery models. ICERs express the difference in costs in ratio to the difference in health benefit that one service delivery model provides relative to another. We estimated one set of ICERs to assess the cost per additional man who tested for HIV and another set to assess the cost per additional man newly diagnosed with HIV. ICERs were calculated for each service delivery model relative to the next less costly service delivery model, except for the least costly service delivery model for which ICERs were calculated relative to the status quo scenario where no community-based service delivery model was provided (109). When one service delivery model was more costly yet less effective than another service delivery model, it

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[4]This value was adjusted to account for false positive results.

was considered dominated and eliminated from consideration as a cost-effective alternative (109).

Although there is considerable interest in identifying efficient service delivery models to expand access to HIV testing to attain the first UNAIDS 90-90-90 target, the amount that decision-makers are willing to pay to increase HIV testing or HIV diagnosis is unknown. Furthermore, the HIV/AIDS response in Uganda is heavily supported by international funders, and it is possible that the various actors engaged in HIV/AIDS activities in Uganda have different willingness-to-pay (WTP) thresholds to realize improvements in testing outcomes. Therefore, we did not compare the ICERs we calculated to benchmark WTP thresholds. Instead, we used the ICERs to rank order the alternatives, eliminate dominated alternatives, and reveal what decision makers must be willing to pay for each remaining service delivery model to be considered the most cost-effective alternative.

Deterministic Sensitivity Analyses

The field of community-based HIV testing has evolved and continues to evolve rapidly, and several parameters that we included in our decision analytic model were uncertain or subject to change. We performed deterministic sensitivity analyses to assess the impact of modifying the base case values for the most uncertain and volatile parameters in the decision analytic model. We performed one-way sensitivity analyses for single parameters and two-way sensitivity analyses when it was possible for two parameters to shift in tandem. We describe our deterministic sensitivity analyses by service delivery model below.

HIVST

The probability that men who use HIVST will be HIV-positive is unknown, and we shifted the probability of testing HIV-positive under HIVST three percentage points below and above the base case value that was approximated using the regional adult male HIV prevalence. The probability that men who test HIV-positive under HIVST will be newly diagnosed with HIV is also unknown. For our base case scenario, we assumed that men would not use HIVST if they had already been diagnosed with HIV. However, repeat testing by HIV-positive persons to confirm prior test results has been observed in other testing contexts (110), and we assessed the impact on our base case results if 30% of men who tested HIV-positive under HIVST were previously diagnosed with HIV. Additionally, oral fluid-based HIV self-tests are new to market in sub-Saharan Africa and the cost to procure the self-tests is subject to considerable fluctuation. A charitable support agreement currently allows for procurement of OraQuick HIV Self-Tests at reduced cost in developing countries (106). Yet, in the absence of such an agreement, the cost to procure self-tests could easily be much higher. We doubled the cost of HIVST to examine the impact that higher procurement costs could have on our base case results.

HBT

Non-disclosure of prior HIV diagnosis before HBT has been observed in other contexts, and it is possible that not all positive test results under this service delivery model constitute new HIV diagnoses (111). We assessed the impact on our base case results if 30% of men who tested HIV-positive under HBT did not disclose a prior HIV diagnosis. Furthermore, higher uptake of HIV testing under HBT has been reported in peer-reviewed literature than the testing uptake that we predicted from the DCE. Asiimwe et al. (2017) investigated HBT in Sheema, a rural district that borders Mbarara District, and estimated that 69% of the adult population tested for HIV

(96). We anticipate that the uptake reported by Asiimwe et al. (2017) is high as the authors assumed all persons previously diagnosed with HIV refrained from testing and excluded the share of the population already diagnosed with HIV from their estimate of testing coverage. Yet, it is possible that higher uptake of HBT can be achieved than what we predicted, and we shifted the uptake estimate for this service delivery model to 69% as a high-end estimate of what might be possible.

CHC

Community health campaigns provide flexible platforms for delivering HIV testing along with other health services, and it is possible that improvements can be made to this service delivery model to promote male testing. During the DCE, we investigated how stated preferences for CHC change when small, monetary incentives of 3,000 Ugandan shilling (approximately US$ 0.85) are provided. We also investigated how stated preferences change when antiretroviral therapy (ART) is provided on-site for HIV-positive persons. We found that the predicted uptake of CHC increased when each of these changes was implemented. For this study, we estimated the additional costs that would be required to offer incentives and provide immediate access to ART for HIV-positive persons as interventions to promote HIV testing (a summary can be found in **Appendix D**). We then conducted two-way sensitivity analyses to evaluate the impact that these interventions are likely to have on the cost-effectiveness of CHC to increase HIV testing and diagnosis among men.

Probabilistic Sensitivity Analysis

To account for uncertainty underlying all model parameters, we performed probabilistic sensitivity analysis. We assigned a beta distribution to model parameters that constituted probabilities and a gamma distribution to all cost parameters and conducted a Monte Carlo simulation with 1,000 draws (Crystal Ball, Oracle Corporation, Redwood Shores, CA). Given that there are not established WTP thresholds to improve uptake of HIV testing and HIV diagnosis among men and that WTP could vary across decision makers, we used a net monetary benefit framework to compare the net monetary benefits of each service delivery model over a range of WTP thresholds and plotted our results as cost-effectiveness acceptability curves (CEACs) which represent the likelihood that each service delivery model is the most cost-effective alternative over a range of WTP thresholds (112).

4.4. Results

Base Case Results

The total annual costs to implement a single community-based service delivery model to promote HIV testing among a population of 5,206,236 adult male residents of rural Uganda ranged from US $8,363,298 to $29,788,000. The number of men who tested for HIV under each service delivery model ranged from 1,665,996 to 3,331,991 (33-64% of the adult male population), and the number of men who were newly diagnosed with HIV ranged from 75,885 to 113,288 (1.5-2.2% of the adult male population). HIVST was the least costly service delivery model and resulted in the fewest men who tested for HIV yet yielded a considerable number of men who were newly diagnosed with HIV. HBT was more costly and resulted in more men who tested for HIV yet yielded fewer men who were newly diagnosed with HIV than HIVST and was therefore dominated by HIVST. CHC was the service delivery model with the greatest total costs and resulted in the greatest number of men who tested for HIV and who were newly diagnosed with HIV. These results produce the efficiency frontiers presented in **Figures 8** and **9**.

The total costs and effectiveness, along with the ICERs associated with the alternative community-based service delivery models to increase HIV testing and identify previously undiagnosed cases of HIV, are presented in **Table 14**. Comparing HIVST as the least costly service delivery model to a scenario where no community-based service delivery model is implemented, we see that the costs per man tested and per man newly diagnosed with HIV under HIVST are $5.02 and $82.54, respectively.

To realize gains in the number of men who test for HIV, decision makers could implement HBT or CHC instead of HIVST. If decision makers are willing to spend at least $9.03 yet less than $16.24 per man tested, then HBT is the preferred alternative and would result in an enhanced uptake of HIV testing by 780,935 additional men. If decision makers are willing to spend $16.24 or more per man who tests for HIV, CHC is the preferred alternative and would result in an enhanced uptake of HIV testing by 1,665,996 additional men.

To realize gains in the number of men newly diagnosed with HIV, decision makers could implement CHC instead of HIVST. The ICER reveals that the incremental cost per additional man newly diagnosed with HIV under CHC is $1,790. If decision makers are willing to spend at least that much per new HIV diagnosis, CHC is the preferred alternative for increasing HIV diagnosis among men and would result in 11,967 additional diagnoses. If decision makers are not willing to spend that much yet are willing to spend at least $83 per new HIV diagnosis, HIVST is the most cost-effective alternative for increasing HIV diagnosis among men.

Deterministic Sensitivity Analyses

Shifting the base case values for uncertain and volatile parameters in our decision analytic model revealed that our results are sensitive to certain changes on the HIV testing landscape (**Tables 15** and **16**). One important parameter dictating the cost-effectiveness of alternative community-based service delivery models to increase HIV diagnosis is the probability that men who use HIVST will test positive. Shifting this parameter input 3 percentage points below the base case value which was estimated using the current adult male HIV prevalence makes it considerably more likely that HBT and CHC will be preferred alternatives for increasing HIV diagnosis. On the other hand, if this parameter input is shifted 3 percentage points above the base case value, HIVST dominates both HBT and CHC as the most cost-effective alternative to increase HIV diagnosis. Changes to other model parameters had less pronounced impacts.

If previously diagnosed HIV-positive are found to use HIVST to confirm their HIV status, it becomes less likely that HIVST is cost-effective and more likely that CHC is cost-effective at increasing HIV diagnosis among men. If the cost of HIVST is doubled, it becomes more likely that HBT is cost-effective at increasing HIV testing yet HBT remains weakly dominated by HIVST as an alternative for increasing HIV diagnosis. If uptake under HBT is increased to 69% of the adult male population, HBT dominates CHC as an alternative for increasing HIV testing and becomes a contender as a cost-effective alternative for increasing HIV diagnosis. However, if non-disclosure of prior HIV diagnoses before HBT is a reality, HBT remains dominated by HIVST as an alternative for increasing HIV diagnosis.[5] Providing immediate access to ART for HIV-positive persons and offering US $0.85 incentives to encourage men to test for HIV under CHC have little effect on the likelihood that CHC is a cost-effective alternative for increasing HIV testing yet do increase the likelihood that CHC is a cost-effective alternative for increasing HIV diagnosis.

Probabilistic Sensitivity Analysis

Compared to our base case results, the range of WTP thresholds over which HIVST was most likely to be cost-effective at increasing the number of men tested for HIV was narrower when probabilistic sensitivity analysis was performed **(Figure 10)**. We found that HIVST is the

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[5]We present the result of a one-way sensitivity analysis for non-disclosure of prior HIV diagnosis in Table 4. Yet, if we were to conduct a two-way sensitivity analysis to investigate higher uptake of HIV testing under HBT that occurred concurrently with non-disclosure of prior HIV diagnosis, we find that non-disclosure by just 2% of men rendered HBT a dominated strategy for increasing HIV diagnosis.

alternative most likely to be cost-effective in terms of total numbers of men tested when decision makers are willing to pay US $5.12 - $7.03 per man who tests for HIV. HBT was the alternative most likely to be cost-effective when decision makers are willing to pay US $7.04 – $17.58 per man tested for HIV, and CHC was most likely to be cost-effective when decision makers are willing to spend $17.59 or more per man tested for HIV.

Probabilistic sensitivity analysis confirmed that HIVST and CHC are the only alternatives that are most likely to be cost-effective at increasing HIV diagnosis (**Figure 11**). We found that HIVST was the alternative most likely to be cost-effective in terms of total new HIV diagnoses when decision makers are willing to spend US $86 - $1,144 per new HIV diagnosis. CHC was most likely to be cost-effective when decision makers are willing to spend more than $1,144 per new diagnosis.

4.5. Discussion

Our decision analytic model revealed that community-based service delivery models for HIV testing vary in their effectiveness and costs to increase HIV testing and HIV diagnosis among men in Uganda. CHC is predicted to yield the greatest number of men who test for HIV and who are newly diagnosed with HIV and is therefore the preferred alternative if WTP thresholds are not constrained. Yet, CHC requires substantially higher costs to implement than the other two service delivery models, and HIVST and HBT are more cost-effective alternatives for increasing male testing at WTP thresholds less than $17.59 per man tested for HIV. If the outcome of interest is new HIV diagnoses, HIVST alone is more cost-effective than CHC at WTP thresholds less than $1,144 per new diagnosis. This latter finding is significant because attainment of the first 90-90-90 target hinges on increasing HIV diagnosis among individuals previously unaware of their HIV status. Although many efforts to attain this target have focused on expanding testing coverage, we demonstrate that service delivery models that are cost-effective alternatives for increasing HIV testing are not necessarily cost-effective alternatives for increasing HIV diagnosis. This important result has not been highlighted in previous studies. One prior cost-effectiveness analysis found that HBT is cost-effective relative to facility-based testing at increasing HIV testing and HIV diagnosis (98). This analysis assumed similar uptake of HIV testing under HBT and facility-based testing which is unlikely is practice. Additionally, that study and others have concluded that the costs of community-based service delivery models to deliver HIV testing are relatively low and comparable (36,97,98). We demonstrate, however, that seemingly small differences in the costs to deliver HIV testing can translate into considerable differences in costs to achieve the immediate secondary outcome of HIV diagnosis. We consider it important to highlight these differences in light of the context where constraints on spending for health are considerable.

Given the focus on increasing awareness among HIV-positive persons, it could be questioned whether decision makers should take interest in the cost-effectiveness of alternative community-based service delivery models to increase HIV testing at all or whether the outcome of interest should simply be new HIV diagnoses. We included HIV testing uptake as an outcome because HIV testing does hold health benefits for testers regardless of testing outcome. For instance, HIV testing leads to safer sexual decision making. A systematic review indicates that individuals who learn that they are HIV positive following HIV testing have fewer sexual partners and increased condom use than individuals who test HIV-negative (10). Depending on the service delivery model, HIV testing can also provide important prevention benefits for HIV-negative men such as linkage to voluntary medical male circumcision and pre-exposure prophylaxis for those at high risk of acquiring HIV (17,113). These prevention benefits were outside the scope of our analysis, yet we present findings regarding the cost-effectiveness of alternative service delivery models to increase HIV testing for decision-makers to consider and as a stepping-stone for further analyses.

We also found that our results are quite sensitive to changes in certain parameter inputs. The probability that men who use HIVST will test HIV-positive, in particular, has a strong impact on our results. We assumed a base case value based on the current male HIV prevalence, yet it is possible that a novel service delivery model such as HIVST could appeal more or less strongly to HIV-positive men. If undiagnosed HIV-positive men are more likely to use HIVST, HIVST has the potential to quickly dominate the other service delivery models as an alternative to increase HIV diagnosis. We altered the probability of a positive test result only for HIVST as a novel service delivery model that has demonstrated potential to appeal to hard-to-reach and high-risk populations in other settings (43,55,114,115). However, we note that altering this parameter input for any of the service delivery models would have a similar impact. To the extent that any of the service delivery models can be modified to encourage undiagnosed HIV-positive men to test for HIV, the likelihood that the service delivery model will be cost-effective at increasing new diagnoses of HIV rapidly increases, even if the initial uptake of HIV testing remains unchanged.

We acknowledge three limitations of our analysis. First, our use of stated preference data collected for a DCE to predict uptake under each of the service delivery models is innovative and advances a methodological frontier for the use of DCEs to furnish uptake estimates in the absence of observed uptake estimates (i.e. revealed preference data). Yet, choices made in a DCE might not be entirely consistent with choices made in reality. A recent systematic review and meta-analysis indicates that stated choices do reasonably predicted revealed choices (25), yet additional evidence to confirm the concordance between stated and revealed preferences is urgently needed. Second, we evaluated outcomes when a single community-based service delivery model for HIV testing is made available in rural Uganda and assumed no other community-based service delivery models for HIV were available at the same time. Yet, such a scenario does not exclude the possibility that HIV testing is also available at health facilities, and we were not able to account for substitution behaviors to know whether men who test for HIV via a community-based service delivery model would have tested at a health facility if a community-based service delivery model for HIV testing was not available. Third, our decision analytic model allows us to evaluate the cost-effectiveness of community-based service delivery models to promote two important HIV testing outcomes, yet we do not consider other health benefits that could result from accessing a community-based service delivery model for HIV testing aside from these testing outcomes. Nor do we consider downstream health outcomes that are of critical importance for HIV-positive men and for HIV prevention. For instance, we do not evaluate linkage to antiretroviral treatment following an HIV-positive test result, which could vary by service delivery model, or long-term retention in care and viral suppression. Modeling these downstream outcomes could lead to an outcome such as disability-adjusted life years or HIV infections averted for which WTP thresholds are more established. Our data are instead most relevant for the community-based testing environment, and we encourage further research to strengthen the evidence base regarding individual health behaviors and engagement with care following HIV testing under community-based service delivery models.

Despite these limitations, our study delivers timely and important findings for decision makers who seek to allocate resources to increase HIV testing and HIV diagnosis among men. We reveal that HIVST is most likely to be cost-effective at increasing HIV testing by men over a range of WTP thresholds of US \$5.12 - \$7.03 per man who tests for HIV; HBT is most likely to be cost-effective at increasing HIV testing by men for WTP thresholds of US $7.04 – $17.58 per man who tests for HIV, and CHC is most likely to be cost-effective at increasing HIV testing by men for WTP thresholds greater than US $17.58. We further show that the alternatives that are most cost-effective at increasing HIV testing are not necessarily the most cost-effective alternatives at increasing HIV diagnosis. We found that HIVST is most likely to be cost-effective at increasing HIV diagnosis among men over a range of WTP thresholds of US $86 - $1,144 per new HIV diagnosis; for WTP thresholds greater than US $1,144 per new diagnosis, CHC was most likely to be cost-effective at increasing HIV diagnosis among men. As testing coverage expands, it is likely that attainment of the first 90-90-90 target will increasingly depend on service delivery models that do not simply increase uptake of HIV testing by men but increase uptake by HIV-positive men who are unaware of their status, and our work suggests that increasing the effectiveness of community-based service delivery models to target undiagnosed HIV-positive men is likely to have a major impact on the cost-effectiveness landscape. Finally, our work identifies priorities for further investigation. We employed innovative methods to predict uptake of HIV testing under existing and novel service delivery models for HIV testing, and further research is warranted to assess the concordance between uptake predictions derived from stated preference research and uptake that is observed under real-world implementation. We also encourage research to evaluate the subsequent health behaviors and health outcomes of individuals who test for HIV and who are diagnosed with HIV under community-based service delivery models.

Figure 7. Decision Tree Comparing Uptake of HIV Testing and New HIV Diagnoses under Alternative Community-Based Service Delivery Models for HIV Testing

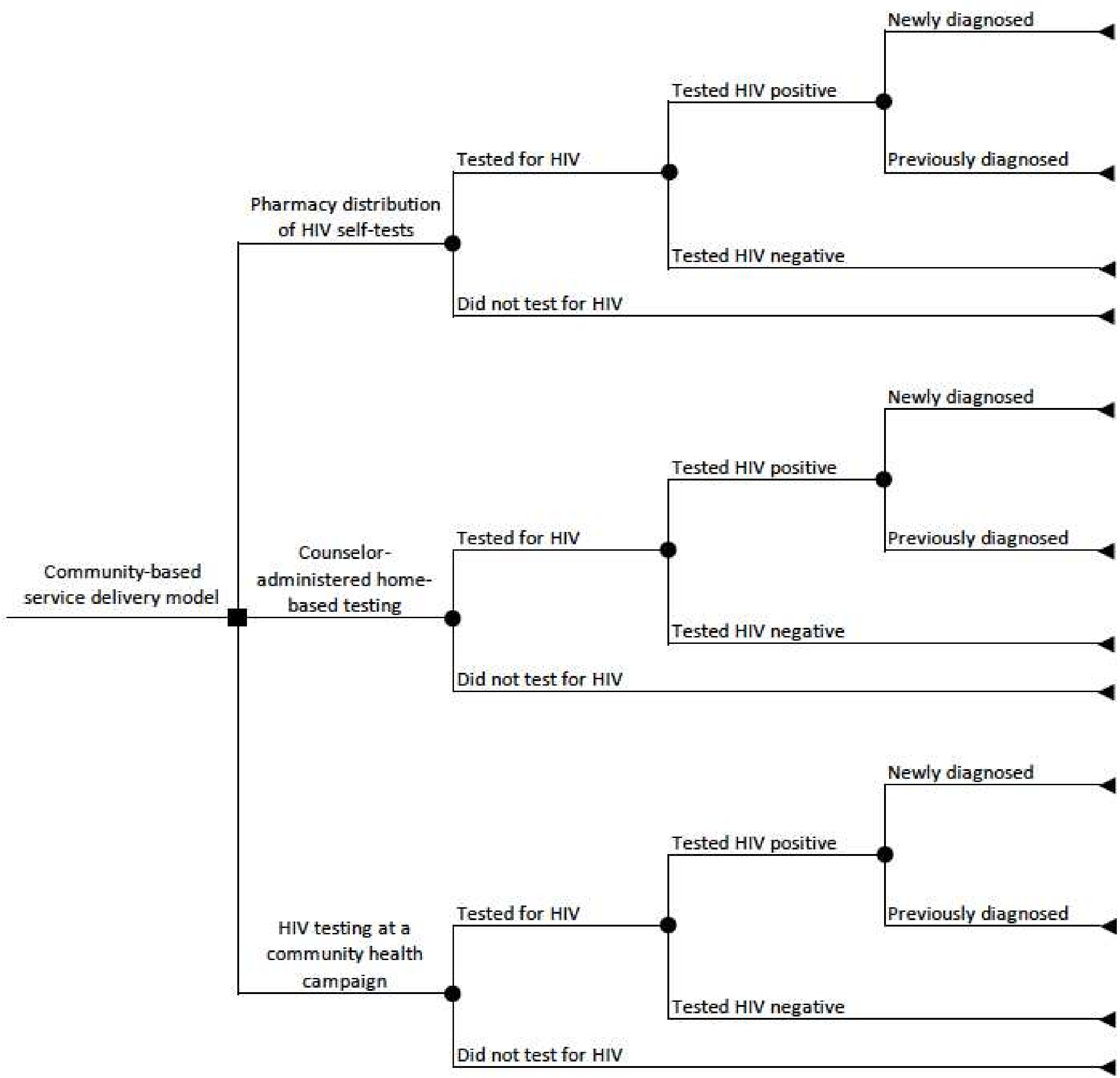


Table 13. Base Case Parameter Inputs

Parameter	Base case value	Source
Adult (≥18 years) male population of rural Uganda	5,206,236	Uganda Bureau of Statistics
Probability of HIV testing (i.e. uptake)		
HIVST	0.32	DCE
HBT	0.47	DCE
CHC	0.64	DCE
Probability of testing HIV-positive		
HIVST[a]	0.061	Assumption; Uganda AIDS Indicator Survey, 2011; FDA Center for Biologics Evaluation and Research, 2018
HBT[b]	0.031	Asiimwe et al., 2017; Tumwesigye et al., 2011
CHC[b]	0.068	Chamie et al., 2018; Chamie et al. 2012
Probability of new HIV diagnosis		
HIVST	1.00	Assumption
HBT	1.00	Asiimwe et al., 2017
CHC	0.50	Chamie et al., 2018; Chamie et al., 2012
Per-person cost to deliver HIV testing (2016 USD)		
HIVST	\$5.02	Micro-costed
HBT	\$6.30	Asiimwe et al., 2017; Tumwesigye et al., 2011; Menzies et al., 2009; Mulogo et al., 2013
CHC	\$8.94	Chang et al., 2016; Chamie et al., 2012

[a] The probability of testing HIV-positive was estimated using the prevalence of HIV among testers and the sensitivity and specificity of OraQuick HIV self-tests. We assumed that the HIV prevalence among testers who use HIVST is 6.6%, the same as the adult male prevalence for the region. We further adjusted this estimate for false positive results using the positive predictive value of OraQuick HIV self-tests.

[b] HBT and CHC employ testing algorithms whereby a confirmatory test is administered following a reactive first test. A tie-breaker test is administered in cases of inconsistent test results. The positive predictive value for HIV testing under these service delivery models is therefore 1.00, and these estimates of the probability that men will test positive under HBT and CHC are pulled directly from the literature.

Table 14. Base Case Results of the Costs and Effectiveness of Different Service Delivery Models to Increase HIV Testing and Diagnosis

Service delivery model	Total cost (US $)	Number of men tested for HIV	Number of new HIV diagnoses	ICER (US $ /Additional man tested)	ICER (US $ /Additional new diagnosis)
No community-based service delivery model	$0	0	0	--	--
HIVST	$8,363,298	1,665,996	101,321	$5.02	$83
HBT	$15,415,665	2,446,931	75,855	$9.03	Dominated
CHC	$29,788,000	3,331,991	113,288	$16.24[a]	$1,790[b]

ICERs are calculated with respect to the next least costly service delivery model. In cases where a service delivery model is more costly yet less effective, it is eliminated from consideration as a dominated alternative and remaining ICERs are calculated excluding the dominated alternative. US $, United States dollars; ICER, incremental cost-effectiveness ratio; HIVST, HIV self-testing using an oral fluid-based test obtained at a local pharmacy; HBT, counselor-administered home-based testing; CHC, HIV testing at a community health campaign.

[a] This ICER was calculated with respect to HBT. If we calculated the incremental costs and effectiveness with respect to HIVST, the ICER would be $12.64 / additional man tested.

[b] This ICER was calculated with respect to HIVST, given that HBT is a dominated alternative.

Figure 8. Efficiency Frontier for Community-Based Service Delivery Models to Increase HIV Testing

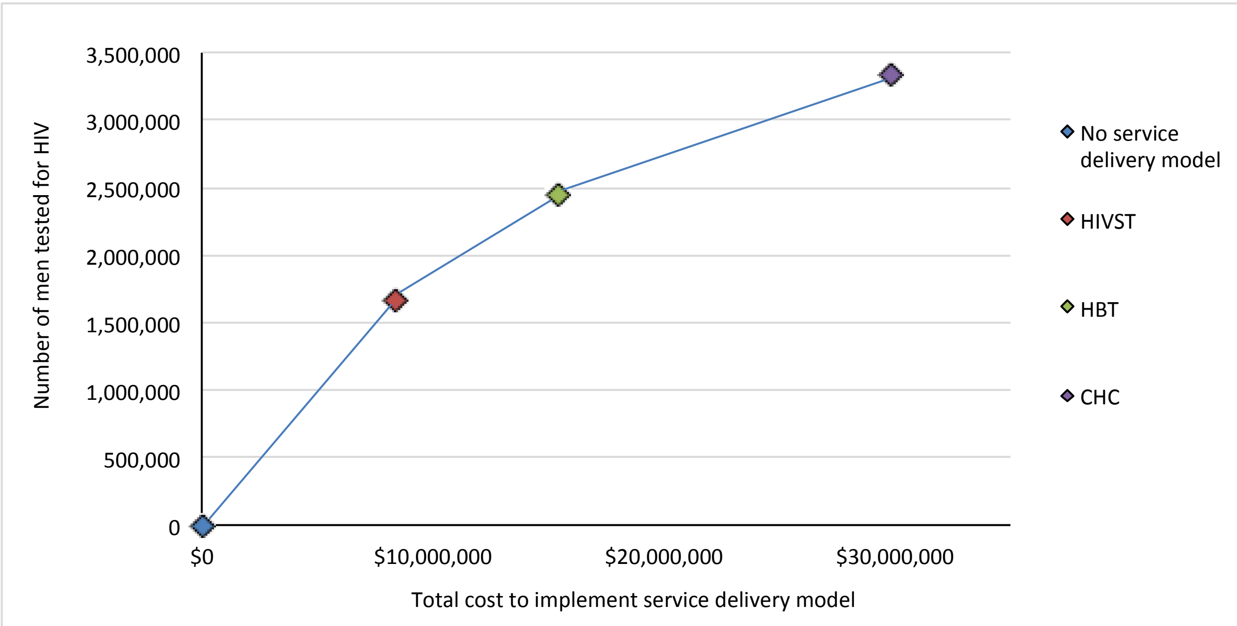
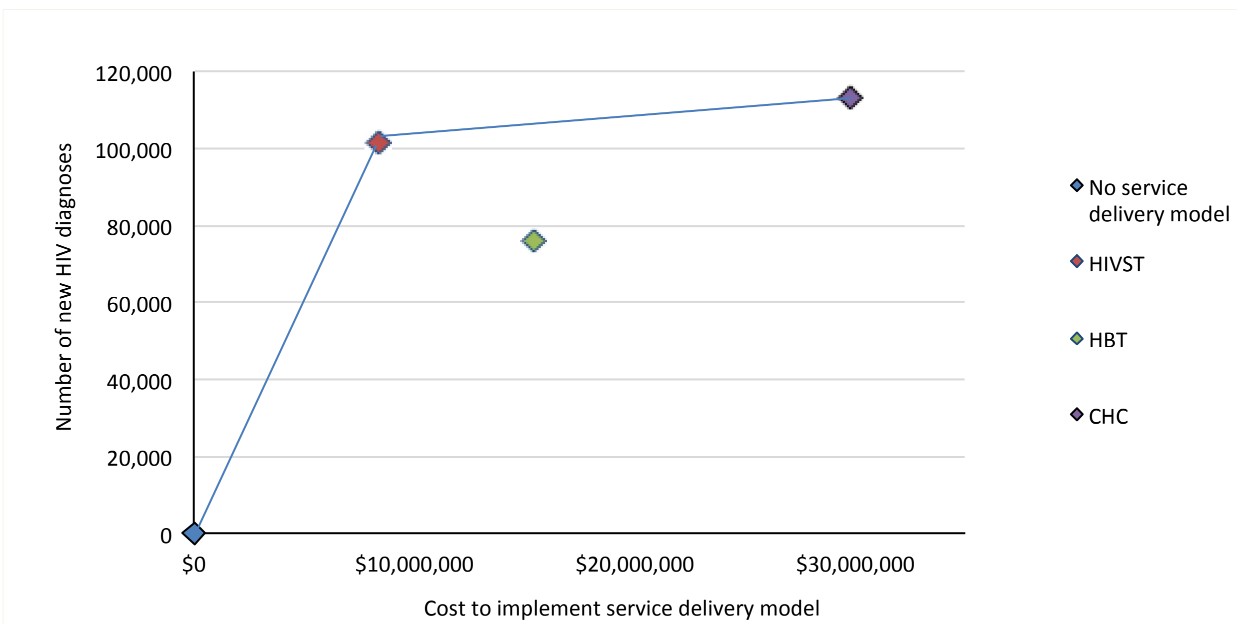


Figure 9. Efficiency Frontier for Community-Based Service Delivery Models to Increase HIV Diagnosis



The total number of men tested for HIV and the number of men newly diagnosed with HIV and are plotted alongside the total costs to implement each service delivery model on the efficiency frontiers. The inverse of the slope of the lines connecting the points provide the incremental cost-effectiveness ratios for one service delivery model relative to another. Points that fall below the lines connecting the points represent dominated alternatives. HIVST, HIV self-testing using an oral fluid-based test obtained at a local pharmacy; HBT, counselor-administered home-based testing; CHC, HIV testing at a community health campaign.

Table 15. Deterministic Sensitivity Analyses of the Cost-Effectiveness of Community-Based Service Delivery Models to Increase HIV Testing

Parameter changed	Analysis type	Base case value(s)	Adjusted value(s)	Adjusted ICER (US $ / additional man tested)	Comparison	Cost-effectiveness result
HIVST						
Per-person cost	One-way	$5.02	$10.04	-$1.68 $6.30 $16.24	HBT relative to HIVST HBT relative to do nothing CHC relative to HBT	HIVST dominated by HBT HBT possibly cost-effective CHC possibly cost-effective
HBT						
Probability of testing for HIV	One-way	0.47	0.69	$7.41	HBT relative to HIVST	HBT possibly cost-effective
CHC						
Probability of testing for HIV & per-person cost when US $0.85 incentives are provided	Two-way	0.64 $8.94	0.76 $10.01	$13.64 $16.02	CHC relative to HIVST CHC relative to HBT	CHC possibly cost-effective
Probability of testing for HIV & per-person cost when immediate access to ART is provided	Two-way	0.64 $8.94	0.90 $10.51	$13.54 $15.11	CHC relative to HIVST CHC relative to HBT	CHC possibly cost-effective

US $, United States dollars; ICER, incremental cost-effectiveness ratio; HIVST, HIV self-testing using an oral fluid-based test obtained at a local pharmacy; HBT, counselor-administered home-based testing; CHC, HIV testing at a community health campaign.

Table 16. Deterministic Sensitivity Analyses of the Cost-Effectiveness of Community-Based Service Delivery Models to Increase HIV Diagnosis

Parameter changed	Analysis type	Base case value(s)	Adjusted value(s)	Adjusted ICER (US $ / additional diagnosis)	Comparison	Cost-effectiveness result
HIVST						
Probability of HIV-positive test result	One-way	0.061	0.033	$288 $384	HBT relative to HIVST CHC relative to HBT	HBT possibly cost-effective CHC possibly cost-effective
Probability of HIV-positive test result	One-way	0.061	0.091	-$93 -$564	HBT relative to HIVST CHC relative to HIVST	HBT dominated by HIVST CHC dominated by HIVST
Probability of new HIV diagnosis	One-way	1.00	0.70	$1,430 $384	HBT relative to HIVST CHC relative to HBT	HBT weakly dominated by CHC CHC possibly cost-effective
Per-person cost	One-way	$5.02	$10.04	$203 $51 $1,091	HBT relative to do nothing HIVST relative to HBT CHC relative to HIVST	HBT weakly dominated by HIVST HIVST possibly cost-effective CHC possibly cost-effective
HBT						
Probability of testing for HIV	One-way	0.47	0.69	$1,421	HBT relative to HIVST	HBT possibly cost-effective
Probability of new HIV diagnosis	One-way	1.00	0.70	-$146	HBT relative to HIVST	HBT dominated by HIVST
CHC						
Probability of testing for HIV & per-person cost when US $0.85 incentives are provided	Two-way	0.64 $8.94	0.76 $10.01	$941	CHC relative to HIVST	CHC possibly cost-effective
Probability of testing for HIV & per-person cost when immediate access to ART is provided	Two-way	0.64 $8.94	0.90 $10.51	$705	CHC relative to HIVST	CHC possibly cost-effective

US $, United States dollars; ICER, incremental cost-effectiveness ratio; HIVST, HIV self-testing using an oral fluid-based test obtained at a local pharmacy; HBT, counselor-administered home-based testing; CHC, HIV testing at a community health campaign.

Figure 10. Cost-Effectiveness Acceptability Curves Representing the Probability that Alternative Community-Based Service Delivery Models are Optimal for Increasing HIV Testing over a Range of Willingness-to-Pay Thresholds

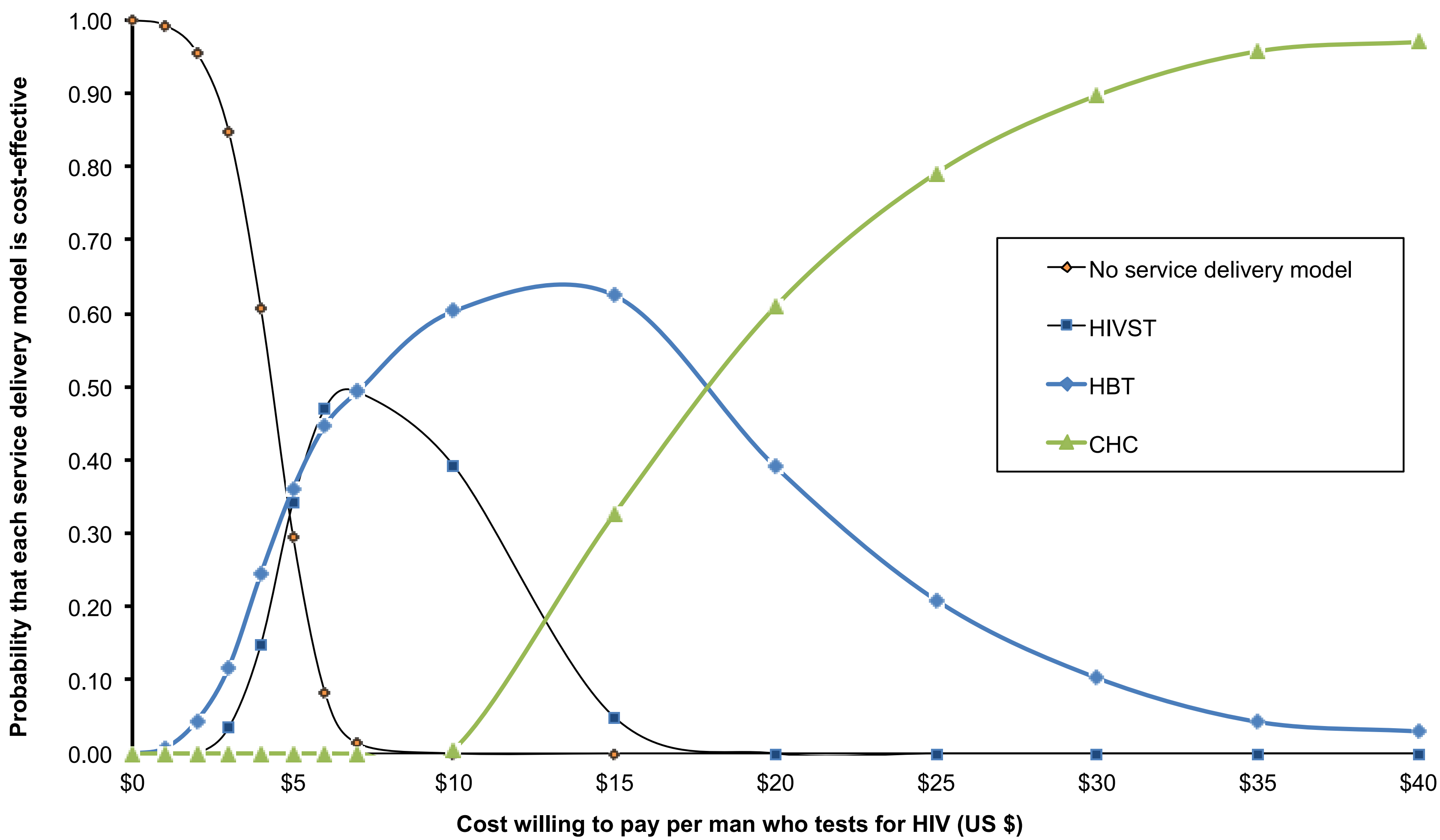
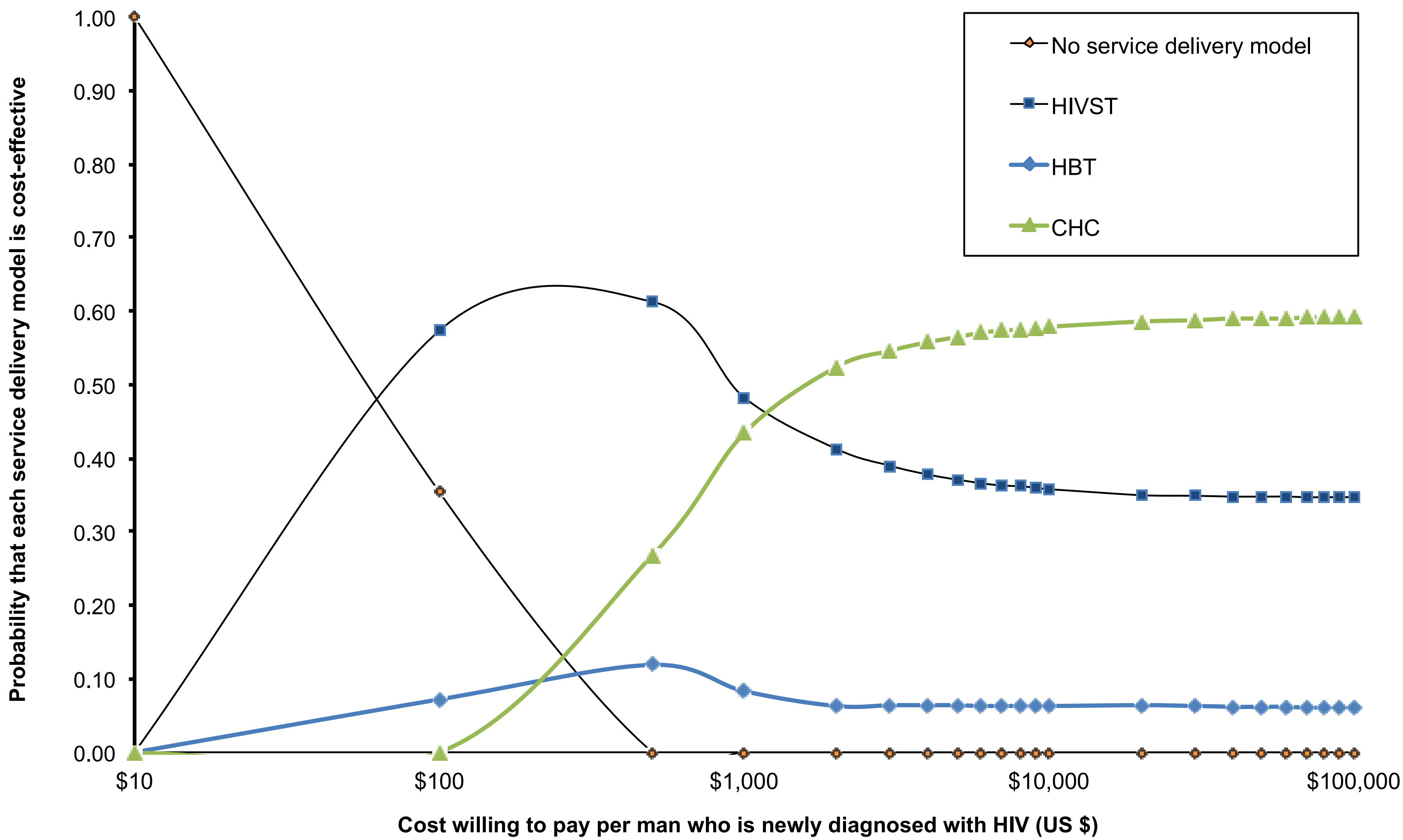


Figure 11. Cost-Effectiveness Acceptability Curves Representing the Probability that Alternative Community-Based Service Delivery Models are Optimal for Increasing HIV Diagnosis over a Range of Willingness-to-Pay Thresholds



CHAPTER 5. SUMMARY, IMPLICATIONS, AND CONCLUSIONS

This dissertation advances knowledge regarding men's stated preferences for attributes of community-based HIV testing in Uganda and is significant because it delivers findings to help address the current gap in male testing coverage in sub-Saharan Africa. The three research papers included in this dissertation respond to questions that are important for policymakers and practitioners to consider when determining how to improve the delivery of community-based HIV testing to promote male testing, and the overall goal of this dissertation was to provide a comprehensive evaluation of the potential of different service delivery models and interventions to promote HIV testing by men. To conclude, I discuss the implications of this dissertation for policy, practice, and future research. I begin by summarizing the key findings and limitations of each research paper.

5.1. Summary of Findings

In the first research paper, I presented the results of a discrete choice experiment (DCE) designed to: 1) elicit stated preferences for policy-relevant attributes of HIV testing that can be modified to encourage men to test for HIV, and 2) predict uptake of HIV testing under alternative community-based service delivery models (HIV testing at a community health campaign, counselor-administered home-based testing, and HIV self-testing using an oral fluid-based self-test obtained at a local pharmacy). The DCE was administered to a representative sample of 203 adult male residents of rural Uganda. I found that the most important attribute to participants was the provision of immediate access to ART for HIV-positive persons which increased the predicted uptake of HIV testing under the alternative community-based service delivery models by 26-44 percentage points. The provision of US $0.85 incentive also influenced participants' choices and increased the predicted uptake of HIV testing under the alternative community-based service delivery models by 6-12 percentage points. Participants' stated preferences suggested that they would much rather test for HIV using the community-based service delivery models presented in the DCE than opt-out of HIV testing, and an important methodological advance made in this paper was the calibration of uptake predictions to match observed estimates of testing uptake reported in peer-reviewed literature (i.e. revealed preference data).

The focus of the second research paper was heterogeneity in men's stated preferences for attributes of HIV testing. I estimated and compared goodness-of-fit measures for conditional, random parameters, and latent class logit model specifications, each of which makes different assumptions about the distribution of preferences in a sample. I also conducted covariate analyses to assess whether preference heterogeneity can be attributed to observed characteristics of participants. Estimation of preferences using random parameters and latent class logit model specifications considerably improved model fit relative to the conditional logit model specification. Both the random parameters and latent class logit model specifications account for preference heterogeneity, and I concluded that men's preferences for attributes of HIV testing are heterogenous. The covariate analyses suggested differences in participants' utility for opting out of HIV testing yet did not reveal differences in preferences for policy-relevant attributes of HIV testing that could be modified to encourage men to test for HIV. It is likely that the DCE was underpowered to detect differences in preferences for attributes of HIV testing associated with observed characteristics of men, and a key limitation of this paper is that it cannot be resolved whether preference heterogeneity can be attributed to observed characteristics of men.

The third research paper presented the results of a cost-effectiveness analysis comparing three community-based service delivery models to promote HIV testing and diagnosis among adult men in rural Uganda. I compared HIV testing at multi-disease community health campaigns, counselor-administered home-based testing, and the distribution of oral fluid-based HIV self-tests at local pharmacies relative to a status quo scenario where no community-based service delivery model for HIV testing is available. I incorporated uptake predictions from the DCE into the cost-effectiveness analysis to estimate the likelihood that adult men will test for HIV under each service delivery model. Doing so made it possible to investigate a novel service delivery model (i.e. the HIV self-test service delivery model) for which no estimates of observed uptake are available. An important conclusion was that service delivery models that are most cost-effective at increasing HIV testing by men are not necessarily the most cost-effective at increasing HIV diagnosis among men. Additionally, the results regarding the cost-effectiveness of the service delivery models to increase HIV diagnosis were highly sensitive to changes in the prevalence of HIV among men who test under each service delivery model. The likelihood that a service delivery model was the most cost-effective alternative increased dramatically when the prevalence of HIV among testers increased by only a few percentage points.

5.2. Implications for Policy and Practice

The findings from this dissertation research hold several implications for policy and practice. It is instructive that men stated strong preferences for the immediate provision of ART when accessing community-based HIV testing. Ensuring access to ART for HIV-positive persons via community-based service delivery models requires a number of enhanced operational capacities. First, personnel who can counsel individuals who test HIV-positive on the use of ART are required. Second, it would be beneficial for disease staging (e.g. point-of-care

CD4 testing) to be provided following HIV diagnosis. Third, it is essential that HIV-positive persons are linked to health systems for long-term treatment and care.

It is also instructive that US$ 0.85 incentives led to a predicted increase in uptake of HIV testing by men. The resource requirements to provide incentives are less intensive than those required to administer ART via community-based service delivery models for HIV testing and the feasibility of implementing incentivized interventions for community-based HIV testing has been demonstrated (20,40). Yet, offering incentives for HIV testing raises a number of social implications. For instance, whether incentives are offered only to men or also to women is a matter for consideration. Aside from the gap in male testing coverage, this dissertation does not focus on other inequalities between men and women, many of which disfavor women. The preference-based approach I assumed for this dissertation reveals attributes of HIV testing that appeal and can be leveraged to increase testing uptake by men, and it is important for decision makers to ensure that potentially effective policies and interventions are implemented in a manner that is consistent with broader policy objectives.

Decision makers should also be aware that men's preferences are heterogeneous. Although it could not be concluded that preferences vary for certain policy-relevant or demographic subgroups of men, decision makers should keep in mind that preference heterogeneity is an area for further investigation and several approaches might be warranted to achieve the greatest uptake of HIV testing.

Lastly, the cost-effectiveness analysis revealed that the landscape of community-based HIV testing is sensitive to a number of changes and particularly to changes in the effectiveness of different service delivery models to induce uptake of HIV testing by undiagnosed HIV-positive men. Implementers of community-based service delivery models should seek to uncover ways to enhance the effectiveness of community-based service delivery models to increase HIV testing by undiagnosed HIV-positive men.

5.3. Next Steps and Future Research

The findings and limitations of my research papers spur further investigation. First, findings from the first paper indicated that providing immediate access to ART and offering US $0.85 incentives are likely to increase HIV testing by men, and research is warranted to assess the feasibility and confirm the effectiveness of these interventions. More generally, research to corroborate the external validity of stated preferences to predict revealed preferences is merited and would advance the field of stated preference research.

Second, my investigation of preference heterogeneity could not resolve whether heterogeneity was associated with observed characteristics of men and further research is needed to determine whether certain service delivery models and interventions can be leveraged to promote testing by priority subpopulations of men.

Third, results from the cost-effectiveness analysis of alternative service delivery models to increase HIV diagnosis among men indicated that providing immediate access to ART for HIV-positive persons and offering US $0.85 incentives at multi-disease community health campaigns would increase the likelihood that a community health campaign is cost-effective. Another type of economic evaluation that would be beneficial for decision makers to understand the financial implications of implementing these interventions is a budget impact analysis (116). Fourth, my dissertation research focused on increasing knowledge of community-based service delivery models and interventions that can be harnessed to increase HIV testing by men yet subsequent health outcomes are of critical importance. Further research is needed to investigate linkage to care following community-based HIV testing and to evaluate health outcomes of HIV-positive men once enrolled in treatment and care for HIV/AIDS.

5.4. Conclusion

Community-based service delivery models for HIV testing hold considerable potential and can be strengthened to promote HIV testing by men in sub-Saharan Africa. I found that modifying attributes of how testing is delivered is likely to have relatively modest to quite profound impacts on uptake of HIV testing by men in rural Uganda. I further found that the cost-effectiveness of alternative community-based service delivery models to increase HIV diagnosis among men hinges on the effectiveness of service delivery models to induce uptake by undiagnosed HIV-positive men. This dissertation provides evidence to strengthen the delivery of community-based HIV testing to promote HIV testing by men in sub-Saharan Africa and motivates future research of strategies to effectively promote HIV testing among undiagnosed HIV-positive men.

APPENDIX A. ATTRIBUTE LEVELS THAT WERE PAIRED AND THAT WERE CONSTRAINED FROM PAIRING WITH SERVICE DELIVERY MODELS

Service delivery model	**HIV testing at a community health campaign**	**Counselor-administered home-based testing**	**HIVST using an oral fluid-based test obtained at a local pharmacy**
Attribute levels	Multi-disease testing is provided	Multi-disease testing is provided	Multi-disease testing is provided
	Multi-disease testing is *not* provided	Multi-disease testing is *not* provided	Multi-disease testing is *not* provided
	ART is immediately available for HIV-positive persons	ART is immediately available for HIV-positive persons	ART is immediately available for HIV-positive persons
	ART is *not* immediately available for HIV-positive persons	ART is *not* immediately available for HIV-positive persons	ART is *not* immediately available for HIV-positive persons
	An incentive of US $0.85 is provided	An incentive of US $0.85 is provided	An incentive of US $0.85 is provided
	An incentive of US $0.85 is *not* provided	An incentive of US $0.85 is *not* provided	An incentive of US $0.85 is *not* provided

The hatched cells represent attribute levels that were constrained from pairing with a specific service delivery model. HIVST, HIV self-testing; ART, antiretroviral therapy; US $, United States dollars.

APPENDIX B. CALIBRATION OF PREDICTED UPTAKE OF HIV TESTING USING REVEALED PREFERENCE DATA REPORTED IN PEER-REVIEWED LITERATURE

Using a discrete choice experiment (DCE) to generate uptake predictions allows us to evaluate the likelihood that men will access different service delivery models to test for HIV when they are made available in rural communities. Yet, one limitation of our approach is that hypothetical choices may not mirror real world choices. To account for this possibility and to strengthen confidence in our uptake predictions, we implemented a calibration procedure to ensure that uptake predictions generated from the DCE matched reference values of testing uptake that have been reported in peer-reviewed literature (i.e. revealed preference data).

Kenneth Train outlines the calibration procedure we implemented. In *Discrete Choice Methods with Simulation* (2009), Train advises adjusting the alternative-specific constants included in the discrete choice model in order to forecast market shares (64). An alternative-specific constant captures the average effect on utility for the alternative of all factors that are not included in the model. An alternative-specific constant is thus analogous to a constant (i.e. an intercept) in other regression frameworks. The rationale underlying calibration is that unobserved factors might differ in the forecast environment from unobserved factors in the experimental environment constructed in a DCE. For our context, it is likely that unobserved factors in a real-world environment (i.e. the forecast environment) differ from unobserved factors that influenced men's choices in the discrete choice experiment.

To account for these differences, Train recommends adjusting the alternative specific constants in an iterative manner using the following formula:

$$\alpha_j^1 = \alpha_j^0 + \ln(S_j \,/\, S_j^0)$$

Here, α_j^0 is the alternative-specific constant estimated by the discrete choice model. S_j is the share of decision makers who choose alternative j in the forecast environment and S_j^0 is the share of decision makers who are predicted to choose alternative j using the results of the discrete choice experiment. Using this formula, we compare the share of decision makers who have actually been observed to choose alternative j in practice relative to the share of individuals that we predict will choose alternative j using DCE-derived preference estimates. If the observed share of decision makers who choose alternative j is greater than the predicted share, we raise the constant. If the observed share of decision makers who choose alternative j is less than the predicted share, we lower the constant. The new constant we obtain is α_j^1. We then use α_j^1 to generate uptake predictions and again, compare the predicted share of decision makers who choose alternative j to the observed share of decision makers who chose alternative j in practice. In this manner, we iteratively adjust the alternative-specific constant until the predicted share of decision makers who choose alternative j matches the observed share of decision makers who chose alternative j in practice. We then make all other relevant predictions using the adjusted alternative-specific constant.

For our analysis, we estimated preferences using a single alternative-specific constant for the alternative to opt-out of HIV testing.[1] We then made predictions for two choice scenarios. In the first scenario, we predicted uptake of HIV testing by adult men when a single community-based service delivery model for HIV testing is implemented. In the second scenario, we predicted uptake of HIV testing when two community-based service delivery models for HIV

[1]The alternative to opt-out of HIV testing was the only alternative that was the same across all choice sets, and the testing alternatives that participants viewed in the choice sets were unlabeled. The use of a single alternative-specific constant is therefore appropriate.

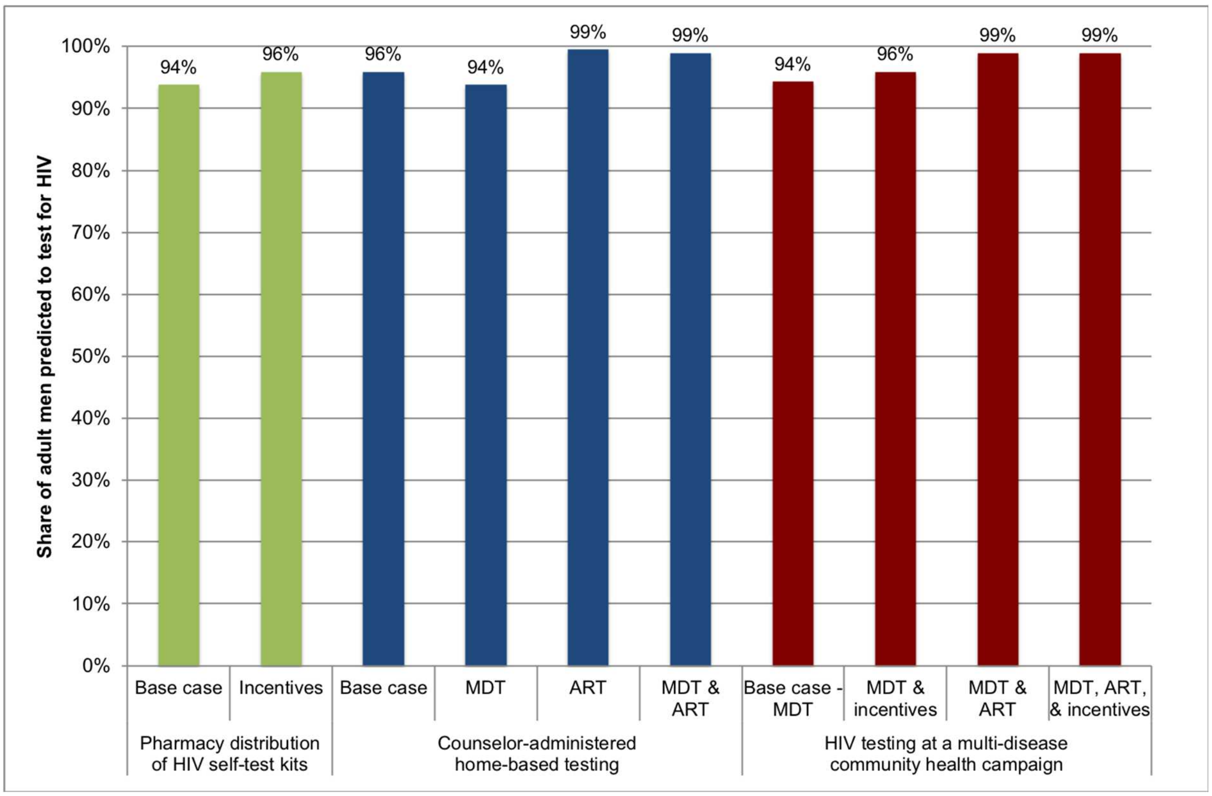
testing are implemented concurrently. To establish calibration reference values, we therefore needed to identify observed estimates of testing uptake (or, more specifically, testing decline) when community-based service delivery models for HIV testing have been implemented in the study context and adult men have been presented with comparable choice scenarios.

Following a review of relevant peer-reviewed studies, we selected a single study that provided reference values for both choice scenarios. In “A hybrid mobile approach for population-wide HIV testing in rural east Africa: an observational study”, Chamie et al. (2016) report uptake of HIV testing by adult residents of 32 communities in Uganda and Kenya under a hybrid mobile strategy to promote HIV testing (68). Prior to the hybrid mobile testing strategy, a door-to-door census was conducted in each study community. Residents were invited to attend a community health campaign that was held in their community. Multi-disease testing was provided at the community health campaign but a US $0.85 incentive and immediate access to ART for HIV-positive persons were not. Adult residents who did not attend the community health campaign were traced and offered home-based testing. Under the hybrid mobile testing strategy, it was estimated that 64% of adult male residents tested for HIV at the community health campaign. An additional 12% tested for HIV by way of home-based testing for a total observed uptake of HIV testing by 86% of adult male residents. It can equally be observed that 36% of adult male residents opted-out of testing for HIV at the community health campaign and that 14% of adult male residents opted-out of HIV testing when it was possible to test either at a community health campaign or by way of home-based testing. We used these observed estimates of testing decline as reference values for calibration. We then applied Train’s adjustment for the alternative-specific constant.

Given that we generated uptake predictions using individual preference estimates, we applied the adjustment on the individual level as well. That is, we adjusted the alternative-specific constant simulated for each individual in the sample, predicted whether each individual in the sample would test for HIV for a given choice scenario, summed the individual predictions to obtain the aggregate predicted uptake for the sample, compared the aggregate predicted uptake to the observed predicted uptake reported by Chamie et al. (2016), and adjusted the individual alternative-specific constants iteratively until the aggregate predicted uptake matched the observed predicted uptake.

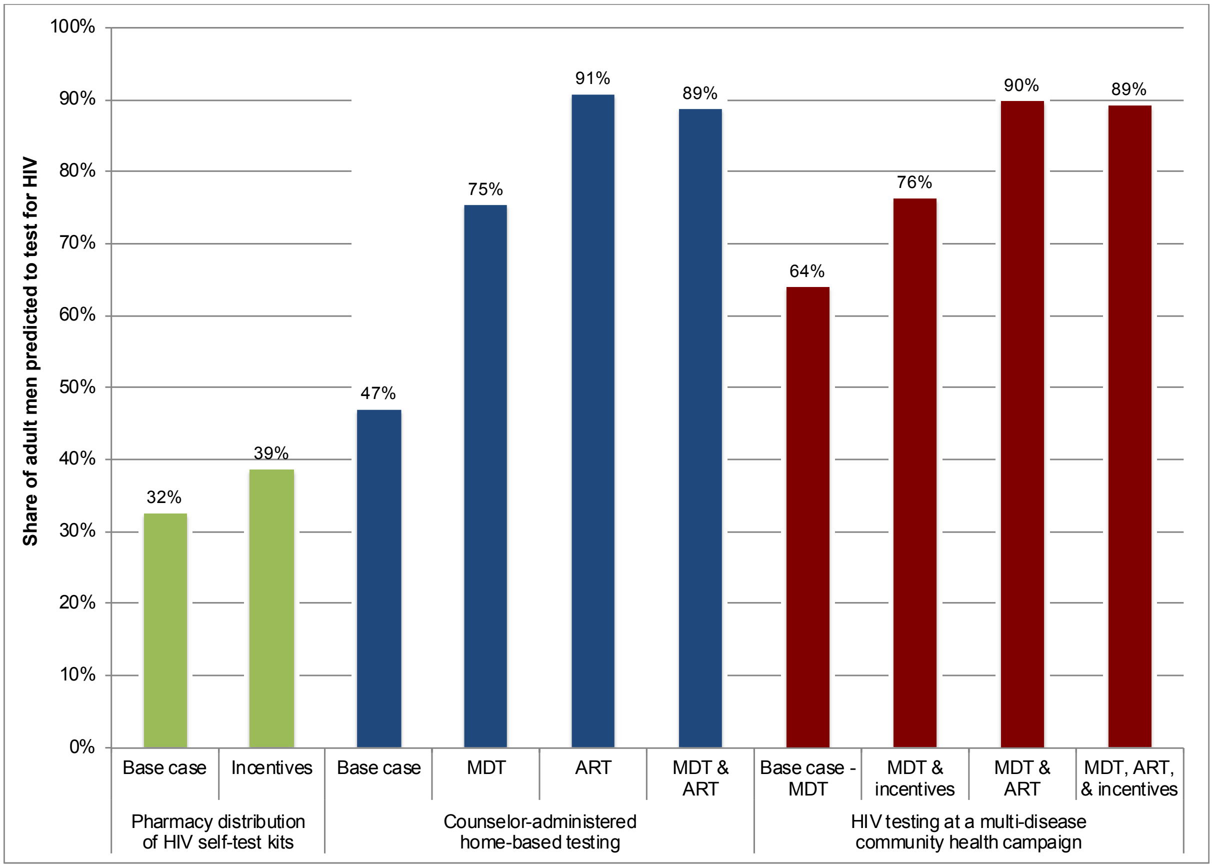
In **Figures B1** and **B2**, we compare our predictions of testing uptake before and after calibration when a single community-based service delivery model is implemented in Uganda. What is starkly evident is that calibration has an important effect when making predictions of testing uptake for this choice scenario. Without calibration, we predict very high rates of testing uptake across all service delivery models. We know from observed estimates of testing uptake reported in peer-reviewed literature that our predictions are not accurate. Following calibration, we obtain predictions of testing uptake that are consistent with a reference value of 64% of adult men who test for HIV at a multi-disease community health campaign. We have far greater confidence in our predictions following calibration. In **Figures B3** and **B4**, we compare our predictions of testing uptake before and after calibration when two community-based service delivery models are implemented concurrently. The differences in uptake before and after calibration are less pronounced for this second choice scenario, yet it can still be observed that calibration adjusts uptake predictions downward to match an 86% reference value of testing uptake by adult men whether both HIV testing at a multi-disease community health campaign and counselor-administered home-based testing are available as service delivery models for HIV testing. It makes sense that the differences in predicted verses observed estimates of testing uptake are less stark as this second choice scenario is consistent with the format of the choice sets that participants viewed in the DCE.

Figure B1. Predicted Uptake of HIV Testing under a Single Service Delivery Model before Calibration



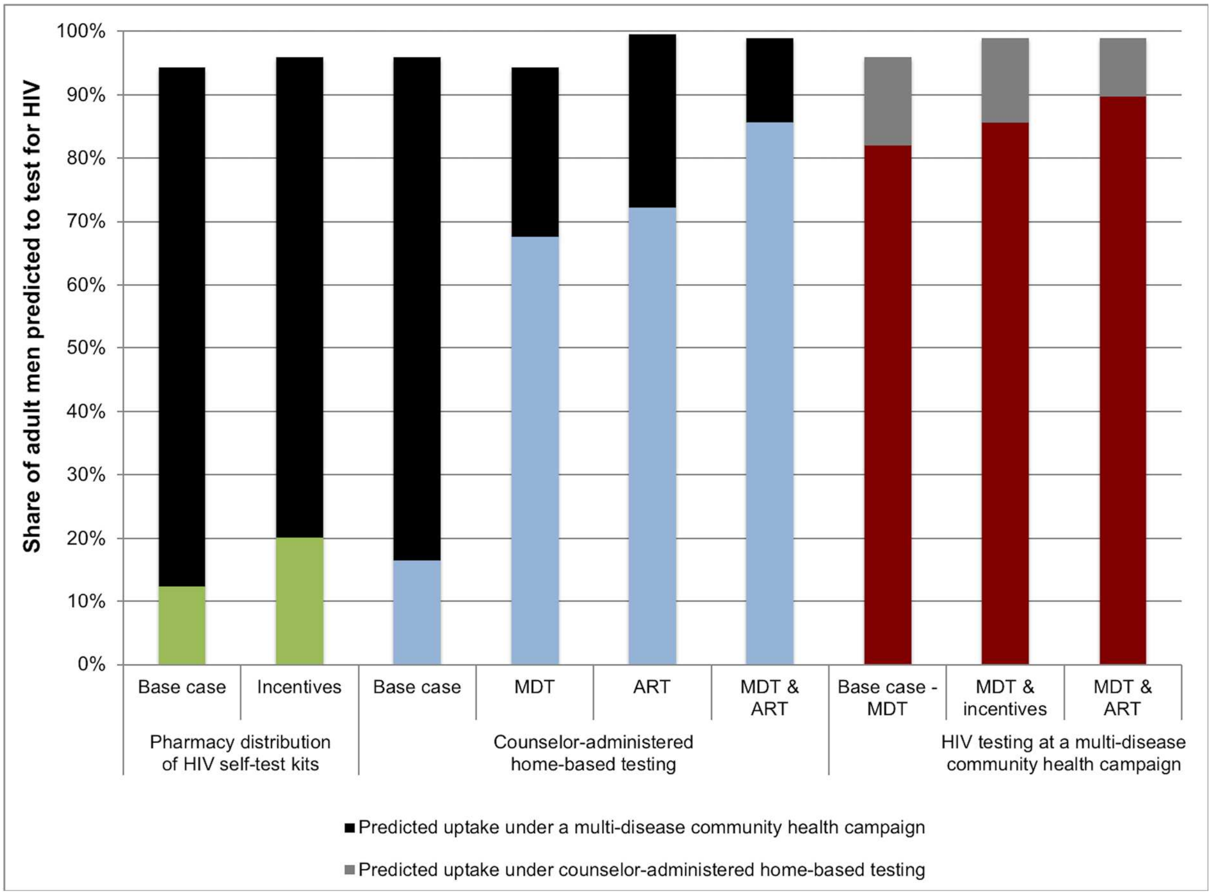
MDT, multi-disease testing; ART, immediate access to antiretroviral therapy for HIV-positive persons

Figure B2. Predicted Uptake of HIV Testing under a Single Service Delivery Model after Calibration



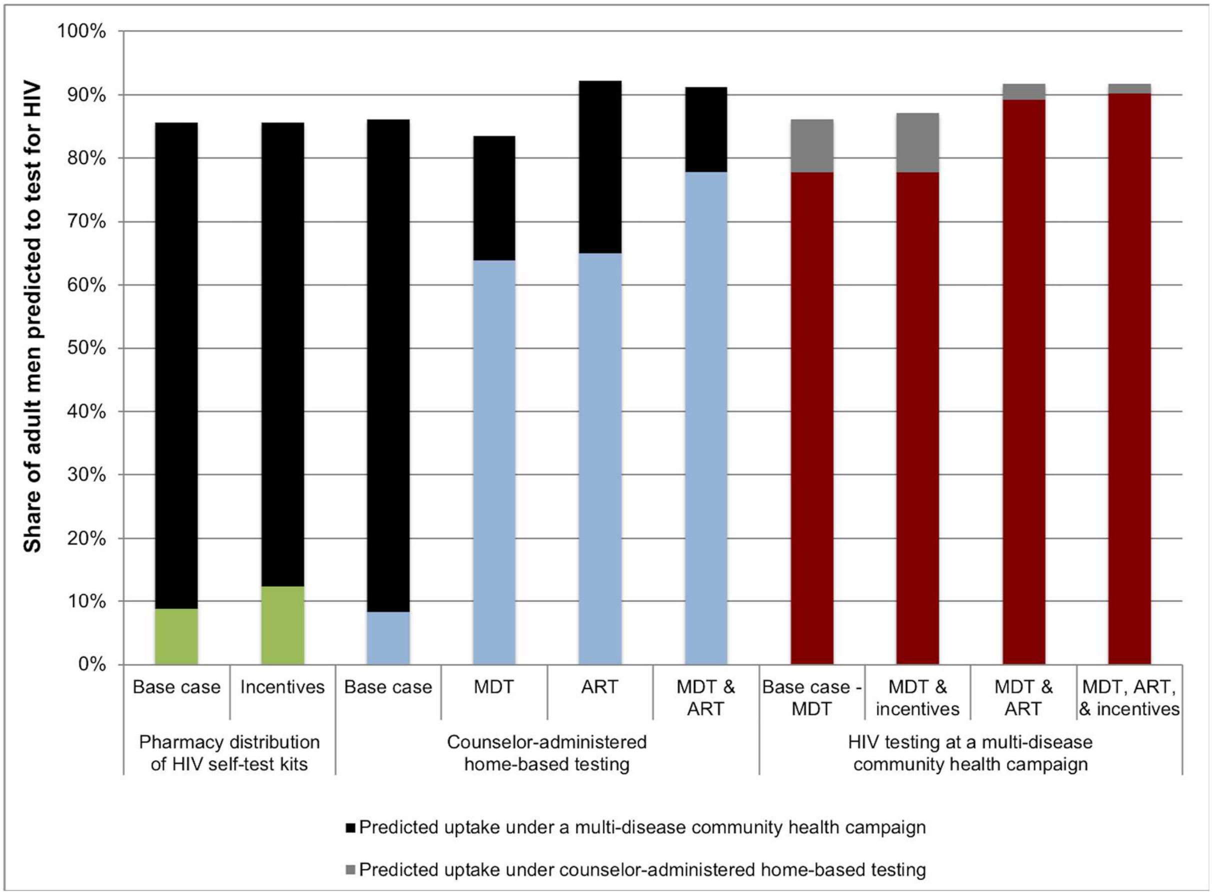
MDT, multi-disease testing; ART, immediate access to antiretroviral therapy for HIV-positive persons

Figure B3. Predicted Uptake of HIV Testing when Two Service Delivery Models are Implemented in Tandem before Calibration



MDT, multi-disease testing; ART, immediate access to antiretroviral therapy for HIV-positive persons.

Figure B4. Predicted Uptake of HIV Testing when Two Service Delivery Models are Implemented in Tandem after Calibration



MDT, multi-disease testing; ART, immediate access to antiretroviral therapy for HIV-positive persons

APPENDIX C. COST CATEGORIES FOR DISTRIBUTION OF HIV SELF-TESTS AT LOCAL PHARMACIES

Component	**Estimated cost (2017 US $)**	**Percentage of total cost**
Mobilization (radio and SMS broadcast announcements and pharmacy posters)	6,545	6%
HIV self-test procurement (purchase of self-tests, freight, import duties, and 18% VAT)	89,220	80%
Delivery of self-tests to retailers (local truck hire with fuel, 3 days/quarter)	480	<1%
Communication with retailers (airtime)	222	<1%
Personnel	13,200	12%
Building & overhead	1,320	1%
Total estimated cost for HIVST service delivery model:	**110,987**	

APPENDIX D. ADDITIONAL COSTS FOR PROVIDING ART AND FINANCIAL INCENTIVES AT COMMUNITY HEALTH CAMPAIGNS

Table D1. Additional costs for providing immediate access to ART for HIV-positive persons at community health campaigns

Component	**Estimated cost (2017 US $)**	**Percentage of total cost**
Point of care CD4 testing	46,516	48%
Drugs - 2 week supply of antiretrovirals	15,820	16%
Linkage support (shuttle service and travel vouchers)	6,252	6%
Personnel	26,400	27%
Building & overhead	2,640	3%
Total estimated cost to provide ART on site for newly diagnosed HIV-positive persons:	**97,628**	

Table D2. Additional costs for providing financial incentives for HIV testing at community health campaigns

Component	**Estimated cost (2017 US $)**	**Percentage of total cost**
3,000 UGX incentives and transaction fees	41,342	74%
Storage and safety	117	<1%
Personnel	13,200	24%
Building & overhead	1,320	2%
Total estimated cost to provide incentives for HIV testing:	**55,979**	

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