Supplementary material

Understanding the HIV epidemic among MSM in Baltimore: a modelling study estimating the impact of past HIV interventions and who acquired and contributed to infections

The following methods sections are adapted from the Supplementary material for Mitchell et al JIAS 2019 [1]

The model presented here differs from that presented in Mitchell et al JIAS[1] *in the following ways:*

1. In Mitchell et al 2019, the number of sex acts per main/casual/commercial partnership were each assumed to remain constant over time, with sex acts per casual partnership estimated from published studies of US MSM, and a low number of sex acts/partnership assumed for commercial partnerships. In this current model, the number of sex acts per casual and commercial partnership is allowed to increase over time, in line with NHBS data showing that the number of new casual and commercial partnerships has decreased over time, but that the proportion of recent sex acts with casual and commercial partners has stayed fairly constant, and the numbers of sex acts per casual/commercial partnership are estimated from the number of sex acts in main partnerships, the number of new partners who are casual/commercial, and the proportion of recent sex acts which are with casual/commercial partners.
2. In Mitchell et al 2019, parameter sets were included which used estimated HIV testing rates from NHBS data, which gave higher predictions of the proportion of MSM diagnosed than CDC estimates for MSM in Maryland; in this study, all parameter sets fit the CDC estimates for the proportion of MSM diagnosed.

Model structure

In the model equations and schematics, uninfected MSM are denoted by $X_{v,w}^{z}$, those with acute HIV infection by $A_{v,w}^{z}$ and chronic HIV infection by $Y_{v,w}^{x,y,z}$. Subscripts refer to the following states: v is age group (0 = 18-24 years old; 1 = >24 years old), w is race (0 = black; 1 = white). Superscripts refer to the following states: x is CD4 count (current CD4 count for those not taking or not adherent to ART, CD4 count at ART initiation for those taking and adherent to ART; 0 = acute, 1 = CD4>500, 2 = CD4 350-500, 3 = CD4 200-350, 4 = CD4 <200 cells/µl), y is set-point viral load (SPVL; 0 = acute, 1 = Log_{10} SPVL<4.0, 2 = Log_{10} SPVL 4.0-4.5, 3 = Log_{10} SPVL 4.5-5.0, 4 = Log_{10} SPVL >5.0), z is care state (0 = never testing, 1 = testing but without diagnosed infection, 2 = with diagnosed infection not linked to care, 3 = linked into HIV care, 4 = on ART, adherent and partially suppressed, 5 = in first year on ART, adherent and fully suppressed, 6 = 2nd year on ART adherent and fully suppressed, 7 = 3rd and subsequent years on ART adherent and fully suppressed, 8 = on ART but non-adherent and not suppressed, 9 = stopped taking ART (due to dropout or failure)). For those uninfected with HIV, the only possible care states are z=0 or 1. Those with acute

infection may be in one of care states z=0-4; after achieving full viral suppression on ART they are assumed to no longer be in the acute stage.

Fig S1 shows the age and race groups, with movement and sexual mixing between them. Of individuals entering the sexually active Baltimore MSM population, a proportion $m_{v,w}$ are assumed to be in each combination of age and race group ($m_{v,w}$ is calculated from m_{black}, the proportion of incoming MSM who are black, and $m_{young,w}$, the proportion of incoming MSM of each race who are aged 18-24 years old. Those in the 18-24 year old group move into the older age group at an annual rate π_w per year, corresponding to an average of 1/ π_w years that sexually active MSM in race group w spend in the 18-24 year old age group.

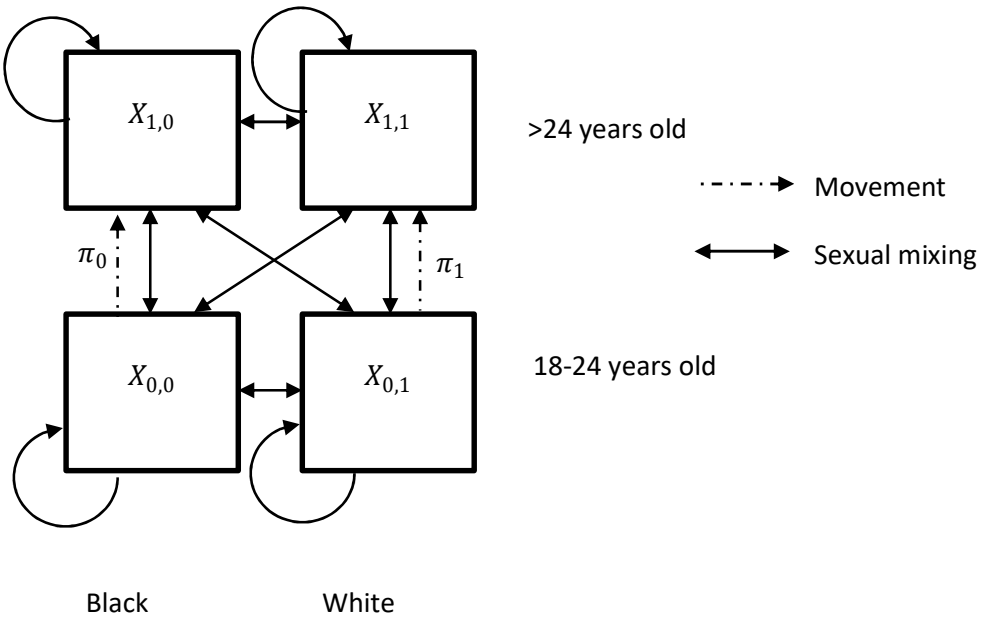


Fig S1: Age groups, race groups, movement and mixing in the model

Fig S2 shows the transitions between different stages of HIV infection for those not currently taking ART and those taking ART but not adherent (z=0,1,2,3,8,9), by current HIV stage and SPVL. These transitions are the same for all age, race and care states (apart from those on

ART and adherent), with the following exceptions: infection rates (λ) and background death rate (μ) differ by age and race.

Susceptible individuals (X^z) become infected with HIV at a rate $\lambda_{v,w}$ and move into the acutely infected compartment (A^z). After a period ($1/\gamma_a$ years) in the acute stage, individuals move into one of 16 compartments ($Y^{x,y,z}$), defined by their SPVL and initial CD4 count after acute infection. A proportion (θ_y) of those leaving the acute stage move into SPVL stratum y. For each SPVL stratum, a proportion $f_{x,y}$ of those entering SPVL stratum y are initially in CD4 compartment $Y^{x,y,z}$. Within each SPVL stratum, HIV-positive people pass sequentially through progressively lower CD4 count categories. The rate of moving from one CD4 compartment to the next is given by $\gamma_{x,y}$.

There is a constant background per-capita rate of non-HIV related death ($\mu_{v,w}$) from every compartment (susceptibles and all infected compartments), and an additional rate of HIV–related death from each infected compartment ($\alpha_{x,y,z}$), which varies by SPVL and current CD4 count, but takes the same value for all those off ART and those on ART but not adherent (z = 0,1,2,3,8,9).

Those on ART and adherent (z=4,5,6,7) do not move between CD4 categories in the model (i.e. increases in CD4 count for those who are adherent to ART are not explicitly modelled). For those who are adherent to ART, survival on ART is modelled as a function of initial CD4 count at ART initiation.

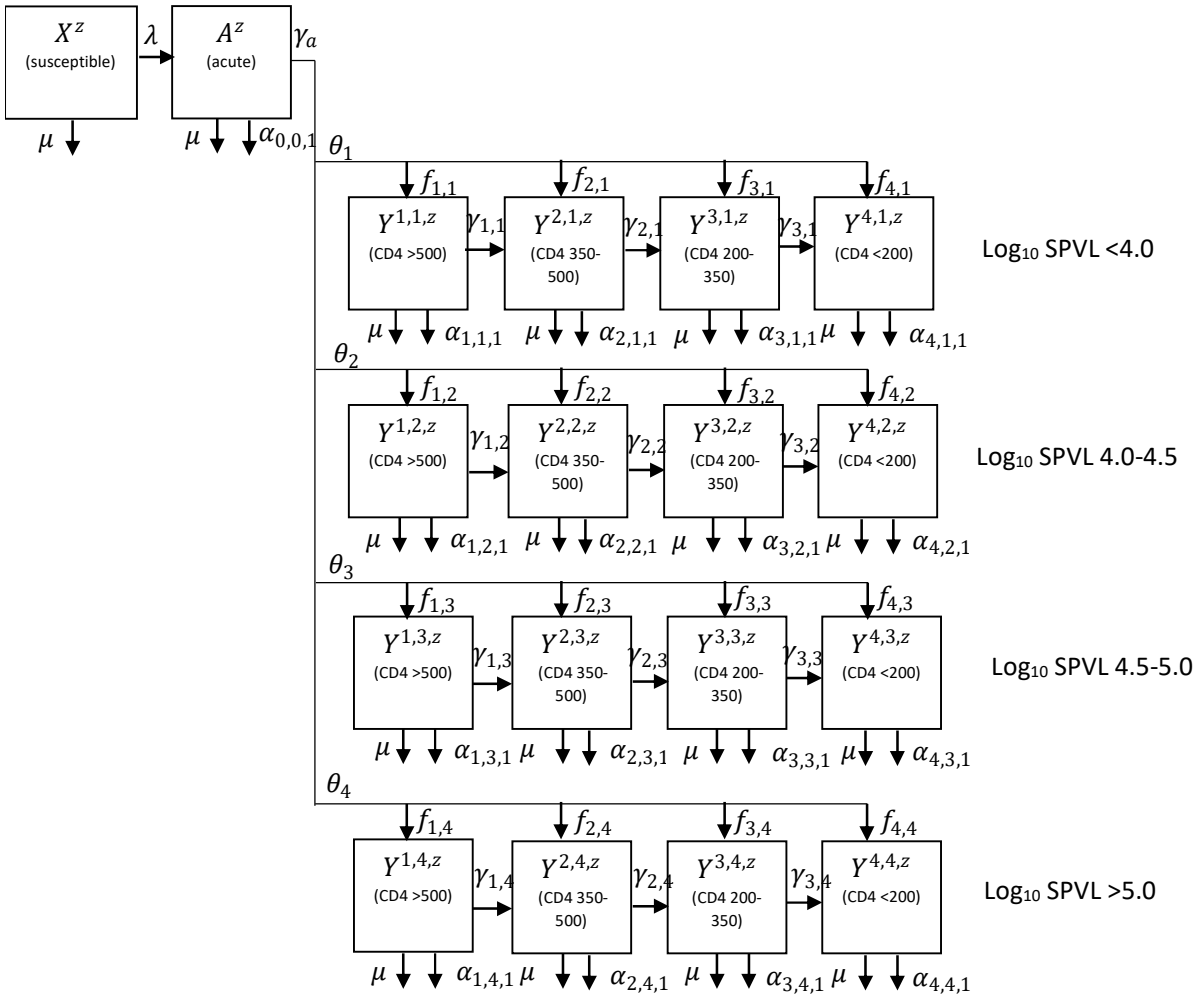


Fig S2. HIV disease progression, by HIV states and SPVL, for those not on ART, and for those on ART but not adherent. Superscripts on states and HIV-related death rates are x,y,z (x = CD4 category; y = set-point viral load category; z = care state); subscripts for age and race are omitted for clarity.

Transitions between the different stages of care are shown in Fig S3. New men join the sexually active MSM population (through ageing into the population, sexual debut or immigration), at a rate Γ and are assumed to all be uninfected with HIV initially. A proportion p of new entrants are assumed to never routinely test for HIV and do not seek treatment until they become symptomatic; they enter the compartment for never-testing susceptibles (X^0). The remainder of new entrants enter compartment X^1, who are susceptibles who may undergo HIV testing. Susceptibles in either state may become infected at a rate λ. Those never testing who become infected enter the acute infected compartment of never

testers (A^0) and progress through the chronic infection compartments of never testers ($Y^{x,y,0}$). . Those who may test who become infected enter the acutely infected compartment of those with undiagnosed infection but who may undergo HIV testing (A^1) and in the absence of testing progress through the chronic infection compartments of those undiagnosed but who may test ($Y^{x,y,1}$). These individuals undergo HIV testing at a per-capita rate $\tau_{v,w}$ (which varies with age and race); a proportion q of those testing are rapidly linked into care and move into the 'in care' compartments $A^3/Y^{x,y,3}$, the remainder (1-q) move into the 'with diagnosed infection but not linked into care' compartment ($A^2/Y^{x,y,2}$). Those with diagnosed infection but not in care can be linked into care, moving into compartments $A^3/Y^{x,y,3}$ at a rate $\epsilon_{v,w}$, and those linked into care may drop out from pre-ART care and go into the 'with diagnosed infection but not linked into care' compartment ($A^2/Y^{x,y,2}$) at a rate $\omega_w\phi_4$ (ϕ_4 is the rate of dropout from ART in the first year of treatment, $\omega_w$is the race-specific ratio of dropout from care relative to rate of dropout from ART). Those linked into care may begin ART, at a rate related to their CD4 count, ξ_x, with a proportion (χ) who are adherent to their treatment moving into the first ART compartment, $A^4/\ Y^{x,y,4}$, and those who are non-adherent (1-χ) moving into compartment , $Y^{x,y,8}$. People at any other stage of the care continuum who are not currently on ART may also begin ART due to becoming symptomatic, at a rate $\psi_{x,z}$, which is related to CD4 count, and to whether or not they have previously taken ART, and also move into the first ART compartment ($A^4/\ Y^{x,y,4}$) if they are adherent (proportion χ), or the "on ART but not adherent" compartment ($Y^{x,y,8}$) if they are not adherent. Those in the non-adherent ART compartment are assumed to have complete likelihood of transmission and have no survival benefit from ART, and progress in the same way as those not on ART.

People in the first ART compartment, $A^4/\ Y^{x,y,4}$, are assumed to be partially virally suppressed, and they leave this compartment at a rate σ_y, where $1/\sigma_y$ is the average duration from ART initiation to achieving viral suppression. σ_y varies by SPVL, but not by initial CD4 count.[2] They move into the first fully virally suppressed compartment ($Y^{x,y,5}$), where they stay for the remainder of their first year on ART, and move into the next ART compartment (2nd year;$Y^{x,y,6}$) at a rate η_y, where $1/\eta_y$ (the average duration spent in the first year compartment) is estimated as 1- $1/\sigma_y$. People move from the 2nd year on ART compartment ($Y^{x,y,6}$) into the >2 years on ART compartment ($Y^{x,y,7}$) at a rate 1/year. The final fully suppressed compartment ($Y^{x,y,7}$) contains those who have remained on ART for

more than 2 years and are still virally suppressed. For those on ART, the additional rate of HIV–related death from each of these compartments ($\alpha_{x,y,z}$) varies by CD4 count at ART initiation and duration on ART.

Those in any of the ART compartments may drop out of treatment at a rate ϕ_z, which varies with time since initiation of ART. Dropouts from ART go initially into the dropout compartments, $Y^{x,y,9}$, where they progress through different CD4 compartments in the same way as those never on ART. Those dropping out of the adherent ART compartments ($A^4, Y^{x,y,4} - Y^{x,y,7}$), move into the same CD4 compartment as the one they were in when they started ART , those dropping out of the non-adherent ART compartment ($Y^{x,y,8}$) retain the CD4 count they had at the point of dropout. People remain in the same SPVL category after dropping out of ART. ART dropouts may re-initiate treatment due to symptoms, at a rate $\psi_{x,9}$, or may re-enrol in HIV care, at a rate ζ. Those re-entering care are not distinguished from those entering care for the first time. Likewise, those re-initiating treatment progress in the same way as those beginning ART for the first time, and are not distinguished from them.

We do not explicitly model individuals on ART gaining and losing viral suppression over time, due to a lack of data, but we do capture overall levels of viral suppression as well as dynamic (re-)entry and dropout from care and treatment.

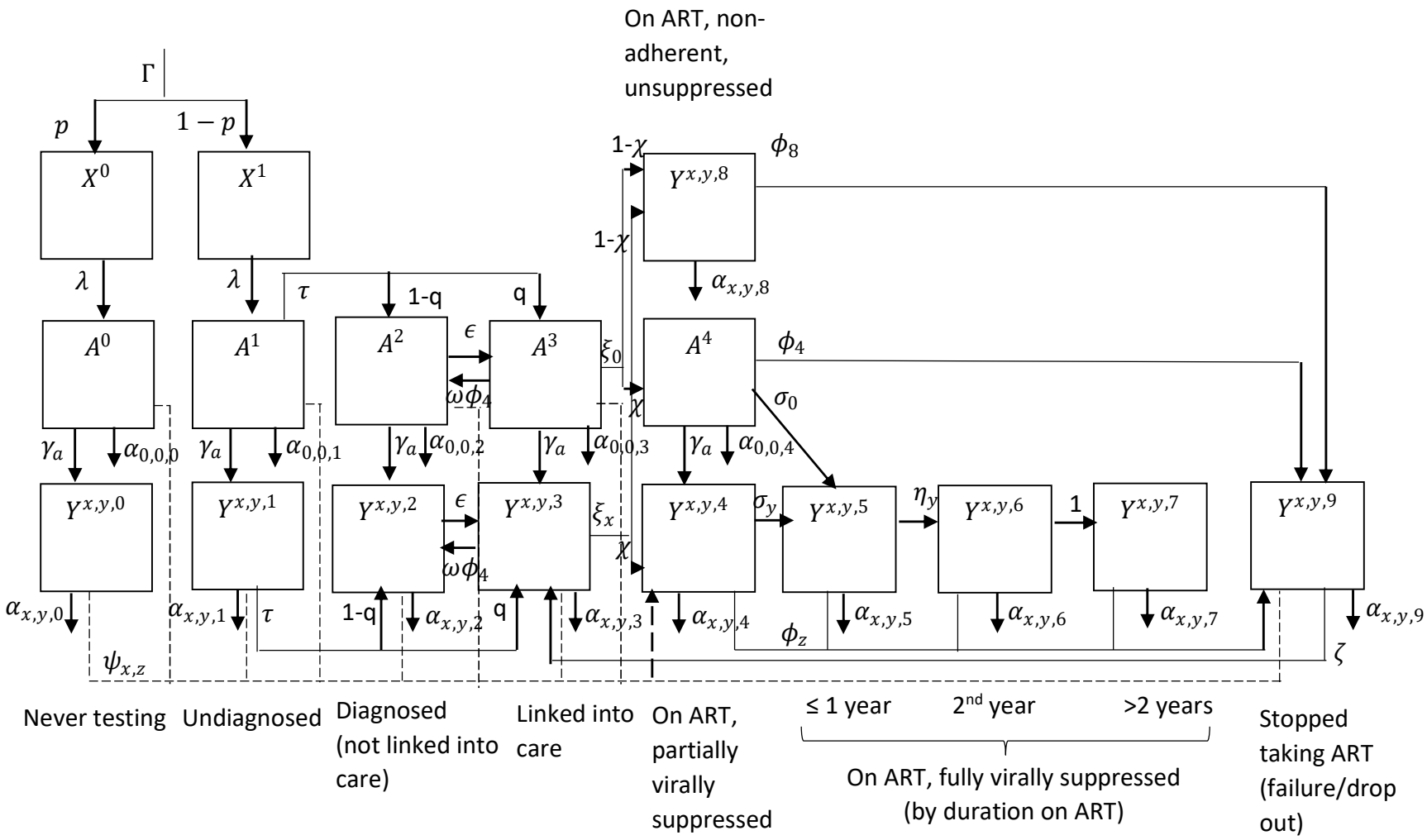


Fig S3: Different stages of HIV care and transitions between them. Subscripts for age and race are omitted for clarity.

Model equations

MSM who never get tested for HIV:

$$\frac{d}{dt}\left(X_{v,w}^{0}\right) = \Gamma p m_{v,w} + v\pi_w X_{1-v,w}^{0} - X_{v,w}^{0}\left(\lambda_{v,w,1} + \mu_{v,w} + (1-v)\pi_w\right)$$

$$\frac{d}{dt}\left(A_{v,w}^{0}\right) = \lambda_{v,w,1} X_{v,w}^{0} + v\pi_w A_{1-v,w}^{0} - A_{v,w}^{0}\left(\gamma_a + \mu_{v,w} + \alpha_{0,0,0} + (1-v)\pi_w + \psi_{0,0}\right)$$

$$\frac{d}{dt}\left(Y_{v,w}^{1,y,0}\right) = \gamma_a \theta_y f_{1,y} A_{v,w}^{0} + v\pi_w Y_{1-v,w}^{1,y,0} - Y_{v,w}^{1,y,0}\left(\gamma_{1,y} + \mu_{v,w} + \alpha_{1,y,0} + (1-v)\pi_w + \psi_{1,0}\right)$$

$$\frac{d}{dt}\left(Y_{v,w}^{x,y,0}\right) = \gamma_a \theta_y f_{x,y} A_{v,w}^{0} + \gamma_{x-1,y} Y_{v,w}^{x-1,y,0} + v\pi_w Y_{1-v,w}^{x,y,0} - Y_{v,w}^{x,y,0}\left(\gamma_{x,y} + \mu_{v,w} + \alpha_{x,y,0} + (1-v)\pi_w + \psi_{x,0}\right); x \in \{2,3\}$$

$$\frac{d}{dt}\left(Y_{v,w}^{4,y,0}\right) = \gamma_a \theta_y f_{4,y} A_{v,w}^{0} + \gamma_{3,y} Y_{v,w}^{3,y,0} + v\pi_w Y_{1-v,w}^{4,y,0} - Y_{v,w}^{4,y,0}\left(\mu_{v,w} + \alpha_{4,y,0} + (1-v)\pi_w + \psi_{4,0}\right)$$

MSM who may get tested, infection not diagnosed:

$$\frac{d}{dt}\left(X_{v,w}^{1}\right) = \Gamma(1-p) m_{v,w} + v\pi_w X_{1-v,w}^{1} - X_{v,w}^{1}\left(\lambda_{v,w,1} + \mu_{v,w} + (1-v)\pi_w\right)$$

$$\frac{d}{dt}\left(A_{v,w}^{1}\right) = \lambda_{v,w,1} X_{v,w}^{1} + v\pi_w A_{1-v,w}^{1} - A_{v,w}^{1}\left(\gamma_a + \mu_{v,w} + \alpha_{0,0,1} + (1-v)\pi_w + \psi_{0,1} + \tau_{v,w}\right)$$

$$\frac{d}{dt}\left(Y_{v,w}^{1,y,1}\right) = \gamma_a \theta_y f_{1,y} A_{v,w}^{1} + v\pi_w Y_{1-v,w}^{1,y,1} - Y_{v,w}^{1,y,1}\left(\gamma_{1,y} + \mu_{v,w} + \alpha_{1,y,1} + (1-v)\pi_w + \psi_{1,1} + \tau_{v,w}\right)$$

$$\frac{d}{dt}\left(Y_{v,w}^{x,y,1}\right) = \gamma_a\theta_y f_{x,y}A_{v,w}^1 + \gamma_{x-1,y}Y_{v,w}^{x-1,y,1} + v\pi_w Y_{1-v,w}^{x,y,1} - Y_{v,w}^{x,y,1}\left(\gamma_{x,y} + \mu_{v,w} + \alpha_{x,y,1} + (1-v)\pi_w + \psi_{x,1} + \tau_{v,w}\right); x \in \{2,3\}$$

$$\frac{d}{dt}\left(Y_{v,w}^{4,y,1}\right) = \gamma_a\theta_y f_{4,y}A_{v,w}^1 + \gamma_{3,y}Y_{v,w}^{3,y,1} + v\pi_w Y_{1-v,w}^{4,y,1} - Y_{v,w}^{4,y,1}\left(\mu_{v,w} + \alpha_{4,y,1} + (1-v)\pi_w + \psi_{4,1} + \tau_{v,w}\right)$$

MSM with diagnosed infection but not in care:

$$\frac{d}{dt}\left(A_{v,w}^2\right) = v\pi_w A_{1-v,w}^2 + (1-q)\tau_{v,w}A_{v,w}^1 + \omega_w\phi_4 A_{v,w}^3 - A_{v,w}^2\left(\gamma_a + \mu_{v,w} + \alpha_{0,0,2} + (1-v)\pi_w + \psi_{0,2} + \epsilon_w\right)$$

$$\frac{d}{dt}\left(Y_{v,w}^{1,y,2}\right) = \gamma_a\theta_y f_{1,y}A_{v,w}^2 + v\pi_w Y_{1-v,w}^{1,y,2} + (1-q)\tau_{v,w}Y_{v,w}^{1,y,1} + \omega_w\phi_4 Y_{v,w}^{1,y,3} - Y_{v,w}^{1,y,2}\left(\gamma_{1,y} + \mu_{v,w} + \alpha_{1,y,2} + (1-v)\pi_w + \psi_{1,2} + \epsilon_w\right)$$

$$\frac{d}{dt}\left(Y_{v,w}^{x,y,2}\right) = \gamma_a\theta_y f_{x,y}A_{v,w}^2 + \gamma_{x-1,y}Y_{v,w}^{x-1,y,2} + v\pi_w Y_{1-v,w}^{x,y,2} + (1-q)\tau_{v,w}Y_{v,w}^{x,y,1} + \omega_w\phi_4 Y_{v,w}^{x,y,3} - Y_{v,w}^{x,y,2}\left(\gamma_{x,y} + \mu_{v,w} + \alpha_{x,y,2} + (1-v)\pi_w + \psi_{x,2} + \epsilon_w\right); x \in \{2,3\}$$

$$\frac{d}{dt}\left(Y_{v,w}^{4,y,2}\right) = \gamma_a\theta_y f_{4,y}A_{v,w}^2 + \gamma_{3,y}Y_{v,w}^{3,y,2} + v\pi_w Y_{1-v,w}^{4,y,2} + (1-q)\tau_{v,w}Y_{v,w}^{4,y,1} + \omega_w\phi_4 Y_{v,w}^{4,y,3} - Y_{v,w}^{4,y,2}\left(\mu_{v,w} + \alpha_{4,y,2} + (1-v)\pi_w + \psi_{4,2} + \epsilon_w\right)$$

MSM in care:

$$\frac{d}{dt}\left(A_{v,w}^{3}\right) = v\pi_w A_{1-v,w}^{3} + q\tau_{v,w}A_{v,w}^{1} + \epsilon_w A_{v,w}^{2} - A_{v,w}^{3}\left(\gamma_a + \mu_{v,w} + \alpha_{0,0,3} + (1-v)\pi_w + \psi_{0,3} + \omega_w\phi_4 + \xi_0\right)$$

$$\frac{d}{dt}\left(Y_{v,w}^{1,y,3}\right) = \gamma_a\theta_y f_{1,y}A_{v,w}^{3} + v\pi_w Y_{1-v,w}^{1,y,3} + q\tau_{v,w}Y_{v,w}^{1,y,1} + \epsilon_w Y_{v,w}^{1,y,2} + \zeta Y_{v,w}^{1,y,9} - Y_{v,w}^{1,y,3}\left(\gamma_{1,y} + \mu_{v,w} + \alpha_{1,y,3} + (1-v)\pi_w + \psi_{1,3} + \omega_w\phi_4 + \xi_1\right)$$

$$\frac{d}{dt}\left(Y_{v,w}^{x,y,3}\right) = \gamma_a\theta_y f_{x,y}A_{v,w}^{3} + \gamma_{x-1,y}Y_{v,w}^{x-1,y,3} + v\pi_w Y_{1-v,w}^{x,y,3} + q\tau_{v,w}Y_{v,w}^{x,y,1} + \epsilon_w Y_{v,w}^{x,y,2} + \zeta Y_{v,w}^{x,y,9} - Y_{v,w}^{x,y,3}\left(\gamma_{x,y} + \mu_{v,w} + \alpha_{x,y,3} + (1-v)\pi_w + \psi_{x,3} + \omega_w\phi_4 + \xi_x\right); x \in \{2,3\}$$

$$\frac{d}{dt}\left(Y_{v,w}^{4,y,3}\right) = \gamma_a\theta_y f_{4,y}A_{v,w}^{3} + \gamma_{3,y}Y_{v,w}^{3,y,3} + v\pi_w Y_{1-v,w}^{4,y,3} + q\tau_{v,w}Y_{v,w}^{4,y,1} + \epsilon_w Y_{v,w}^{4,y,2} + \zeta Y_{v,w}^{4,y,9} - Y_{v,w}^{4,y,3}\left(\mu_{v,w} + \alpha_{4,y,3} + (1-v)\pi_w + \psi_{4,3} + \omega_w\phi_4 + \xi_4\right)$$

MSM on ART and adherent:

$$\frac{d}{dt}\left(A_{v,w}^{4}\right) = v\pi_w A_{1-v,w}^{4} + \chi\xi_0 A_{v,w}^{3} + \sum_{Z=0}^{Z=3}\chi\psi_{0,Z}A_{v,w}^{Z} - A_{v,w}^{4}\left(\gamma_a + \mu_{v,w} + \alpha_{0,0,4} + (1-v)\pi_w + \sigma_0 + \phi_4\right)$$

$$\frac{d}{dt}\left(Y_{v,w}^{x,y,4}\right) = \gamma_a \theta_y f_{x,y} A_{v,w}^4 + v\pi_w Y_{1-v,w}^{x,y,4} + \chi\xi_x Y_{v,w}^{x,y,3} + \sum_{Z=0}^{Z=3} \chi\psi_{x,Z} Y_{v,w}^{x,y,Z}$$
$$+ \chi\psi_{x,9} Y_{v,w}^{x,y,9} - Y_{v,w}^{x,y,4}\left(\mu_{v,w} + \alpha_{x,y,4} + (1-v)\pi_w + \sigma_y + \phi_4\right)$$

$$\frac{d}{dt}\left(Y_{v,w}^{x,y,5}\right) = v\pi_w Y_{1-v,w}^{x,y,5} + \sigma_0 \theta_y f_{x,y} A_{v,w}^4 + \sigma_y Y_{v,w}^{x,y,4}$$
$$- Y_{v,w}^{x,y,5}\left(\mu_{v,w} + \alpha_{x,y,5} + (1-v)\pi_w + \eta_y + \phi_5\right)$$

$$\frac{d}{dt}\left(Y_{v,w}^{x,y,6}\right) = v\pi_w Y_{1-v,w}^{x,y,6} + \eta_y Y_{v,w}^{x,y,5}$$
$$- Y_{v,w}^{x,y,6}\left(\mu_{v,w} + \alpha_{x,y,6} + (1-v)\pi_w + 1 + \phi_6\right)$$

$$\frac{d}{dt}\left(Y_{v,w}^{x,y,7}\right) = v\pi_w Y_{1-v,w}^{x,y,7} + Y_{v,w}^{x,y,6} - Y_{v,w}^{x,y,7}\left(\mu_{v,w} + \alpha_{x,y,7} + (1-v)\pi_w + \phi_7\right)$$

MSM on ART but non-adherent:

$$\frac{d}{dt}\left(Y_{v,w}^{1,y,8}\right) = (1-\chi)\xi_0\theta_y f_{1,y}A_{v,w}^3 + (1-\chi)\xi_1 Y_{v,w}^{1,y,3} + \sum_{Z=0}^{Z=3}(1-\chi)\psi_{0,Z}\theta_y f_{1,y}A_{v,w}^Z + \sum_{Z=0}^{Z=3}(1-\chi)\psi_{1,Z}Y_{v,w}^{1,y,Z} + (1 - \chi)\psi_{x,9}Y_{v,w}^{1,y,9} + v\pi_w Y_{1-v,w}^{1,y,8} - Y_{v,w}^{1,y,8}\left(\gamma_{1,y} + \mu_{v,w} + \alpha_{1,y,8} + (1-v)\pi_w + \phi_8\right)$$

$$\frac{d}{dt}\left(Y_{v,w}^{x,y,8}\right) = (1-\chi)\xi_0\theta_y f_{x,y}A_{v,w}^3 + (1-\chi)\xi_1 Y_{v,w}^{x,y,3} + \sum_{Z=0}^{Z=3}(1-\chi)\psi_{0,Z}\theta_y f_{x,y}A_{v,w}^Z + \sum_{Z=0}^{Z=3}(1-\chi)\psi_{x,Z}Y_{v,w}^{x,y,Z} + (1 - \chi)\psi_{x,9}Y_{v,w}^{x,y,9} + v\pi_w Y_{1-v,w}^{x,y,8} + \gamma_{x-1,y}Y_{v,w}^{x-1,y,8} - Y_{v,w}^{x,y,8}\left(\gamma_{x,y} + \mu_{v,w} + \alpha_{x,y,8} + (1-v)\pi_w + \phi_8\right); x \in \{2,3\}$$

$$\frac{d}{dt}\left(Y_{v,w}^{4,y,8}\right) = (1-\chi)\xi_0\theta_y f_{4,y}A_{v,w}^3 + (1-\chi)\xi_1 Y_{v,w}^{4,y,3} + \sum_{Z=0}^{Z=3}(1-\chi)\psi_{0,Z}\theta_y f_{4,y}A_{v,w}^Z + \sum_{Z=0}^{Z=3}(1-\chi)\psi_{x,Z}Y_{v,w}^{4,y,Z} + (1 - \chi)\psi_{x,9}Y_{v,w}^{4,y,9} + v\pi_w Y_{1-v,w}^{4,y,8} + \gamma_{3,y}Y_{v,w}^{3,y,8} - Y_{v,w}^{4,y,8}\left(\mu_{v,w} + \alpha_{4,y,8} + (1-v)\pi_w + \phi_8\right)$$

MSM dropped out of ART:

$$\frac{d}{dt}\left(Y_{v,w}^{1,y,9}\right) = \sum_{Z=4}^{Z=8}\phi_Z Y_{v,w}^{1,y,Z} + v\pi_w Y_{1-v,w}^{1,y,9} + \theta_y f_{x,y}\phi_4 A_{v,w}^4 - Y_{v,w}^{1,y,9}\left(\gamma_{1,y} + \mu_{v,w} + \alpha_{1,y,9} + (1-v)\pi_w + \psi_{1,9} + \zeta\right)$$

$$\frac{d}{dt}\left(Y_{v,w}^{x,y,9}\right) = \sum_{Z=4}^{Z=8} \phi_Z Y_{v,w}^{x,y,Z} + v\pi_w Y_{1-v,w}^{x,y,9} + \theta_y f_{x,y} \phi_4 A_{v,w}^4 + \gamma_{x-1,y} Y_{v,w}^{x-1,y,9} - Y_{v,w}^{x,y,9}\left(\gamma_{x,y} + \mu_{v,w} + \alpha_{x,y,9} + (1-v)\pi_w + \psi_{x,9} + \zeta\right); x \in \{2,3\}$$

$$\frac{d}{dt}\left(Y_{v,w}^{4,y,9}\right) = \sum_{Z=4}^{Z=8} \phi_Z Y_{v,w}^{4,y,Z} + v\pi_w Y_{1-v,w}^{4,y,9} + \theta_y f_{x,y} \phi_4 A_{v,w}^4 + \gamma_{3,y} Y_{v,w}^{3,y,9} - Y_{v,w}^{4,y,9}\left(\mu_{v,w} + \alpha_{4,y,9} + (1-v)\pi_w + \psi_{4,9} + \zeta\right)$$

Force of infection

$$\lambda_{v,w} = 1 - \left(\prod_{j=1}^{j=3} \prod_{v'=0}^{v'=1} \prod_{w'=0}^{w'=1} \left(\frac{\sum_{z=0}^{z=1}\left(X_{v',w'}^z\right)}{N_{v',w'}} + \frac{\sum_{z=0}^{z=3}\left(A_{v',w'}^z\right)}{N_{v',w'}}\left(1 - d_1\beta\left(1 - e_c s_{c,j}\right)\left(1 - e_n s_n\right)\right)^{n_{w,j}} + \sum_{y=1}^{y=4}\left(\frac{\sum_{x=1}^{x=3}\left(\sum_{z=0}^{z=3}\left(Y_{v',w'}^{x,y,z}\right) + Y_{v',w'}^{x,y,8} + Y_{v',w'}^{x,y,9}\right)}{N_{v',w'}}\left(1 - h_y\beta\left(1 - e_c s_{c,j}\right)\left(1 - e_n s_n\right)\right)^{n_{w,j}} \right) + \sum_{y=1}^{y=4}\left(\frac{\left(\sum_{z=0}^{z=3}\left(Y_{v',w'}^{4,y,z}\right) + Y_{v',w'}^{4,y,8} + Y_{v',w'}^{4,y,9}\right)}{N_{v',w'}}\left(1 - d_2 h_y\beta\left(1 - e_c s_{c,j}\right)\left(1 - e_n s_n\right)\right)^{n_{w,j}} \right) + \frac{A_{v',w'}^4}{N_{v',w'}}\left(1 - d_3\beta\left(1 - e_c s_{c,j}\right)\left(1 - e_n s_n\right)\right)^{n_{w,j}} + \sum_{y=1}^{y=4}\left(\frac{\sum_{x=1}^{x=3}\left(Y_{v',w'}^{x,y,4}\right)}{N_{v',w'}}\left(1 - d_4 h_y\beta\left(1 - e_c s_{c,j}\right)\left(1 - e_n s_n\right)\right)^{n_{w,j}} \right) + \sum_{y=1}^{y=4}\left(\frac{\left(Y_{v',w'}^{4,y,4}\right)}{N_{v',w'}}\left(1 - d_5 h_y\beta\left(1 - e_c s_{c,j}\right)\left(1 - e_n s_n\right)\right)^{n_{w.j}} \right) + \sum_{y=1}^{y=4}\left(\frac{\sum_{x=1}^{x=4}\sum_{z=5}^{z=7}\left(Y_{v',w'}^{x,y,z}\right)}{N_{v',w'}}\left(1 - d_6 h_y\beta\left(1 - e_c s_{c,j}\right)\left(1 - e_n s_n\right)\right)^{n_{w,j}} \right) \right)^{\rho_{vw,v'w',j} c_{v,w,j}} \right)$$

where the total number of MSM partners in age group v' and race group w' is calculated as:

$$N_{v\prime,w\prime} = \sum_{z=0}^{z=1}\left(X_{v\prime,w\prime}^{z}\right) + \sum_{z=0}^{z=4}\left(A_{v\prime,w\prime}^{z}\right) + \sum_{x=1}^{x=4}\sum_{y=1}^{y=4}\sum_{z=0}^{z=9}\left(Y_{v\prime,w\prime}^{x,y,z}\right)$$

Infection risk is estimated for three partner types (j = 1: regular partners, j = 2: casual partners; j = 3: commercial partners). e_c is per-sex-act condom efficacy, $s_{c,j}$ is the proportion of sex acts in which a condom is used with partners of type j, e_n is per-sex act reduction in HIV acquisition risk due to male circumcision, and s_n is the proportion of MSM who are circumcised. β is the average probability of acquiring HIV infection from an anal sex act with an HIV-positive male partner with chronic infection and CD4>200 cells/µl who is not taking ART, $\rho_{vw,v\prime w\prime,j}$ is, for MSM in age group v and race group w, the proportion of partners of type j who are in age group v' and race group w' . $c_{v,w,j}$ is the average number of new partners per year of type j for MSM in age group v and race group w, $n_{w,j}$ is the average number of sex acts per partnership for a partnership of type j for those in race group w, $d_1$is the relative likelihood of transmission of those in the acute versus chronic stage of infection, d_2 is the relative likelihood of transmission of those with CD4<200 cells/µl versus those with chronic infection and CD4>200 cells/µl, d_3, d_4, d_5 are the relative likelihood of transmission of those on ART with a partially suppressed viral load who have acute infection, chronic infection (CD4>200 cells/µl) or CD4<200 cells/µl, respectively, versus those untreated with chronic infection and CD4>200 cells/µl , $d_6$is the relative likelihood of transmission of those on ART with a fully suppressed viral load versus those untreated with chronic infection and CD4>200 cells/µl, and h_y is the relative likelihood of transmission of those not fully virally suppressed who have SPVL y.

The relative likelihood of transmission of those on ART with a partially suppressed viral load are calculated as follows:

$$d_3 = d_6 + d_r(d_1 - d_6)$$

$$d_4 = d_6 + d_r(1 - d_6)$$

$$d_5 = d_6 + d_r(d_2 - d_6)$$

Where d_r is the relative level of likelihood of transmission of those partially suppressed, scaled between the level for those fully suppressed ($d_r = 0$).and those unsuppressed ($d_r = 1$).

Model parameters

Demographic parameters describing the initial age- and race-composition of the MSM population in 1984, and the age-and race-composition of new MSM entering the population, were estimated from NHBS and census data. Non-HIV related age- and race-specific death rates came from CDC data for Maryland state.[3] Following trends in Baltimore City census data, we assume the MSM population has declined at a similar rate as the total population from 1980 until 2010, primarily due to out-migration of white residents.[4] Rates of in- and out-migration were estimated to fit demography data.

Sexual behaviour parameters including age- and race-specific numbers of new main, casual and commercial anal sex partners per year, proportion of sex acts which are with main, casual and commercial partners, condom use in each type of partnership, circumcision status, and sexual mixing by age and race, were estimated from NHBS surveys.

The number of sex acts in main partnerships were estimated from published studies of US MSM.[5-7] The number of sex acts in casual and commercial partners were estimated from the number of sex acts in main partnerships, the number of new main partners who are casual or commercial, and the proportion of sex acts which are with casual and commercial partners.

Based upon trends in NHBS data, condom use is assumed to increase over time up until 2008, and then to decrease (or, in a small proportion of runs, to increase) between 2008 and 2011, staying constant after 2011. Condom use in main partnerships is higher for black than white MSM (59% vs 36%), and higher in casual partnerships (67%). At the beginning of the epidemic, condom use is assumed to be fixed at a certain level for all partnership types.

The number of new casual and commercial partners is assumed to decline linearly over time from 1984 until 2011, subsequently staying constant, consistent with NHBS and historical data,[8] while the number of new main partners is assumed to have stayed the same over time in line with NHBS data. The number of sex acts per casual or commercial partnership is allowed to increase over time in the model as the number of new casual and commercial partnerships decreases but the proportion of recent sex acts reported to be with casual or commercial partnerships stays relatively constant over time in NHBS data. In 2011, the greatest numbers of new partners were reported by black MSM aged 18-24, and the fewest by white MSM aged 18-24 (table S1).

Mixing parameters (by age and race) were estimated from 2008 NHBS data on the percentage of partners of black and white MSM who were black or white, and 2011 NHBS data on the age and race of partners by age and race (N.B. the age-group of partners could only be estimated for MSM aged 18-24). Assuming that the proportion of people in each age and race group in the survey was representative of the wider MSM population, and using the overall number of anal sex partners per year reported by each group, least-squares fitting was used to identify the most likely values for the mixing parameters by age and race. The data suggested some preference for partners of a similar age and strong preference for partners of the same race.

Disease progression parameters by SPVL, transmission probabilities and intervention efficacies (for condoms, circumcision, and HIV treatment) were obtained from published studies. [9-19]

PrEP use was not modelled as very low levels of use were reported in the 2014 NHBS survey.

For care continuum parameters, age- and race specific HIV testing rates were estimated from NHBS data for 2004-2011 - as no clear trend was seen over these surveys, testing rates were assumed to remain constant after 2004 (ranging from 51% (>24 year old white men) to 79% (18-24 year old black men) testing each year. The overall percentage of MSM testing in the last year was estimated at 25% for MSM in a national survey in 1996,[20] and so the percentage testing in the last 12 months is assumed to have increased linearly over time prior to 2004 to give the overall percentage consistent with this data in 1996.

Similarly, race-specific percentages linking to care immediately after HIV infection diagnosis was estimated from DH data for Baltimore, national surveys and US national CDC data on the proportion linking to care within three months of infection diagnosis, and assumed to increase linearly until 2008 (in line with US national CDC data), then stay constant (at 81% for white MSM, 70% for black MSM [21-27]).

Historical US ART guidelines were used to determine at which CD4 count ART initiation occurred between 1998 and 2012, when universal ART was recommended.

Data from MSM in the Johns Hopkins HIV cohort (Baltimore) who initiated ART after 1/1/2005 with VL>1000 copies/ml (N=251), and data from NA-ACCORD from Fenway electronic monitoring data (Boston) for patients who achieved viral suppression and had

VL>200 copies/ml at ART initiation (N=998) were used to estimate median time to viral suppression stratified by initial viral load (log10VL<4.0,4.0-4.5,4.5-5.0.>5.0).

Other care continuum parameters including race-related rates of ART initiation, race-related rates of dropout from care and ART and ART adherence by race were taken from published studies among US populations, where possible studies of MSM.[21,25,28-32] ART adherence was based upon estimates of the proportion of PLHIV achieving viral suppression.

Estimates and sources for all parameters are given in Table S1.

Model calibration

The model was fitted to MSM population size, age and race distribution, HIV prevalence by age and race, percentage of HIV-positive MSM with diagnosed infection, percentage of MSM with diagnosed infection in care and percentage virally suppressed, ART coverage and percentage on ART virally suppressed (table 1, table S2). Model predictions were accepted as fits if they fell within designated ranges for these quantities at all time-points before 2014 (HIV prevalence had to fall within range at 2 out of 3 time-points).

Addressing uncertainties across data sources

Estimates of the annual HIV testing rate parameter obtained from NHBS data produced higher predictions of the proportion of MSM with diagnosed infection than CDC estimates for MSM in Maryland; for this study we fitted the proportion of HIV-infected MSM with diagnosed infection predicted by the model to CDC estimates for Maryland (allowing HIV testing rate parameters to take lower values than suggested by the NHBS data).

We found that fitting to ART coverage data estimated from NHBS plasma testing suggested higher levels of viral suppression than fitting to Maryland DHMH data on the proportion of MSM with diagnosed infection who are virally suppressed (and the proportion in care), and so the model was fitted separately under two care cascade assumptions, either fitting to NHBS ART coverage data or DHMH cascade data (whilst simultaneously fitting to all of the HIV prevalence, diagnosis and demography data).

Table S1. Parameters used in the HIV transmission model, with source and justification

Symbol	Parameter	Prior range of values (min-max)	Posterior range of values (min-max)	Source/justification
Initial Conditions				
N_0	Initial size of MSM population (1984)	6765-8326	6771-8326	260,199 men aged 18+ in the 1980 Baltimore census; Purcell et al. 2012[33] estimate % of US men had same-sex behaviour last 12 months 2.9% (95% CI 2.6-3.2%)
	Percentage of MSM who are black in 1984	50-64	50-64	Main estimate: overall population 1980 census. Upper limit: MSM in NHBS 2004; lower limit: lower 95% CI in NHBS 2004
	Percentage of black MSM aged 18-24 in 1984	16-31	16-31	Lower bound: black men in 2010 census Upper bound: black MSM NHBS 2004 (upper 95% CI)
	Percentage of white MSM aged 18-24 in 1984	14-28	14-28	Lower bound: white men in 2010 census Upper bound: white MSM NHBS 004 (upper 95% CI)
	HIV prevalence black MSM 1984 (%)	15-44	15-44	MACS baseline black MSM [34]– lower bound a third of this as non-random sample
	HIV prevalence white MSM 1984 (%)	9-28	9-28	MACS baseline white MSM [34]– lower bound a third of this as non-random sample
Demography				
Γ	Rate at which new MSM join the sexually active MSM population (per year)	100-400 (fitting to census demography)	262-637	estimate

		200-800 (fitting to NHBS demography)		
m_{black}	Percentage of new incoming MSM who are black	60-85	65-83	Baltimore census 1990-2010; NHBS 2004-2011
m_{y0}	Percentage of new incoming black MSM who are aged 18-24 years old	72-87	72-87	% of black MSM in NHBS who say they entered sexually active Baltimore MSM population aged <25 – 2008 & 2011 NHBS
m_{y1}	Percentage of new incoming white MSM who are aged 18-24 years old	50-71 (fitting to census demography) 37-71 (fitting to NHBS demography)	39-71	% of white MSM in NHBS who say they entered sexually active Baltimore MSM population aged <25 – 2008 & 2011 NHBS
π_0	rate of moving from 18-24 year old age group to >24 year old age group, black MSM, per year	0.17 (fixed)		Mean age at joining the local MSM population in NHBS 2008 and 2011 for 18-24 yr old MSM ~16 yrs old (95% CI 15-17)
π_1	rate of moving from 18-24 year old age group to >24 year old age group, white MSM, per year	0.17-0.25	0.17-0.25	Mean age at joining the local MSM population in NHBS 2008 and 2011 for 18-24 yr old MSM ~18/19 yrs old (95% CI 16/17-20)
$\mu_{0,0}$	Non-HIV related death rate, 18-24 year old black men, per year	0.0011-0.0015	0.0011-0.0015	CDC WONDER database data for Maryland; data for 15-24 years olds
$\mu_{1,0}$	Non-HIV related death/leaving rate, >24 year old black men, per year	0.011-0.04 (census fitting) 0.041-0.11 (NHBS fitting)	0.05-0.094	CDC WONDER database data for Maryland; average death rate over ages 26-64 years old Upper bound: add on 1/36 (double current duration as an MSM) NHBS fitting: additionally assume extra rate of ceasing to attend NHBS venues
$\mu_{0,1}$	Non-HIV related death rate, 18-24 year old white men, per year	0.00075-0.001	0.00075-0.001	CDC WONDER database data for Maryland; data for 15-24 years olds

$\mu_{1,1}$	Non-HIV related death/leaving rate, >24 year old white men, per year	0.033-0.1 (census fitting) 0.058-0.128 (NHBS fitting)	0.063-0.127	High rates reflecting out-migration plus rates of ceasing sexual activity; NHBS fitting: additionally assume extra rate of ceasing to attend NHBS venues
Sexual behaviours				
n_1	Number of sex acts per main partnership	40-470	43-150	48.2-85.1 sex episodes/year with main partners [7], partnerships last 3.5-5.5 years [5,6], but assume some are shorter (~1 year)
	Percentage of recent sex acts with main partners, black MSM	0.43-0.56	0.43-0.56	Percentage of last sex acts reported to be with main partners NHBS 2008, 2011, 2014
	Percentage of recent sex acts with commercial partners, black MSM	0.08-0.16	0.08-0.16	Percentage of last sex acts reported to be with commercial partners NHBS 2008, 2011, 2014
	Ratio of percentage of recent sex acts with main partners, white:black MSM	1.18 (fixed)		Average ratio of percentage of last sex acts reported to be with main partners for white vs black MSM NHBS 2008, 2011, 2014
	Ratio of percentage of recent sex acts with commercial partners, white:black MSM	0.24 (fixed)		Average ratio of percentage of last sex acts reported to be with commercial partners for white vs black MSM NHBS 2008, 2011, 2014
$c_{0,0,1}$	Number of new main partners per year, 18-24 year old black MSM	0.58-0.8	0.58-0.8	NHBS 2004, 2008, 2011
$c_{0,0,2}$	Number of new casual partners per year, 18-24 year old black MSM 2011 onwards‡	1.54-2.09	1.54-2.09	NHBS 2011
$c_{0,0,3}$	Number of new commercial partners per year, 18-24 year old black MSM 2011 onwards‡	0-1.36	0-1.35	NHBS 2011
$c_{1,0,1}$	Number of new main partners per year, >24 year old black MSM	0.36-0.57	0.36-0.57	NHBS 2004, 2008, 2011

$c_{1,0,2}$	Number of new casual partners per year, >24 year old black MSM 2011 onwards‡	0.81-1.24	0.81-1.23	NHBS 2011
$c_{1,0,3}$	Number of new commercial partners per year, >24 year old black MSM 2011 onwards‡	0.15-0.85	0.16-0.83	NHBS 2011
$c_{0,1,1}$	Number of new main partners per year, 18-24 year old white MSM	0.08-0.37	0.08-0.67	NHBS 2004, 2008, 2011
$c_{0,1,2}$	Number of new casual partners per year, 18-24 year old white MSM 2011 onwards‡	0.05-0.93	0.07-0.93	NHBS 2011
$c_{0,1,3}$	Number of new commercial partners per year, 18-24 year old white MSM 2011 onwards‡	0-0.28	0-0.27	NHBS 2011
$c_{1,1,1}$	Number of new main partners per year, >24 year old white MSM	0.11-0.21	0.11-0.21	NHBS 2004, 2008, 2011
$c_{1,1,2}$	Number of new casual partners per year, >24 year old white MSM 2011 onwards‡	0.28-1.07	0.30-1.06	NHBS 2011
$c_{1,1,3}$	Number of new commercial partners per year, >24 year old white MSM 2011 onwards‡	0-0.07	0-0.07	NHBS 2011
Partner_number_decline	absolute decline per year in the number of new casual or commercial partners	0.17-0.36	0.17-0.36	From trends in NHBS data on number of commercial and causal partners 2004-2011
Mixing_age	Scale between fully proportionate and fully assortative mixing by age	0.25-0.35	0.25-0.35	estimated from NHBS 2011 data on last partner
Mixing_race	Scale between fully proportionate and fully assortative mixing by race	0.7-0.8	0.7-0.8	0.75 estimated from NHBS 2011 data on last partner and 0.74 from NHBS additional data 2008 [35]
Early_condom_use	Minimum level of condom use at start of the HIV epidemic (% of sex acts)	0-30	0-30	No data
$s_{c,1,0}$	Percentage of sex acts in which a condom is used, main partnerships where both partners are black, 2004 onwards‡	47-67	47-67	condom use last sex act reported by black MSM with main partners NHBS 2004-2011
$s_{c,1,1}$	Percentage of sex acts in which a condom is used, main partnerships where one or both partners are white, 2004 onwards‡	30-39	30-39	condom use last sex act reported by white MSM with main partners NHBS 2004-2011
$s_{c,2}$	Percentage of sex acts in which a condom is used, casual partnerships (any race partner), 2004 onwards‡	63-72	63-72	condom use last sex act reported in casual partnerships NHBS 2004-2011

$s_{c,3}$	Percentage of sex acts in which a condom is used, commercial partnerships (any race partner), 2004 onwards‡	21-78	21-77	condom use last sex act reported in commercial partnerships NHBS 2004 & 2008
Condom_change_1	Yearly change in % of sex acts in which condoms are used, all partnerships prior to 2008	2.4-4	2.4-4	From trend in data from NHBS 2004-2008, averaging over condom use in main and casual partnerships
Condom_change_2	Yearly change in % of sex acts in which condoms are used, all partnerships between 2008 and 2011	-2.4-+0.2	-0.24-0	From trends in data from NHBS 2008-2011 and 2008-2014, averaging over condom use in main and casual partnerships
HIV disease progression				
$1/\gamma_a$	Average duration of acute infection, months	2-6	2-6	[13,36]
$\alpha_{0,0,1}$	HIV-related death rate for those with acute HIV infection, per year	0 (fixed)		assumption
$\alpha_{1,y,1}$	HIV-related death rate for those with CD4>500, off ART, per year	0.0009-0.0054	0.0009-0.0053	aged 25-44 in the European CASCADE cohort [12]; general population death rate subtracted
$\alpha_{2,y,1}$	HIV-related death rate for those with CD4 350-500, off ART, per year	0.0009-0.0069	0.0009-0.0069	aged 25-44 in the European CASCADE cohort [12]; general population death rate subtracted
$\alpha_{3,y,1}$	HIV related death rate for those with CD4 200-350, off ART, per year	0.0045-0.0135	0.0045-0.0135	aged 25-44 in the European CASCADE cohort [12]; general population death rate subtracted
$1/\alpha_{4,1,1}$	Inverse of HIV-related death rate for those with CD4<200, SPVL<4.0, off ART (years)	3.28-12.87	3.36-12.68	Netherlands ATHENA cohort [10]
$1/\alpha_{4,2,1}$	Inverse of HIV-related death rate for those with CD4<200, SPVL 4.0-4.5, off ART (years)	1.43-6.09	1.50-6.09	Netherlands ATHENA cohort [10]
$1/\alpha_{4,3,1}$	Inverse of HIV-related death rate for those with CD4<200, SPVL 4,5-5,0, off ART (years)	4.41-23.64	4.50-23.36	Netherlands ATHENA cohort [10]
$1/\alpha_{4,4,1}$	Inverse of HIV-related death rate for those with CD4<200, SPVL>5.0, off ART (years)	1.32-3.59	1.33-3.57	Netherlands ATHENA cohort [10]
$\alpha_{1,y,2}$,$\alpha_{2,y,2}$ $\alpha_{1,y,3}$,$\alpha_{2,y,3}$ $\alpha_{1,y,4}$,$\alpha_{2,y,4}$	HIV-related mortality for those with CD4>500 or CD4 350-500 at start of treatment, for 1st , 2nd and subsequent years on ART, per year	0-0.003	0-0.003	From probabilities for those with CD4>350 [37]; general population death rate subtracted [38]

a_1	Relative mortality of those with CD4 200-350 vs CD4>350 at start of treatment, 1st year on ART	1.2-2.8	1.2-2.8	[9]
a_2	Relative mortality of those with CD4 200-350 vs CD4>350 at start of treatment, 2nd year on ART	1-2.2	1-2.2	[9] Upper limit reduced to give main estimate as midpoint
a_3	Relative mortality of those with CD4 200-350 vs CD4>350 at start of treatment, 3rd year + on ART	1-1.4	1-1.4	[9] Upper limit reduced to give main estimate as midpoint
a_4	Relative mortality of those with CD4 <200 vs CD4>350 at start of treatment, 1st year on ART	1.8-5.2	1.8-5.1	[9] Main estimate and lower bound: CD4 100-199; upper bound from those with CD4 25-49
a_5	Relative mortality of those with CD4 <200 vs CD4>350 at start of treatment, 2nd year on ART	1.3-6.2	1.4-6.2	[9] Main estimate and lower bound: CD4 100-199; upper bound from those with CD4 25-49
a_6	Relative mortality of those with CD4 <200 vs CD4>350 at start of treatment, 3rd year + on ART	1-3.2	1-3.2	[9] Main estimate and lower bound: CD4 100-199; upper bound from those with CD4 50-99
b_1	Relative mortality of those with AIDS before ART initiation vs without, 1st year on ART	3.0-4.8	3.0-4.8	[9]
b_2, b_3	Relative mortality of those with AIDS before ART initiation vs without, 2nd , 3rd + years on ART	1.4-2.6	1.4-2.6	[9]
k_4	Percentage of those starting ART with CD4<200 who have a prior AIDS diagnosis	40-60	40-60	[39]
θ_2	Percentage of infected MSM with a SPVL 4.0-4.5	25 (fixed)		Netherlands ATHENA cohort [10]; US MSM (MACS cohort)[40,41]
θ_3	Percentage of infected MSM with a SPVL 4.5-5.0	25-40	25-40	Netherlands ATHENA cohort [10]; US MSM (MACS cohort)[40,41]
θ_4	Percentage of infected MSM with a SPVL >5.0	10-25	10-25	Netherlands ATHENA cohort [10]; US MSM (MACS cohort)[41]
$1/\gamma_{1,1}$	Average duration spent with CD4>500 cells/µl, for those with SPVL <4.0 (years)	4.56-6.37	4.58-6.35	Netherlands ATHENA cohort [10]
$1/\gamma_{2,1}$	Average duration spent with CD4 350-500, for those with SPVL <4.0 (years)	2.98-4.53	2.99-4.53	Netherlands ATHENA cohort [10]
$1/\gamma_{3,1}$	Average duration spent with CD4 200-350, for those with SPVL <4.0 (years)	5.04-13.69	5.09-13.6	Netherlands ATHENA cohort [10]
$1/\gamma_{1,2}$	Average duration spent with CD4>500, for those with SPVL 4.0-4.5 (years)	2.68-3.64	2.69-3.64	Netherlands ATHENA cohort [10]

$1/\gamma_{2,2}$	Average duration spent with CD4 350-500, for those with SPVL 4.0-4.5 (years)	2.65-3.64	2.68-3.64	Netherlands ATHENA cohort [10]
$1/\gamma_{3,2}$	Average duration spent with CD4 200-350, for those with SPVL 4.0-4.5 (years)	5.46-15.55	5.71-15.36	Netherlands ATHENA cohort [10]
$1/\gamma_{1,3}$	Average duration spent with CD4>500, for those with SPVL 4.5-5.0 (years)	2.08-2.64	2.08-2.63	Netherlands ATHENA cohort [10]
$1/\gamma_{2,3}$	Average duration spent with CD4 350-500, for those with SPVL 4.5-5.0 (years)	1.98-2.72	1.98-2.72	Netherlands ATHENA cohort [10]
$1/\gamma_{3,3}$	Average duration spent with CD4 200-350, for those with SPVL 4.5-5.0 (years)	4.73-10.22	4.75-10.15	Netherlands ATHENA cohort [10]
$1/\gamma_{1,4}$	Average duration spent with CD4>500, for those with SPVL ≥5.0 (years)	1.28-1.76	1.28-1.76	Netherlands ATHENA cohort [10]
$1/\gamma_{2,4}$	Average duration spent with CD4 350-500, for those with SPVL ≥5.0 (years)	1.22-1.69	1.23-1.69	Netherlands ATHENA cohort [10]
$1/\gamma_{3,4}$	Average duration spent with CD4 200-350, for those with SPVL ≥5.0 (years)	2.12-4.19	2.14-4.17	Netherlands ATHENA cohort [10]
$1/\sigma_0$	Average duration from ART initiation to viral suppression (VL < 200 copies/ml) for those with acute HIV infection (months)	3.93-8.50	3.95-8.47	Pregnant women, Kenya[42]
$1/\sigma_1$	Average duration from ART initiation to viral suppression (VL < 200 copies/ml) for those with $\log_{10}$ SPVL <4.0 (months)	0.95-4.1	0.95-4.09	Data from Johns Hopkins (Baltimore) and Fenway (Boston); estimate is weighted average of median values from 2 sites
$1/\sigma_2$	Average duration from ART initiation to viral suppression (VL < 200 copies/ml) for those with $\log_{10}$ SPVL 4.0-4.5 (months)	1.03-4.75	1.10-4.73	Data from Johns Hopkins (Baltimore) and Fenway (Boston); estimate is weighted average of median values from 2 sites
$1/\sigma_3$	Average duration from ART initiation to viral suppression (VL < 200 copies/ml) for those with $\log_{10}$ SPVL 4.5-5.0 (months)	1.4-6.43	1.41-6.41	Data from Johns Hopkins (Baltimore) and Fenway (Boston); estimate is weighted average of median values from 2 sites
$1/\sigma_4$	Average duration from ART initiation to viral suppression (VL < 200 copies/ml) for those with $\log_{10}$ SPVL >5.0 (months)	2.03-6.49	2.12-6.45	Data from Johns Hopkins (Baltimore) and Fenway (Boston); estimate is weighted average of median values from 2 sites

$f_{1,1}$	Percentage with CD4 >500 after seroconversion, for those with SPVL <4.0	81-91	81-91	Netherlands ATHENA cohort [10]
$f_{3,1}$	Percentage with CD4 200-350 after seroconversion, for those with SPVL <4.0	0-4	0-4	Netherlands ATHENA cohort [10]
$f_{4,1}$	Percentage with CD4 <200 after seroconversion, for those with SPVL <4.0	0 (fixed)		Netherlands ATHENA cohort [10]
$f_{1,2}$	Percentage with CD4 >500 after seroconversion, for those with SPVL 4.0-4.5	72-83	72-83	Netherlands ATHENA cohort [10]
$f_{3,2}$	Percentage with CD4 200-350 after seroconversion, for those with SPVL 4.0-4.5	1-5	1-5	Netherlands ATHENA cohort [10]
$f_{4,2}$	Percentage with CD4 <200 after seroconversion, for those with SPVL 4.0-4.5	0 (fixed)		Netherlands ATHENA cohort [10]
$f_{1,3}$	Percentage with CD4 >500 after seroconversion, for those with SPVL 4.5-5.0	69-79	69-79	Netherlands ATHENA cohort [10]
$f_{3,3}$	Percentage with CD4 200-350 after seroconversion, for those with SPVL 4.5-5.0	3-8	3-8	Netherlands ATHENA cohort [10]
$f_{4,3}$	Percentage with CD4 <200 after seroconversion, for those with SPVL 4.5-5.0	0 (fixed)		Netherlands ATHENA cohort [10]
$f_{1,4}$	Percentage with CD4 >500 after seroconversion, for those with SPVL ≥5.0	64-77	64-77	Netherlands ATHENA cohort [10]
$f_{3,4}$	Percentage with CD4 200-350 after seroconversion, for those with SPVL ≥5.0	2-7	2-7	Netherlands ATHENA cohort [10]
$f_{4,4}$	Percentage with CD4 <200 after seroconversion, for those with SPVL ≥5.0	0 (fixed)		Netherlands ATHENA cohort [10]
$r_{y,Y}$	Percentage going into each SPVL compartment after dropping out of ART			Stay in same SPVL compartment after dropping out of ART
$q_{x,X,Z}$	Percentage going from each starting CD4 count to new CD4 compartment upon dropping out of ART			Assume CD4 count when drop out of ART same as when started ART
Transmission probabilities				
d_1	Relative likelihood of transmission of HIV-positive partner in acute stage of infection vs chronic & CD4>200 (off ART)	4.47-18.81	4.73-18.65	[36]
d_2	Relative likelihood of transmission of HIV-positive partner in late stage of infection – CD4<200 cells/µl vs chronic and CD4>200 (off ART)	2-8	2-8	[11,43]

β	Average probability of acquiring HIV infection per sex act with an HIV-positive partner with chronic untreated infection	0.0007-0.0285	0.001-0.004	[14,15]; assume 50% of sex acts are insertive
h_1	Relative likelihood of transmission of HIV-positive person with $\log_{10}$ SPVL <4.0 vs 4.0-4.5	0.337-0.68	0.339-0.68	[17] Inverse of pooled increase in transmissibility per log10 decrease in viral load
h_2	Relative likelihood of transmission of HIV-positive person with $\log_{10}$ SPVL 4.0-4.5 vs 4.0-4.5	1 (fixed)		
h_3	Relative likelihood of transmission of HIV-positive person with $\log_{10}$ SPVL 4.5-5.0 vs 4.0-4.5	1 (fixed)		
h_4	Relative likelihood of transmission of HIV-positive person with $\log_{10}$ SPVL >5.0 vs 4.0-4.5	1.47-2.97	1.51-2.95	[17] pooled increase in transmissibility per log10 increase in viral load
Intervention behaviours				
p	Percentage of new entrants to MSM population who never routinely test for HIV	5-13	5-13	NHBS Baltimore MSM 2004-2011: % of those aged >24 years old who report never testing for HIV
$\tau_{0,0}$	Percentage of black MSM with undiagnosed infection aged 18-24 testing for HIV in the last year, 2004 onwards	63.8-95.0 (reported testing rates) 25.5-47.5 (diagnosis fitting)	25.7-47.5	NHBS data 2004-2011, self-reported HIV negative men; converted into rate of testing at least once per year in the model Diagnosis fitting: 60% reduction
$\tau_{0,1}$	Percentage of white MSM with undiagnosed infection aged 18-24 testing for HIV in the last year, 2004 onwards	32.1-82.3 (reported testing rates) 12.8-41.2 (diagnosis fitting)	13.0-40.9	NHBS data 2004-2008(highest and lowest from ranges), self-reported HIV negative men Diagnosis fitting: 60% reduction
$\tau_{1,0}$	Percentage of black MSM with undiagnosed infection aged >24 years old testing for HIV in the last year, 2004 onwards	50.0-70.2 (reported testing rates) 20.0-35.1 (diagnosis fitting)	20.2-35.0	NHBS data 2004-2011 (highest and lowest from ranges), self-reported HIV negative men Diagnosis fitting: 60% reduction
$\tau_{1,1}$	Percentage of white MSM with undiagnosed infection aged >24 years old testing for HIV in the last year, 2004 onwards	32.7-69.7 (reported testing rates)	13.4-34.7	NHBS data 2004-2011 (highest and lowest from ranges), self-reported HIV negative men

		13.1-34.9(diagnosis fitting)		Diagnosis fitting: 60% reduction
τ_{early}	Percentage of all MSM who tested for HIV in the last year, 1996	20-30 (reported testing rates) 8-15 (diagnosis fitting)	8-15	MSM in national NHSDA survey 1996 [20] Diagnosis fitting: 60% reduction
ω	Ratio of rate of dropout from care: rate of dropout from ART	1-7	1-7	Estimates from US studies - risk of dropout from care for those on vs off ART [28,44,45]
q_1	Percentage of white MSM testing positive for HIV who link to care straight away	67-85	67-85	[21,23-25] From estimates of linkage to care within three months of HIV diagnosis.
ϵ	Rate of linkage to care for those not linking immediately or dropped out, per year	0-0.1 (fitting to care and viral suppression data) 0-0.5 (fitting to ART coverage data)	0-0.5	Estimate
linkage_inc	Annual absolute increase in percentage of white MSM who link to care straight away after testing positive for HIV	3.5 (fixed)	3.5	From changes for MSM in national CDC data [26,27]
χ	Percentage of white MSM initiating ART who are adherent (achieve viral suppression)	73-99	73-99	[25,30,31,46]
ξ_x	Rate of initiation onto ART from care, when meeting CD4 criteria*, per year‡	0.5-2.1 (fitting to care and viral suppression data) 1.1-4 (fitting to ART coverage data)	0.5-3.96	Assuming CD4 testing every 3-6 months (national guidelines), acceptance 80-90% [47]
$\psi_{0,z}, \psi_{1,z}$	Rate of starting HAART due to AIDS symptoms, CD4>500, per year (post-1996)	0.001-0.01	0.001-0.01	Incidence of AIDS-defining illness among ART naives, CASCADE collaboration [48]; similar estimates

				from EURO-COORD data analysis [49]
$\psi_{2,z}$	Rate of starting HAART due to AIDS symptoms, CD4 350-500, per year (post-1996)	0.004-0.015	0.004-0.015	Incidence of AIDS-defining illness among ART naives, CASCADE collaboration [48]; similar estimates from EURO-COORD data analysis [49]
$\psi_{3,z}$	Rate of starting HAART due to AIDS symptoms, CD4 200-350, per year (post-1996)	0.009-0.032	0.009-0.032	Incidence of AIDS-defining illness among ART naives, CASCADE collaboration [48]; similar estimates from EURO-COORD data analysis [49]
$\psi_{4,z}$	Rate of starting HAART due to AIDS symptoms, CD4<200, per year (post-1996)	0.086-0.262	0.086-0.261	Incidence of AIDS-defining illness among ART naives, CASCADE collaboration [48]
$\phi_4\phi_5\phi_6$	Dropout from ART, not fully suppressed/1st year on ART/2nd year on ART, per year	0.06-0.13	0.06-0.13	Rate of dropout from ART, US [28,29,44,45,50]
$\phi_{z\,ratio}$	Ratio of dropout from ART 3rd+ years: dropout 1st, 2nd years (ϕ_7: ϕ_4)	0.5-1.0	0.5-1.0	Rate of dropout from US ART cohorts [32]
ζ	Rate of re-enrolment into pre-ART HIV care for those dropping out of ART, per year	0.05-1	0.05-0.97	From rate of dropout and re-joining US ART cohorts [32]
s_n	Percentage of MSM circumcised	77-89	77-89	NHBS 2008 & 2011
ϵ_{ratio}	Ratio of rates of linkage to care for black:white MSM (ratio also applied to percentage linking immediately after infection diagnosis)	1-2 (fitting to care and viral suppression data) 0.84-1.5 (fitting to ART coverage data)	0.85-1.99	[21,25]
ω_{ratio}	Ratio of dropout from care for white:black MSM	1-3 (fitting to care and viral suppression data) 0.46-1.54 (fitting to ART coverage data)	0.48-2.95	[29,44,50] [28,45,51]

ξ_{ratio}	Ratio of ART initiation rate for black:white MSM	0.4-1.0	0.4-1.0	[28]
$\phi_{w\,ratio}$	Ratio of ART dropout for black:white MSM	0.7-1.6	0.7-1.6	[29,32]
χ_{ratio}	Ratio of percentage adherent to ART black:white MSM	0.82-1	0.82-1	[25,30,31,44,46,52] From estimates of the proportion of PLHIV achieving viral suppression in multi-site US cohorts and surveillance
Intervention efficacies				
e_c	Per-sex-act reduction in HIV acquisition risk due to correct condom use (%)	58-79	58-79	Estimate for US MSM [18]
e_n	Per-sex-act reduction in HIV acquisition risk due to male circumcision (%)	12-23	12-23	Assuming same efficacy as for heterosexual men from RCTs [19], only protective in insertive acts, half of all sex acts are insertive, receptive sex acts carry a 2.3x higher risk of transmission than insertive[15].
d_r	Relative level of likelihood of transmission of those on ART and partially suppressed, scaled between the level for those fully suppressed ($d_r = 0$).and those unsuppressed ($d_r = 1$)	0.5 (fixed)	0.5	assumption
d_6	Per-sex-act reduction in HIV transmission risk when on ART and fully suppressed vs chronic infection untreated (CD4>200) (%)	99-100	99-100	Estimates from discordant MSM partnerships where HIV-positive partner on ART and virally suppressed [16]

*Guideline changes coded in: HAART first available 1996, [53]. 1998 guidelines: CD4<500; Feb 2001: CD4<350; Dec 2009 CD4<500; March 2012: all

‡Final values for time-varying parameters. Earlier values or earlier gradient of parameter function given elsewhere in Table S1.

Table S2: Data fitted to, with fitting bounds, source and justification

Output	Year	Estimate	Min	Max	Source & justification	Used for fitting	Used for validation
Demography							
Total MSM population size	2010	6518	4270	8765	Range 1.9-3.9%[33] of male population aged 18+ in Baltimore 2010 census (224,742)	✓	
Percentage of population aged 18-24	2004	24.8	20.3	30.0	NHBS data 95% CI	✓	
	2008	30.6	22.9	40.0	NHBS data 95% CI	✓	
	2011	30.9	21.5	42.2	NHBS data 95% CI	✓	
	2014	23.9	18.0	31.0	NHBS data 95% CI		✓
Percentage of white MSM aged 18-24	2004	21.0	15.6	27.6	NHBS data 95% CI	✓	
	2008	17.1	9.4	29.3	NHBS data 95% CI	✓	
	2011	20.7	11.8	33.7	NHBS data 95% CI	✓	
	2014	14.6	8.6	23.6	NHBS data 95% CI		✓
Percentage of black MSM aged 18-24	2004	24.0	18.0	31.2	NHBS data 95% CI	✓	
	2008	32.5	23.8	42.6	NHBS data 95% CI	✓	
	2011	34.3	22.3	48.7	NHBS data 95% CI	✓	
	2014	27.2	19.4	36.7	NHBS data 95% CI		✓
Percentage of MSM who are black	2004	64.1	49.8	76.3	NHBS data 95% CI	✓	
	2008	73.1	59.3	83.6	NHBS data 95% CI	✓	
	2011	84.2	71.6	91.8	NHBS data 95% CI	✓	
	2014	73.8	64.6	81.3	NHBS data 95% CI		✓
HIV prevalence							
HIV prevalence black MSM aged 18-24 years old (%)	2004	33.0	23.6	43.8	NHBS data 95% CI	✓	
	2008	31.2	20.6	44.2	NHBS data 95% CI	✓	
	2011	39.6	32.0	47.8	NHBS data 95% CI	✓	
	2014	24.1	14.5	37.1	NHBS data 95% CI		✓
HIV prevalence black MSM aged >24 years old	2004	58.4	46.7	69.3	NHBS data 95% CI	✓	
	2008	51.8	42.9	60.7	NHBS data 95% CI	✓	
	2011	52.2	44.1	60.3	NHBS data 95% CI	✓	
	2014	47.4	39.4	55.5	NHBS data 95% CI		✓
HIV prevalence white MSM aged 18-24 years old	2004		0	100	Numbers too small		
	2008	22.2	10.1	42.0	NHBS data 95% CI	✓	
	2011		0	100	Numbers too small		
	2014		0	100	Numbers too small		

HIV prevalence white MSM aged >24 years old	2004	16.7	10.7	25.0	NHBS data 95% CI	✓	
	2008	18.4	9.4	32.9	NHBS data 95% CI	✓	
	2011	19.6	12.2	29.8	NHBS data 95% CI	✓	
	2014	9.1	5.0	15.9	NHBS data 95% CI		✓
Care cascade indicators							
Percentage of infected MSM with diagnosed infection	2012	75.9	71.7	80.5	CDC data for Maryland state[54]	✓	
Percentage of all HIV-positive MSM on ART	2008	39.5	31.9	47.5	NHBS ARV detection analysis [55]	✓	
	2011	55.4	48.0	62.6	NHBS ARV detection analysis	✓	
	2014	70.3	61.6	77.7	NHBS ARV detection analysis		✓
Percentage of black HIV-positive MSM on ART	2008	36.9	28.5	46.2	NHBS ARV detection analysis [55]	✓	
	2011	51.6	43.8	59.4	NHBS ARV detection analysis	✓	
	2014	70.2	60.8	78.1	NHBS ARV detection analysis		✓
Percentage of white HIV-positive MSM on ART	2008	61.1	38.6	79.7	NHBS ARV detection analysis [55]	✓	
	2011		0	100	Numbers too small		
	2014		0	100	Numbers too small		
Percentage of black MSM with diagnosed infection who are in care	2012-2013	63.5	56.7	70.3	Maryland DHMH[a] ± 5pp min-max for 2012-2013	✓	
	2014	60.3	55.3	65.3	Maryland DHMH[a] ± 5pp		✓
	2015	57.6	52.6	62.6	Maryland DHMH[a] ± 5pp		✓
	2016	57.1	52.1	62.1	Maryland DH[a] ± 5pp		✓
	2017	59.9	54.9	64.9	Maryland DH[a] ± 5pp		✓
Percentage of white MSM with diagnosed infection who are in care	2012-2013	51.6	44.6	58.6	Maryland DHMH[a] ± 5pp min-max for 2012-2013	✓	
	2014	54.5	49.5	59.5	Maryland DHMH[a] ± 5pp		✓
	2015	49.7	44.7	54.7	Maryland DHMH[a] ± 5pp		✓
	2016	51.5	46.5	56.5	Maryland DH[a] ± 5pp		✓
	2017	56.0	51.0	61.0	Maryland DH[a] ± 5pp		✓
Percentage of black MSM with diagnosed infection who are virally suppressed	2012	31.6	26.6	36.6	Maryland DHMH[b] ± 5pp	✓	
	2013	37.0	32.0	42.0	Maryland DHMH[b] ± 5pp	✓	
	2014	46.0	41.0	51.0	Maryland DHMH[b] ± 5pp		✓
	2015	44.9	39.9	49.9	Maryland DHMH[b] ± 5pp		✓
	2016	46.3	41.3	51.3	Maryland DH[a] ± 5pp		✓
	2017	50.9	45.9	55.9	Maryland DH[a] ± 5pp		✓
Percentage of white MSM with diagnosed infection who are virally suppressed	2012	35.1	30.1	40.1	Maryland DHMH[b] ± 5pp	✓	

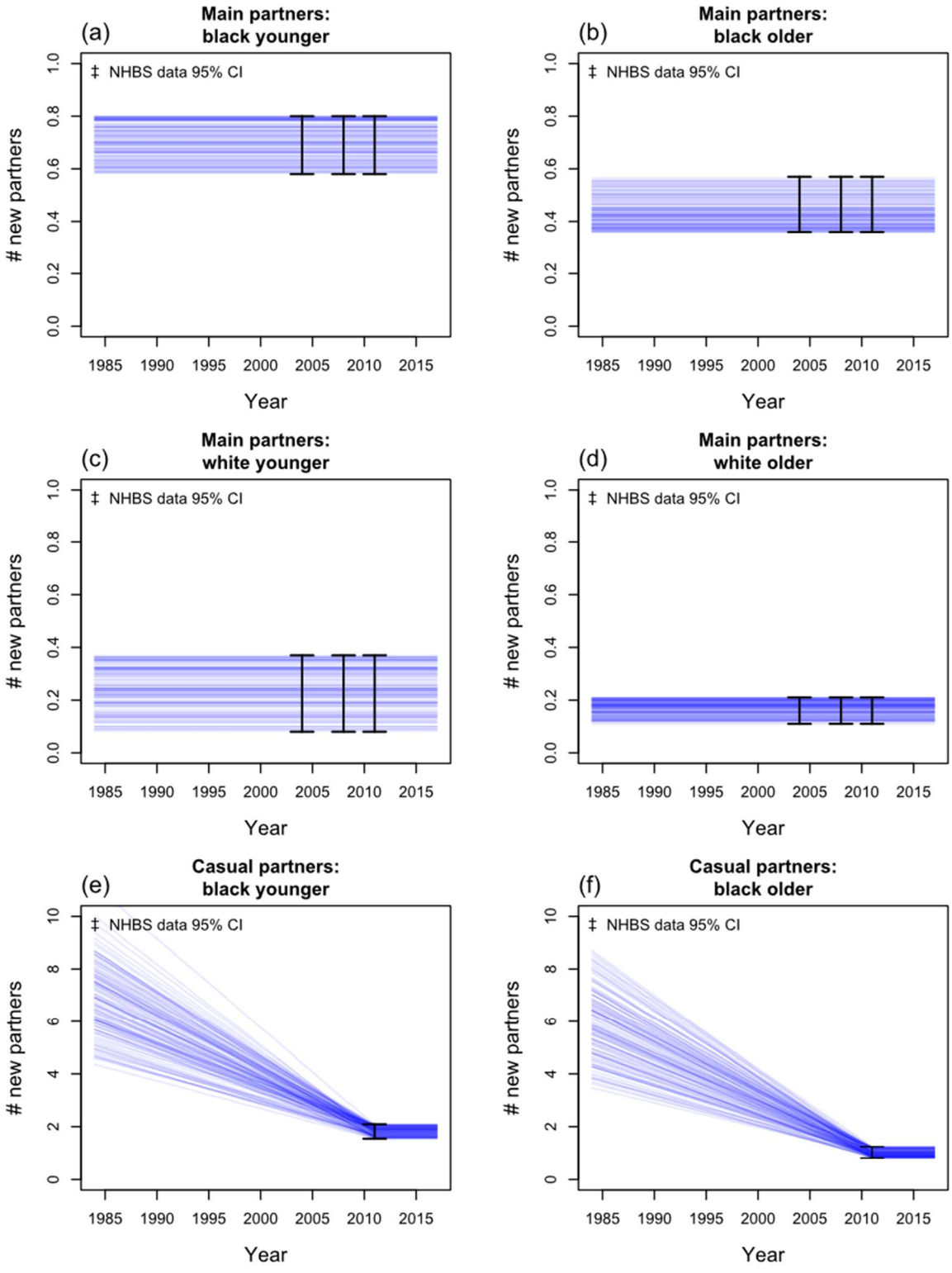
	2013	38.5	33.5	43.5	Maryland DHMH[b] ± 5pp	✓	
	2014	51.2	46.2	56.2	Maryland DHMH[b] ± 5pp		✓
	2015	51.4	46.4	56.4	Maryland DHMH[b] ± 5pp		✓
	2016	50.5	45.5	55.5	Maryland DH[a] ± 5pp		✓
	2017	55.0	50.0	60.0	Maryland DH[a] ± 5pp		✓
Percentage of MSM on ART virally suppressed	2010	85	75	90	National estimates for MSM[25,56]	✓	

[a]definition of in care: Percentage of those with diagnosed infection with at least one CD4 test past 12 months

[b]definition of virally suppressed: Percentage of those with diagnosed infection with at least one viral load test last 12 months and most recent viral load <200 copies/ml

Supplementary results

Figure S4. Simulated number of new anal sex partners per year among MSM over the simulation period. Each of the 118 blue lines represents the outcome of one single model fit. Plain dark bars represent data that was used to fit the model.



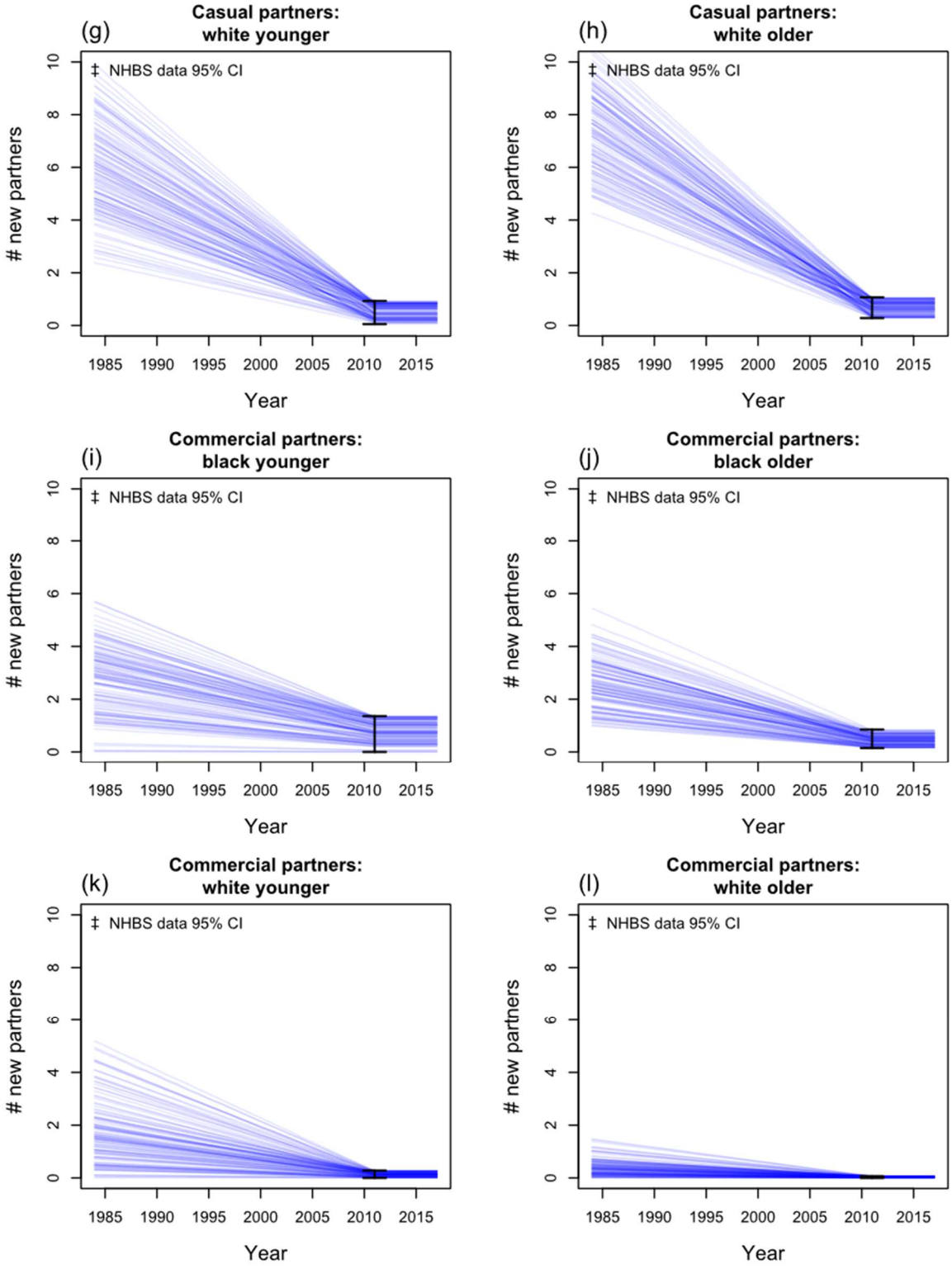

(g)
Casual partners:
white younger
‡ NHBS data 95% CI
# new partners
Year
(h)
Casual partners:
white older
‡ NHBS data 95% CI
# new partners
Year
(i)
Commercial partners:
black younger
‡ NHBS data 95% CI
# new partners
Year
(j)
Commercial partners:
black older
‡ NHBS data 95% CI
# new partners
Year
(k)
Commercial partners:
white younger
‡ NHBS data 95% CI
# new partners
Year
(l)
Commercial partners:
white older
‡ NHBS data 95% CI
# new partners
Year

Figure S5. Simulated annual number of anal sex acts per partner among MSM over the simulation period. Each of the 118 blue lines represents the outcome of one single model fit.

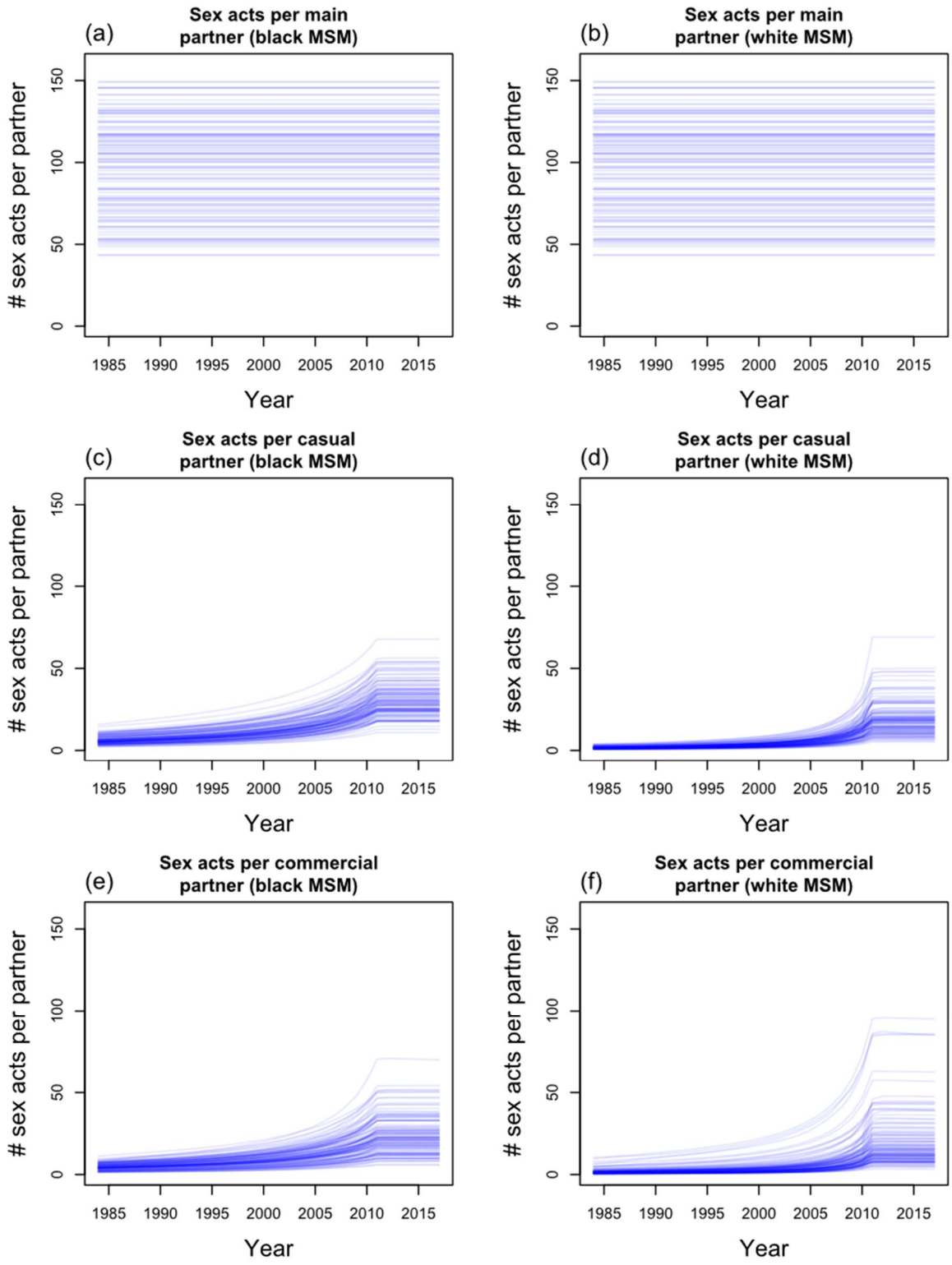
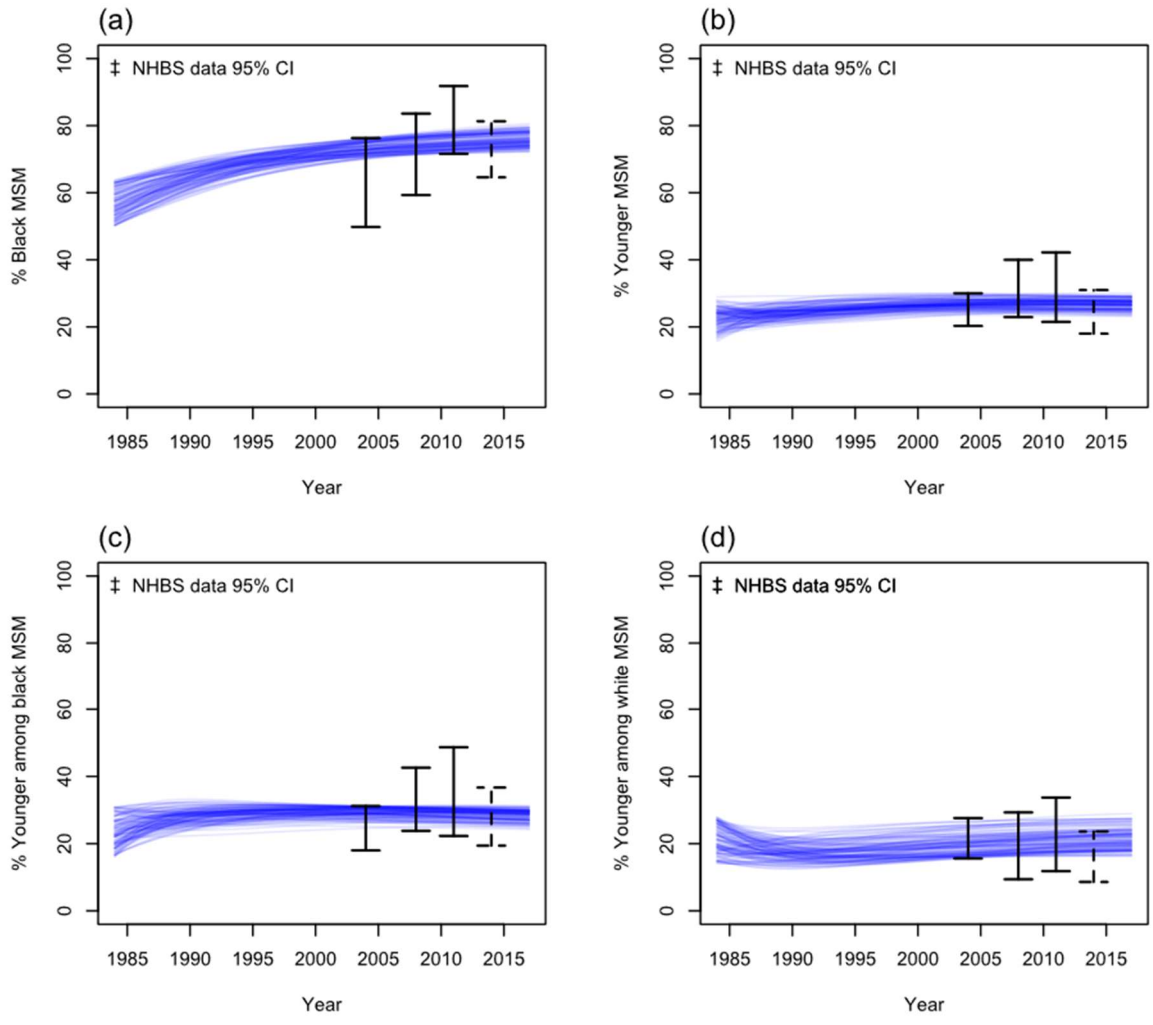
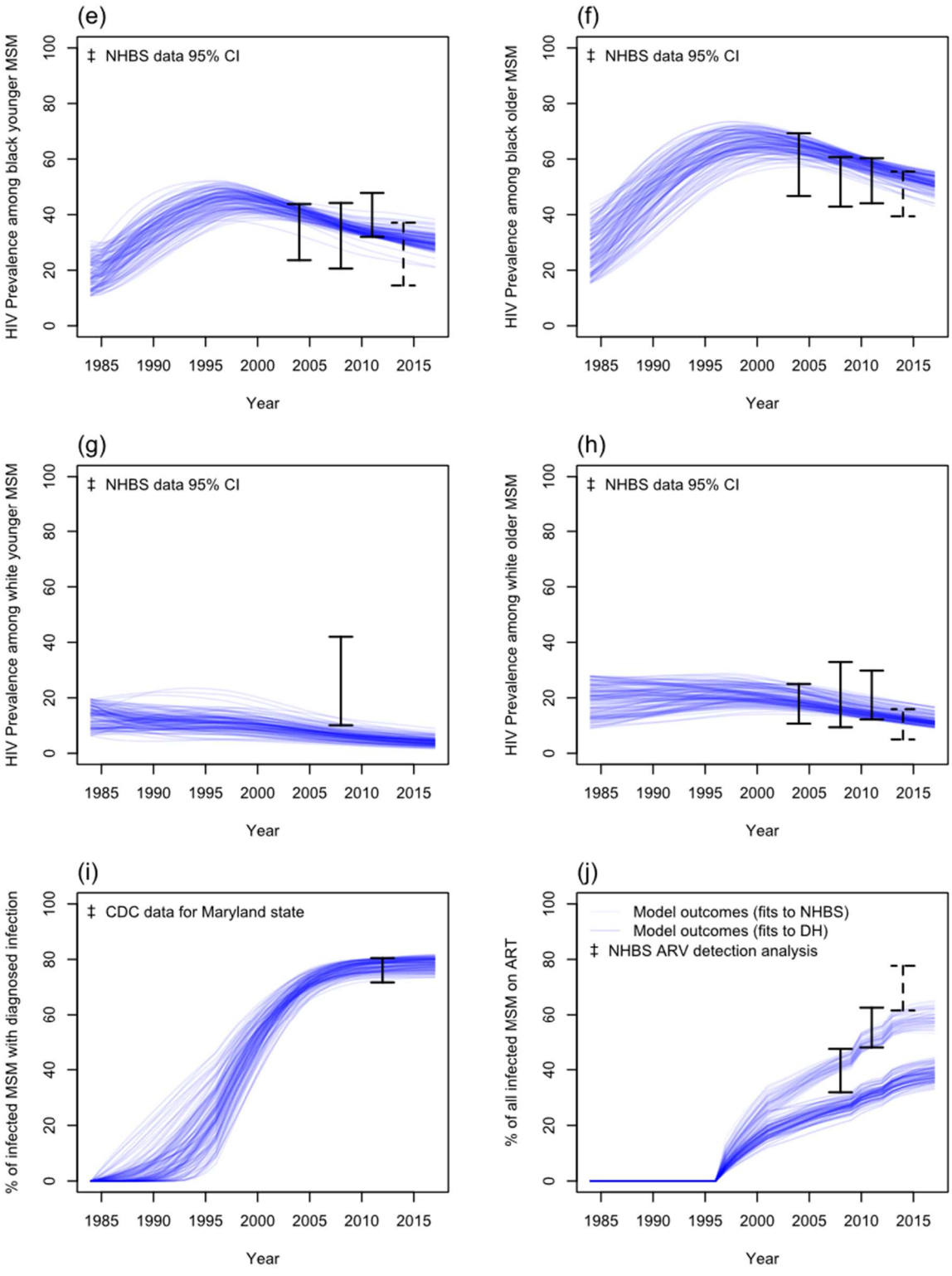
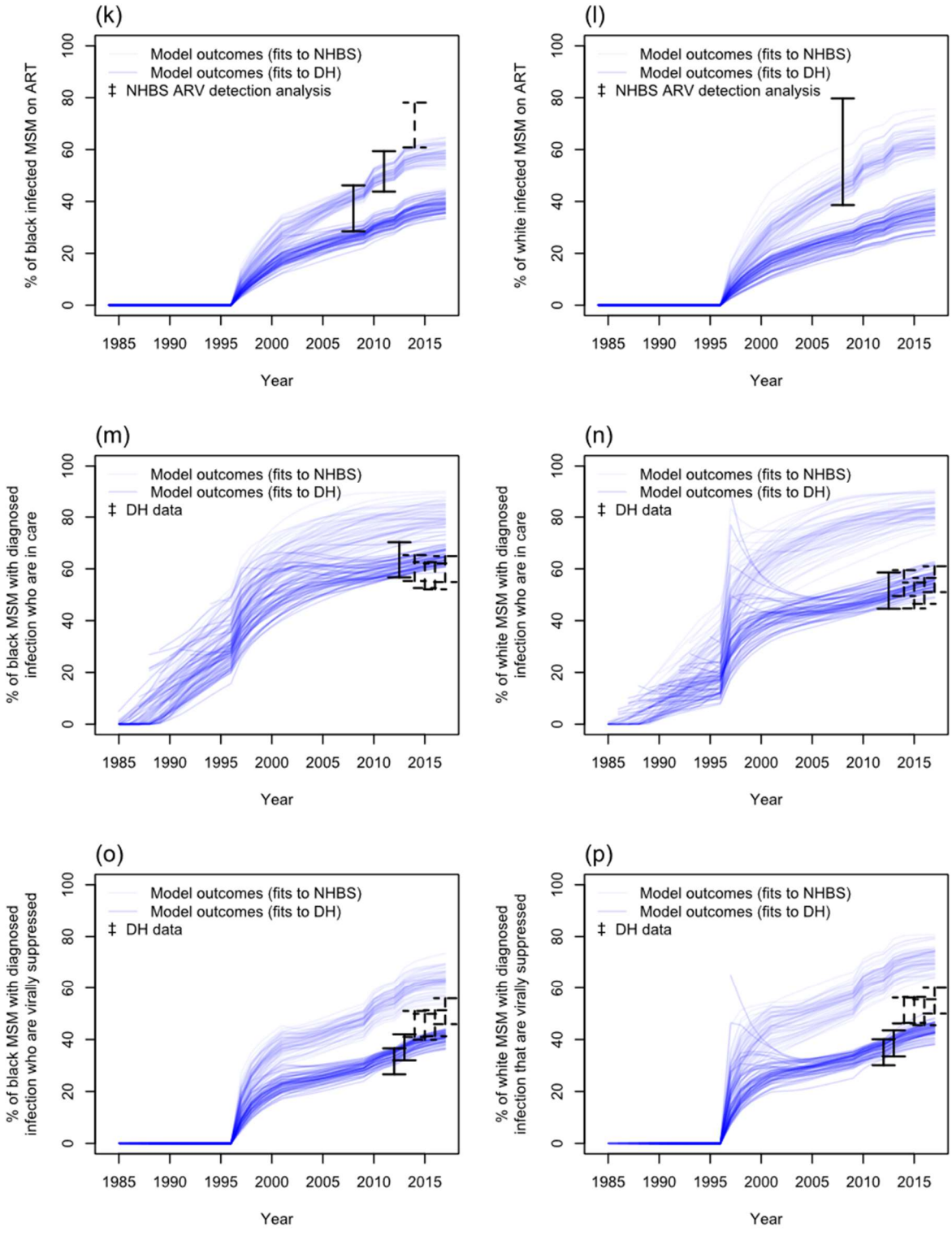


Figure S6. Fitting model to empirical data: proportion of all MSM who are black (a), proportion of all MSM who are younger (b), proportion of black MSM who are younger (c), proportion of white MSM who are younger (d). HIV prevalence among black younger (e), black older (f), white younger (g), white older (h) MSM (HIV prevalence had to fall within range at 2 out of 3 time-points). Proportion of all HIV-infected MSM with diagnosed infection (i), on ART (j). Proportion of black (k), white (l) HIV-infected MSM that are on ART. Proportion of black (m), white (n) MSM with diagnosed infection that are in care. Proportion of black (o), white (p) MSM with diagnosed infection that are virally suppressed. Proportion of MSM on ART that are virally suppressed (q). Each of the 118 blue lines represents the outcome of one single model fit. Plain dark bars represent data that was used to fit the model, dashed bars represent other data that was used to validate the model. Our analysis uses the 118 different combinations of model parameters ('fits') which were consistent with CDC estimates of the proportion of infected MSM with a diagnosed infection in Maryland (panel (i)).




(e)
‡ NHBS data 95% CI
HIV Prevalence among black younger MSM
(f)
‡ NHBS data 95% CI
HIV Prevalence among black older MSM
(g)
‡ NHBS data 95% CI
HIV Prevalence among white younger MSM
(h)
‡ NHBS data 95% CI
HIV Prevalence among white older MSM
(i)
‡ CDC data for Maryland state
% of infected MSM with diagnosed infection
(j)
Model outcomes (fits to NHBS)
Model outcomes (fits to DH)
‡ NHBS ARV detection analysis
% of all infected MSM on ART
0
20
40
60
80
100
1985
1990
1995
2000
2005
2010
2015
Year


(k)
% of black infected MSM on ART
Model outcomes (fits to NHBS)
Model outcomes (fits to DH)
‡ NHBS ARV detection analysis
Year
(l)
% of white infected MSM on ART
Model outcomes (fits to NHBS)
Model outcomes (fits to DH)
‡ NHBS ARV detection analysis
Year
(m)
% of black MSM with diagnosed infection who are in care
Model outcomes (fits to NHBS)
Model outcomes (fits to DH)
‡ DH data
Year
(n)
% of white MSM with diagnosed infection who are in care
Model outcomes (fits to NHBS)
Model outcomes (fits to DH)
‡ DH data
Year
(o)
% of black MSM with diagnosed infection who are virally suppressed
Model outcomes (fits to NHBS)
Model outcomes (fits to DH)
‡ DH data
Year
(p)
% of white MSM with diagnosed infection that are virally suppressed
Model outcomes (fits to NHBS)
Model outcomes (fits to DH)
‡ DH data
Year

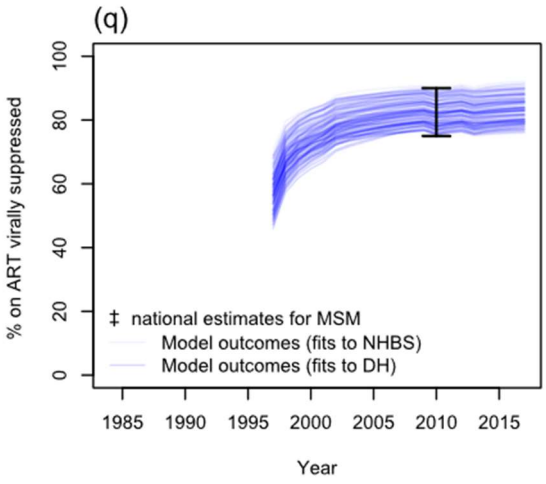

(q)
% on ART virally suppressed
0
20
40
60
80
100
1985
1990
1995
2000
2005
2010
2015
Year
‡ national estimates for MSM
Model outcomes (fits to NHBS)
Model outcomes (fits to DH)

Figure S7. Simulated proportions of sex acts between partners of a given race and for a given type of partnership that involve condoms. Each of the 118 blue lines represents the outcome of one single model fit. Plain dark bars represent data that was used to fit the model.

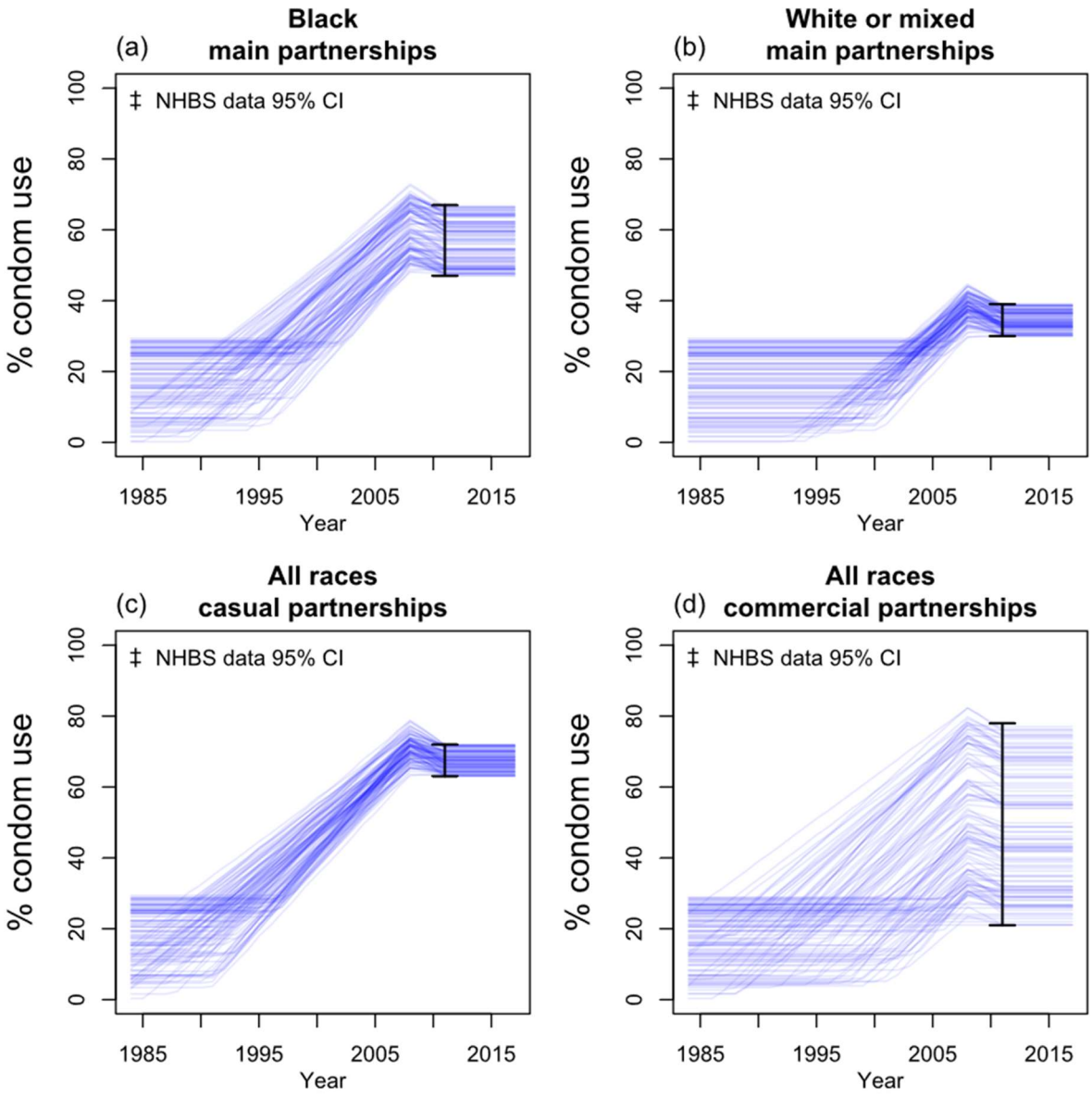


Table S3: fraction of infections averted by interventions (AF_{to-t}), calculated over a defined period, in the overall population, and among demographic populations, median and 95% UI across all 118 model fits.

	Time Period		
	1984-2017	**1996-2017**	**2008-2017**
Condom use			
Overall	19.2% (13.9-24.6)	23.0% (18.8-28.1)	37.2% (29.5-46.0)
Black	17.8% (13.5-23.2)	21.8% (17.2-26.8)	36.9% (28.8-45.7)
White	27.7% (17.7-35.8)	35.4% (27.2-43.1)	42.3% (35.4-51.1)
Younger	23.6% (17.5-29.5)	28.1% (23.0-33.9)	38.7% (29.7-47.7)
Old	15.6% (12.0-21.1)	18.6% (14.0-24.3)	36.0% (28.7-45.6)
Black younger	23.2% (17.4-28.7)	27.5% (21.8-33.0)	38.5% (29.5-47.7)
Black older	13.4% (10.0-18.7)	15.4% (10.3-21.0)	35.1% (27.7-44.6)
White younger	29.1% (19.9-40.1)	37.0% (28.5-48.0)	42.6% (33.7-52.7)
White older	27.3% (17.6-35.7)	35.1% (26.7-42.5)	42.4% (34.9-50.8)
ART			
Overall	14.7% (9.6-21.3)	22.8% (14.9-30.8)	35.7% (22.5-45.5)
Black	13.9% (9.3-20.6)	21.6% (14.4-29.2)	34.7% (22.0-44.7)
White	19.4% (11.2-29.0)	32.1% (19.9-41.6)	46.3% (28.8-56.0)
Younger	16.9% (10.7-24.6)	23.9% (15.4-32.4)	34.7% (21.4-44.7)
Old	12.9% (8.4-19.5)	22.1% (14.1-29.4)	36.2% (23.5-47.1)
Black younger	16.6% (10.4-24.4)	23.3% (15.1-31.4)	34.3% (21.0-44.3)
Black older	11.8% (7.9-17.7)	19.9% (13.2-27.4)	34.7% (22.8-45.7)
White younger	20.1% (11.9-31.3)	32.9% (20.4-43.2)	45.9% (28.5-55.5)
White older	18.9% (11.1-27.6)	31.7% (19.6-41.4)	46.6% (29.1-56.4)
Both condoms and ART			
Overall	28.1% (22.1-35.0)	35.9% (28.8-42.5)	54.4% (43.4-63.6)
Black	26.0% (20.5-31.7)	33.1% (26.2-39.3)	53.1% (42.1-62.1)
White	42.4% (30.9-52.2)	55.1% (45.6-64.0)	66.7% (55.3-75.2)
Younger	33.8% (26.8-41.1)	41.2% (32.8-47.9)	54.6% (43.3-63.1)
Older	23.7% (17.8-30.3)	31.5% (23.9-38.9)	53.6% (43.0-63.5)
Black younger	33.1% (26.2-39.9)	40.1% (32.0-46.1)	54.0% (42.8-61.7)
Black older	19.8% (15.0-25.4)	25.6% (18.7-34.3)	51.5% (40.9-61.5)
White younger	44.9% (32.8-56.9)	56.6% (47.1-66.6)	66.0% (53.9-75.8)
White older	42.0% (30.5-51.5)	54.8% (44.9-63.3)	66.9% (55.5-75.4)

Table S4: Modelled proportion of all MSM belonging to a specific demographic subgroup, calculated over different time periods, median and 95% UI across all 118 model fits.

	Time Periods		
	1988-1997	1998-2007	2008-2017
Black	67.0% (62.1-70.5)	72.4% (69.6-75.4)	74.9% (72.1-78.6)
White	33.0% (29.5-37.9)	27.6% (24.6-30.4)	25.1% (21.4-27.9)
Younger	24.9% (21.9-28.0)	26.5% (23.8-29.3)	26.9% (23.9-29.3)
Older	75.1% (72.0-78.1)	73.5% (70.7-76.2)	73.1% (70.7-76.1)
Black younger	19.0% (16.4-21.7)	21.3% (18.8-23.1)	21.7% (19.0-23.8)
Black older	47.8% (43.6-50.8)	51.2% (48.5-53.9)	53.6% (50.6-57.1)
White younger	5.9% (4.4-7.5)	5.2% (4.0-7.0)	5.0% (3.9-6.9)
White older	27.2% (23.4-31.6)	22.2% (18.9-25.2)	19.9% (16.5-22.6)

Table S5: Sources of acquisition and transmission of HIV among MSM residing in Baltimore, median and 95%UI across all 118 model fits.

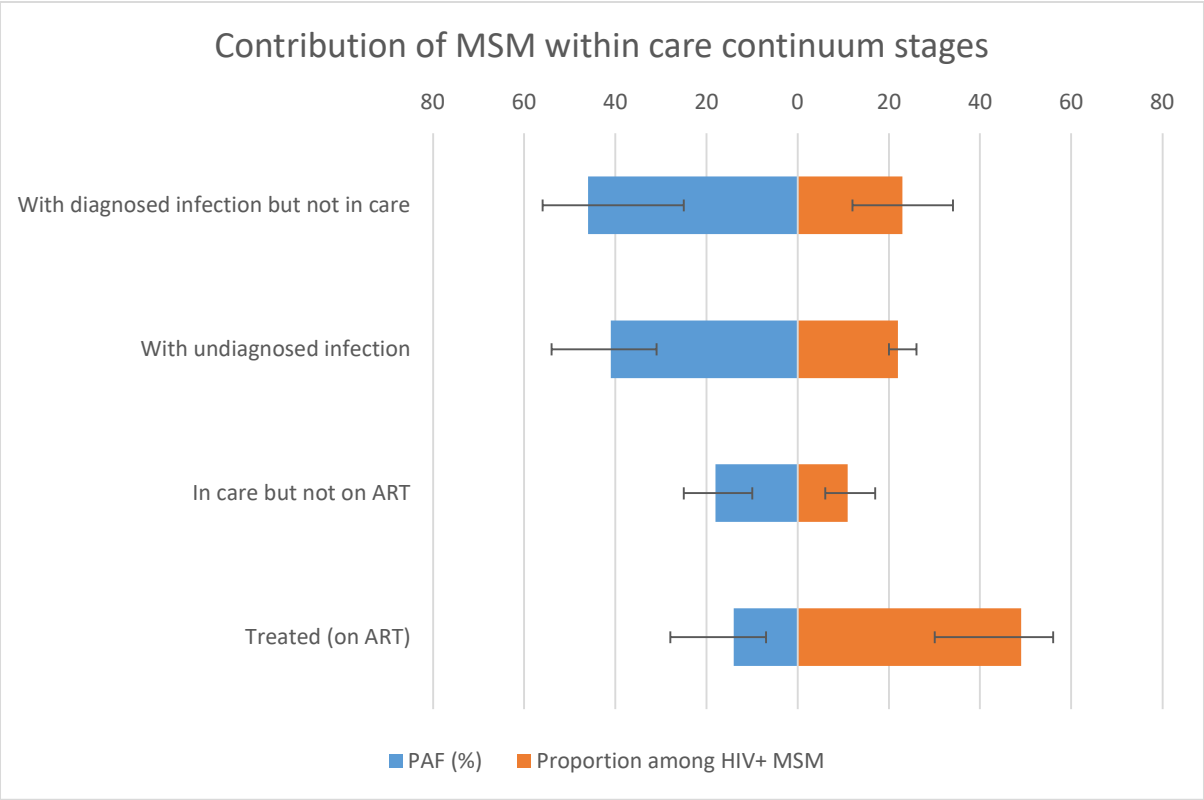
	Time periods			
	1988-1997	**1998-2007**	**2008-2017**	**2008-2017**
A) Who acquired infections	Proportion of Acquired Infections (%)			HIV incidence rate (per 100 susceptible person-years)
Demography				
Black	88.2% (85.0-91.3)	90.2% (87.0-93.4)	93.0% (89.8-95.8)	6.4 (5.0-8.2)
White	11.8% (8.7-15.0)	9.8% (6.6-13.0)	7.0% (4.2-10.2)	0.8 (0.5-1.3)
Younger	38.0% (33.3-43.1)	44.9% (40.6-49.2)	46.3% (40.7-52.2)	6.2 (5.1-8.9)
Older	62.0% (56.9-66.7)	55.1% (50.8-59.4)	53.7% (47.8-59.3)	3.6 (2.6-4.6)
Black younger	35.7% (31.4-40.9)	42.5% (38.1-47.2)	44.6% (39.4-50.1)	8.1 (6.6-10.9)
Black older	52.4% (47.2-58.0)	47.7% (43.1-52.9)	48.2% (42.8-53.4)	5.6 (3.7-7.2)
White younger	2.4% (1.3-4.2)	2.2% (1.2-4.0)	1.6% (0.8-3.3)	0.9 (0.4-1.7)
White older	9.4% (6.8-11.9)	7.5% (5.2-10.0)	5.2% (3.2-7.9)	0.8 (0.5-1.3)
B) Who contributed to transmissions	Population Attributable Fraction (PAF %)			HIV transmission rate (per 100 infected person-years)
Demography				
Black	91.1% (86.7-94.5)	94.5% (91.6-96.2)	97.1% (95.1-98.2)	7.0 (5.85-8.23)
White	8.7% (5.8-12.4)	6.1% (4.0-9.2)	3.7% (2.2-5.9)	3.3 (2.11-4.87)
Younger	25.2% (18.4-33.9)	29.5% (23.2-38.3)	35.4% (27.2-49.1)	12.7 (10.5-16.0)
Older	78.2% (70.8-85.3)	74.4% (67.8-80.0)	75.4% (66.6-81.0)	6.2 (4.9-7.43)
Black younger	24.0% (17.4-32.2)	28.6% (22.7-37.9)	35.0% (26.4-48.6)	13.0 (10.8-16.4)
Black older	69.2% (62.0-76.5)	68.9% (62.5-74.7)	72.2% (63.5-78.1)	6.5 (5.1-7.8)
White younger	1.2% (0.5-2.9)	0.9% (0.3-2.5)	0.6% (0.2-1.7)	5.7 (3.0-9.3)
White older	7.8% (5.1-11.5)	5.3% (3.6-8.0)	3.2% (2.0-5.1)	3.2 (2.0-4.8)
Partnership type				
Main	47.0% (38.5-55.6)	50.0% (42.9-57.1)	55.2% (47.6-62.7)	na
Casual	45.3% (33.3-58.2)	40.5% (32.3-51.1)	43.5% (34.7-54.8)	na
Commercial	12.2% (7.8-18.1)	13.2% (8.8-20.9)	16.4% (10.4-26.1)	na
Stages of untreated infection				
Untreated acute infection	19.4% (7.3-33.8)	15.7% (6.3-28.2)	19.7% (8.3-35.2)	54.4 (31.1-85.2)
Untreated with CD4 >500	12.3% (8.22-19.4)	11.9% (8.15-16.9)	13.2% (8.5-19.8)	6.6 (4.1-9.9)
Untreated with CD4 350-500	11.9% (8.1-18.1)	12.2% (8.6-18.0)	12.3% (8.3-18.6)	7.05 (4.6-10.4)
Untreated with CD4 200-350	19.3% (13.4-28.6)	19.5% (13.9-29.2)	20.6% (13.8-32.2)	7.2 (4.6-10.9)
Untreated with CD4 <200	41.1% (22.2-59.1)	37.1% (22.8-52.9)	39.5% (23.7-55.7)	31.1 (20.3-44.3)
Untreated with Log_{10} SPVL < 4.0	9.2% (3.4-17.2)	10.6% (4.4-19.6)	11.7% (5.2-21.2)	4.9 (3.2-7.3)

Untreated with Log_{10} SPVL in 4.0-4.5	16.7% (12.4-22.3)	18.3% (13.1-22.6)	19.4% (13.9-24.2)	9.22 (6.47-12.1)
Untreated with Log_{10} SPVL in 4.5-5.0	31.7% (21.3-45.1)	31.3% (22.9-41.4)	32.8% (23.2-44.0)	12.6 (10.3-16.4)
Untreated with Log_{10} SPVL >5.0	25.1% (10.5-38.6)	20.3% (9.8-29.8)	20.6% (10.6-30.6)	23.5 (16.1-32.2)
Care status				
With undiagnosed infection	90.1% (66.7-97.8)	48.6% (37.4-60.6)	41.3% (30.6-53.8)	12.1 (9.6-15.5)
With diagnosed infection	12.7% (3.3-34.4)	60.1% (47.3-71.2)	80.3% (71.3-87.0)	7.0 (5.2-8.7)
Untreated (not on ART)	99.6% (99.0-99.8)	90.9% (83.6-95.4)	88.4% (79.0-94.2)	10.3 (8.7-11.9)
Treated (on ART)	0.5% (0.3-1.1)	8.0% (4.1-14.6)	14.2% (7.2-28.0)	2.4 (1.3-3.4)
With diagnosed infection and untreated	12.3% (2.9-33.7)	49.0% (34.9-60.3)	63.8% (43.7-74.4)	12.1 (10.2-14.5)
With diagnosed infection but not in care	9.2% (2.28-27.4)	33.9% (20.7-45.6)	45.9% (24.6-56.3)	12.6 (10.2-15.7)
In care but not on ART	2.7% (0.6-5.8)	13.1% (7.6-18.8)	17.8% (9.5-25.0)	10.5 (8.4-13.2)

Table S6. Proportions of HIV susceptible and HIV+ MSM residing in Baltimore that belong to a subgroup calculated over the last three decades, median and 95%UI across all 118 model fits

	Time periods		
	1988-1997	**1998-2007**	**2008-2017**
	% among HIV susceptible population		
Demography			
Black	55.0% (47.3-61.9)	57.4% (53.0-62.5)	63.4% (58.8-68.4)
White	45.0% (38.1-52.7)	42.6% (37.5-47.0)	36.6% (31.6-41.2)
Younger	27.6% (24.4-32.6)	32.2% (28.9-36.6)	32.4% (29.1-36.2)
Older	72.4% (67.4-75.6)	67.8% (63.4-71.1)	67.6% (63.8-70.9)
Black Younger	19.3% (15.9-22.3)	23.3% (20.2-26.4)	24.5% (21.4-27.1)
Black Older	35.7% (30.3-42.4)	34.1% (29.9-38.0)	39.4% (35.7-43.5)
White Younger	8.5% (6.8-11.6)	8.9% (7.0-11.9)	8.0% (6.3-10.8)
White Older	35.8% (29.4-43.2)	33.5% (28.8-38.2)	28.4% (23.8-32.2)
	% among HIV+		
Demography			
Black	83.8% (78.1-89.1)	90.0% (86.8-91.9)	92.5% (89.4-94.4)
White	16.2% (10.9-21.9)	10.0% (8.1-13.2)	7.5% (5.64-10.6)
Younger	20.2% (17.6-23.2)	20.3% (17.2-22.1)	18.5% (15.3-21.1)
Older	79.8% (76.8-82.4)	79.7% (77.9-82.8)	81.5% (78.9-84.7)
Black younger	18.6% (15.5-21.4)	19.1% (16.1-21.1)	17.9% (14.6-20.3)
Black Older	65.7% (59.9-71.0)	70.8% (67.1-73.9)	74.8% (71.0-78.3)
White younger	1.7% (1.0-3.0)	1.0% (0.5-1.8)	0.6% (0.3-1.3)
White older population	14.3% (9.6-19.3)	9.2% (7.1-12.3)	6.8% (5.2-9.5)
Stages of infection			
Acute infection	4.8% (2.5-6.6)	2.9% (1.5-4.0)	2.4% (1.2-3.5)
Untreated with CD4 >500	25.0% (21.3-28.5)	18.3% (15.5-21.8)	13.4% (10.4-17.3)
Untreated with CD4 350-500	22.0% (19.9-23.8)	16.9% (14.9-19.1)	11.4% (9.57-14.8)
Untreated with CD4 200-350	32.9% (29.2-37.9)	26.8% (21.2-32.5)	19.6% (13.7-27.8)
Untreated with CD4 <200	14.4% (10.7-19.0)	10.6% (7.42-15.8)	8.4% (5.2-14.7)
Untreated with Log_{10} SPVL < 4.0	25.0% (14.2-35.9)	21.4% (11.4-31.8)	15.8% (8.0-26.7)
Untreated with Log_{10} SPVL in 4.0-4.5	24.1% (22.7-25.3)	19.1% (16.5-21.9)	13.2% (10.7-18.3)
Untreated with Log_{10} SPVL in 4.5-5	31.9% (24.8-40.1)	23.5% (17.1-32.2)	17.6% (11.2-26.8)
Untreated with Log_{10} SPVL >5	12.9% (7.5-18.5)	8.0% (4.8-12.7)	5.8% (3.3-9.8)
Care status			
With undiagnosed infection	86.8% (68.0-96.3)	39.1% (32.0-47.6)	21.9% (19.6-26.3)
With diagnosed infection	13.2% (3.7-32.0)	60.9% (52.4-68.0)	78.1% (73.7-80.4)
Untreated (not on ART)	99.2% (98.6-99.6)	73.9% (66.8-84.4)	50.6% (43.7-70.3)
Treated (on ART)	0.8% (0.4-1.4)	26.1% (15.6-33.2)	49.4% (29.7-56.3)
With diagnosed infection and untreated	12.5% (3.2-31.3)	35.8% (26.0-46.4)	29.7% (21.8-46.1)
With diagnosed infection but not in care	9.3% (2.5-26.3)	24.7% (14.1-34.7)	22.8% (11.7-33.8)
In care but not on ART	2.9% (0.7-7.1)	11.4% (6.9-16.3)	10.6% (5.6-17.0)

Figure S8. Proportion of MSM within different stages of the care continuum over 2008-2017, and associated PAFs over the same period. Error bars represent 95% UI across all 118 model fits.



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