**Supplement to**

# Projected Effectiveness of HIV Detection during Early Infection and Rapid ART Initiation among MSM and Transgender Women in Peru: A Modeling Study

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## Model Summary

The MSM population in the model is first stratified into two groups by HIV status: the susceptible population and the infected population (see Model Diagram, Figure 1 in main text). The susceptible population is denoted ***S***. The infected individuals are stratified by disease progression and where they fit into the HIV care cascade. Those infected but unaware of their HIV status are in group $I_\phi$, where $\phi${1 (acute), 2 (CD4>500), 3 (CD4 350-500), 4 (CD4 200-350), 5 (CD4$<200)} represents the disease stage of the individual stratified by CD4 count. Those diagnosed with HIV, but not engaged in care are in group $D_\phi$. Those engaged in care, but not on antiretroviral therapy (ART) are in group $E_\phi$. Those on ART, but not virally suppressed are in group $U_\phi$. Finally, those on ART and virally suppressed are in group $T_\phi$. The CD4 classification of treated individuals is not informative for the actual CD4 count on ART but represents the state they would return if treatment was interrupted. In absence of intervention, we assume the acute HIV stage is too short so no acutely infected individuals become diagnosed. After the start of the intervention, we initiate flows from the acute compartment, $I_1$, into the diagnosed compartment, $D_1$.

Population is further stratified by age (young 15-24, middle-aged 25-34, or old 35-49), risk behavior (low risk <5 partners, or high risk 5+ partners) and sexual role (insertive, receptive, or versatile). Insertive MSM partner predominantly (but not exclusively) with receptive and versatile MSM. Receptive MSM partner predominantly (but not exclusively) with insertive and versatile MSM. Role assignment remain constant over time.

HIV transmission depends on the annual rate of condom use, ART status, HIV stage, risk, role and age group, the annual number of partners and sexual acts between partnerships. The rate of mixing between populations depends on the current distribution of risk, role and age groups. We ensure the overall number of partnerships between groups remains balanced by continually updating the fraction of partners someone with a particular risk, role and age group has with the rest of the population.

Individuals move between age groups at rate inversely proportional to the length of the age groups. The proportion of high-risk MSM at the age transition is adjusted to preserve the conditional risk distribution of each age group. Individuals entering the population (non-

immigration) join the youngest susceptible compartments. Background mortality rate depends only on age while HIV related mortality depend on the HIV stage and ART status.

Model simulations start in 2004 when the ART eligibility criteria is at CD4<200. ART eligibility is expanded to CD4<350 in 2012, to CD4<500 in 2015 with universal access to ART assumed after 2018.

### Detailed Model Description

*We use the following indexing to represent:*

- Risk status $i \in$ {1 (low risk), 2 (high risk)}
- Role status $j \in$ {1 (insertive), 2 (receptive), 3 (versatile)}
- Age group $k \in$ {1 (young), 2 (middle), 3 (old)}
- Disease stage status $\phi \in$ {1 (acute), 2 (CD4>500), 3 (CD4 350-500), 4 (CD4 200-350), 5 (CD4<200)}
- Awareness/treatment status $A \in$ { I (Infected, unaware), D (Diagnosed), E (Engaged in care), U (on ART, virally Unsuppressed), T (on ART, virally Suppressed)}

*The MSM population is stratified in the following compartments:*

$S^{i,j,k}$ : Susceptible population with risk status $i$, role status $j$ and age group $k$

$I_{\phi}^{i,j,k}$: Undiagnosed infected population with risk status $i$, role status $j$ and age group $k$ who are in disease stage $\phi$

$D_{\phi}^{i,j,k}$ : Diagnosed infected population with risk status $i$, role status $j$ and age group $k$ who are in disease stage $\phi$

$E_{\phi}^{i,j,k}$ : Infected population who are engaged in care but not on ART with risk status $i$, role group $j$ and age group $k$ who are in disease stage $\phi$

$U_{\phi}^{i,j,k}$ : Infected population who on ART but unsuppressed with risk status $i$, role group $j$ and age group $k$ who will return to disease stage $\phi$ if ART is interrupted

$T_{\phi}^{i,j,k}$ : Infected population who on ART and suppressed with risk status $i$, role group $j$ and age group $k$ who will return to disease stage $\phi$ if ART is interrupted

$I$ : Infected population size $I = \sum_{i,j,k,\phi} \left( I_{\phi}^{i,j,k} + I_{P,\phi}^{i,j,k} + D_{\phi}^{i,j,k} + E_{\phi}^{i,j,k} + U_{\phi}^{i,j,k} + T_{\phi}^{i,j,k} \right)$. Here $T_1^{x,y,z} = 0.$

$S$ : Susceptible population size $S = \sum_{i,j,k} \left( S^{i,j,k} + S_P^{i,j,k} + S_V^{i,j,k} + S_P^{i,j,k} \right)$

$N$ : Total population size $N = S + I$

*Model parameters:*

$d_k$ : Death rate (non-HIV related) for age group $k$

$\mu_\phi$: HIV-related death rate for disease stage $\phi$

$a_k$: Aging rate from age $k$ to age $k+1$

$\rho_{i,k}$: Fraction of population with risk status $i$ and in age group $k$

$r_j$: Fraction of population with role status $j$

$b$: Population recruitment rate (aging into population)

$\sigma_{A,\phi}$: Progression rate through the awareness/treatment cascade (vertical flows in the model diagram) by disease stage $\phi$ and awareness/ treatment status $A$

$\tau_{A,\phi}$: Drop rate from awareness/treatment state $A$ (losing suppression, dropping ART or leaving care) into disease stage $\phi$

$\epsilon_{A,\phi}$: Disease progression rate (horizontal flows in the model diagram) by disease stage $\phi$ and awareness/treatment status $A$

$\lambda^{i,j,k}$: Force of infection for newly infected population entering $I_1^{i,j,k}$

$\delta_{i,j}$: Kronecker delta function

*Model Equations*

For simplicity, all variables corresponding to age group $k=0$ have a value 0.

$$\frac{dS^{i,j,k}}{dt} = b\delta_{1,i} r_j \rho_{i,k} N + a_{k-1}\frac{\rho_{i,k}}{\sum_l \rho_{l,k}}\sum_l S^{l,j,k-1} - \left(d_k + a_k\right) S^{i,j,k} - \lambda^{i,j,k} S^{i,j,k},$$

$$i=1,2; \quad j=1,2,3; \quad k=1,2,3;$$

$$\frac{dI_1^{i,j,k}}{dt} = \lambda^{i,j,k} S^{i,j,k} + a_{k-1}\frac{\rho_{i,k}}{\sum_l \rho_{l,k}}\sum_l I_1^{l,j,k-1} - (d_k + \epsilon_{I,1} + a_k) I_1^{i,j,k},$$

$$i=1,2; \quad j=1,2,3; \quad k=1,2,3;$$

$$\frac{dI_\phi^{i,j,k}}{dt} = \epsilon_{I,\phi-1} I_{\phi-1}^{i,j,k} + a_{k-1}\frac{\rho_{i,k}}{\sum_l \rho_{l,k}}\sum_l I_\phi^{l,j,k-1} - (\mu_\phi + d_k + \epsilon_{I,\phi} + \sigma_{I,\phi} + a_k) I_\phi^{i,j,k},$$

$$i=1,2; \quad j=1,2,3; \quad k=1,2,3; \quad \phi=2,\ldots,5$$

$$\frac{dD_1^{i,j,k}}{dt} = \sigma_{\mathrm{I},1} I_1^{i,j,k} + a_{k-1}\frac{\rho_{i,k}}{\sum_l \rho_{l,k}}\sum_l D_1^{l,j,k-1} - (d_k + \epsilon_{D,1} + \sigma_{D,1} + a_k) D_1^{i,j,k},$$

$$i=1,2; \quad j=1,2,3; \quad k=1,2,3;$$

$$\frac{dD_\phi^{i,j,k}}{dt} = \epsilon_{D,\phi-1} D_{\phi-1}^{i,j,k} + \sigma_{I,\phi} I_\phi^{i,j,k} + \tau_{E,\phi} E_\phi^{i,j,k} + a_{k-1}\frac{\rho_{i,k}}{\sum_l \rho_{l,k}}\sum_l D_\phi^{l,j,k-1}$$

$$-(\mu_\phi + d_k + \epsilon_{D,\phi} + \sigma_{D,\phi} + a_k) D_\phi^{i,j,k},$$

$$i=1,2; \quad j=1,2,3; \quad k=1,2,3; \quad \phi=2,\ldots,5$$

$$\frac{dE_1^{i,j,k}}{dt} = \sigma_{D,1} D_1^{i,j,k} + a_{k-1} \frac{\rho_{i,k}}{\sum_l \rho_{l,k}} \sum_l E_1^{l,j,k-1} - (d_k + \epsilon_{E,1} + \sigma_{E,1} + a_k) E_1^{i,j,k},$$

$$i = 1, 2; \quad j = 1, 2, 3; \quad k = 1, 2, 3;$$

$$\frac{dE_\phi^{i,j,k}}{dt} = \epsilon_{E,\phi-1} E_{\phi-1}^{i,j,k} + \sigma_{D,\phi} D_\phi^{i,j,k} + \tau_{U,\phi} U^{i,j,k} + a_{k-1} \frac{\rho_{i,k}}{\sum_l \rho_{l,k}} \sum_l E_\phi^{l,j,k-1}$$

$$-(\mu_\phi + d_k + \tau_{E,\phi} + \epsilon_{E,\phi} + \sigma_{E,\phi} + a_k) E_\phi^{i,j,k},$$

$$i = 1, 2; \quad j = 1, 2, 3; \quad k = 1, 2, 3; \quad \phi = 2, \ldots, 5$$

$$\frac{dU_1^{i,j,k}}{dt} = \sigma_{E,1} E_1^{i,j,k} + a_{k-1} \frac{\rho_{i,k}}{\sum_l \rho_{l,k}} \sum_l U_1^{l,j,k-1} - (d_k + \epsilon_{U,1} + \sigma_{U,1} + a_k) U_1^{i,j,k},$$

$$i = 1, 2; \quad j = 1, 2, 3; \quad k = 1, 2, 3;$$

$$\frac{dU_\phi^{i,j,k}}{dt} = \epsilon_{U,\phi-1} U_{\phi-1}^{i,j,k} + \sigma_{E,\phi} E_\phi^{i,j,k} + \tau_{T,\phi} T_\phi^{i,j,k} + a_{k-1} \frac{\rho_{i,k}}{\sum_l \rho_{l,k}} \sum_l U_\phi^{l,j,k-1}$$

$$-(\mu_\phi + d_k + \tau_{U,\phi} + \epsilon_{U,\phi} + \sigma_{U,\phi} + a_k) U_\phi^{i,j,k},$$

$$i = 1, 2; \quad j = 1, 2, 3; \quad k = 1, 2, 3; \quad \phi = 2, \ldots, 5$$

$$\frac{dT_2^{i,j,k}}{dt} = \sigma_{U,1} U_1^{i,j,k} + \sigma_{U,2} U_2^{i,j,k} + a_{k-1} \frac{\rho_{i,k}}{\sum_l \rho_{l,k}} \sum_l T_2^{l,j,k-1} - (d_k + \tau_{T,\phi} + a_k) T_2^{i,j,k},$$

$$i = 1, 2; \quad j = 1, 2, 3; \quad k = 1, 2, 3;$$

$$\frac{dT_\phi^{i,j,k}}{dt} = \sigma_{U,\phi} U_\phi^{i,j,k} + a_{k-1} \frac{\rho_{i,k}}{\sum_l \rho_{l,k}} \sum_l T_\phi^{l,j,k-1} - (d_k + \tau_{T,\phi} + a_k) T_\phi^{i,j,k},$$

$$i = 1, 2; \quad j = 1, 2, 3; \quad k = 1, 2, 3; \quad \phi = 3, 4, 5$$

*Force of infection*

The number of new infections among the susceptible class $S^{i,j,k}$ (risk status *i*, role status *j* and age group *k*) due to contacts with the infected class $W_\phi^{x,y,z}$ (risk status *x*, role status *y* and age group *z* who are in disease stage $\phi$) are calculated using the following formula:

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Number of susceptibles in class $S^{i,j,k}$ | X | Estimated # partners for age group *k* with risk status *i* | X | likelihood that the partner is from age group *z* with risk status *x* and role status *y* | X | probability that the partner is infected in the awareness/ treatment state W and disease stage $\phi$ | X | annual transmission probability in partnership between $S^{i,j,k}$ and $W_\phi^{x,y,z}$ |

Partnership likelihood is based on mixing matrices by age, risk and role, i.e, proportion of partnership that a person from each group has with every other group. These matrices are updated at each step to balance the participating parties (see below). Age/risk mixing is assumed independent from role mixing.

As a result the force of infection on susceptible individuals with risk status *i*, role status *j* from age group *k* is:

$$\lambda^{i,j,k} = \eta^{i,k} \sum_{x,y,z} m_r^{i,k,x,z} m_\rho^{j,y} \Bigg[ \sum_\phi \Big(1-(1-(1-\alpha_c)\theta_\phi\beta)^{(1-\psi^{j,y})c^{i,k,x,z}\theta_{n,\phi}n^{i,k,x,z}} \cdot (1-\theta_\phi\beta)^{(1-\psi^{j,y})(1-c^{i,k,x,z})\theta_{n,\phi}n^{i,k,x,z}} \cdot$$

$$(1-(1-\alpha_c)\theta_R\theta_\phi\beta)^{\psi^{j,y}c^{i,k,x,z}\theta_{n,\phi}n^{i,k,x,z}} \cdot (1-\theta_R\theta_\phi\beta)^{\psi^{j,y}(1-c^{i,k,x,z})\theta_{n,\phi}n^{i,k,x,z}} \Big) \frac{\left(I_\phi^{x,y,z} + D_\phi^{x,y,z} + E_\phi^{x,y,z}\right)}{N^{x,y,z}} +$$

$$\sum_\phi \Big(1-(1-(1-\alpha_c)\theta_\phi\beta(1-\alpha_{U,\mathrm{ART}}))^{(1-\psi^{j,y})c^{i,k,x,z}\theta_{n,\phi}n^{i,k,x,z}} \cdot (1-\theta_\phi\beta(1-\alpha_{U,\mathrm{ART}}))^{(1-\psi^{j,y})(1-c^{i,k,x,z})\theta_{n,\phi}n^{i,k,x,z}} \cdot$$

$$(1-(1-\alpha_c)\theta_R\theta_\phi\beta(1-\alpha_{U,\mathrm{ART}}))^{\psi^{j,y}c^{i,k,x,z}\theta_{n,\phi}n^{i,k,x,z}} \cdot (1-\theta_R\theta_\phi\beta(1-\alpha_{U,\mathrm{ART}}))^{\psi^{j,y}(1-c^{i,k,x,z})\theta_{n,\phi}n^{i,k,x,z}} \Big) \frac{U_\phi^{x,y,z}}{N^{x,y,z}} \Big) \Bigg],$$

$$i=1,2; \quad j=1,2,3; \quad k=1,2,3$$

Here:

$\eta^{i,k}$ : number of partners for individuals in risk status $i$ and age group $k$,

$n^{i,k,x,z}$ : number of acts per year in partnership between risk status $i$, age group $k$ and risk status $x$, age group $z$,

$\theta_\phi$ : multiplier for the number of acts per year in partnership by disease stage $\phi$ to account for reduced sexual activity during late HIV stages using CD4 >500 as a reference,

$m_\rho^{i,k,x,z}$ : probability for the partner of a person with risk status $i$ and age group $k$ to be with risk status $x$, age group $z$ (risk mixing)

$m_r^{j,y}$ : mixing probability between people with role $j$ and role $y$ (role mixing)

$\alpha_c$ : condom efficacy in reducing HIV susceptibility per act,

$c^{i,k,x,z}$ : rate of condom use in partnership between people with risk status $i$, age group $k$ and risk status $x$, age group $z$,

$\beta$ : HIV-transmission risk per unprotected insertive anal act from untreated infected MSM in CD4>500 stage to uninfected MSM,

$\psi^{j,y}$ : fraction of acts which are receptive in partnership between role groups $j$ and $y$,

$\theta_R$ : multiplier for HIV acquisition risk per receptive act using insertive acts as a reference,

$\alpha_{U,ART}$ : ART efficacy in reducing infectiousness per act when virally unsuppressed,

$N^{x,y,z}$ : The size of the population with risk status *x*, role status *y* from age group *z*

$N^{x,y,z} = S^{x,y,z} + \sum_\phi \left(I_\phi^{x,y,z} + D_\phi^{x,y,z} + E_\phi^{x,y,z} + U_\phi^{x,y,z} + T_\phi^{x,y,z}\right)$. Here $T_1^{x,y,z} = 0.$

## Partnership Balancing

*Balancing by age and risk*

We consider mixing between all possible 6 age/risk groups. Likelihood of partnerships between 2 age/risk groups are stored in 6x6 age/risk mixing matrix $\boldsymbol{A}=\boldsymbol{a}_{ij}$ representing the likelihood that each partner of an individual from group $i$ to be from group $j$. $\boldsymbol{A}$ is informed initially by data collected in SABES study. The matrix is constantly updated to balance the number of partnerships between different age/risk groups. The procedure aims to equilize the number of people participating at each end of the partnerships between 2 different age/risk groups ($i$ and $j$) calculated as:
(Number of people in group $i$)*(Number of partners per individual)*(Likelihood $a_{ij}$)

At each time step, the balancing procedure proceeds as follows:

1) All off-diagonal pairs $a_{ij}$ and $a_{ij}$ are adjusted to equilize the number of people participating at each end of the partnerships. Adjusted is the entry which leads to decrease in the sum of the off-diagonal values
2) Diagonal entries are adjusted to guarantee that each row sums up to 1.

Step 1) of the procedure guarantees that the sum of the off-diagonal entries decreases and therefore remains below 1. This makes step 2) always possible. The procedure favors sexual mixing within each age/risk group which is supported by self-reported behavioral data.

*Balancing by role*

Fractions of partners by role are constantly updated to balance the number of partnerships between different role groups.

We use the following likelihood matrix of partnering between sexual role groups:

| Role group | Insertive | Receptive | Versatile |
|---|---|---|---|
| Insertive | a | 1-a-b | b |
| Receptive | x | 1-x-z | z |
| Versatile | y | 1-y-c | c |

Assuming that the overall number of partners per year is the same for each role group our balancing procedure requires that:
$x*N_{rec}= (1-a-b) *N_{ins}$
$y*N_{ver}= b *N_{ins}$
$z*N_{rec}= (1-y-c) *N_{ver}$

In all simulations, the values of a, b and c remain constant while x, y and z are updated at each time step. Simulations which result in negative mixing rates are discarded.

## Model Parameterization and Calibration

The model simulations start in 2004, parameterized with values listed in Table S1. We calibrated the model outcomes to match data from 2012 to select parameter sets that best captures the epidemic trends and clinical disease progression among MSM in Peru. We fit model outcomes to the HIV prevalence and the treatment cascade (% diagnosed, % engaged in care, % on ART, % virally suppressed). Monte Carlo filtering was used to select 1000 parameter sets for which all targets are within calibrated ranges listed in Table 2 of the main text.
The procedure of parameter sets selection consist of the following:

1) All uncertain parameters are sampled from their ranges in Table S2 and HIV prevalence target is checked against its 2012 target range
2) If HIV prevalence is accepted, then all awareness/treatment parameters (#1 - #16 in Table S2) are resampled while keeping behavioral and transmission parameters fixed (#17 - #23 in Table S2). This step is repeated up to 50 times while all HIV prevalence and treatment cascade outcomes are within targeted ranges.
3) The procedure is repeated while 1000 parameter sets are selected

**Table S1. Complete list of fixed parameter values used in the analysis**

| | |
|---|---|
| *Initial population size in 2004* | 400000 |
| *Initial fraction of acutely infected MSM who are diagnosed* | 0 |
| *Initial fraction of infected population who are on ART and virally suppressed* | 0 |
| *Duration of the young age group (15-24)* | 10 |
| *Duration of the middle age group (25-34)* | 10 |
| *Duration of the old age group (35-49)* | 15 |
| *Fraction of the population in the young age group* | 0.285714 |
| *Fraction of the population in the middle age group* | 0.285714 |
| *Fraction of MSM in the young age group with high risk status* | 0.551 |
| *Fraction of MSM in the middle age group with high risk status* | 0.611 |
| *Fraction of MSM in the old age group with high risk status* | 0.557 |
| *Death rate (non-HIV related) for the young age group* | 0.002 |
| *Death rate (non-HIV related) for the middle age group* | 0.002 |
| *Death rate (non-HIV related) for the old age group* | 0.003 |
| *Fraction of MSM with insertive role status* | 0.368 |
| *Fraction of MSM with versatile role group* | 0.329 |
| *Population recruitment rate (MSM turning 15)* | 0.0443 |
| *Annual rate of HIV diagnosis for acutely infected MSM in absence of intervention* | 0 |
| *Rate of HIV diagnosis for infected MSM with CD4 > 200* | Calculated to match total annual screening rate given screening rate for those with CD4<200 |
| *Annual rate of engagement in care for acutely diagnosed MSM as part of the intervention* | 25 |

| | |
|---|---|
| *Annual rate of ART initiation for acutely infected MSM in care as part of the intervention* | 25 |
| *Duration of acute stage* | 0.25 |
| *Duration of HIV stage with CD4>500* | 1.12 |
| *Duration of HIV stage with CD4 350-500* | 3.7 |
| *Duration of HIV stage with CD4 200-350* | 4.2 |
| *Duration of HIV stage with CD4<200* | 2.95 |
| *HIV-related death rate for MSM with CD4>500, off ART* | 0.0032 |
| *HIV-related death rate for MSM with CD4 350-500, off ART* | 0.0039 |
| *HIV-related death rate for MSM with CD4 200-350, off ART* | 0.009 |
| *Annual number of partners for MSM in the young age group with high risk status*[1] | 56 |
| *Annual number of partners for MSM in the middle age group with high risk status*[1] | 57.9 |
| *Annual number of partners for MSM in the old age group with high risk status*[1] | 51.1 |
| *Annual number of partners for MSM in the young age group with low risk status*[1] | 1.45 |
| *Annual number of partners for MSM in the middle age group with low risk status*[1] | 1.29 |
| *Annual number of partners for MSM in the old age group with low risk status*[1] | 1.65 |
| *Multiplier for reduced sexual activity when partner is in AIDS stage (CD4<200)* | 0.75 |
| *Probability for MSM with low risk status from the young age group to have a partner with low risk status from the young age group* | 0.23 |
| *Probability for MSM with low risk status from the young age group to have a partner with low risk status from the middle age group* | 0.08 |
| *Probability for MSM with low risk status from the young age group to have a partner with low risk status from the old age group* | 0.10 |
| *Probability for MSM with low risk status from the young age group to have a partner with high risk status from the young age group* | 0.34 |
| *Probability for MSM with low risk status from the young age group to have a partner with high risk status from the middle age group* | 0.12 |
| *Probability for MSM with low risk status from the young age group to have a partner with high risk status from the old age group* | 0.13 |
| *Probability for MSM with low risk status from the middle age group to have a partner with low risk status from the young age group* | 0.14 |
| *Probability for MSM with low risk status from the middle age group to have a partner with low risk status from the middle age group* | 0.23 |
| *Probability for MSM with low risk status from the middle age group to have a partner with low risk status from the old age group* | 0.15 |
| *Probability for MSM with low risk status from the middle age group to have a partner with high risk status from the young age group* | 0.12 |
| *Probability for MSM with low risk status from the middle age group to have a partner with high risk status from the middle age group* | 0.23 |

| | |
|---|---|
| *Probability for MSM with low risk status from the middle age group to have a partner with high risk status from the old age group* | 0.12 |
| *Probability for MSM with low risk status from the old age group to have a partner with low risk status from the young age group* | 0.13 |
| *Probability for MSM with low risk status from the old age group to have a partner with low risk status from the middle age group* | 0.00 |
| *Probability for MSM with low risk status from the old age group to have a partner with low risk status from the old age group* | 0.35 |
| *Probability for MSM with low risk status from the old age group to have a partner with high risk status from the young age group* | 0.11 |
| *Probability for MSM with low risk status from the old age group to have a partner with high risk status from the middle age group* | 0.00 |
| *Probability for MSM with low risk status from the old age group to have a partner with high risk status from the old age group* | 0.40 |
| *Probability for MSM with high risk status from the young age group to have a partner with low risk status from the young age group* | 0.15 |
| *Probability for MSM with high risk status from the young age group to have a partner with low risk status from the middle age group* | 0.04 |
| *Probability for MSM with high risk status from the young age group to have a partner with low risk status from the old age group* | 0.07 |
| *Probability for MSM with high risk status from the young age group to have a partner with high risk status from the young age group* | 0.40 |
| *Probability for MSM with high risk status from the young age group to have a partner with high risk status from the middle age group* | 0.11 |
| *Probability for MSM with high risk status from the young age group to have a partner with high risk status from the old age group* | 0.23 |
| *Probability for MSM with high risk status from the middle age group to have a partner with low risk status from the young age group* | 0.09 |
| *Probability for MSM with high risk status from the middle age group to have a partner with low risk status from the middle age group* | 0.11 |
| *Probability for MSM with high risk status from the middle age group to have a partner with low risk status from the old age group* | 0.07 |
| *Probability for MSM with high risk status from the middle age group to have a partner with high risk status from the young age group* | 0.18 |
| *Probability for MSM with high risk status from the middle age group to have a partner with high risk status from the middle age group* | 0.35 |
| *Probability for MSM with high risk status from the middle age group to have a partner with high risk status from the old age group* | 0.20 |
| *Probability for MSM with high risk status from the old age group to have a partner with low risk status from the young age group* | 0.09 |
| *Probability for MSM with high risk status from the old age group to have a partner with low risk status from the middle age group* | 0.00 |
| *Probability for MSM with high risk status from the old age group to have a partner with low risk status from the old age group* | 0.17 |
| *Probability for MSM with high risk status from the old age group to have a partner with high risk status from the young age group* | 0.25 |

| | |
|---|---|
| *Probability for MSM with high risk status from the old age group to have a partner with high risk status from the middle age group* | 0.00 |
| *Probability for MSM with high risk status from the old age group to have a partner with high risk status from the old age group* | 0.48 |
| *Probability for MSM with insertive role status to partner with another MSM with insertive role status* | 0.18 |
| *Probability for MSM with receptive role status to partner with another MSM with receptive role status* | 0.08 |
| *Probability for MSM with insertive role status to partner with MSM with receptive role status* | 0.74 |
| *Fraction of acts which are protected by a condom* | 0.5 |
| *Relative infectiousness of acutely infected MSM compared to MSM with CD4>200* | 26 |
| *Relative infectiousness of MSM with CD4<200 compared to MSM with CD4>200* | 3 |
| *Fraction of receptive acts in partnership between two MSM with insertive role status* | 0.5 |
| *Fraction of receptive acts for MSM with insertive role status partnering MSM with receptive role status* | 0 |
| *Fraction of receptive acts for MSM with insertive role status partnering MSM with versatile role status* | 0 |
| *Fraction of receptive acts for MSM with receptive role status partnering MSM with insertive role status* | 1 |
| *Fraction of receptive acts in partnership between two MSM with receptive role status* | 0.5 |
| *Fraction of receptive acts for MSM with receptive role status partnering MSM with versatile role status* | 1 |
| *Fraction of receptive acts for MSM with versatile role status partnering MSM with insertive role status* | 1 |
| *Fraction of receptive acts for MSM with versatile role status partnering MSM with receptive role status* | 0 |
| *Fraction of receptive acts in partnership between two MSM with versatile role status* | 0.5 |
| *ART efficacy in reducing infectiousness per act when virally suppressed* | 1 |

[1] The number of partners used in the analysis for the subgroups by age and risk are the average annual numbers reported by Sabes participants in each subgroups.

## Table S2. List of parameters ranges used in model calibration

| | | |
|---|---|---|
| 1 | *Annual rate of HIV diagnosis for infected MSM with CD4<200 in absence of intervention* | 0.2 - 0.4 |
| 2 | *Overall rate of HIV diagnosis for infected MSM* | 0.05 - 0.1 |
| 3 | *Annual rate of engagement in care for acutely diagnosed MSM with CD4>200* | 1 - 2 |
| 4 | *Annual rate of engagement in care for acutely diagnosed MSM with CD4<200* | 4 - 6 |

| | | |
|---|---|---|
| 5 | *Annual rate of ART initiation for MSM in care who meet eligibility criteria at the time* | 1.1 - 2 |
| 6 | *Annual rate of achieving viral suppression on ART for MSM with CD4>200* | 3 - 12 |
| 7 | *Annual rate of achieving viral suppression on ART for MSM with CD4<200* | 2 - 6 |
| 8 | *Rate at which engaged in care MSM drop from care* | 1 - 3 |
| 9 | *Annual ART drop rate* | 6% - 8% |
| 10 | *Rate of losing virally suppression due to inconsistent use of ART* | 0.11 - 0.33 |
| 11 | *Multiplicative factor which extends duration of HIV stages due to detectible viral load on ART (virally unsuppressed)* | 1 - 1.5 |
| 12 | *Multiplicative factor which adjusts for overreported (overlapping) partnerships of high-risk MSM* | 0.5-1 |
| 13 | *Multiplicative factor which adjusts for overreported (overlapping) partnerships of low-risk MSM* | 0.78-1 |
| 14 | *Number of acts per year in partnership in which both MSM have low risk status* | 40 - 60 |
| 15 | *Number of acts per year in partnership between MSM with low risk status* | 2 - 5 |
| 16 | *Number of acts per year in partnership in which both MSM have high risk status* | 1 - 2 |
| 17 | *Condom efficacy in reducing infectiousness per act* | 70% - 90% |
| 18 | *HIV-transmission probability per unprotected insertive anal act with untreated infected MSM with CD4>200* | 0.1% - 0.2% |
| 19 | *Relative HIV acquisition risk per receptive sex act compared to insertive act* | 3 - 7 |
| 20 | *ART efficacy in reducing infectiousness per act when virally unsuppressed* | 30% - 70% |
| 21 | *HIV prevalence in 2004* | 11.9% - 12.8% |
| 22 | *Initial fraction of infected MSM (CD4>200) who are diagnosed* | 4% - 6% |
| 23 | *Initial fraction of infected MSM (CD4<200) who are diagnosed* | 20% - 40% |
| 24 | *Initial fraction of diagnosed MSM who are engaged in care* | 25% - 80% |

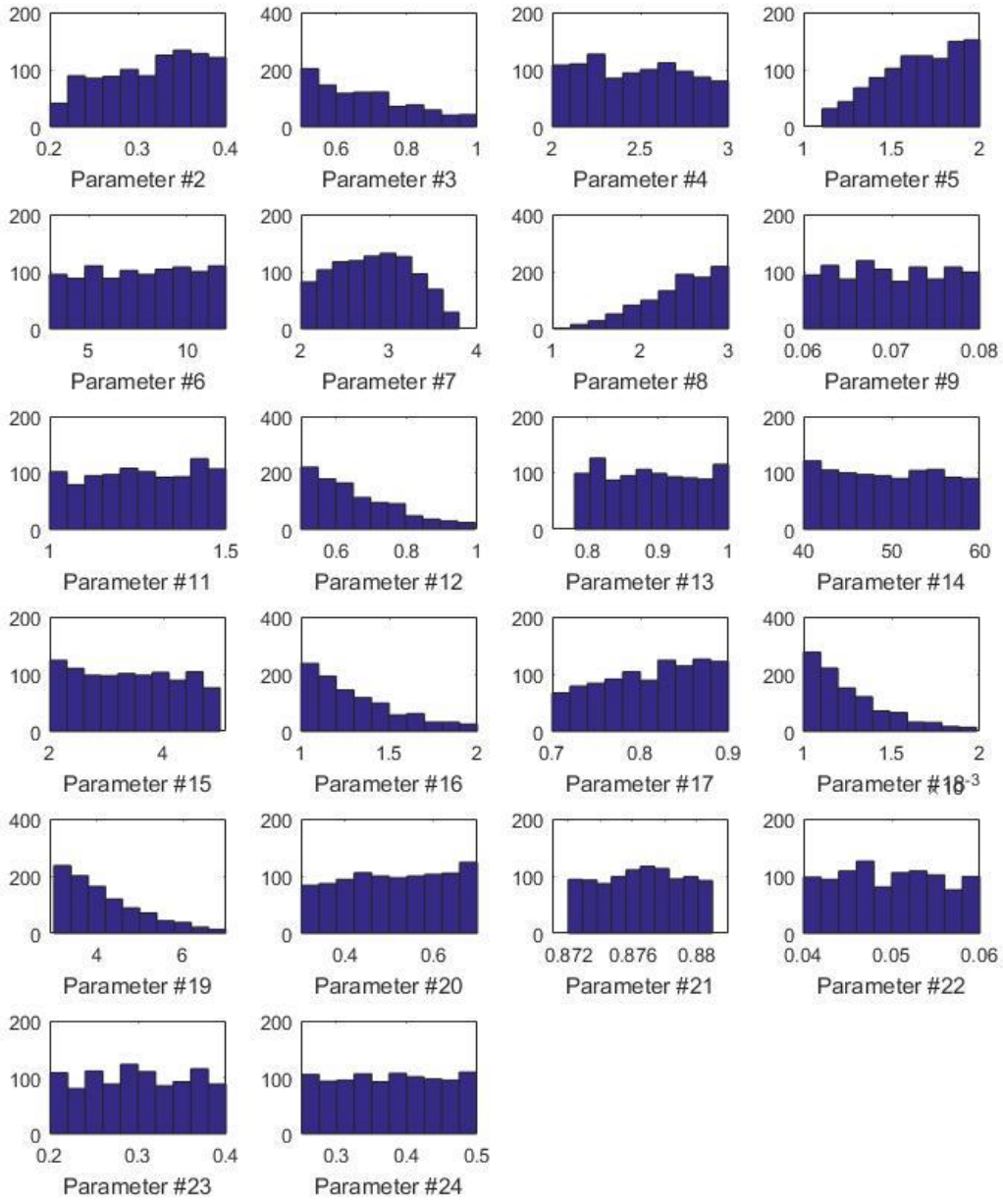


**Figure S1. Posterior distributions** of the model parameters as a result of the calibration procedure used to select 1000 epidemic simulations.

## Additional results

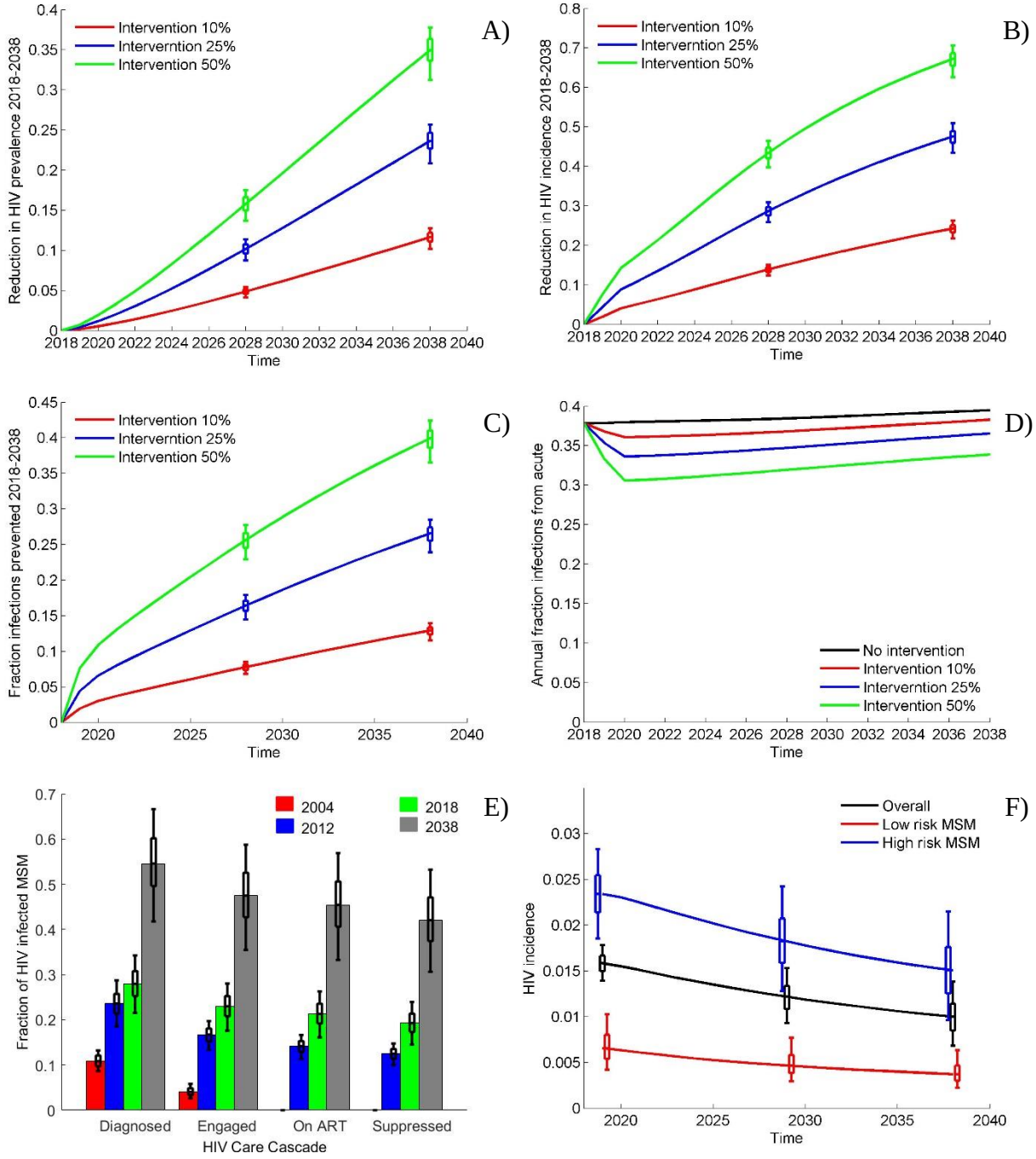


**Figure S2. HIV epidemic and projected impact of the *Sabes* intervention under the optimistic reference scenario.** A) Reduction in HIV prevalence due to intervention; B) Reduction in HIV Incidence due to intervention; C) Infections prevented due to intervention D) Annual proportion of HIV transmissions attributed to acute infections; E) Projected improvement of care cascade from 2004 to 2038 in absence of intervention presented as fractions of all infected being diagnosed, engaged in care, on ART and virally suppressed; F) Projected dynamics of HIV incidence among high- and low-risk MSM from 2004 to 2038. Initially, ART is offered to infected individuals with CD4 < 200 cells per mm3 only, later expanded to individuals with CD4 < 350 at the end of 2011 and to individuals with CD4 < 500 at the end of 2014. Universal access to ART is introduced in 2018. In this optimistic scenario, we assumed that

the rate of HIV diagnoses is tripled compared to before 2018. Box plots reflect estimated variation (interquartile range and 90% uncertainty interval [UI]) over 1000 epidemic simulations selected in the calibration procedure while the solid lines represent the median estimates.

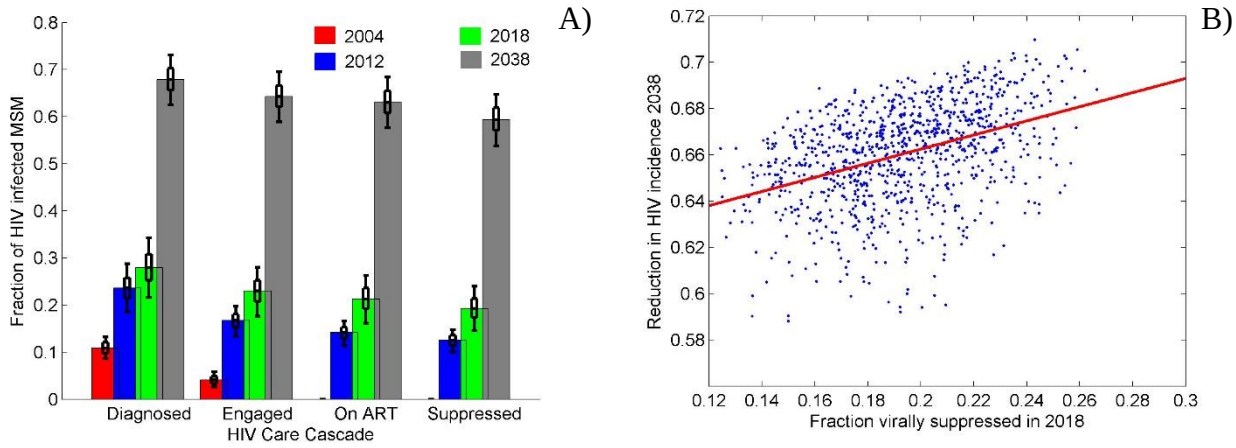


**Figure S3. Additional results on intervention impact.** A) Dynamics of the care cascade from 2004 to 2038 in the intervention scenario presented as fractions of all infected being diagnosed, engaged in care, on ART and virally suppressed under the main reference scenario + intervention initiated in 2018. B) Correlation between viral suppression and reduction in HIV incidence. Scatter plot of proportion of infected MSM who are virally suppressed at the start of the intervention in 2018 versus relative reduction in HIV incidence after 20 years of intervention compared to simulations without intervention. In the intervention scenarios, 50% of acutely infected MSM are assumed to be diagnosed, linked to care and to initiate ART within 1 month of diagnosis.

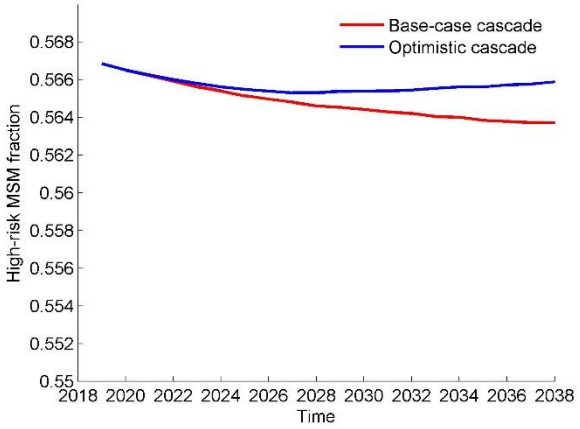


**Figure S4. Proportion high-risk MSM in the reference scenarios.** Median estimates over 1000 epidemic simulations selected in the calibration procedure.

## Sensitivity analysis

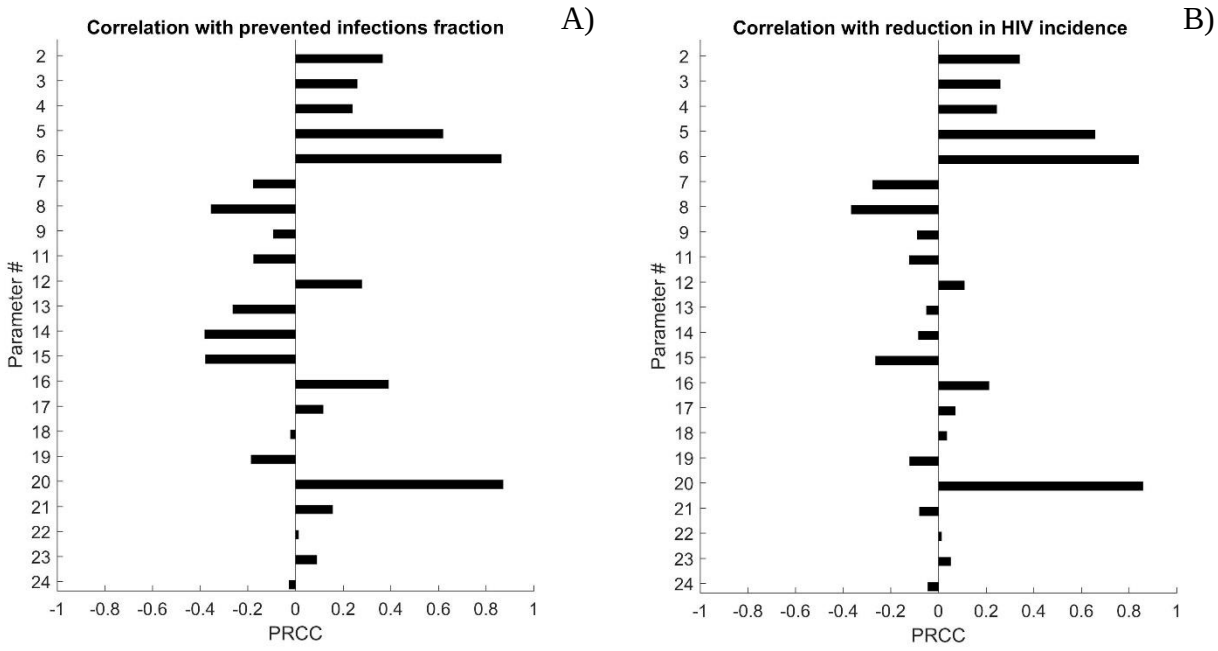


**Figure S5. Partial rank correlation coefficients (PRCC)** between parameters varied in the analysis (Table S2) and intervention outcomes: A) fraction of prevented infections and B) reduction in HIV incidence over 20 years based on 1000 simulations selected in the calibration procedure. Parameters #1 and #10 were excluded from the analysis because they were highly correlated with parameters #2 and #7, respectively. Remaining parameters are fixed on their baseline values from Table S1.