# Supplementary Methods for "Optimization by Bayesian adaptive locally linear stochastic descent" by Kerr *et al.* (2014)

## Contents

## A. Model structure

The aim of the HIV transmission and progression model is to estimate the movement of people between population groups and between health states over time. Each combination of population group and health state is a single compartment in the model, and these evolve in time according to a set of differential equations. Seven types of movement are possible: people can enter the model by being born or leave the model by dying, or they can move between compartments by becoming infected, having their CD4 count decline, becoming diagnosed, or by going on or off treatment. Each compartment is described by a single ordinary differential equation, and each of the seven types of movement described above is a term in a differential equation. Positive terms result in an increase in population in a given compartment, while negative terms reduce the population of a given compartment. Movement between population groups (e.g., from female sex workers to low-risk females and vice versa; from male children to male adolescents, etc.) is also possible.

The model dynamics are determined by the initial conditions (i.e., the number of people in each compartment at the initial time point) and the model parameter values. Model parameters can depend on time $t$ (e.g., 2002 vs. 2007), population group $g$ (e.g., female sex workers vs. male injecting drug users), health state $h$ (e.g. infected, CD4>500 vs. infected, CD4<200), and interaction type $i$ (i.e., casual, regular, commercial, or injecting partnerships). The model supports up to 14 distinct population groups; since there are 21 health states (susceptible plus undiagnosed, diagnosed, first-line treatment, treatment failure, and second-line treatment for each of four CD4 stratifications), the model may have up to 294 compartments.

Transmission dynamics are determined by the rate at which susceptible (i.e., uninfected) individuals become infected. The probability that a susceptible individual in population group $g_1$ will be infected by an individual of population group $g_2$ at time $t$ via sexual intercourse of interaction type $i$ is defined as the force-of-infection:

$$\lambda(t, g_1, g_2, i) = 1 - \left(1 - \varsigma(t, g_1)\psi(t, g_1)I(t, g_2, i)\right)^{m(t, g_1, g_2, i)},$$

where $\lambda$ is the force-of-infection; $\varsigma$ is the effect of circumcision; $\psi$ is the effect of coinfection with ulcerative STIs; $I$ is the infectiousness, which is determined by prevalence and transmissibility; and $m$ is the number of unprotected acts.

The effect of circumcision is defined as $\varsigma(t, g) = 1 - e_\varsigma p_\varsigma(t, g)$, where $e_\varsigma$ is the fractional reduction in transmission probability per act due to circumcision (i.e., its efficacy), and $p_\varsigma$ is the probability that an individual is circumcised. This probability is zero for female populations, so circumcision only affects male populations. The effect of STI coinfection is $\psi(t, g) = e_\psi p_\psi(t, g)$, where $e_\psi$ is the fractional increase in transmissibility caused by ulcerative STIs (such as HSV-2 and syphilis), and $p_\psi$ is the probability of infection (i.e., prevalence) of these STIs.

The infectiousness of a population is

$$I(t, g) = \sum_h P(t, g, h)\beta(h),$$

where $I$ is the infectiousness, $\beta$ is the biological transmission probability, which depends on whether the intercourse is insertive, vaginal receptive, or anal receptive; $P$ is the prevalence of each health state (such that $P(t, g) = \sum_h P(t, g, h)$ is the prevalence of HIV in that population); and $\beta(h)$ is the biological transmission probability, which depends on the viral load, which in turn can be approximated from the individual's CD4 count category $h$.

The number of unprotected acts is $m(t, g_1, g_2, i) = n(t, g_1, g_2, i)\left(1 - e_\kappa p_\kappa(t, g_1)\right)$, where $n$ is the number of acts between individuals in two populations, $e_\kappa$ is the fractional reduction in transmission probability per act due to condom use, and $p_\kappa$ is the probability of condom use. While it may seem odd that the effect of condom use appears in the exponent while the effect of circumcision appears in the

base term, circumcision affects the biological transmission probability and thus affects the risk per act, whereas condom use can be considered as a reduction in the number of acts. The two approaches are equivalent to first order, and since the transmission probability is typically $<10^{-3}$, it makes negligible difference whether these terms appear in the base or exponent.

The force-of-infection due to injecting drug use is

$$\lambda_d(t) = 1 - \left(1 - \chi(t) I_d(t)\right)^{\omega(t) m_d(t)},$$

where $\lambda_d$ is the force-of-infection for injection interactions between injecting drug users, $\chi$ is the effect of syringe cleaning, $I_d$ is the infectiousness of injecting drug users, $\omega$ is the effect of methadone treatment, and $m_d$ is the number of receptively shared injections.

The effect of syringe cleaning is $\chi(t) = 1 - e_\chi p_\chi(t)$, where $e_\chi$ is the fractional reduction in transmission probability per act, and $p_\chi$ is the probability that a syringe is cleaned before use. The infectiousness $I_d$ has the same form as before, but now includes only injecting drug users. The effect of methadone is $\omega(t) = 1 - e_\omega p_\omega(t)$, where $e_\omega$ is the fractional reduction in the number of injections, and $p_\omega$ is the probability that a given injecting drug user is on methadone. The number of receptively-shared injections is given by $m_d(t) = n_d(t) s(t)$, where $n_d$ is the total number of injections, and $s$ is the probability that a given syringe has been receptively shared prior to use.

Finally, the force-of-infection for a given population group $g_1$ at a given point in time $t$ is the product of all individual forces-of-infection (including injecting interactions, if applicable):

$$\Lambda(t, g_1) = 1 - \prod_{g_2} \prod_{i} \left(1 - \lambda(t, g_1, g_2, i)\right)$$

This quantity is the instantaneous risk of an individual in population group $g_1$ becoming infected. The indices $g_2$ and $i$ include all interactions an individual has. For example, direct female sex workers have commercial interactions with male clients, as well as regular and casual relationships with all four heterosexual male populations, for a total of nine interaction types.

In contrast to the force-of-infection, most types of movement between population compartments are described by a single rate, and thus the remaining equations are relatively straightforward. Labeling the health states $h$ such that 1=CD4>500, 2=350<CD4<500, 3=200<CD4<350, and 4=CD4<200, the full set of differential equations is as follows.

The change in the number of susceptible individuals is

$$\frac{dS(t,g)}{dt} = \varepsilon(t,g) - \left(\Lambda(t,g) + \mu_{0g}\right) S(t,g),$$

where $S$ is the number of susceptible individuals, $\epsilon$ is the entry rate into the population, $\lambda$ is the force-of-infection, and $\mu_{0g}$ is the background mortality rate for population group $g$. Note that the term $\Lambda S$ in this equation is the number of new infections, while $\lambda S$ would be the incidence.

The change in the number of infected but undiagnosed individuals is

$$\frac{dU_{h=1}(t,g)}{dt} = \Lambda(t,g)\, S(t,g) - \left(\mu_{hg} + \zeta_h(t,g) + \pi_h\right) U_h(t,g),$$
$$\frac{dU_{h>1}(t,g)}{dt} = \pi_{h-1} U_{h-1}(t,g) - \left(\mu_{hg} + \zeta_h(t,g) + \pi_h\right) U_h(t,g),$$

where $U_h$ is the number of undiagnosed individuals in health state $h$ (note that newly infected individuals $\Lambda S$ only enter $U_{h=1}$, the CD4>500 compartment), $\mu_{hg}$ is the mortality rate for the given health state and population group, $\zeta_h$ is the testing rate, and $\pi_h$ is the disease progression rate ($\pi_{h=4} = 0$, since no progression occurs after CD4<200).

The change in the number of diagnosed individuals is

$$\frac{dD_h(t,g)}{dt} = \zeta_h(t,g)U_h(t,g) + \pi_{h-1}D_{h-1}(t,g) - \left(\mu_{hg} + \tau_h(t,g) + \pi_h\right)D_h(t,g),$$

where $D_h$ is the number of infected and diagnosed individuals in a particular health state $h$, and $\tau_h$ is the HIV treatment rate.

The change in the number of individuals on treatment or with treatment failure is

$$\frac{dA_1(t,g)}{dt} = \sum_h \sigma_h(t,g)D_h(t,g) - (\mu_A + \phi_1)A_1(t,g),$$
$$\frac{dA_2(t,g)}{dt} = \sigma_F(t,g)A_F(t,g) - (\mu_A + \phi_2)A_2(t,g),$$
$$\frac{dA_F(t,g)}{dt} = \phi_1 A_1(t,g) + \phi_2 A_2(t,g) - (\mu_F + \sigma_F(t,g))A_F(t,g),$$

where $A_1$, $A_2$, and $A_F$ are the numbers of people on first- and subsequent-lines of ART and treatment failure, respectively; $\mu_A$ and $\mu_F$ are the mortality rates for individuals on ART and with treatment failure, respectively; and $\phi_1$ and $\phi_2$ are the failure rates for first- and subsequent-lines of ART, respectively.

This set of coupled differential equations can be solved numerically; in practice, maximum computational efficiency is achieved by converting these to difference equations with a suitable time step (usually 0.1–1 years). Running the MATLAB implementation of this model for 10 population groups for a 50-year time span with an 0.2-year time step on an Intel Xeon 2.4 GHz CPU takes approximately 2 s.

## B. Swaziland calibrations and cost-outcome relationships

This section describes the model calibration and cost-outcome relationships that were used to analyze the Swaziland epidemic and calculate the optimal resource allocations.

### B.1 Calibration

By adjusting appropriate behavioral and clinical parameters, we manually calibrated the model to the HIV epidemic in Swaziland from 2000 to 2012 to match prevalence estimates for each population group, as well as the number of people on treatment. The resulting set of parameters and corresponding epidemic projection represents the baseline simulation. These calibrations are shown in **Figure S1**.

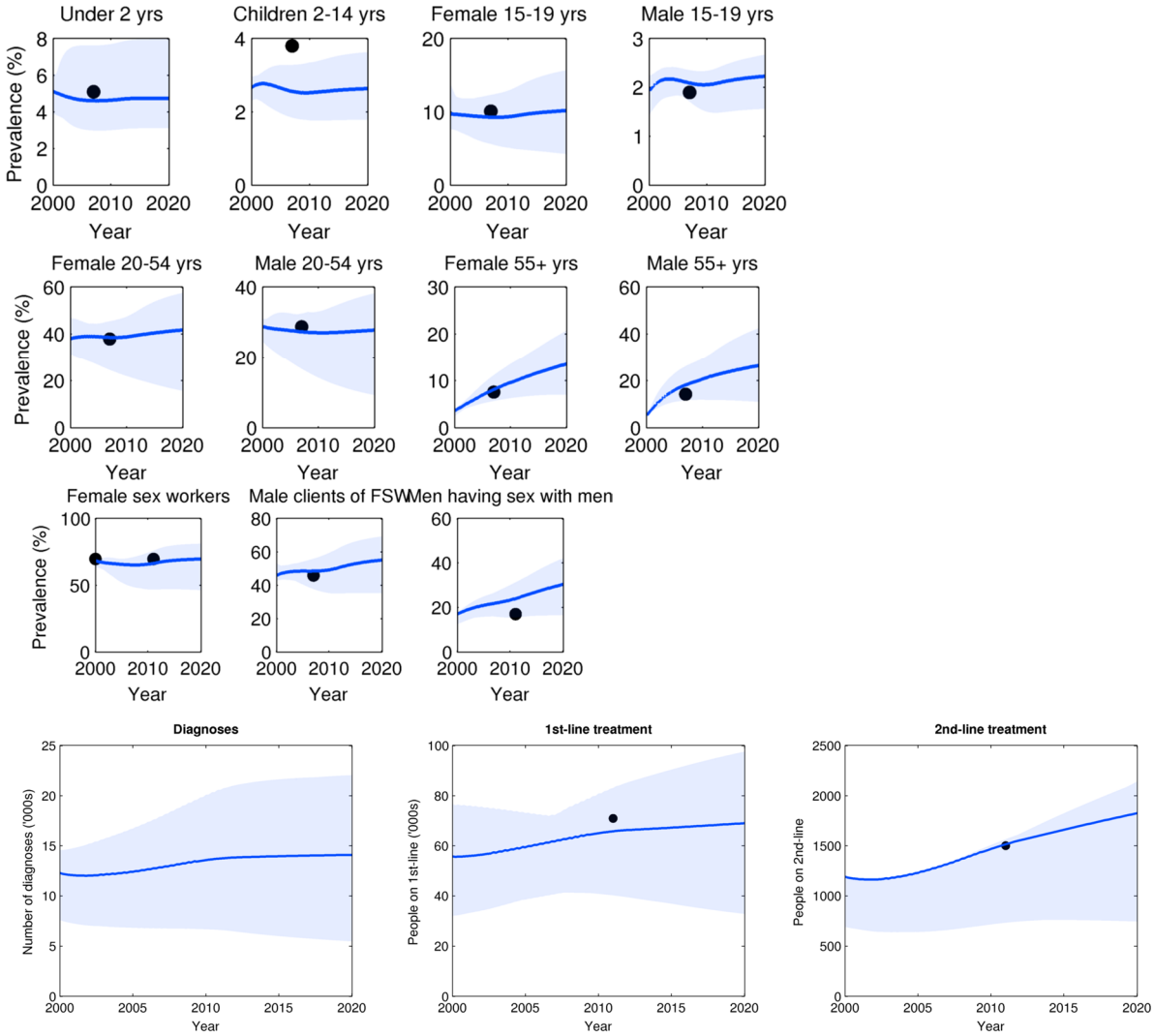


**Figure S1:** Calibration of the model to the HIV epidemic in Swaziland. Black discs represent available data for HIV prevalence, and the number of people on first- and second-line antiretroviral treatment. Solid curves are the best fitting simulation; shaded regions show uncertainty in the simulation.

## B.2 Cost-outcome relationships

Resource optimization was performed by relating HIV program spending to changes in behavior via series of cost-outcome relationships. These relationships are shown in **Figure S2**.

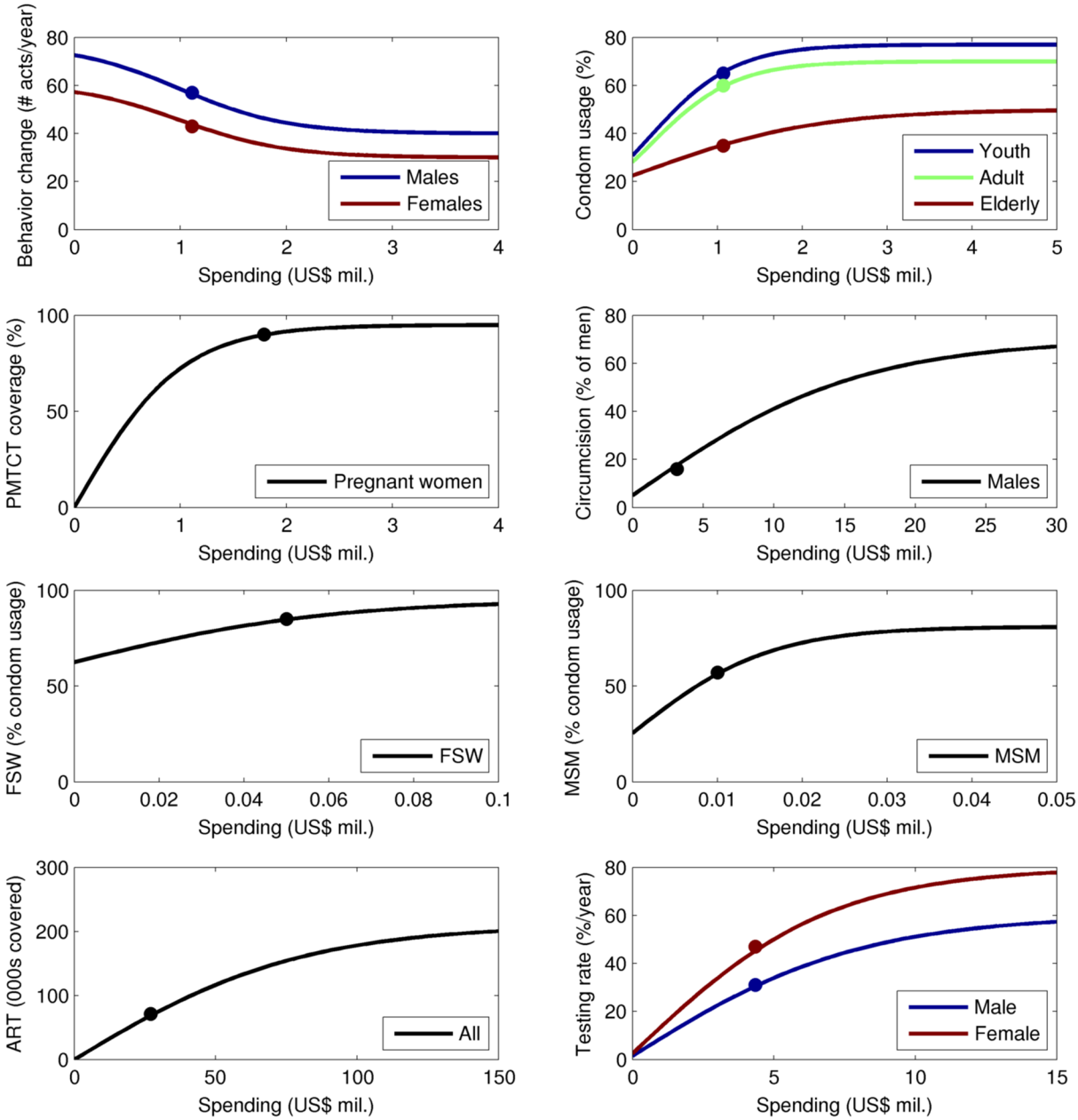


**Figure S2:** Logistic cost-outcome relationships for Swaziland. The spending axis is in millions of 2012 US dollars and is the overall spending allocated to each population for HIV prevention or treatment. Black discs represent available spending data and associated behaviors. The zero spending outcome data are based on the values available for the year 2000. The solid curve is the best fitting or assumed relationship used in our analysis.

## C. Input data

These tables list all input data available for Swaziland. Assumptions are indicated by minus signs; no quantities are actually negative. Population group abbreviations are as follows:
INF: Infants (<2 years)
CHLD: Children (2-10)
FYTH: Females (10-14)
MYTH: Males (10-14)
FTEEN: Females (15-19)
MTEEN: Males (15-19)
FYAD: Females (20-24)
MYAD: Males (20-24)
FAD: Females (25-49)
MAD: Males (25-49)
FOLD: Females (>50)
MOLD: Males (>50)
FSW: Female sex workers
MSM: Men who have sex with men

### C.1 Population size (thousands)

| | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| INF | 87 | | | | | | | | | | | |
| CHLD | 243 | | | | | | | | | | | |
| FYTH | 62 | | | | | | | | | | | |
| MYTH | 61 | | | | | | | | | | | |
| FTEEN | 53 | | | | | | | | | | | |
| MTEEN | 50 | | | | | | | | | | | |
| FYAD | 43 | | | | | | | | | | | |
| MYAD | 35 | | | | | | | | | | | |
| FAD | 126 | | | | | | | | | | | |
| MAD | 100 | | | | | | | | | | | |
| FOLD | 52 | | | | | | | | | | | |
| MOLD | 42 | | | | | | | | | | | |
| FSW | 3.04 | | | | | | | | | | | |
| MSM | 3.552 | | | | | | | | | | | |

## C.2 HIV prevalence (percent)

| | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| INF | -5.1 | | | | | | | 5.1 | | | | |
| CHLD | -3.8 | | | | | | | 3.8 | | | | |
| FYTH | -10.1 | | | | | | | 10.1 | | | | |
| MYTH | -3 | | | | | | | 1.9 | | | | |
| FTEEN | -16 | | | | | | | 16 | | | | 14 |
| MTEEN | -3 | | | | | | | 3 | | | | 1 |
| FYAD | -38 | | | | | | | 38 | | | | 31 |
| MYAD | -12 | | | | | | | 12 | | | | 7 |
| FAD | -40 | | | | | | | 40 | | | | 48 |
| MAD | -40 | | | | | | | 40 | | | | 38 |
| FOLD | -21 | | | | | | | 21 | | | | 32 |
| MOLD | -28 | | | | | | | 28 | | | | 42 |
| FSW | -69.7 | | | | | | | | | | | 69.7 |
| MSM | -17.1 | | | | | | | | | | | 17.1 |

## C.3 STI prevalence (percent)

| | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| INF | | | | | | | | 0 | | | | |
| CHLD | | | | | | | | 0.05 | | | | |
| FYTH | | | | | | | | 2.4 | | | | |
| MYTH | | | | | | | | 1.04 | | | | |
| FTEEN | | | | | | | | 4 | | | | |
| MTEEN | | | | | | | | 3 | | | | |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| FYAD | | | | | | | | 6.93 | | | | |
| MYAD | | | | | | | | 6.49 | | | | |
| FAD | | | | | | | | 6.5 | | | | |
| MAD | | | | | | | | 1 | | | | |
| FOLD | | | | | | | | 1 | | | | |
| MOLD | | | | | | | | 1.3 | | | | |
| FSW | | | | | | | | 16.1 | | | | |
| MSM | | | | | | | | 15.8 | | | | |

## C.4 Testing rate (%/year)

| | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| INF | | | | | | | 5 | | | | | |
| CHLD | | | | | | | 0.5 | | | | | |
| FYTH | | | | | | | 10 | | | | | |
| MYTH | | | | | | | 1.8 | | | | | |
| FTEEN | | | | | | | 10 | | | | | |
| MTEEN | | | | | | | 1.8 | | | | | |
| FYAD | | | | | | | 26 | | | | | |
| MYAD | | | | | | | 12.3 | | | | | |
| FAD | | | | | | | 26 | | | | | |
| MAD | | | | | | | 12.3 | | | | | |
| FOLD | | | | | | | 10.2 | | | | | |
| MOLD | | | | | | | 9.8 | | | | | |
| FSW | | | | | | | | | | | 61.7 | |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MSM | | | | | | | | | | | 51 | |
| AIDS stage | | | | | | | | | | | 80 | |

## C.5 Treatment rate (%/year)

| | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CD4(500) | | | | | | | | 3.6 | | | | |
| CD4(350,500) | | | | | | | | 7.4 | | | | |
| CD4(200,350) | | | | | | | | 27.5 | | | | |
| CD4(200) | | | | | | | | 57.8 | | | | |
| Treatment failure | | | | | | | | -1 | | | | |

## C.6 Mother-to-child transmission

| | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Birth rate (births/woman/year) | | | 0.13 | | | | | | | | | |
| Pregnant women covered (%) | | | 95 | | | | | | | | | |

## C.7 Number of people on ART

| | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1st-line | | | | | | | | | | | | 70901 |
| 2nd-line | | | | | | | | | | | | 1501 |

## C.8 Average number of regular sex acts (per person per year)

| | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| INF | | | | | | | | 0 | | | | |
| CHLD | | | | | | | | 0 | | | | |
| FYTH | | | | | | | | 10 | | | | |
| MYTH | | | | | | | | 1 | | | | |
| FTEEN | | | | | | | | 13.2 | | | | |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MTEEN | | | | | | | | 5.23 | | | | |
| FYAD | | | | | | | | 43 | | | | |
| MYAD | | | | | | | | 20 | | | | |
| FAD | | | | | | | | 43 | | | | |
| MAD | | | | | | | | 40 | | | | |
| FOLD | | | | | | | | 4.7 | | | | |
| MOLD | | | | | | | | 32.1 | | | | |
| FSW | | | | | | | | | | | | 7.5 |
| MSM | | | | | | | | | | | | 37.6 |

## C.9 Average number of casual sex acts (per person per year)

| | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| INF | | | | | | | | 0 | | | | |
| CHLD | | | | | | | | 0.16 | | | | |
| FYTH | | | | | | | | 15 | | | | |
| MYTH | | | | | | | | 2 | | | | |
| FTEEN | | | | | | | | 14.55 | | | | |
| MTEEN | | | | | | | | 7.22 | | | | |
| FYAD | | | | | | | | 15.4 | | | | |
| MYAD | | | | | | | | 26.5 | | | | |
| FAD | | | | | | | | 15.4 | | | | |
| MAD | | | | | | | | 10 | | | | |
| FOLD | | | | | | | | 0.6 | | | | |
| MOLD | | | | | | | | 3.6 | | | | |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| FSW | | | | | | | | | | | | 43.5 |
| MSM | | | | | | | | | | | | 33 |

## C.10 Average number of commercial sex acts (per person per year)

| | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| INF | | | | | | | | | | | | |
| CHLD | | | | | | | | | | | | |
| FYTH | | | | | | | | | | | | |
| MYTH | | | | | | | | | | | | |
| FTEEN | | | | | | | | | | | | |
| MTEEN | | | | | | | | | | | | |
| FYAD | | | | | | | | | | | | |
| MYAD | | | | | | | | 2 | | | | |
| FAD | | | | | | | | | | | | |
| MAD | | | | | | | | 2 | | | | |
| FOLD | | | | | | | | | | | | |
| MOLD | | | | | | | | 3 | | | | |
| FSW | | | | | | | | | | | | 228 |
| MSM | | | | | | | | | | | | 10 |

## C.11 Condom usage probability for regular acts (%)

| | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| INF | | | | | | | | 0 | | | | |
| CHLD | | | | | | | | 52.5 | | | | |
| FYTH | | | | | | | | 35 | | | | |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MYTH | | | | | | | | 45 | | | | |
| FTEEN | | | | | | | | 35 | | | | |
| MTEEN | | | | | | | | 45 | | | | |
| FYAD | | | | | | | | 27 | | | | |
| MYAD | | | | | | | | 36 | | | | |
| FAD | | | | | | | | 27 | | | | |
| MAD | | | | | | | | 36 | | | | |
| FOLD | | | | | | | | 15 | | | | |
| MOLD | | | | | | | | 20 | | | | |
| FSW | | | | | | | | | | | | 48.9 |
| MSM | | | | | | | | | | | | 51.9 |

## C.12 Condom usage probability for casual acts (%)

| | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| INF | | | | | | | | | | | | |
| CHLD | | | | | | | | 52.5 | | | | |
| FYTH | | | | | | | | 51.9 | | | 66.3 | |
| MYTH | | | | | | | | 68.8 | | | 93.6 | |
| FTEEN | | | | | | | | 51.9 | | | 66.3 | |
| MTEEN | | | | | | | | 68.8 | | | 93.6 | |
| FYAD | | | | | | | | 55.5 | | | | |
| MYAD | | | | | | | | 67.9 | | | | |
| FAD | | | | | | | | 55.5 | | | | |
| MAD | | | | | | | | 67.9 | | | | |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| FOLD | | | | | | | | 35 | | | | |
| MOLD | | | | | | | | 35.3 | | | | |
| FSW | | | | | | | | | | | | 48.9 |
| MSM | | | | | | | | | | | | 57.1 |

## C.13 Condom usage probability for commercial acts (%)

| | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| INF | | | | | | | | | | | | |
| CHLD | | | | | | | | | | | | |
| FYTH | | | | | | | | | | | | |
| MYTH | | | | | | | | | | | | |
| FTEEN | | | | | | | | | | | | |
| MTEEN | | | | | | | | | | | | |
| FYAD | | | | | | | | | | | | |
| MYAD | | | | | | | | 75 | | | | |
| FAD | | | | | | | | | | | | |
| MAD | | | | | | | | 75 | | | | |
| FOLD | | | | | | | | | | | | |
| MOLD | | | | | | | | 75 | | | | |
| FSW | | | | | | | | | | | | 85 |
| MSM | | | | | | | | | | | | 57 |

## C.14 Circumcision probability (%)

| | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| INF | | | | | | | | 0.5 | | | | |
| CHLD | | | | | | | | 2 | | | | |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| FYTH | | | | | | | | | | | | |
| MYTH | | | | | | | | 4.2 | | | | |
| FTEEN | | | | | | | | | | | | |
| MTEEN | | | | | | | | 4.2 | | | | |
| FYAD | | | | | | | | | | | | |
| MYAD | | | | | | | | 10.1 | | | | |
| FAD | | | | | | | | | | | | |
| MAD | | | | | | | | 10.1 | | | | 16 |
| FOLD | | | | | | | | | | | | |
| MOLD | | | | | | | | 11.9 | | | | |
| FSW | | | | | | | | | | | | |
| MSM | | | | | | | | 10.1 | | | | |

## C.15 Biological constants

| | | |
|---|---|---|
| **Interaction-related transmissibility (% per act):** | Male & female (insertive) | 0.09 |
| | Male & female (receptive) | 0.25 |
| | Male & male (insertive) | 0.02 |
| | Male & male (receptive) | 0.02 |
| | Injecting | 0.3 |
| | Mother-to-child | -35 |

| | | |
|---|---|---|
| **Disease-related transmissibility** | CD4(500) | 4 |
| | CD4(350,500) | 1 |
| | CD4(200,350) | 1 |
| | CD4(200) | 3.8 |
| | Treatment | 0.25 |

| | | |
|---|---|---|
| **Disease progression rate: (% per year)** | CD4 (500) to CD4 (350,500) | 24.5 |
| | CD4 (350,500) to CD4 (200,350) | 51 |
| | CD4 (200,350) to CD4 (200) | 51 |

| | | |
|---|---|---|
| **Treatment recovery rate: (% per year)** | CD4 (350,500) to CD4 (500) | 45 |
| | CD4(200,350) to CD4 (350,500) | 70 |
| | CD4 (200) to CD4 (200,350) | 36 |

| | | |
|---|---|---|
| **Death rate: (% mortality per year)** | Background | 1.45 |
| | Injecting | 1 |
| | CD4 (500) | 0.0515 |

| | | |
|---|---|---|
| | CD4 (350,500) | 0.128 |
| | CD4 (200,350) | 1.1 |
| | CD4 (200) | 50 |
| | Treatment (CD4<200) | 4 |
| **Treatment failure rate: (% per year)** | 1st-line | 4.5 |
| | 2nd-line | 4.5 |
| **Efficacy/change in transmissibility due to:** | Condom (%) | 80 |
| | Circumcision (%) | 60 |
| | Diagnosis (%) | -1 |
| | STI cofactor increase (%) | 700 |
| | Syringe cleaning (%) | 75 |
| | Methadone (%) | 95 |
| | PMTCT (%) | -78 |
| | Treatment risk compensation (%) | -100 |

## C.16 Partnerships

Entries indicate insertive populations (rows) and receptive populations (columns). Numbers indicate relative partnership formation probability; e.g., male teenagers are three times as likely to pair with female teenagers as they are with female youth, hence the entries of 1 and 3 in the corresponding cells of the table below.

**Regular sexual interactions**

| | INF | CHLD | FYTH | MYTH | FTEEN | MTEEN | FYAD | MYAD | FAD | MAD | FOLD | MOLD | FSW | MSM |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| INF | | | | | | | | | | | | | | |
| CHLD | | | | | | | | | | | | | | |
| FYTH | | | | | | | | | | | | | | |
| MYTH | | | 1 | | | | | | | | | | | |
| FTEEN | | | | | | | | | | | | | | |
| MTEEN | | | 1 | | 3 | | | | | | | | | |
| FYAD | | | | | | | | | | | | | | |
| MYAD | | | 1 | | 3 | | 9 | | | | | | | |
| FAD | | | | | | | | | | | | | | |
| MAD | | | 1 | | 3 | | 9 | | 9 | | | | | |
| FOLD | | | | | | | | | | | | | | |
| MOLD | | | | | 1 | | 3 | | 9 | | 9 | | | |
| FSW | | | | | | | | | | | | | | |
| MSM | | | | | | | | | | | | | | 1 |

**Casual sexual interactions**

| | INF | CHLD | FYTH | MYTH | FTEEN | MTEEN | FYAD | MYAD | FAD | MAD | FOLD | MOLD | FSW | MSM |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| INF | | | | | | | | | | | | | | |
| CHLD | | | | | | | | | | | | | | |
| FYTH | | | | | | | | | | | | | | |
| MYTH | | | 1 | | | | | | | | | | | |
| FTEEN | | | | | | | | | | | | | | |
| MTEEN | | | 1 | | 3 | | | | | | | | | |
| FYAD | | | | | | | | | | | | | | |
| MYAD | | | 1 | | 3 | | 9 | | | | | | | |
| FAD | | | | | | | | | | | | | | |
| MAD | | | 1 | | 3 | | 9 | | 9 | | | | | |
| FOLD | | | | | | | | | | | | | | |
| MOLD | | | | | 1 | | 3 | | 9 | | 9 | | | |
| FSW | | | | | | | | | | | | | | |
| MSM | | | | | | | | | | | | | | 1 |

| Other sexual interactions | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | INF | CHLD | FYTH | MYTH | FTEEN | MTEEN | FYAD | MYAD | FAD | MAD | FOLD | MOLD | FSW | MSM |
| INF | | | | | | | | | | | | | | |
| CHLD | | | | | | | | | | | | | | |
| FYTH | | | | | | | | | | | | | | |
| MYTH | | | | | | | | | | | | | | |
| FTEEN | | | | | | | | | | | | | | |
| MTEEN | | | | | | | | | | | | | | |
| FYAD | | | | | | | | | | | | | | |
| MYAD | | | | | | | | | | | | | 1 | |
| FAD | | | | | | | | | | | | | | |
| MAD | | | | | | | | | | | | | 1 | |
| FOLD | | | | | | | | | | | | | | |
| MOLD | | | | | | | | | | | | | 1 | |
| FSW | | | | | | | | | | | | | | |
| MSM | | | | | | | | | | | | | | |

## C.17 Transitions

Optima allows two types of transition: in asymmetric transitions, individuals move from one population (rows) to another (columns), and individuals are not replaced. In symmetric transitions, the number of people leaving the first population is replaced by an equal number of people from the second population. For example, aging is an asymmetric transition, whereas it is assumed that female sex workers can transition into the low-risk population and vice versa, so this is a symmetric transition.

**Asymmetric population transitions (% leaving per year)**

| | INF | CHLD | FYTH | MYTH | FTEEN | MTEEN | FYAD | MYAD | FAD | MAD | FOLD | MOLD | FSW | MSM | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| INF | | 50 | | | | | | | | | | | | | 50 |
| CHLD | | | 6 | 6 | | | | | | | | | | | 12 |
| FYTH | | | | | 20 | | | | | | | | | | 20 |
| MYTH | | | | | | 20 | | | | | | | | | 20 |
| FTEEN | -12.4 | | | | | | 20 | | | | | | | | 7.6 |
| MTEEN | | | | | | | | 20 | | | | | | | 20 |
| FYAD | -12.4 | | | | | | | | 20 | | | | | | 7.6 |
| MYAD | | | | | | | | | | 20 | | | | | 20 |
| FAD | -12.4 | | | | | | | | | | 4 | | | | -8.4 |
| MAD | | | | | | | | | | | | 4 | | | 4 |
| FOLD | | | | | | | | | | | | | | | 0 |
| MOLD | | | | | | | | | | | | | | | 0 |
| FSW | | | | | | | | | | | | | | | 0 |
| MSM | | | | | | | | | | | | | | | 0 |

**Symmetric population transitions (% leaving per year)**

| | INF | CHLD | FYTH | MYTH | FTEEN | MTEEN | FYAD | MYAD | FAD | MAD | FOLD | MOLD | FSW | MSM | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| INF | | | | | | | | | | | | | | | 0 |
| CHLD | | | | | | | | | | | | | | | 0 |
| FYTH | | | | | | | | | | | | | | | 0 |
| MYTH | | | | | | | | | | | | | | | 0 |
| FTEEN | | | | | | | | | | | | | | | 0 |
| MTEEN | | | | | | | | | | | | | | | 0 |
| FYAD | | | | | | | | | | | | | | | 0 |
| MYAD | | | | | | | | | | | | | | | 0 |
| FAD | | | | | | | | | | | | | | | 0 |
| MAD | | | | | | | | | | | | | | | 0 |
| FOLD | | | | | | | | | | | | | | | 0 |
| MOLD | | | | | | | | | | | | | | | 0 |
| FSW | | | | | | | 5 | | 5 | | | | | | 10 |
| MSM | | | | | | | | | | | | | | | 0 |

## C.18 Economics

| | | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Health-care costs (US$/year) | CD4>500 (per person per year) | | | | | | | | | | 566.6 |
| | 500>CD4>350 | | | | | | | | | | 213.9 |
| | 350>CD4>200 | | | | | | | | | | 348.6 |
| | CD4<200 | | | | | | | | | | 426.5 |
| | HIV testing (per test) | | | | | | | | | | 7.2 |
| | 1st-line ART | | | | | | | | | | 519 |
| | Subsequent ART | | | | | | | | | | 1176.7 |

| | | Value |
|---|---|---|
| Health utilities (QALYs) | Uninfected IDUs | 0.86 |
| | Untreated HIV, CD4>500 | 0.72 |
| | Untreated HIV, 350<CD4<500 | 0.57 |
| | Untreated HIV, 200<CD4<350 | 0.43 |
| | Untreated HIV, CD4<200 | 0.14 |
| | Treated HIV, CD4>500 | 0.762 |
| | Treated HIV, 350<CD4<500 | 0.756 |
| | Treated HIV, 200<CD4<350 | 0.716 |
| | Treated HIV, CD4<200 | 0.645 |