Analysis of the Demographic Models Used to Incorporate HIV/AIDS Related Mortality

by

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INTRODUCTION

Since the onset of HIV/AIDS, demographers have attempted to model the mortality impact of the pandemic on population. The importance of such models has increased as the prevalence levels rose and the devastating impact became clear in many countries. With the ever-increasing demand for information on the demographic consequences of the pandemic, demographic-based programs incorporating an epidemiological component were developed by different organizations. Results from these programs can be used to advise those responsible for policy development and program formulation in the fields of public health, education, and general welfare. Consequently, it is critical that decision makers have a clear understanding of the quality and accuracy of these results.

This paper will compare three models: the AIDS Impact Model (AIM) module of the Spectrum Policy Modeling System, developed by the Futures Group, which is widely used by organizations around the world, including the Joint United Nations Programme on HIV/AIDS (UNAIDS); the RupHivAids model developed by the U.S. Census Bureau, which is used by the Census Bureau and several national statistical offices; and the abcDIM module, which is the model used by the United Nations Population Division (UNPD) to produce country estimates and projections incorporating the impact of HIV/AIDS. In order to understand the applicability and reliability of the methods and assumptions used, we compare the differences in the underlying assumptions of the three models, as well as the impact on the resulting demographic and epidemiological outcomes.

BACKGROUND

To facilitate the evaluation of each program, it is necessary to have a basic understanding of the origin and purpose of both the demographic and epidemiologic modules. The purpose and use of each program differs, further influencing the methodology, operational structure, and usability.

The Futures Group works in developing countries facilitating public health and social programs with host-country government and non-government entities. As part of the POLICY and POLICY II Project funded by the United States Agency for International Development (USAID), the Futures Group (in collaboration with Research Triangle Institute) developed Spectrum to help policymakers and others better understand policy implications of population-related events and potential scenarios. As a result, the software is designed for ease of use and transportability.

Spectrum consists of several modules. The most commonly used are Demography (DemProj) and the AIDS Impact Model (AIM). DemProj projects the population using a cohort-component methodology. AIM focuses on modeling HIV/AIDS in order to determine the demographic, social, and economic impact of the pandemic. We use version 2.36 of Spectrum with an April 12, 2005, release date for this analysis.

In contrast to Spectrum, the Abacus software developed by the United Nations Population Division (UNPD) and Rural/Urban Projection (RUP) software developed by the International Programs Center (IPC) of the U.S. Census Bureau, were created mainly for producing population estimates and projections and were designed to be used by a statistical agency or technical user.

Both apply the cohort-component method and use a similar approach toward epidemiological modeling.

Abacus is the demographic projections software used by the UNPD to produce population projections for products published and disseminated throughout the world. Because the program operates using an SQL Server database, it is non-portable and is used internally by UNPD staff. This program projects the population by 5-year intervals and reports 5-year averaged demographic events beginning in 1950-55.

In order to incorporate the epidemiological impact of HIV/AIDS on the population, a separate module named abcDIM was added. This module models the epidemic and the demographic consequences associated with it by single year of age and time. The final results are re-integrated into Abacus to produce a combined population projection including the impact of HIV/AIDS. We will be analyzing data projected using the May 2005 version of Abacus and abcDIM.

First developed in 1982 by IPC, RUP is used to produce population projections for internal projects and is disseminated to other statistical agencies as part of IPC's program of technical assistance and capacity building. The software is designed to be flexible in terms of inputs and assumptions. However, the user must have knowledge of demographic methods and computer-related technical skills. The main interface is Excel-based and the processing is done using a DOS-based Fortran program. Data are input into a file using a text editor.

As with abcDIM, the RupHivAids module was designed to model the epidemic and project the demographic impact. This module interface is implemented in Excel using Visual Basic for Applications (VBA). In addition, the final results are re-integrated into RUP to produce a combined population projection including the impact of HIV/AIDS. We will be using RupHivAids006.xls developed in 2004 for this analysis.

RESEARCH DESIGN AND METHODS

In order to properly gauge the similarities and differences between the three programs and HIV/AIDS projection modules, an exploratory analysis is conducted in two stages. First, the three demographic programs used to estimate and project the population by age and sex without the HIV/AIDS module are compared. Evaluation of the demographic processing of the main program is necessary in order to determine the underlying differences in the application of the cohort-component method. Second, the three HIV/AIDS module results are compared to isolate the differences in modeling the epidemic and the resulting population and demographic parameters independent of the underlying demographic model.

Demographic Programs Evaluation

Each of the three programs applies a cohort-component methodology to estimate and project the population. (See Methodology and Modeling Features of the Software for a detailed discussion of the cohort-component method.) However, the programs vary in how the estimation and projection procedures occur. To isolate the differences between the programs we input a

stationary population model and assume demographic parameters are constant throughout the projection horizon of 1980 to 2010. The stationary population is unique in that age-specific mortality (by sex) and age-specific fertility rates (ASFR) are constant over time, and net migration is held at zero for all ages, resulting in a closed population. The ASFRs are estimated to obtain a population growth rate of zero. As a result, the stationary population growth rate for the 30-year projection horizon should be zero, crude birth and death rates should be equal, and the output mortality and fertility estimates should remain the same. Consequently, the stationary population allows us to ascertain whether the programs are properly applying the cohort-component method. In addition, we should be able to rule out the population estimates and projections procedure as a source of differences found in the combined demographic and epidemiological model.

Epidemiological Module Evaluation I & II

Each epidemiological module applies a different approach to model the HIV/AIDS pandemic, but generally requires similar input data based on the equations and recommendations of the UNAIDS Reference Group on Estimates, Modeling and Projections (2002). Although much of the input data is similar, there are implicit assumptions built into each program that prevent an easy exchange of input parameters between programs. For example, RupHivAids and abcDIM each model the epidemic with HIV incidence age patterns and require incidence-specific inputs, while AIM applies prevalence age patterns and requires prevalence-related assumptions. In addition, how each program models survival to AIDS or death after seroconversion[1] differs,

[1] "The development of antibodies to a particular antigen. When people develop antibodies to HIV, they 'seroconvert' from antibody-negative to antibody-positive. It may take from as little as 1 week to several months or

among other variables. (See the Methodology and Modeling Features of the Software section for further details.)

Unlike the evaluation of the demographic components, we cannot easily compare the three models using equivalent epidemiological input parameters. Therefore, in order to identify contrasting modeling procedures between the three modules, we complete two assessments. The first assessment (Evaluation I) relies on the default assumptions and input parameters used in the estimation and projection process for each module. By using the results for the first module assessment from abcDIM, we are able to conduct a second assessment (Evaluation II) in which we attempt to match the results of abcDIM using AIM and RupHivAids. By completing these two evaluations, we are able to isolate similarities and differences in modeling HIV/AIDS and the resulting demographic outcomes.

Input Parameters: Demographic Programs Evaluation

Table 1 presents the stationary population and parameters, or input values, used in each demographic program. The input population totals 1 million. In order to correlate mortality assumptions, it was decided to use the West model life table level 13 from Coale, Demeny, and Vaughan (1983, pg. 48). The model life tables generate a life expectancy at birth of 47.08 years for males and 50.00 years for females. The infant mortality rate (IMR) is 140.17 for males and 118.79 for females. The default survival ratios, based on the model life table, used in DemProj and Abacus Mx are presented in Table 2.

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more after infection with HIV for antibodies to the virus to develop. After antibodies to HIV appear in the blood, a person should test positive on antibody tests." <aids.about.com/library/glossary/bldef-sero.htm>

Input Parameters: HIV/AIDS Module Evaluation I & II

The stationary population projection from the demographic programs evaluation is used as the basis for the three HIV/AIDS modules. The input HIV prevalence rates are based on Tanzania projected prevalence rates for 1980-2010 and are presented in Figure 1. These rates are an estimated and projected time series of the HIV prevalence for the 15- to 49-year-old population for both sexes combined from the UNAIDS/WHO (World Health Organization) Estimation and Projection Package (EPP) software. The virus is estimated to begin in 1980 and peak in 1997 and 1998 at 9.33 percent.

The default epidemiological parameters used in the first epidemiological module evaluation are presented in Table 3. For input prevalence rates, RupHivAids and AIM assume rates apply to the 15- to 49-year-old population, while abcDIM assumes the rates apply to the population 15 years and older. For the input of prevalence patterns by sex and age for AIM, we assume the default generalized epidemic pattern. The default age pattern is based on an analysis of the WHO database of AIDS cases and surveys reported throughout time (Stover 2004). The age pattern is operationalized as the ratio of prevalence rates to rates of the age group 25-29. These patterns differ by sex and throughout the projection horizon based on models of change. The AIM prevalence patterns by sex are based on the sex ratio of the female prevalence rate divided by the male prevalence rate ages 15-49.

Standard incidence patterns by age used in RupHivAids are based on an age pattern of incidence for Masaka, Uganda, from 1990-1994 by varied age groups and sex (Grassly 2004) and are assumed constant over time. The sex ratios are based on simulations in order to approximate the time series of sex ratios of prevalence used by AIM for the heterosexual pattern. For abcDIM, the age distribution of incidence is based on a Weibull curve with a median age of infection of 29.05 years for males and 26.13 years for females. The assumption is held constant throughout the projection horizon. Incidence by sex for abcDIM is based on the AIM generalized epidemic sex ratio of prevalence converted to the percent male of new infections.

Once seroconversion occurs, each program applies a Weibull curve with differing median years to AIDS (to AIDS death for AIM). abcDIM uses a median survival time to AIDS of 8.59 years for males and 9.41 years for females. AIM applies survival to AIDS death with a median survival time of 8.6 years for males and 9.4 years for females. RupHivAids assumes a median survival to AIDS of 7.55 years for males and 8.40 years for females.

After the infected population converts to AIDS, the survival for abcDIM is based on a Weibull curve and has a median survival of one year. RupHivAids assumes a mean survival of one year using an exponential function. In contrast, AIM allows exactly one-year survival, which is build into the aforementioned survival to AIDS death curve.

Child survival assumptions for each program are based on a double-Weibull curve. The median child progression from HIV infection to AIDS death for AIM and RupHivAids is 2.1 years.

While abcDIM uses a median of 2.1 years survival, it appears that it is survival to AIDS, not to AIDS death.

In order to model the effects of HIV/AIDS on fertility, a ratio of fertility of HIV-infected women to the fertility of uninfected women is used to adjust the age-specific fertility. Both AIM and RupHivAids apply default values of 1.5 for 15- to 19-year-old women and 0.7 for all other ages (20-24 through 45-49). abcDIM applies an adjustment factor of 0.8 for each age group (15-19 through 45-49).

The epidemiological assumptions modified in RupHivAids and AIM in order to match abcDIM in the second epidemiological module evaluation are presented in Table 4. After multiple attempts to match the abcDIM results, the final inputs presented in the table were used in each program. A detailed discussion relating to the source of the assumption is included in the Results and Analysis section.

It should be noted that we have copies of both RUP and Spectrum, thereby permitting us to obtain the results in-house. However, Abacus is non-portable, requiring UNPD to generate results based on our specified input parameters.

METHODOLOGY AND MODELING FEATURES OF THE SOFTWARE

The methodology used as the foundation for the three demographic programs is the cohort-component method, which estimates the demographic change for each cohort of a population by age and sex. Equations (1a) and (1b) present an overview of this method:

Equation (1a) $P_{(s, a, t)} = P_{(s, a-1, t-1)} - D_{(s, a-1, t-1, t)} + M_{(s, a-1, t-1, t)}$

Equation (1b) $P_{(s, 0, t)} = B_{(s, t-1, t)} - D_{(s, b, t-1, t)} + M_{(s, b, t-1, t)}$

where:

$P_{(s, a, t)}$ = population of sex s and age a at time t

$D_{(s, a-1, t-1, t)}$ = deaths to people of sex s who were age a-1 at time t-1, in the interval from time t-1 to time t

$M_{(s, a-1, t-1, t)}$ = net migration of people of sex s who were age a-1 at time t-1, in the interval from time t-1 to time t

$B_{(s, t-1, t)}$ = births of sex s, in the interval from time t-1 to time t

$D_{(s, b, t-1, t)}$ = number of people of sex s who were born in the interval from time t-1 to time t and died during that period

$M_{(s, b, t-1, t)}$ = net number of people of sex s who were born in the interval from time t-1 to time t and migrated during that period

Note: Deaths include those to immigrants after they have entered the area of study.

In summary, the starting population for sex s and age a-1, $P_{(s, a-1, t-1)}$, is reduced by the deaths to that cohort, $D_{(s, a-1, t-1, t)}$ and then the net number migrants to the cohort, $M_{(s, a-1, t-1, t)}$, is added to

get the population age a at time t, $P_{(s, a, t)}$. To get the population under age 1 at time t, $P_{(s, 0, t)}$, we start with the number of births in the period t-1 to t, $B_{(s, t-1, t)}$, then subtract the estimated deaths to that cohort during the interval, $D_{(s, b, t-1, t)}$, followed by the addition of the estimated net number of migrants $M_{(s, b, t-1, t)}$.[2]

For each program, competing risk is modeled in order to allow for a population to make a transition from one state to one of two or more states. In mortality terms, competing risk determines the relative risk of dying from different causes, such as death due to AIDS or non-AIDS causes. Since the person can only die once, the competing risk formulas determine the distribution of deaths by cause by assuming the causes are working independently. The formulas are constructed assuming the population is moving from the state "alive" to "dead" from one of two causes: "cause a" and "cause b":

Equation (2) $$d = p\{1 - e^{-\Delta t[\mu(a)+\mu(b)]}\}$$

Equation (3) $$d(a) = d * \mu(a) / [\mu(a) + \mu(b)]$$

Equation (4) $$d(b) = d - d(a)$$

where:

d = "deaths" due to all causes

p = starting population

Δt = time period

$\mu(x)$ = force of "mortality" for cause x where x equals either a or b

d(x) = "deaths" due to cause x where x equals either a or b

[2] Net migration can be operationalized as international migration at the national level and/or internal migration occurring between political boundaries.

Note that the words “death” and “mortality” are in quotes above because in some cases the competing risk is, for example, between non-AIDS death and conversion from HIV-infected to AIDS.

Abacus and abcDIM

The United Nations modeling process starts with a non-AIDS cohort-component demographic projection. This is done using the Abacus program. Populations are given by 5-year age groups (up to 100 and over) at midyear and computed every 5 years based on the demographic components of mortality, fertility, and migration that apply to the 5-year periods from midyear to midyear (5X5). Mortality is modeled using 5-year survival ratios. These ratios are generally based on model life tables matched to an input life expectancy at birth. Estimated life tables are sometimes used for those countries with vital registration systems. Infant and child mortality estimates are therefore generally based on the matched model life tables. Fertility is modeled using total fertility rates (TFRs) and a percent age distribution of ASFRs. Mortality and fertility are then projected to an ultimate pattern in 2045-2050. Migration is modeled using net migrants in each 5-year interval and corresponding 5-year age and sex distribution.

The projection with AIDS is accomplished by sending the results of the non-AIDS projection to the abcDIM program. These include:

- The population by age and sex for the base year (mid-year 1980).
- ASFRs for 5-year periods from 1950-1955 to 2045-2050.

- Survival ratios by 5-year age group and sex and IMR by sex for the periods from 1950-1955 to 2045-2050.
- Net migration, which is currently ignored in abcDIM.

These inputs are converted to single years of age and single calendar years using the following procedures:

- The base population is split using Sprague multipliers.
- The percent distribution for fertility by age is assumed constant at each single age within each 5-year age group.
- Single-year survival ratios are calculated by developing a complete life table consistent with the 5-year survival ratios and the IMR.
- The rates are assumed to be constant for each midyear-to-midyear period of the original 5-year interval.

The abcDIM module contains its own enhanced version of EPP, which is used to generate the sequence of adult HIV prevalence rates that drive the epidemic. The enhanced EPP allows for demographic changes in the adult population (rather than the fixed assumptions of EPP). The enhanced EPP also allows for some of the model parameters to be varied to give more control over the projected epidemic. The enhanced EPP/abcDIM application prevalence rates are assumed to represent the population 15 years and older as opposed to the population 15 to 49 years. The justification for this is that the EPP modeling process only allows for exits by death (not by leaving the population by reaching age 50).

The abcDIM program divides the population into four groups:

1. At risk (people who are not infected)
2. People who are HIV infected but have not converted to AIDS (and are not on antiretroviral therapy (ART))
3. People who have AIDS but are not on ART
4. People who have AIDS and are on ART

All four groups are exposed to the risk of background mortality, but only groups 3 and 4 can die of AIDS.

For each year of the projection horizon, the program determines the number of new infections needed to match the HIV prevalence level from the enhanced EPP. The distribution of these new infections by age and sex is estimated based on the infection distribution function modeled as a Weibull curve and the sex ratio of incidence. Figure 2 presents the age and sex infection distribution function used in AIM. The default sex ratio of incidence originates from the female-to-male prevalence ratio reported in AIM. The overall level of incidence is determined iteratively to ensure a match to the HIV prevalence.

The at-risk population is projected forward one year using the product of the background survival ratio and the probability of not getting infected (competing risk).

New infections are assumed to happen between the two midyears, and therefore are exposed to further risks for about one half of a year. During that half year the infected population can either convert to AIDS, die of background mortality, or survive to the next midyear.

The conversion from infection to AIDS is modeled as a function of duration since infection. This conversion function is modeled as a Weibull distribution (see Table 5). It should be noted that this conversion function is the same as the function used by AIM for the transition from infection to AIDS death. This is because the cohort studies used to develop this curve did not adjust for background mortality (Porter and Zaba 2004). As a result, the UNPD increased the mean time to AIDS by one year to correct for this. As each infected cohort moves through time, the age, duration, and year all progress forward. The infected population for a given sex, age, year, and duration is survived forward based on the product of the background survival ratio (a function of sex, age, and time) and the probability of not converting to AIDS (competing risk).

When people convert to AIDS, the input proportion on ART is applied to split the population into the AIDS and ART groups. Within the AIDS group, AIDS mortality is modeled using a Weibull with a mean of 1.0 year as a competing risk with the background mortality. See Table 6 for the adult cumulative conversion from AIDS to AIDS death distributions. The modeling of the ART population is beyond the scope of this paper and will not be covered. Therefore, for the three models, it is assumed that none of the infected population has access to ART.

After the HIV/AIDS projection is completed, the data are aggregated in order to estimate the 5X5 survival ratios to be exported back to Abacus. Abacus is then re-run with the AIDS-impacted survival ratios and the original base population, fertility, and migration to get the final projection results.

Spectrum - DemProj and AIM

In Spectrum, the process of modeling a population that includes the impact of AIDS starts with the entry of the demographic inputs to DemProj. The basic demographic inputs are:

- Base population by sex and 5-year age groups to 80 and over.
- TFR for each year of the projection.
- ASFR age pattern (entered as a percent distribution) by 5-year age group for each year of the projection.
- Sex ratio at birth for each year of the projection.
- Life expectancy at birth by sex for each year of the projection.
- Model life table family or user-generated model.
- Net numbers of migrants by sex for each year of the projection.
- Percent distribution of migrants by sex for each year of the projection.

Using the EasyProj option (which reads in the appropriate information from the latest United Nations World Population Prospects 2004 Revision) can ease entering these data. Note that these are the no-AIDS data only for the respective countries where the UNPD modeled HIV/AIDS.

After entering the demographic data, the user can move directly to entering the epidemiological data for the AIM module. These inputs include (but are not limited to):

- Adult HIV prevalence in percent (assumed to be for ages 15-49). This can be read in from the output file created by EPP.

- HIV progression to AIDS death (in the absence of ART) for adults and children. These are entered as the cumulative percent dying of AIDS by number of years since infection. The program provides two models based on patterns for developing (fast) and developed (slow) countries for both adults (by sex) and children, or users can enter their own data.
- Age distribution of prevalence by sex for each year of the projection. This is entered as the ratio of the HIV prevalence rate in each age group to the prevalence rate in the age group 25-29.
- Sex ratio of adult (15-49) prevalence rates, entered as the ratio of the female prevalence rate to the male prevalence rate.
- A series of inputs related to mother-to-child transmission.
- Fertility reduction by age. This entry is the ratio of the ASFR for HIV infected women relative to non-infected women. Note that the fertility entered in the demography section is assumed to already include this reduction, and these factors are simply used to distribute births by infection status.

Once the inputs are complete, displaying any of the outputs will cause the projection to be run.

The basic demographic inputs are converted to single years of age using the following procedures:

- The population by age is split using the Beers osculatory interpolation method.
- The fertility rates for each year are computed by multiplying the TFR by the ASFR percent distribution. The ASFRs by single years of age within each 5-year age group are assumed to be the same as the rate for the 5-year age group.

- The survival ratios are converted to single years in different ways depending on the age group. According to the DemProj documentation, the first 5 survival ratios (for surviving to age 0 through age 4) are part of the life table input that are the ratios l(x+1)/l(x), while the remaining input survival ratios are computed as $({}_5S_x)^{1/5}$ (1999, pg. 68).
- Migrants by single year of age are computed as one-fifth of the product of the net number of migrants for a given sex and the percent of those migrants in the corresponding 5-year age group.
- The relative HIV prevalence rates by age for a given sex (expressed as a ratio to the rate for 25-29) are assumed constant within each 5-year age group.

For each year of the projection, DemProj starts by projecting the total population by age and sex forward one year. Total deaths are calculated on a cohort basis using the survival ratios (with an adjustment for migration), which are then used to project the population to the next year. Total births for the period prior to the projected year are computed by multiplying the single-year ASFR values by the projected midyear female population.

The epidemic starts in the first year with a non-zero HIV prevalence rate. The program uses the prevalence rate, sex ratio, and age distribution of infection to distribute the new infections by age and sex in order to match the input adult prevalence rate. Figure 3 presents the default age distribution of prevalence rates used in AIM. These new infections can be considered to be occurring during the year prior to the midyear, although there is no competing risk for the partial year between infection and the next midyear. The new infections are then projected forward through time to determine when death due to AIDS occurs, based on the input HIV progression

to AIDS death (see Table 5 and Figure 4). The estimated "AIDS cases" from AIM are considered to have converted to AIDS one year prior to death. Prior to conversion to AIDS, those infected are also subject to competing risk of death due to background mortality.

In the absence of ART, there is no competing risk of dying of background mortality between conversion to AIDS and AIDS death. The events and surviving midyear populations from this forward projection are aggregated to combine the results of populations infected at different times and at different ages. This includes the surviving population that is HIV positive and AIDS deaths. One way to interpret this is to assume that the new infections occur immediately before midyear. In the forward projection of those infections, the conversion to AIDS and AIDS deaths can also be interpreted as happening right before midyear. The total midyear projected population by age is adjusted by subtracting AIDS deaths at the end of the year they die. The AIDS deaths are also added to the deaths estimated during the projection of the total population.

RUP and RupHivAids

The RUP program is used to produce the demographic inputs to the RupHivAids module. The RUP program was designed to deal with midyear populations and calendar year events. The inputs are very flexible and include:

- Population by age and sex (5-year age groups or single-year age groups)
- Fertility
    - ASFRs
    - TFRs

    - Births (optionally by age of mother)
- Mortality
    - Age-specific death rates (Mx)
    - The probability of dying by age and sex (Qx)
    - Life expectancy at birth by sex
    - Deaths by age and sex
- Net migration (international and internal)
    - Numbers by age and sex OR
    - Rates by age and sex

To convert from 5-year ages to single ages, RUP uses the following methods:

- The population is split using the Beers osculatory interpolation method. A modified version is also available to reproduce an input population under age 1.
- Single year rates in a 5-year age group are generally set to the 5-year age group rate.
- Net numbers of migrants in a 5-year age group are evenly distributed into each single age group.
- The input Coale and Demeny life table model and any inputs of separation factors for ages 0 and 1-4 are used to split the mortality under age 5 based on the Coale and Demeny (1966) formulas.
- Values for years before the first input for a component are assumed to be equal to the first input. Similarly, projections after the last input are held constant using the last input.
- Values for years between input values are interpolated (linear for most items, exponential for Mx values).

The non-AIDS RUP projection creates an intermediate file with population, deaths, births, and migrants by sex and single years of age.

The RupHivAids spreadsheet has a number of inputs:

- Both sexes prevalence rates (usually from an output file generated by EPP) and/or relative incidence for each year.
- Age distribution of adult incidence rates (by 5-year age group) for each year.
- Sex ratio of incidence for ages 15-49 for each year.
- Adult progression from seroconversion to AIDS (input parameters to a Weibull curve by sex).
- Average years lived by adults after conversion to AIDS.
- Child progression from infection (at birth) to AIDS death.
- Mother-to-child transmission rates for each year of the projection.
- Proportion of adults needing ART that will receive it for each year of the projection.
- Probability of surviving one year after conversion to AIDS for patients on ART.
- Fertility change parameters for infected women.

The program reads the non-AIDS RUP intermediate file and does the following:

- Stores the base population by sex and single year of age.
- Computes Mx values by single year of age as deaths/population for each single age and year of the projection. These are then interpreted as the force of mortality for estimating

deaths. The separation factors of infant deaths by sex are also read in and used to compute the force of mortality by quarter year for infants.

- Computes overall ASFRs by single year of age as births/female population 10 to 49.
- Stores the net numbers of migrants by single ages and sex for use during the projection phase.

The epidemiological inputs are processed using the following steps:

- The age distributions of incidence rates by sex are split into single years of age by cumulating the 5-year values, applying the Beers multipliers, and de-cumulating. In order to control the start and end of the distribution, a mirror image of the first 3 age groups is appended to the rates so that the curve will hit zero at exact age 15, and a similar process is used at the older ages so the curve will hit zero at exact age 80 (or the beginning of the youngest age group where the value is zero).
- The inputs regarding survival of the AIDS and ART populations are converted to a force of mortality for each group.

The RupHivAids projection starts by moving forward the non-infected population. The program progresses in one-year intervals, but splits each year into two halves so that the events between midyears can be recombined to obtain calendar year values. When the first non-zero prevalence rate is found, the population is projected forward one year with the competing risks of dying from non-AIDS causes or becoming infected with HIV. The overall level of incidence by sex needed to reach the projected prevalence and the sex ratio of incidence are determined by iteration.

In order to be able to track the new infections by cohort and years since infection, the program creates two cohorts: one that is infected immediately after the earlier midyear and the second that is infected immediately before the projected midyear. The first half-year cohort is then exposed to the risk of non-AIDS mortality and conversion to AIDS for a full year (but this is done in two half-year intervals). The second cohort is exposed to non-AIDS mortality for the full year prior to infection. Each of the two cohorts are then projected forward and exposed to the competing risks of non-AIDS death and conversion to AIDS. The non-AIDS deaths are accumulated by calendar year, as are the conversions to AIDS. The new AIDS cases are then exposed to a quarter year of risk of dying from the competing risks of non-AIDS and AIDS causes. These deaths are separately accumulated by sex and age for each time unit.

After the future projection of new infections to AIDS, the accumulated midyear AIDS population is projected forward from the midyear after conversion using the constant hazard model with competing risk of non-AIDS death.

Infected births are computed by first computing the adjustment factors of fertility for infected women, as a function of the input ratios of infected to non-infected fertility rates and the infected and non-infected female populations by age. These total births are then multiplied by the perinatal transmission rate to get the infected births.

Infected births are projected forward with competing risk of non-AIDS mortality (from the non-AIDS input) and AIDS mortality based on the input double-Weibull curve. In order to

model the rapid changes in non-AIDS mortality in infancy, the process is broken down into quarter years.

RESULTS AND ANALYSIS

Demographic Program Evaluation

For this evaluation, we compare Abacus, DemProj, and RUP population projections, focusing on the demographic estimation and projection component of each program. The stationary model population is special in that the total population should remain constant throughout the projection horizon. In this case, the stationary population entered in each demographic program totaled 1 million. Table 7 presents the results for the total projected population from 1980 to 2010. Each of the programs arrived at different results than 1 million in 2010. Abacus projected a total population of 999,644 in 2010, only 356 from the target total. RUP was also under 1 million by 1,265. DemProj, however, under-projected the population by 12,704 (1.3 percent of the total).

The sex ratio for each of the programs produced differing results, but remained close to the initial ratio. Each began with a ratio of 96.99 males per 100 females. Abacus projected a decline in the sex ratio, resulting in a final ratio in 2010 of 96.95. RUP estimated a ratio of 96.98 and DemProj estimated the lowest ratio of 96.93.

In order to correctly interpret flow or event data, such as births, deaths, or HIV incidence, it is necessary to recognize the differences of the timing between the three modules. In other words,

when does each program report the date an event occurred? abcDIM refers to events occurring at the beginning of the mid-year, while AIM refer to events that occur by the end of the referenced mid-year, and RupHivAids reports some events by calendar year and some for the year ending at midyear. Refer to Table 8 for the reporting of timing for demographic outputs and Table 9 for epidemiological outputs

The demographic components of change (fertility, mortality and migration) allow us to isolate how well the programs are applying the cohort-component method. In theory the number of births and deaths for a stationary population should remain equal and net migrants equal zero. Because the total populations for each program deviated from 1 million, we would expect that the number of births and deaths are not equal. Figure 5 presents the ratio of births to deaths. Abacus remains very close to 1.00 with RUP slightly deviating throughout the horizon. DemProj estimates an increase in deaths and decrease in births, resulting in a declining and stabilizing ratio.

In order to isolate the reasons why DemProj results deviate from the stationary population, we simulated the survival process by projecting the population by single year of age and sex for a single year. In so doing, it was determined that there were issues with the application of survival ratios, the extrapolation procedure to estimate the single year age distribution from 5-year age groups, and the application of Beers osculatory interpolation technique to the oldest age groups of the population.

When splitting the population 5-year age groups into single year of age, the Beers interpolation method is applied to each age group (Stover 1999). The wrong panels are applied to the 70-74 and 75-79 age groups and incorrect age groups are applied within each panel.[3] This will affect the population distribution in the oldest ages for the first few years of the projection.

According to the DemProj manual (1999), the 5-year survival ratios for the population 5 years and older are extrapolated to single year of age by using the fifth root of the ratio $({}_5S_x)^{1/5}$ (pg. 68). However, through discussion, review of the code, and the simulation procedure, we were able to determine that input survival ratios are computed as $1-(1-{}_5S_x)/5$. As a result, the same survival ratios are applied within each 5-year group. The application of either procedure to create single-year survival rates for the 80 years and older is also problematic. In addition, the first 5 single-year survival ratios (for surviving to age 0 through age 4) are part of the life table input, but are currently calculated incorrectly as l(x+1)/l(x) rather than L(0)/l(0) then L(x)/L(x-1) for x=0 to 4.

The application of the above-described survival ratios results in higher age-specific death rates (Mx) compared to the West Model life table level 13 specified as an input mortality assumption. Figure 6 presents the ratio of age-specific death rates based on the output of deaths by age and the population for 1980 from DemProj and the model Mx values (Coale, Demeny, and Vaughan 1983, pg. 48). For males, the DemProj rates are higher for each age group except 20-to-26-year-olds and 75-79, and 80 and over. Rates for females are higher for each age group, except 75-79 and 80 and over. Therefore, mortality is being increased throughout the age

[3] For the 70-to-74-year-olds, the middle panel was used as opposed to the last -1 panel and included the 80and over terminal group. The 75-to-79-year-olds are applied to the last -1 panel instead of the last panel and also included the 80 and over group.

distribution, resulting in a larger number of deaths than would be expected for the stationary population.

The estimated fertility from DemProj is shaped by the estimated number of deaths in two ways. Because mortality rates are higher for females in the reproductive ages, there are fewer females eligible to give birth. Also, the incorrect calculation of survival rates to the population under 5 and 5 to 9 results in a ripple effect to the population, as a larger cohort followed by a smaller cohort are aged through the population distribution. Figure 7 presents the General Fertility Rate for each year of the horizon. Both the increase and the decrease in the rate are a result of the size of the 0-to-4-year-olds and 5-to 9-year-old cohorts from 1980.

The estimated deaths for Abacus and RUP are similar throughout the horizon; however, RUP estimates slightly more deaths throughout. Between the two, RUP consistently estimates more deaths for the 0 to 4 and the 80 and older population, while less for those 5 to 9. In all likelihood, the manner in which RUP and Abacus apply mortality rates for the open-ended age group differs, resulting in slightly higher death rates in the oldest ages for RUP.

Table 10 presents the estimated life expectancy at birth, IMR, and under-5 mortality rates for the years reported for the Abacus program (mid-5-year average). Each program estimates values close to that of the West model life table.

However, DemProj estimates an IMR that is not related to the input survival ratios. It may be originating from the IMR listed on the input life table for DemProj, which seems to be the IMR

from an older version of the West model life table (Coale and Demeny 1966, pg. 14). Further research is necessary in order to determine the exact origins of the estimated values for DemProj. Also, reported life expectancy at birth for males from DemProj is off slightly at 47.1. In all likelihood, this is a result of the fact that DemProj allows for the entry of life expectancy at birth to just one decimal place.

HIV/AIDS Module Evaluation I

The first HIV/AIDS module evaluation is designed to identify differences in the implicit assumptions made by abcDIM, AIM and RupHivAids in order to model the impact of the epidemic. Therefore, by using the stationary population and identifying the potential confounding demographic variables in the first evaluation, we are able to better understand the implicit differences between modules. Although there are assumptions made by each module that vary, we only focus on summarizing differences in results and identifying assumptions that produce notably different outcomes.

Discussed in the Research Design and Methods section, the modules approach modeling the impact of the epidemic using either incidence (abcDIM and RupHivAids) or prevalence (AIM). As a result, the age and sex distribution assumptions differ. Also, the survival to AIDS or death ratios applied after seroconversion for adults and children are implicitly different. Lastly, the fertility reduction factor for abcDIM differs from RupHivAids and AIM.

Population

Table 7 presents the population projected to 2010 for each module. By 2010, abcDIM experienced the largest decline of 127,777 from 1980, a 12.8 percent difference. In comparison, RupHivAids projected a decline of 105,394 in 30 years (10.5 percent) and AIM projected (a 9.6 percent difference). The large differences in the projected population, and most of the differences discussed below, are invariably tied to abcDIM's assumptions for prevalence. According to the EPP manual (2005), the estimated prevalence rate time series output from EPP used in the three demographic modules refers to the adult population 15-49. While RupHivAids and AIM apply the rates to the respective population to estimate incidence and prevalence, abcDIM applies the rates to the population 15 years and older to estimate incidence. Consequently, the output prevalence rates for the 15-49-year-olds are higher than estimated by EPP, resulting in more infections and deaths in each age group to maintain input prevalence rates. Figure 8 presents the output prevalence rates for each module for the population 15-to-49-years-old.

HIV Incidence and Prevalence

When discussing HIV incidence throughout the next two evaluations, we will always be referring to the population 15 years and over.

Based on the application of prevalence rates to the 15 years and older population, abcDIM estimated the largest cumulative new infections totaling 179,857, of which 54.3 percent were females. In comparison, RupHivAids estimated 159,819 and AIM estimated 122,870 with

54.4 percent and 53.4 percent of the infections to females respectively. Figure 9 presents HIV incidence (new infections) by 5-year age groups and sex for 1990 and 2010. Patterns differ greatly between modules, with RupHivAids estimating the most new infections in the oldest ages and abcDIM estimating the youngest distribution.

The assumed relative proportionate age distribution for incidence rates from abcDIM and RupHivAids are presented in Figure 2. It is clear in this figure that abcDIM assumes a younger distribution of new infections. Females peak at age 21 at 0.052 and males peak at 24 at 0.042, while RupHivAids estimates that incidence peaks for females at 22 with 0.045 and males at 27 with 0.027. The assumed distributions are held constant throughout the projection. Figure 3 presents the ratio of the HIV prevalence rate to the prevalence rate for the 25-to-29-year-olds for AIM. These ratios are used to estimate new infections by age to meet the respective prevalence rates.

Upon closer examination, it appears that abcDIM does not infect 15- and 16-year-olds. The 15 year-olds are never infected because of the assumed age distribution presented in Figure 2. After reviewing the software code relating to estimating new infections for abcDIM, it was discovered that a possible error might be the reason the 16-year-olds appear never to be infected (or that 16 year olds are infected but only show up after they turn 17).

According to the input EPP prevalence rates, the number of HIV-infected people 15-49 relative to the base population should peak in 1997 and 1998 at 9.33 infections per 100 people. The output rates estimated by each program differ substantially as noted above (see Figure 8). While

RupHivAids peaks at the reported 9.33 infections per 100 people in the correct years, AIM peaks at 9.30 in 1998, and abcDIM at 13.05 in 1997 (the prevalence rate for 15 and over for abcDIM peaks at 9.37 in 1998). RupHivAids has the lowest male prevalence rate of 7.43 in 1997, AIM estimates 8.07, and abcDIM estimates 11.13. For females, RupHivAids peaks at 11.31 in 1998, AIM at 10.54, and abcDIM at 15.09. AIM seems to slightly underestimate the total prevalence rate each year, but by a very small amount.

Estimated prevalence rates by 5-year age groups and sex for 1990 and 2010 are presented in Figure 10. As discussed above for incidence, the prevalence rates for abcDIM are highest in the younger ages, while RupHivAids estimates higher prevalence in the older ages. These rates also differ substantially in magnitude by age for abcDIM due to the estimated higher prevalence rates for the 15-49 population. Another noteworthy difference between modules is the estimated prevalence rates in the oldest ages. By 2010, AIM has very low prevalence rates beyond those 70 and over and RupHivAids has a larger number of infected people up to 80 and over. Between 1995 and 2010, we begin to see higher prevalence rates for the oldest age groups for abcDIM, higher than RupHivAids for males 80 and over.

abcDIM estimates a longer survival time of seroconversion to AIDS and from AIDS to AIDS death than both RupHivAids and AIM. Discussed earlier, each of the three modules bases their survival curve of seroconversion to AIDS or to death (AIM) based on the research of the UNAIDS Reference Group (2002). However, abcDIM assumes a median survival to AIDS one year later than the other modules (see Methodology and Modeling Features of the Software for a detailed discussion). Each of these issues contributes to a larger HIV infected and AIDS

population throughout the time series, but should not be responsible for a large amount of that differential.

Fertility

Based on the results from the demographic projection, we assume that the total number of projected births should be lowest for AIM. Contrary to our assumption, RupHivAids projects fewer births than AIM after 1990 (Figure 11). Because we did not obtain projected total births for abcDIM, we are unable to include the module in this part of the discussion.

Two default assumptions directly influence the outcome of the modeled number of infected births: the mother-to-child transmission rate, assumed at 0.32 percent for each module, and the fertility reduction factor. Figure 12 presents the time series of the infected births. The estimated infected births for each year is highest for abcDIM and lowest for AIM.

Because the mother-to-child transmission assumption is identical for each module and the fertility reduction factor is equivalent for AIM and RupHivAids, we theorize that the estimated differences may be related to the number of infected women in reproductive ages. In order to verify this theory we calculated the ratio of infected births to infected women 15-49 (Figure 13). According to this figure, relative to the size of the infected female population, abcDIM infects more births than RupHivAids or AIM. RupHivAids remains constant near 2.3-2.4 percent of births to infected women 15 to 49 throughout the time series. AIM infects the least number of births relative to the other modules. Only RupHivAids projects a constant ratio, leading to

potential concerns of modeling issues for abcDIM and AIM. This theory is further examined in the second module evaluation.

Mortality

Table 10 presents the mortality statistics for the resulting population projections. These are aggregate estimates of both AIDS and non-AIDS mortality. Within the first ten years, life expectancy at birth for each module is similar. However, afterward, estimates deviate for abcDIM, projecting a greater decline. By 2007, abcDIM estimates a life expectancy at birth roughly two years lower than RupHivAids and AIM for males, two years lower for RupHivAids females, and 3 years lower for AIM females. RupHivAids and AIM results do not deviate dramatically. Between 1982 and 2007, life expectancy at birth is projected to decline for men by 6.1 years for RupHivAids, 6.5 years for AIM, and 8.0 years abcDIM. In turn, females are projected to decline by 9.3 for RupHivAids, 8.6 for AIM, and 11.5 years for abcDIM.

IMRs also differ by module. By 1992, the IMR for abcDIM begins to increase at a slower pace than that of the other modules. RupHivAids maintains the highest IMR throughout the series increasing from 1982 to 2007 by 8.4 deaths per 1,000 births (148.6) for males and 8.6 (127.4) for females.

Mortality rates for the population under age 5 are the highest for abcDIM, reaching 222.0 deaths per 1,000 for males and 202.6 deaths per 1,000 for females by 2007. RupHivAids estimated lower rates with 215.0 for males and 196.4 for females in 2007. AIM estimates the lowest

under-5 mortality for 2007 with 209.7 deaths per 1,000 for males and 191.0 deaths per 1,000 for females.

Because abcDIM estimates the highest number of infected births, we assume that it should have the highest IMR and under-5 mortality. This is not the case for infant mortality, but is true for under-5 mortality. This may be the result of the assumption for the Weibull curve survival to AIDS and death for children. Because abcDIM assumes an additional year in the survival curve, it may be postponing the death to older ages. It may also be the result of the application of the AIDS to AIDS death survival assumption and how they are applied between modules. We will attempt to isolate these issues in the next evaluation.

Also, because AIM estimated a life expectancy at birth similar to RupHivAids, we would assume the IMR and child mortality to also be similar. However, AIM estimates the lowest under-5 mortality and the second-lowest IMR. This may be related to the questions arising in the demographic projection analysis in regards to the source of the input IMR statistics for AIM.

Mortality: AIDS Related

Of the three modules, abcDIM estimates the greatest (128,045) while AIM estimates the fewest cumulative AIDS-related deaths (79,073). In order to maintain a higher prevalence due to the interpretation of the EPP estimates, abcDIM must infect a larger number of people, resulting in more AIDS-related deaths. In addition, abcDIM also has the greatest proportion of cumulative AIDS-related deaths among deaths due to all causes. abcDIM estimates that 17.2 percent of the

cumulative deaths are AIDS related, while RupHivAids estimates 14.2 percent and AIM estimates 11.1 percent.

Each program estimates that roughly 47-48 percent of the cumulative AIDS-related deaths are to females. However, the patterns by age and sex differ dramatically. Figure 14 presents the Mx values by 5-year age group and sex for 1990 and 2010. Based on the prevalence patterns by age, we would expect to see a greater number of AIDS deaths for abcDIM in the youngest adult ages and for RupHivAids in the oldest. This is true for 1990 and 2010 for each sex. However, abcDIM estimates that rates increase in the oldest ages. Also, rates are higher for abcDIM for the 10- to 14-year-olds. In 1990, AIM tends to have the lowest AIDS-Mx rates except ages 15-19 for males and 55-59 for females. In 2010, however, AIM still estimates the lowest for 0-4 and 5-9 for each sex, for 25-34 and 75-79 for males, and 20-44 and 75-79 for females. Rates for 15-19 are equal to or greater than abcDIM.

Because each program assumes a similar survival assumption for children, we would not expect to see such a large difference in this age group. For abcDIM, the difference may originate from the assumption to include an additional year to the survival curve, as was done for the adults. Further research is needed to isolate the reasons for these observations.

Mortality: Non-AIDS Related

In comparison to AIDS-related mortality, AIM estimates the highest number of deaths due to non-AIDS-related causes. Figure 15 presents the ratio of AIDS-related deaths to non-AIDS-related deaths for each year of the time horizon. AIM estimates that 88.95 percent of

the cumulative deaths are non-AIDS related, in comparison to 85.8 and 82.8 for RupHivAids and abcDIM respectively. Because AIM estimates the fewest total deaths throughout the time series after 1990, but estimates the largest number of deaths due to non-AIDS causes, we assume that deaths due to non-AIDS-related causes are overestimated. This assumption is analyzed further in the second module evaluation.

HIV/AIDS Module Evaluation II

Following the first evaluation of the HIV/AIDS modules, we attempt to match the implicit assumptions from abcDIM in both RupHivAids and AIM. Through matching abcDIM assumptions, we gain a better understanding of the operational and methodological applications and assumptions for each module. The section Research Design and Methods outlines the assumptions made in RupHivAids and AIM in order to match abcDIM and are presented in Table 4. In summary, we took the following steps:

- Entered the abcDIM estimated prevalence rate time series for 1980 to 2010 for the 15-to 49-year-old population.
- Assumed a 20.0 percent reduction of each age-specific fertility rate for infected women.
- Entered the abcDIM age and sex incidence patterns into RupHivAids.
- Entered the output abcDIM age and sex prevalence patterns into AIM.
- Recalibrated the survival-to-AIDS Weibull curve in RupHivAids and survival-to-death in AIM.
- Recalibrated the Weibull survival curve for children in both modules.

Population

After attempting to match the abcDIM assumptions, the projected total populations for RupHivAids and AIM are very close to abcDIM throughout the time series. The total projected population is presented in Table 7. By 2010, RupHivAids is 0.5 percent (4,424) less than abcDIM's projected 2010 population. AIM is greater than abcDIM by 1,238 people (0.14 percent). Even though we attempted to align the sex-related assumptions, the sex ratio for the population for the two modules still does not match that of abcDIM (see Figure 16). Both RupHivAids and AIM project a similar change as the number of males declines relative to females. In contrast, abcDIM estimates a similar sex ratio pattern, but with greater change throughout the projection horizon.

HIV Incidence and Prevalence

After considering the differences in reporting the timing of a new infection, RupHivAids closely replicated the abcDIM HIV incidence pattern for the 15 years and older population. By 2010, the projected cumulative incidence for RupHivAids is only different by 2.12 percent, compared to 11.1 percent in Evaluation I (not shown). Figure 17 presents HIV incidence estimates for the 15 years and older populations by sex for 1990 and 2010. RupHivAids replicates the age distribution by sex in terms of pattern, but not by the overall level. AIM is unable to replicate the pattern by age and sex, with the largest differences occurring to 15-19 year olds. In earlier years of the projection, abcDIM maintains a larger number of new infections for each age group. By 2010, AIM has the greatest number of new infection for 25-to-29 and 30-to-34-year-olds.

AIM reduces its difference from abcDIM in cumulative incidence from 31.7 percent lower in Evaluation I to 13.1 percent in Evaluation II. After review of the internal code for AIM, it appears that the number of estimated AIDS deaths is subtracted from the HIV population one year late during the modeling process. As a result, the surviving HIV population appears too large, artificially reducing incidence.

Figure 18 presents the age-specific HIV prevalence rates by sex for 1990 and 2010. For each year in the time series, RupHivAids and AIM generally replicate the prevalence rates by age and sex. However, differences between the three programs still exist for the youngest age groups (0-4 and 5-9).

Fertility

For this evaluation, the two fertility-related assumptions for AIM and RupHivAids are matched to abcDIM. In comparison to Evaluation I with default fertility assumptions, AIM projected fewer total births, which decreases the difference with RupHivAids (Figure 11). This may be a result of the fact that there are fewer females in the AIM projection due to mortality differentials mentioned in the demographic evaluation.

Figure 19 presents the ratio of infected births to 15- to 49-year-old infected women. Neither RupHivAids nor AIM is able to match abcDIM's ratio. Both abcDIM and AIM produce results that are not constant over time. Based on this assessment, it is necessary to conduct further analysis to determine the issues with modeling infected births for AIM and abcDIM.

Mortality

After finalizing the matched input assumptions, both AIM and RupHivAids generally replicates the estimated number of total deaths (not shown). AIM slightly overestimates deaths in the 1980s and underestimates deaths during the 1990s. The differences for AIM from abcDIM are further exemplified by sex. The male pattern is similar to the total pattern; however, females exhibit a greater pattern of under- and overestimation.

Estimated mortality statistics are presented in Table 10. Life expectancy at birth is very similar, but infant and under-5 mortality rates differ throughout the series. From 1992 onward, RupHivAids maintains a much higher IMR by sex than abcDIM while AIM is in the middle. For the under-5 mortality rate, RupHivAids starts lower but ends up close to abcDIM. AIM remains lower than abcDIM throughout. This may be due to differences in surviving the infected population in the youngest ages, even though attempts were made to standardize this assumption. Further research is necessary.

Mortality: AIDS Related

After several unsuccessful attempts to replicate AIDS-related mortality and the infected population from abcDIM, we assume that an inconsistency exists between the applications of the Weibull survival curve to AIDS across modules. The reported Weibull curves are presented in Table 5 and Figure 4. Review of the internal code for abcDIM highlights a possible error with the application of the code by year of infection. In the three cases where the cumulative Weibull curve was used to estimate "survival ratios," the ratios for the first period (equivalent to the survival from birth to age 0 in the life table) were done correctly. However, the second survival

ratio used was the equivalent of L_2/L_1 instead of L_1/L_0. This reduced the overall "survival" in the current state, meaning that infected adults and children progressed to AIDS and AIDS to death faster than intended. The Weibull curves were re-estimated for RupHivAids and AIM (median one year later than RupHivAids) based on the assumed coding issue (see Table 11 and Figure 4). This adjustment was not made separately for the AIDS to AIDS death survival in RupHivAids or AIM. We were unable to do so in AIM as the assumption of exactly one-year survival for AIDS is implicit in the coding, so we estimated a Weibull curve that is the best fit to the effective abcDIM HIV to AIDS death curve.

After adjusting the survival-to-AIDS survival curves, RupHivAids closely replicates the projected total AIDS deaths by sex. Figure 20 presents AIDS age-specific death rates by 5-year age group and sex for 1990 and 2010. Although levels are slightly different in 1990 (RupHivAids is lower), this difference in all likelihood due to rounding and timing issues and is minimized through the remainder of the time series. As mentioned in the first epidemiological evaluation, AIDS death rates are higher for abcDIM than RupHivAids in the oldest age groups (75 to 79 and 80 and over). In addition, rates are higher in the 10-to-14-year-old age group. By 2010, rates increase in the oldest ages for AIM (70-80 and above) for males, but not for females. This upturn for AIDS specific rates in the oldest ages for abcDIM and AIM cannot be explained at this time.

AIM continues to underestimate AIDS-related deaths throughout the horizon for both males and females. Although the difference in the number of cumulative deaths between programs has been reduced in Evaluation II, AIM still estimates 18.4 percent fewer cumulative AIDS deaths

than abcDIM, each sex with equivalent percent differences as the total. These results are further verified by reviewing the AIDS age-specific death rates in Figure 20. For each sex, the AIDS Mx values are lower for AIM than abcDIM with exception of the oldest ages by 2010 (65-69 to 75-79 for males and females).

Mortality: Non-AIDS Related

Non-AIDS-related mortality is replicated by RupHivAids for total deaths by sex and the non-AIDS age-specific death rates (Figure 21). As was noted in the previous evaluation, AIM estimates the largest number of non-AIDS deaths for both males and females (except 75-79 and 80 and over), while the deaths related to AIDS are lower than abcDIM.

Upon review of the methodology described in the AIM (Stover 2005) and DemProj manuals (Stover 1999) and that implicit in the internal code, we think non-AIDS related mortality is overestimated as a result of overestimating deaths attributed to the non-infected population and competing risk to the infected population. Review of the internal code indicates when modeling competing risk, the wrong survival ratios may be used, which are one year younger and for one year earlier than they should be. In addition, as was noted in the demographic program analysis, death rates for non-AIDS causes are higher than implied by the West model life table.

CONCLUSIONS AND RECOMMENDATIONS

When assuming the default assumptions for each program in Evaluation I, we find substantial differences in both the demographic and epidemiological results. This analysis provides greater insight into the ramifications of particular epidemiological assumptions made for each module. For example, the abcDIM assumption that prevalence rates from EPP apply to the 15-year-old and over population resulted in higher prevalence rates for the 15- to 49-year-old population than that of RupHivAids and AIM. Also, the assumed age distribution of new infections for RupHivAids appears to overestimate prevalence to the population in the oldest ages (although there is little data available to verify this) while the abcDIM distribution may be too concentrated in younger ages. As a result of these differences, the estimated mortality parameters are quite different across modules. For example, life expectancy at birth estimated by abcDIM is approximately two years lower than the other modules for the stationary population. If someone were to produce projections using the three modules and their respective default assumptions, they would most likely get a range of mortality results.

After attempting to match the epidemiological parameters in Evaluation II, we find that there is very little difference in the overall size of the projected population. RupHivAids closely replicated both the demographic and epidemiological results from abcDIM for Evaluation II, with the population in 2010 only a half percent lower than abcDIM, and within two percent of abcDIM in cumulative new infections and AIDS deaths. We feel that this generally validates that the model structures of RupHivAids and abcDIM are comparable.

However, we were less successful aligning AIM to abcDIM. Although the total population in 2010 from Spectrum is close to abcDIM (only 0.1 percent higher), this was in spite of substantially lower new infections (especially infected births) as well as lower AIDS deaths (14 percent lower than abcDIM). The continued differences in the AIM results are probably due to fundamental differences in the model structure as well as possible problems in implementing the model.

Based on our analysis, we have a series of specific recommendations to improve each of the programs as well as general recommendations that apply to all of the programs. The specific recommendations include problems that were discovered in the process of doing the comparisons or in the review of the computer code, as well as areas of further review and improvements to the user interfaces. Although we are comfortable with our analysis of the programs, we have not had time to fully discuss and get explanations from the developers.

Spectrum (DemProj and AIM)

First, the modeling of non-AIDS-related mortality needs to be corrected to properly implement the demographic cohort-component model. Second, the process of projecting the total population and then separately projecting the infected population (and subtracting the AIDS deaths from the total population) may not be working properly. In part, this may be due to a lack of implementation of competing risk (for example, the new AIDS cases all die in one year of AIDS, while we would expect some to die of other causes).

The output patterns of incidence by age and sex seem somewhat erratic and the causes of this need to be investigated. This may be due to the a combination of the use of age patterns of prevalence (rather than incidence) and of some populations being tracked by single years of age while others are tracked only in 5-year age groups. Another epidemiological aspect that needs to be reviewed is the lower estimates of infected births in AIM compared to those of the other models (we have not been able to reproduce the reported values using the formulas given in the documentation or other possible procedures).

Finally, a full review is needed of the timing of demographic and epidemiological events. The labeling or use of demographic events needs to be made clear and consistent. Currently, births and deaths for 1981 refer to the events for the year ending at midyear 1981 while the migrants for 1981 refer to those occurring between midyear 1981 and 1982. In addition, the births for the period 1981-1982 are computed using the ASFRs for the period multiplied by the female population at the end of the period. This has virtually no impact in our stationary population tests, but in growing populations, this would over-estimate the number of births when compared to the usual procedure of using an average of the 1981 and 1982 populations. In the epidemiological model, the tracking of the infected population needs to be checked: it appears that although the AIDS deaths are removed from the total population and added to the non-AIDS deaths at the correct time, they may be removed from the infected population a year later than intended. This could be the reason behind the lower incidence for AIM in Evaluation II.

A review of the procedures used by Spectrum to estimate the mortality indicators to include the impact of AIDS was incomplete, but although the results were very close to the other models, we would like a more detailed explanation and justification for some of the methods used.

Abacus and abcDIM

The highest priority is to correct the HIV-to-AIDS and AIDS- (or ART-) to-AIDS death Weibull curve processing errors that resulted in faster progressions than intended. It would also be useful if an attempt could be made to make the programs transportable to other researchers to ease the process of external review and allow this model to be a possible choice for others doing projections.

RUP and RupHivAids

Since we were the developers of these modules, we are generally confident in the results. The fact that we were able to closely replicate the abcDIM results in Evaluation II is partial confirmation that the model is working as expected. However, some remaining differences require us to more closely examine each of the programs. One of the remaining differences in Evaluation II is in the levels of infant and child mortality. The RupHivAids calculations are quite detailed, being broken down by quarter years for the first year of life in order to replicate the separation factor of infant deaths and to try to match the RUP non-AIDS results as closely as possible. These infant and child mortality calculations need to be reviewed again in more detail to be sure they are being performed correctly. The RupHivAids infant mortality rates were

higher than the other models while the under-5 mortality rates matched those in abcDIM quite closely in Evaluation II. More generally, perhaps the approach to the mortality projection in RupHivAids (using the force of mortality) should be adopted by the RUP program in order to make the two programs more consistent and simplify some of these calculations.

The procedure currently used to split the incidence rate patterns (based on the Beers interpolation method) should be generalized more (e.g., by using splines) to allow more flexibility in the possible range of assumed incidence patterns. The splitting of the new infections into two half-year groups should be improved to allow for more change within each one-year period. Finally, the installation procedures and the user interfaces need to be made more user-friendly.

General Recommendations

We feel that all three programs (and the EPP program) need to clarify the interpretation of the EPP program output prevalence: does it refer to the 15- to 49-year-old or 15 years and older population? The other epidemiological inputs also need to be more clearly defined (e.g., clear specification of age groups covered by the parameters and whether sex ratios relate to rates or populations). The timing of events or flows (births, deaths, new infections) relative to stocks (populations, by age, sex, and various categories) needs to be more clearly defined and communicated to the user (e.g., calendar year x vs. the year ending at midyear x). This is true for all demographic and epidemiological inputs and outputs.

As evidenced by the different interpretations of available data, we feel that further research is needed on a number of the epidemiological inputs. First, there needs to be clarification of the available data on the survival curve of infected populations by duration of infection and clear development of estimates with background mortality removed. If this survival curve is separated into the infection-to-AIDS and AIDS-to-AIDS death components (as is done in the abcDIM and RupHivAids models), then research is needed into the AIDS to AIDS death distribution as a function of time since conversion to AIDS. More research is also needed on the age and sex distribution of the epidemic. While it is tempting to try to use directly the data on prevalence rates by age, such as are becoming available from some DHS and other surveys, we need to continue to get a better understanding of how incidence rates and prevalence rates by age and sex change over time and by the duration of the epidemic.

All of the programs would be more useful if there were more flexible output choices. This would include custom tables and graphs for user-selected age groups, years, and variables. Also the labeling of the output choices and results need to be as clear as possible, including the age groups involved (see above), the time references (see above) and whether the output is a rate or number (e.g., does the term "prevalence" mean "prevalence rate" or the number of infected people).

A final recommendation is that users of all three programs need to be reminded to review the results, both demographic and epidemiological, to make sure that they match the observed data as closely as possible. The current versions of the programs need to be recognized as part of an iterative process where the researcher tries to model the real world as closely as possible, not as

magic black boxes that when given the requisite data produce accurate models of the populations and processes involved (see the red arrows in Figure 22). This iterative process includes comparing the result of the model to observed data such as: census populations by age and sex; estimates of mortality based on data from censuses, surveys, and vital registration; or data on seroprevalence rates by age and sex from surveys such as the DHS. Since all of the data sources have sources of errors and the models do not perfectly represent the processes involved, the researcher should seek explanations for any differences between the model outputs and the observed data, and evaluate the need to update the model based on the findings.

RESOURCES

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Table 1. Summary of input population and demographic parameters

Projection Input Variables	Both sexes	Male	Female
Population projection horizon	1980-2010		
Base population	1,000,000	492,358	507,642
Growth rate (%)	0.00	0.00	0.00
Crude birth rate	20.61	21.24	20.00
Crude death rate	20.61	21.24	20.00
Sex ratio (male/female)			96.99
Life expectancy at birth		47.08	50.00
Infant mortality rate		139.42	118.79
Total fertility rate (TFR)	2.81		
Sex ratio at birth	1.03		

Table 2. Survival ratios from the Coale and Demeny model life table and those used in Abacus and DemProj

	Coale & Demeny West		Abacus		DemProj	
AGE	Males	Females	Male	Female	Male	Female
0-4	0.83657	0.85589	0.83694	0.85560	0.83657	0.85589
5-9	0.94355	0.94385	0.94356	0.94387	0.94355	0.94385
10-14	0.98344	0.98228	0.98338	0.98237	0.98344	0.98228
15-19	0.98165	0.98043	0.98183	0.98040	0.98165	0.98043
20-24	0.97359	0.97432	0.97330	0.97398	0.97359	0.97432
25-29	0.96733	0.96921	0.96698	0.96908	0.96733	0.96921
30-34	0.96339	0.96513	0.96356	0.96525	0.96339	0.96513
35-39	0.95728	0.96070	0.95740	0.96082	0.95728	0.96070
40-44	0.94815	0.95601	0.94805	0.95616	0.94815	0.95601
45-49	0.93584	0.94996	0.93593	0.95023	0.93584	0.94996
50-54	0.91779	0.93770	0.91788	0.93792	0.91779	0.93770
55-59	0.89148	0.91720	0.89140	0.91751	0.89148	0.91720
60-64	0.85258	0.88405	0.85197	0.88411	0.85258	0.88405
65-69	0.79631	0.83396	0.79458	0.83326	0.79631	0.83396
70-74	0.71969	0.76172	0.71604	0.75922	0.71969	0.76172
75-79	0.60754	0.65169	0.60713	0.65282	0.60754	0.65169
80-84	0.46596	0.51379	0.47002	0.51478	0.46596	0.51379
85-89	0.31944	0.35702	0.32828	0.37021	0.27538	0.30331
90-94	0.17649	0.20184	0.20381	0.24283		
95-99	0.07298	0.08495	0.11253	0.14578		
100+	0.01926	0.02243	0.05339	0.07808		

Sources:

Coale, A., P. Demeny and B. Vaughan. 1983. *Regional Model Life Tables and Stable Populations Second Edition.* New York: Academic Press.

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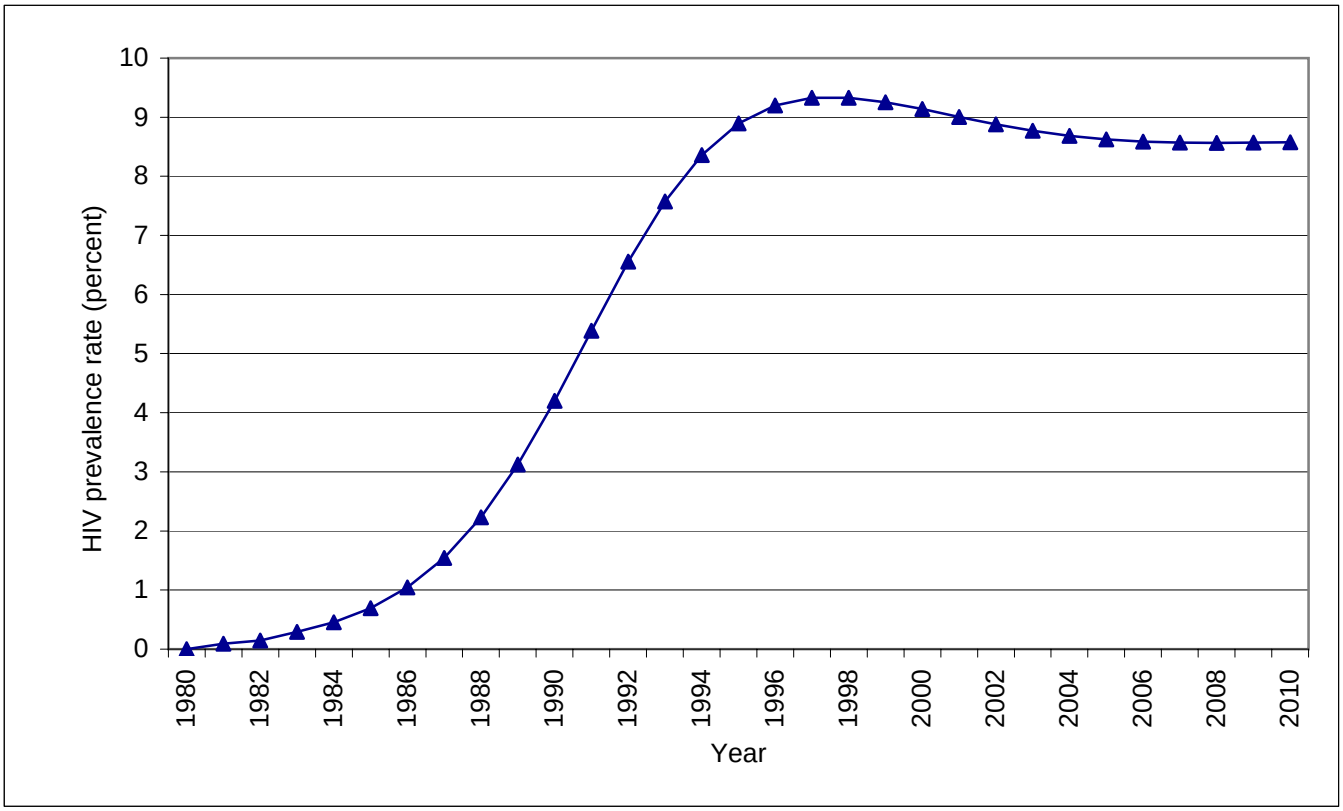
Figure 1. Tanzania adult HIV prevalence rate projections from EPP



Source: U.S. Census Bureau, 2004, unpublished worktable.

Table 3. Default epidemiological assumptions for the HIV/AIDS module (Evaluation I)

Input variables	Epidemiological module		
	RupHivAids	AIM	abcDIM
Prevalence rates	EPP for Tanzania: assumed to be 15-49	EPP for Tanzania: assumed to be 15-49	Fit to same data as EPP for Tanzania: assumed to be 15+
Prevalence pattern by age	N/A	Generalized epidemic pattern: ratio of prevalence rates to rate for 25-29	N/A
Prevalence by sex	N/A	Generalized epidemic pattern: sex ratio of prevalence rates 15-49 (female/male)	N/A
Incidence pattern by age	Based on Grassly estimates for Masaka, Uganda, 1990-94: split into single ages using Beers	N/A	Weibull curve of new infections: median age: male=29.05 female=26.13
Incidence by sex	Constructed to approximately duplicate AIM prevalence sex breakdown: sex ratio of new infections 15-49 (male/female)	N/A	AIM generalized epidemic pattern of prevalence: percent male of total incidence
Mother to child transmission	0.32	0.32	0.32
Adult HIV survival curve	Weibull curve to AIDS: median time: male=7.55 years female=8.40 years	Weibull curve to AIDS death: median time: male=8.6 years female=9.4 years	Weibull curve to AIDS: mean time: male=8.59 years female=9.41 years
Survival after AIDS conversion	Exponential function with mean 1 year (median=0.7)	Exactly one year	Weibull curve with median 1 year
Child HIV survival curve	Double Weibull curve to AIDS death: median time=2.1 years	Double Weibull curve to AIDS death: median time=2.1 years	Double Weibull curve to AIDS: median time=2.1 years
Fertility reduction by age	Reduction factors: 1.5 for 15-19 0.7 for 20-24 to 45-49	Reduction factors: 1.5 for 15-19 0.7 for 20-24 to 45-49	Reduction factors: 0.8 for 15-19 to 45-49

Table 4. Epidemiological assumptions for the RupHivAids and AIM HIV/AIDS module (Evaluation II)

	Epidemiological module		
Input variable	RupHivAids	AIM	abcDIM
Prevalence rates	abcDIM prevalence rates output for 15-49	abcDIM prevalence rates output for 15-49	Fit to same data as EPP for Tanzania: assumed to be 15+
Prevalence pattern by age	N/A	Based on abcDIM estimated prevalence rates: ratio of prevalence rates to rate for 25-29	N/A
Prevalence by sex	N/A	Based on abcDIM estimated prevalence rates: sex ratio of prevalence rates 15-49 (female/male)	N/A
Incidence pattern by age	Based on abcDIM output rates of incidence by sex: split into single ages using Beers	N/A	Weibull curve of new infections: median age: male=29.05 female=26.13
Incidence by sex	Based on abcDIM assumption for incidence by sex: ratio of new infections (male/female)	N/A	AIM generalized epidemic pattern of prevalence: percent male of total incidence
Mother to child transmission	0.32	0.32	0.32
Adult HIV survival curve	Weibull curve to AIDS: median time: male=7.69 female=8.45	Weibull curve to AIDS death: median time: male=8.69 female=9.45	Survival to AIDS: median time: male=7.69 female=8.45
Survival after AIDS conversion	Exponential function with survival times: mean = 1.0 median = 0.70	Exactly one year (implicit)	Approximate survival time: mean=0.75 years
Child HIV survival curve	Double Weibull curve to AIDS death: median time=2.1 years	Double Weibull curve to AIDS death: median time=2.1 years	Double Weibull curve to AIDS: median time=2.1 years
Fertility reduction by age	Reduction factors: 0.8 for 15-19 to 45-49	Reduction factors: 0.8 for 15-19 to 45-49	Reduction factors: 0.8 for 15-19 to 45-49

Figure 2. Default incidence pattern by age and sex for abcDIM and RupHivAids (Evaluation I)

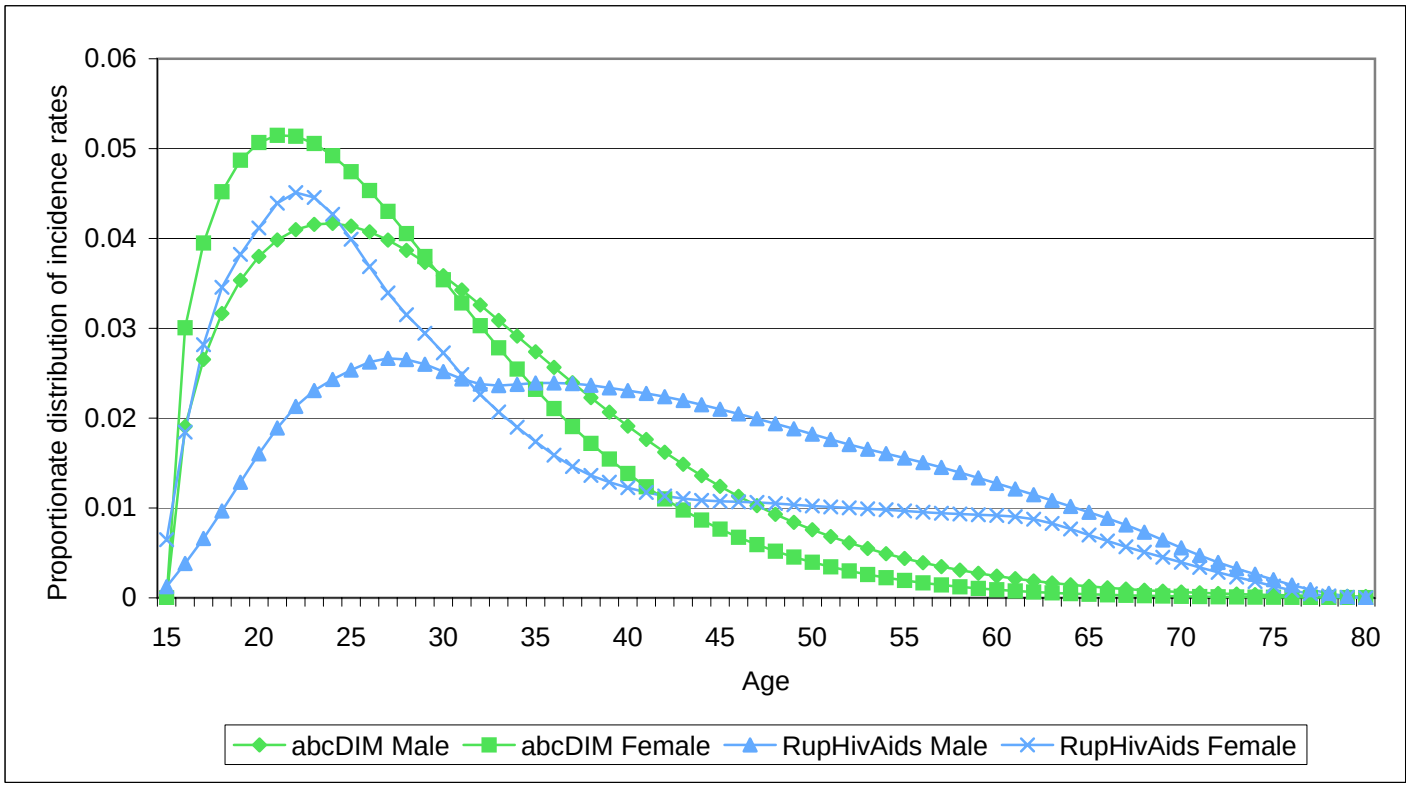


Table 5. Cumulative proportion converting to AIDS or AIDS death Weibull curve distributions (Evaluation I)

Years since infection	abcDIM		RupHivAids		AIM	
	Cumulative proportion converting to AIDS		Cumulative proportion converting to AIDS		Cumulative proportion dying of AIDS	
	Males	Females	Males	Females	Males	Females
Median years	8.59	9.41	7.55	8.40	8.60	9.40
0	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
1	0.00651	0.00180	0.01310	0.00377	0.00000	0.00000
2	0.02894	0.01127	0.05003	0.02042	0.03000	0.01000
3	0.06830	0.03271	0.10740	0.05418	0.07000	0.03000
4	0.12366	0.06891	0.18100	0.10660	0.12000	0.07000
5	0.19277	0.12115	0.26598	0.17694	0.19000	0.12000
6	0.27239	0.18908	0.35727	0.26242	0.27000	0.19000
7	0.35866	0.27067	0.45007	0.35856	0.36000	0.27000
8	0.44754	0.36236	0.54015	0.45984	0.45000	0.36000
9	0.53515	0.45949	0.62415	0.56042	0.54000	0.46000
10	0.61812	0.55687	0.69972	0.65492	0.62000	0.56000
11	0.69384	0.64948	0.76546	0.73916	0.69000	0.65000
12	0.76055	0.73310	0.82090	0.81046	0.76000	0.73000
13	0.81738	0.80481	0.86627	0.86781	0.82000	0.81000
14	0.86423	0.86319	0.90236	0.91164	0.86000	0.86000
15	0.90163	0.90829	0.93028	0.94348	0.90000	0.91000
16	0.93056	0.94133	0.95132	0.96545	0.93000	0.94000
17	0.95226	0.96425	0.96675	0.97984	0.95000	0.96000
18	0.96805	0.97930	0.97779	0.98879	0.97000	0.98000
19	0.97918	0.98862	0.98549	0.99407	0.98000	0.99000
20	0.98680	0.99408	0.99073	0.99701	0.99000	0.99000
21	0.99185	0.99709				
22	0.99511	0.99865				
23	0.99715	0.99941				
24	0.99838	0.99976				
25	0.99911	0.99991				
26	0.99952	0.99997				
27	0.99975	0.99999				
28	0.99987	1.00000				
29	0.99994	1.00000				
30	0.99997	1.00000				

NOTE: The reported AIM assumption is divided by 100 for comparison purposes.
Sources:
U.S. Census Bureau. 2004. RupHivAids.xls
Buettner, Thomas. 2005. Email Correspondence
Stover, John. 2005. pg. 15.

Table 6. Adult cumulative conversion from AIDS to AIDS death distributions (Evaluation I)

Years	abcDIM	RupHivAids	AIM
Median years	0.991	0.700	1.000
Mean years	**1.000**	**1.000**	**1.000**
0	0.000	0.000	0.000
1	0.509	0.632	1.000
2	0.997	0.865	1.000
3	1.000	0.950	1.000
4	1.000	0.982	1.000

Source:
United Nations Population Division, 2005, Email Correspondence
U.S. Census Bureau, 2004, RupHivAids.xls

Figure 3. Default AIM ratios of age-specific HIV prevalence rates to the prevalence rate for ages 25-29 by sex

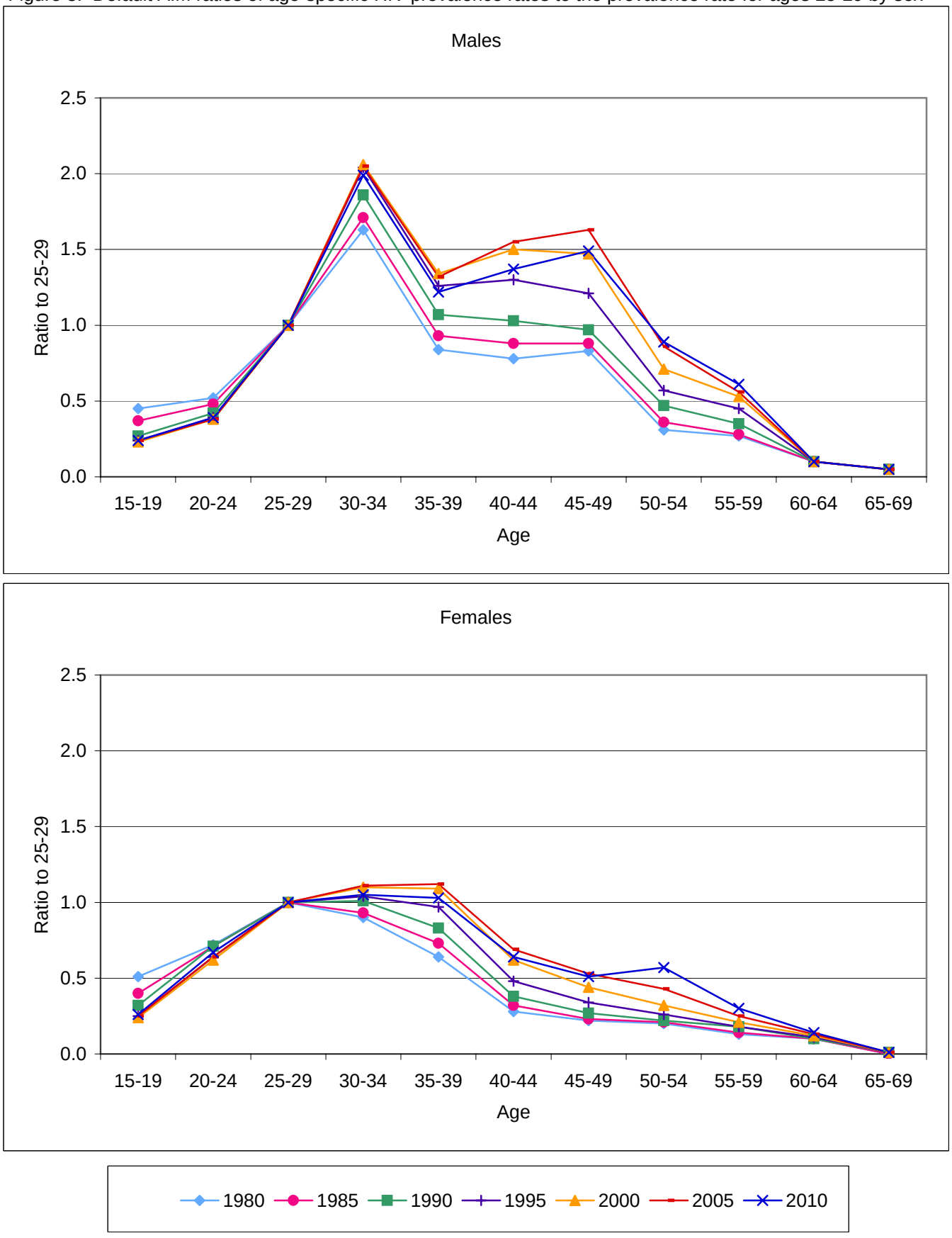


Figure 4. Cumulative proportion progressing from HIV infection to AIDS death

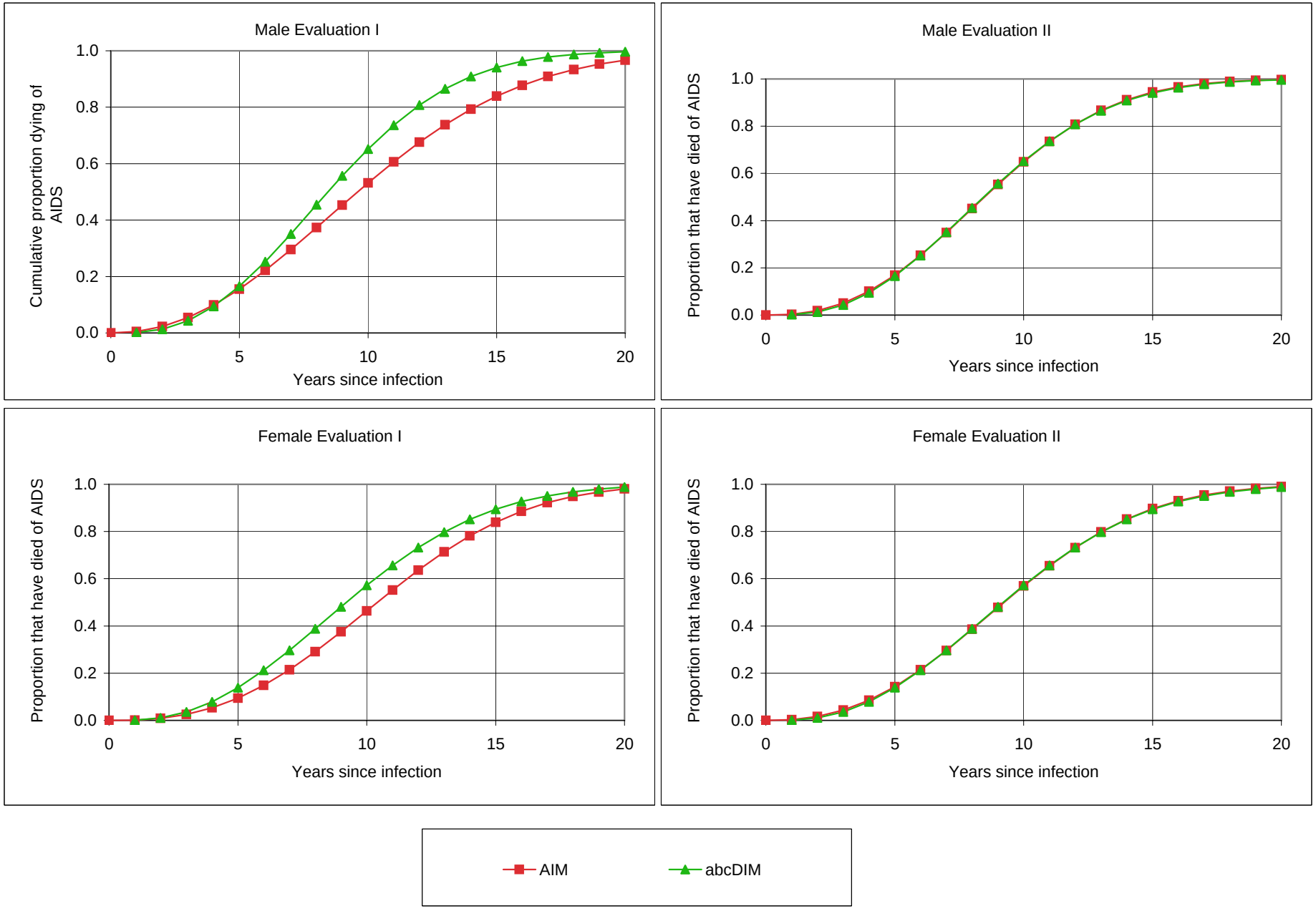


Table 7. Projected total population for each program and evaluation series.

	Demographic Projection			Epidemiological Evaluation I			Epidemiological Evaluation II		
Year	RUP	DemProj	Abacus	RupHivAids	AIM	abcDIM	RupHivAids	AIM	abcDIM
1980	1,000,000	1,000,000	999,999	1,000,000	1,000,000	999,999	1,000,000	1,000,000	999,999
1981	999,995	999,978	1,000,000	999,984	999,978	1,000,033	999,987	999,979	1,000,033
1982	999,982	999,857	1,000,003	999,967	999,856	1,000,039	999,957	999,847	1,000,039
1983	999,954	999,650	1,000,005	999,916	999,633	1,000,009	999,890	999,604	1,000,009
1984	999,915	999,370	1,000,004	999,807	999,323	999,946	999,769	999,249	999,946
1985	999,868	999,032	1,000,000	999,670	998,925	999,814	999,576	998,777	999,814
1986	999,819	998,650	999,992	999,469	998,438	999,602	999,285	998,175	999,602
1987	999,767	998,225	999,981	999,174	997,843	999,280	998,856	997,410	999,280
1988	999,712	997,765	999,966	998,742	997,113	998,729	998,235	996,442	998,729
1989	999,654	997,277	999,952	998,120	996,213	997,949	997,353	995,217	997,949
1990	999,597	996,773	999,937	997,225	995,094	996,833	996,125	993,666	996,833
1991	999,542	996,259	999,923	995,969	993,693	995,298	994,447	991,705	995,298
1992	999,486	995,740	999,911	994,248	991,929	993,220	992,201	989,233	993,220
1993	999,430	995,221	999,898	991,967	989,721	990,507	989,277	986,160	990,507
1994	999,375	994,707	999,885	989,035	987,000	987,039	985,585	982,413	987,039
1995	999,323	994,197	999,873	985,418	983,716	982,769	981,067	977,944	982,769
1996	999,274	993,694	999,860	981,099	979,849	977,687	975,708	972,748	977,687
1997	999,225	993,200	999,847	976,104	975,424	971,801	969,541	966,862	971,801
1998	999,176	992,716	999,834	970,526	970,494	965,233	962,646	960,364	965,233
1999	999,130	992,246	999,821	964,460	965,140	958,067	955,146	953,361	958,067
2000	999,087	991,780	999,808	958,028	959,466	950,406	947,186	945,972	950,406
2001	999,048	991,319	999,794	951,351	953,583	942,388	938,922	938,337	942,388
2002	999,010	990,862	999,780	944,578	947,608	934,199	930,502	930,587	934,199
2003	998,973	990,408	999,765	937,802	941,643	925,915	922,057	922,835	925,915
2004	998,936	989,958	999,750	931,099	935,770	917,690	913,696	915,175	917,690
2005	998,901	989,510	999,734	924,550	930,047	909,590	905,498	907,679	909,590
2006	998,867	989,065	999,717	918,188	924,504	901,687	897,512	900,392	901,687
2007	998,834	988,622	999,700	912,001	919,148	893,976	889,756	893,332	893,976
2008	998,801	988,179	999,682	906,033	913,967	886,516	882,232	886,499	886,516
2009	998,768	987,736	999,664	900,229	908,938	879,276	874,920	879,882	879,276
2010	998,735	987,296	999,644	894,606	904,036	872,222	867,798	873,460	872,222

Table 8. Time references for demographic measures

Item	RUP	DemProj	Abacus
ASFR/TFR	C	M \1	P
Births	C	M \2	P
e0/IMR	C	M \1	P
Deaths	C	M \3	P
Migrants	C	M-1 \4	P

C = Calendar year
M = Midyear t-1 to midyear t refered to as year t
M-1 = Midyear t-1 to midear t refered to as year t-1
P = 5-year period from midyear to midyear

1/ Input data for the first year are not used.
2/ Input ASFRs are multiplied by the population female population at the end of the period
Births for the first year are calculated but not used in the projection.
3/ Deaths for the first year are calculated but not used.
4/ Migration data for the last year are not used.

Table 9. Time references of epidemiological outputs

Item	RupHivAids	AIM	abcDIM
Stocks			
Prevalence	0.5	0.5	0.5
AIDS cases	0.5	0.5	
Flows			
Incidence	C or M	M	M-1
Infected births	C	M	M-1
AIDS deaths	C	M	M-1
New AIDS cases	C	M	M-1

0.5 = Stock at midyear
C = Calendar year
M = Midyear to midyear (displayed for the ending year)
M-1 = Midyear to midyear (displayed for the starting year)
P = 5-year period from midyear to midyear

Figure 5. Ratio of births to deaths from the demographic projections

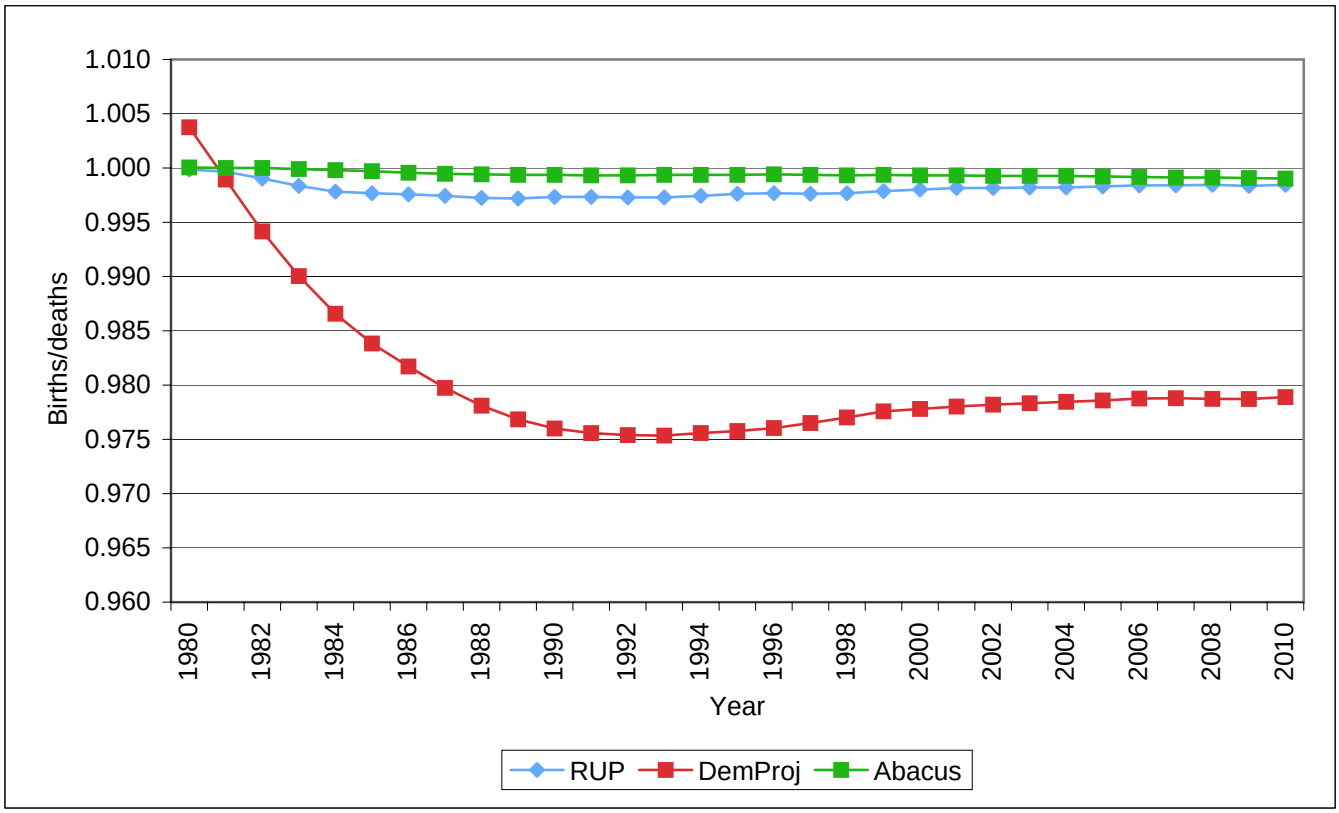
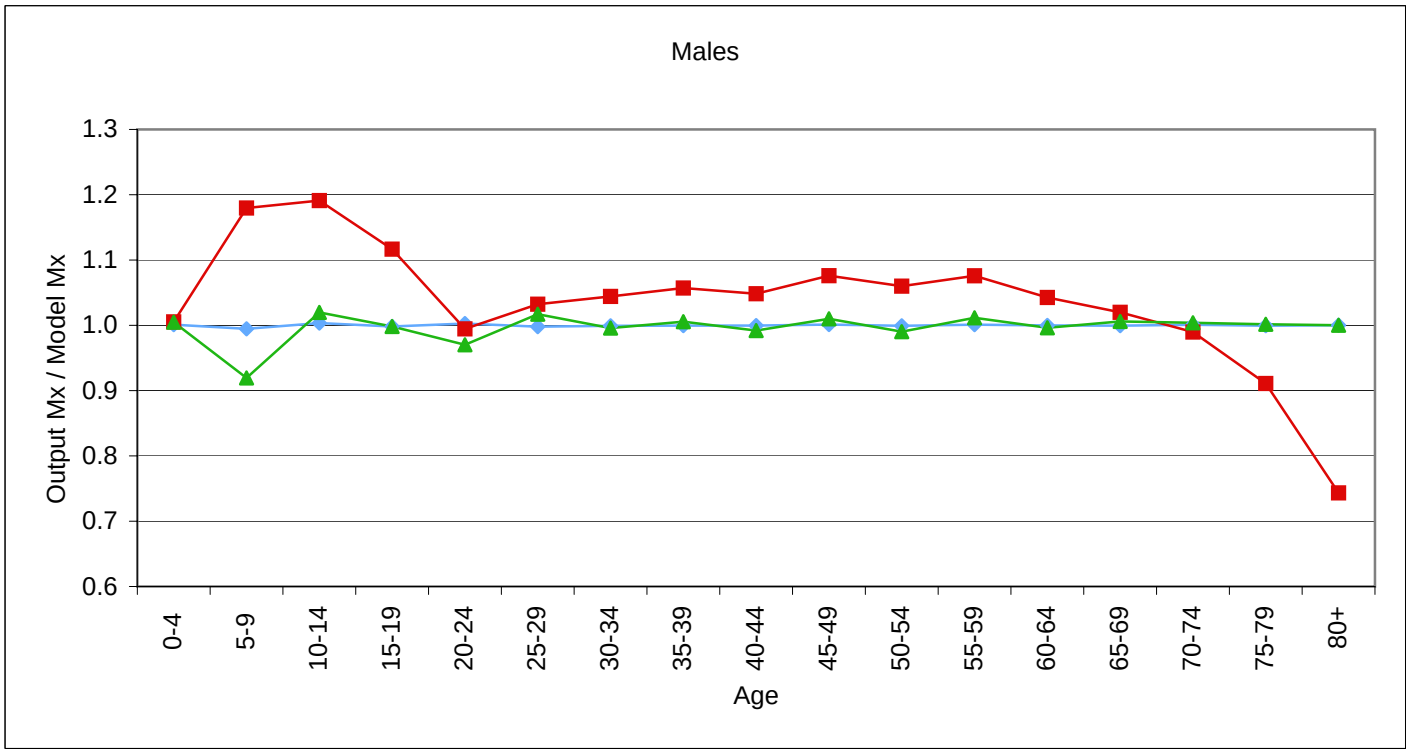


Figure 6. Ratio of output age-specific death rates (Mx) by sex from demographic projections to Coale, Demeny, and Vaughan (1983) West model level 13



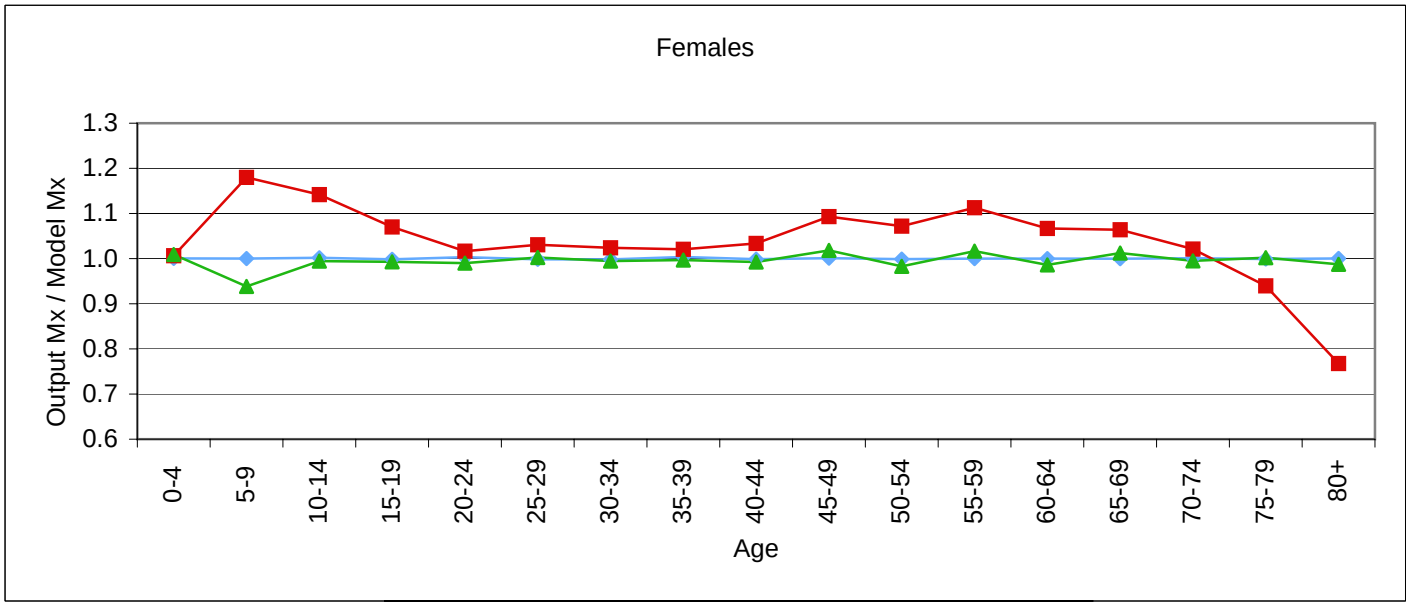
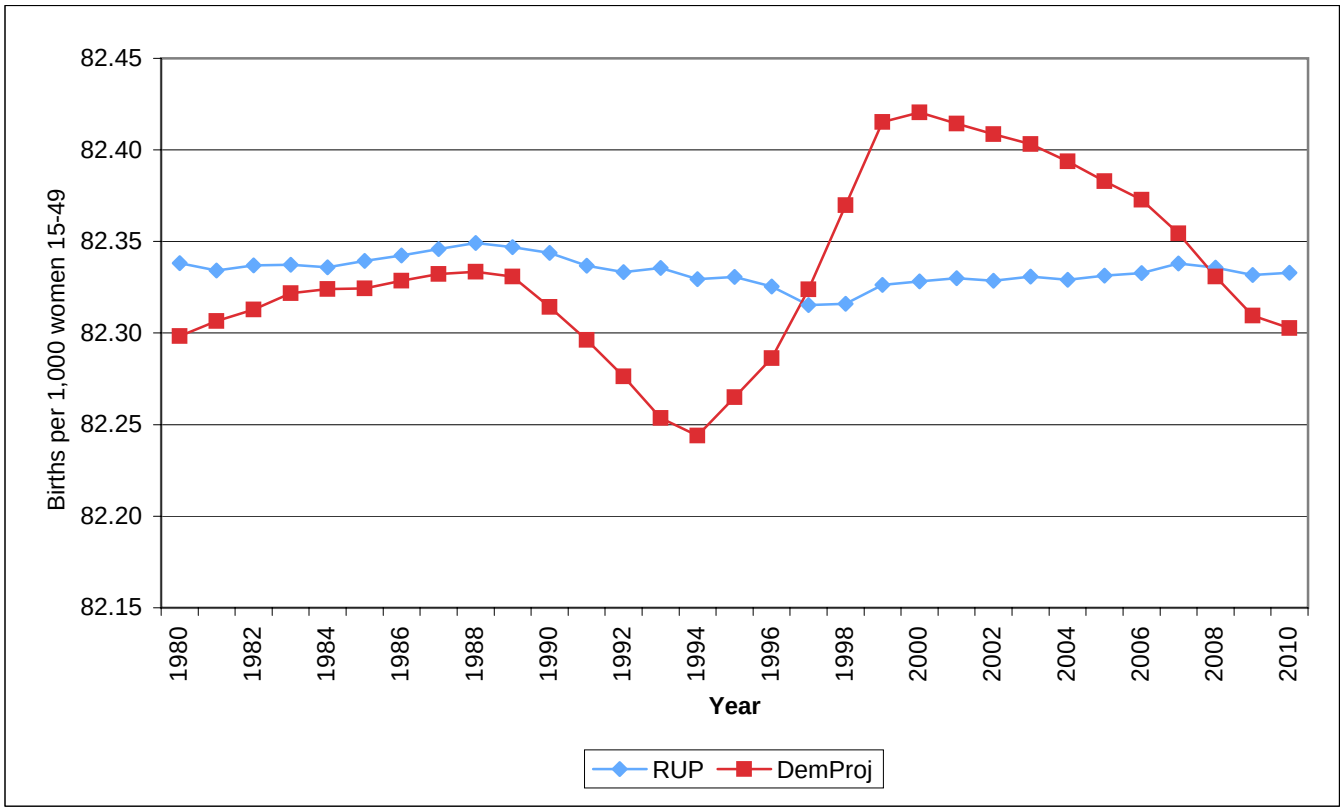


Figure 7. General fertility rate



NOTE: Abacus results not available.

Table 10. Estimated mortality statistics for each evaluation

Year	e0-Males			e0-Females		
	RUP - RupHivAids	DemProj - AIM	Abacus - abcDIM	RUP - RupHivAids	DemProj - AIM	Abacus - abcDIM
Demographic Projection						
1982	47.05	47.10	47.08	49.97	50.00	50.00
2007	47.05	47.10	47.08	49.97	50.00	50.00
Epidemiological Evaluation I						
1982	47.05	47.30	46.83	49.96	50.20	49.89
1987	46.54	46.90	45.73	49.62	49.90	49.27
1992	44.51	45.00	42.72	47.21	48.00	45.98
1997	41.59	41.80	39.32	42.58	43.50	40.68
2002	40.70	40.60	38.46	40.35	41.00	38.11
2007	40.91	40.80	38.84	40.69	41.60	38.39
Epidemiological Evaluation II						
1982	47.01	47.30	46.83	49.96	50.20	49.89
1987	46.17	46.40	45.73	49.39	49.70	49.27
1992	43.31	43.50	42.72	46.28	46.60	45.98
1997	39.25	39.20	39.32	40.86	41.00	40.68
2002	37.98	37.90	38.46	38.22	38.00	38.11
2007	38.67	38.80	38.84	38.39	38.20	38.39

Table 10. Estimated mortality statistics for each evaluation--Continued

Year	1q0-Males			1q0-Females		
	RUP - RupHivAids	DemProj - AIM	Abacus - abcDIM	RUP - RupHivAids	DemProj - AIM	Abacus - abcDIM
Demographic Projection						
1982	140.17	139.30	139.77	118.79	118.30	119.05
2007	140.17	139.30	139.77	118.79	118.30	119.05
Epidemiological Evaluation I						
1982	140.19	139.30	139.78	118.78	118.40	119.06
1987	141.30	140.00	140.34	119.92	119.00	119.58
1992	146.04	142.90	142.06	124.79	122.00	121.47
1997	149.24	145.40	143.52	128.14	124.50	123.00
2002	148.77	145.10	143.41	127.78	124.10	122.93
2007	148.57	144.70	143.23	127.41	123.80	122.70
Epidemiological Evaluation II						
1982	140.29	139.40	139.78	118.89	118.50	119.06
1987	141.92	140.50	140.34	120.55	119.50	119.58
1992	148.39	144.50	142.06	127.22	123.50	121.47
1997	153.39	147.80	143.52	132.44	126.80	123.00
2002	152.79	147.30	143.41	131.89	126.30	122.93
2007	152.21	146.70	143.23	131.17	125.80	122.70

Table 10. Estimated mortality statistics for each evaluation--Continued

Year	5q0-Males			5q0-Females		
	RUP - RupHivAids	DemProj - AIM	Abacus - abcDIM	RUP - RupHivAids	DemProj - AIM	Abacus - abcDIM
Demographic Projection						
1982	201.55	201.30	201.17	182.53	182.50	182.87
2007	201.55	201.30	201.17	182.53	182.50	182.87
Epidemiological Evaluation I						
1982	201.53	201.40	206.46	182.57	182.60	186.83
1987	202.96	202.20	208.18	183.82	183.40	188.10
1992	209.58	206.10	214.57	190.73	187.30	195.05
1997	215.76	210.50	221.81	197.15	191.70	202.49
2002	215.54	210.30	222.72	197.14	191.60	203.47
2007	215.03	209.70	221.96	196.40	191.00	202.60
Epidemiological Evaluation II						
1982	201.62	201.50	206.46	182.66	182.60	186.83
1987	203.75	202.90	208.18	184.73	184.10	188.10
1992	212.76	208.40	214.57	194.11	189.60	195.05
1997	222.19	214.30	221.81	203.79	195.60	202.49
2002	222.31	214.10	222.72	204.11	195.40	203.47
2007	221.17	213.10	221.96	202.65	194.30	202.60

Figure 8. Estimated adult HIV prevalence rates for ages 15 to 49 (Evaluation I)

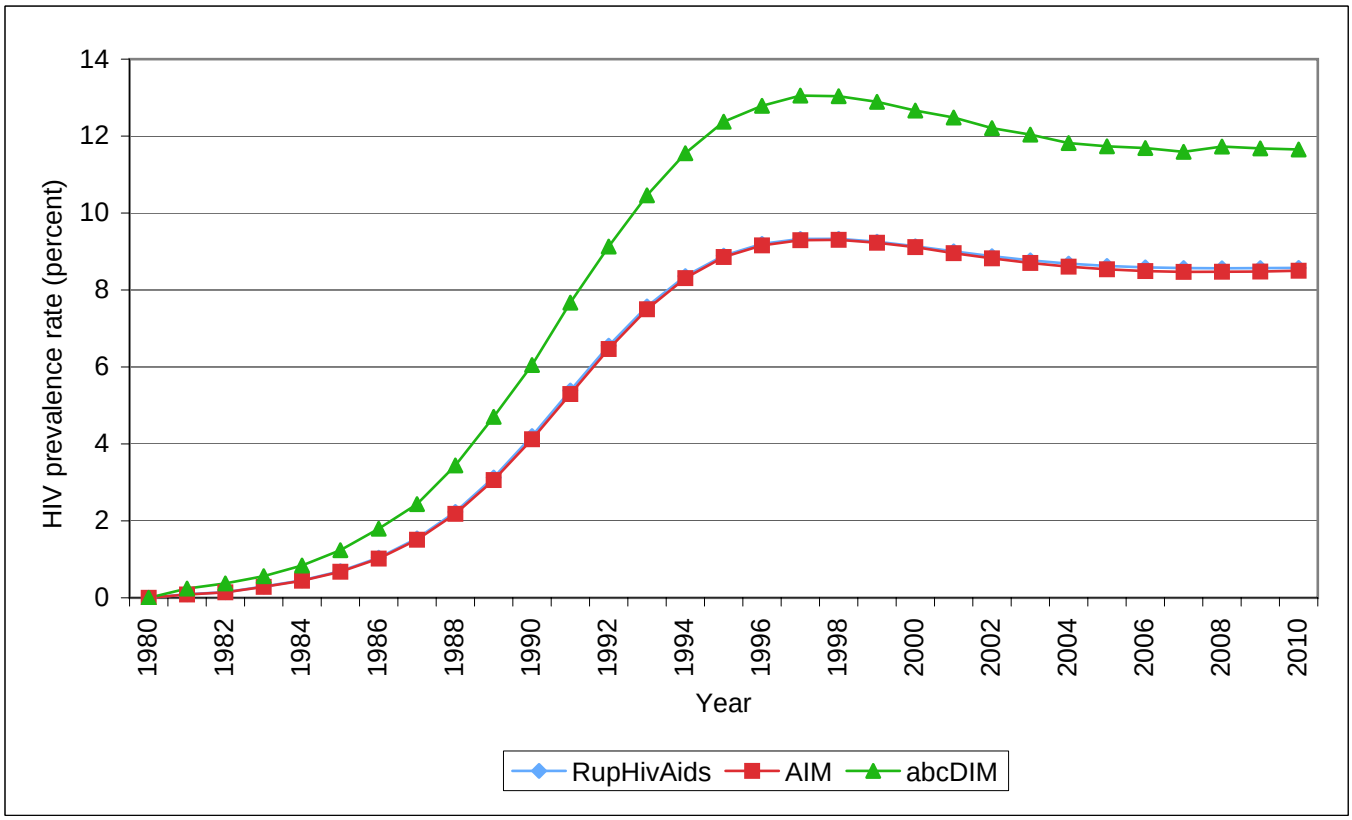


Figure 9. Estimated incidence by age and sex for 1990 and 2010 (Evaluation I)

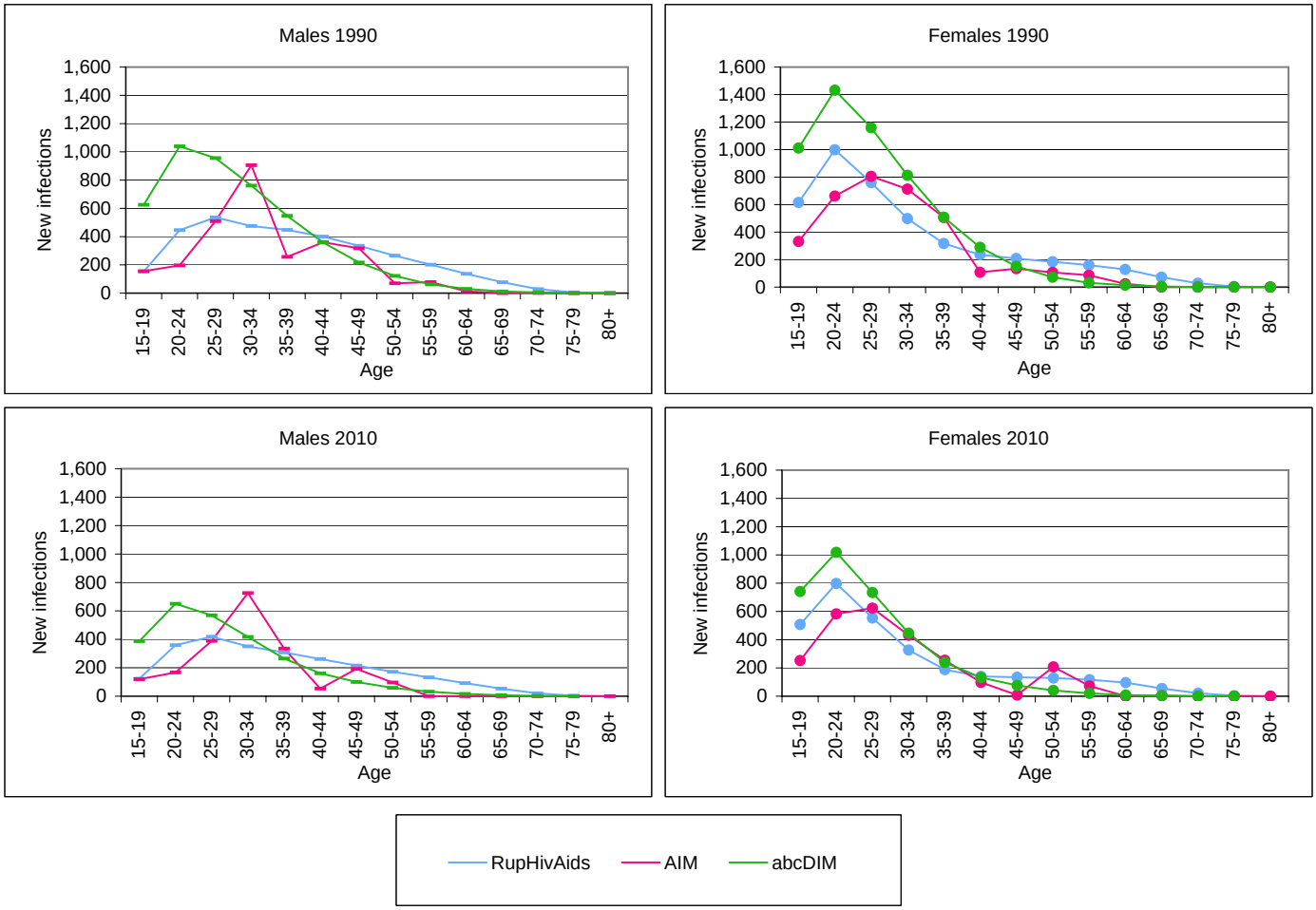


Figure 10. Estimated HIV prevalence rates by age and sex (Evaluation I)

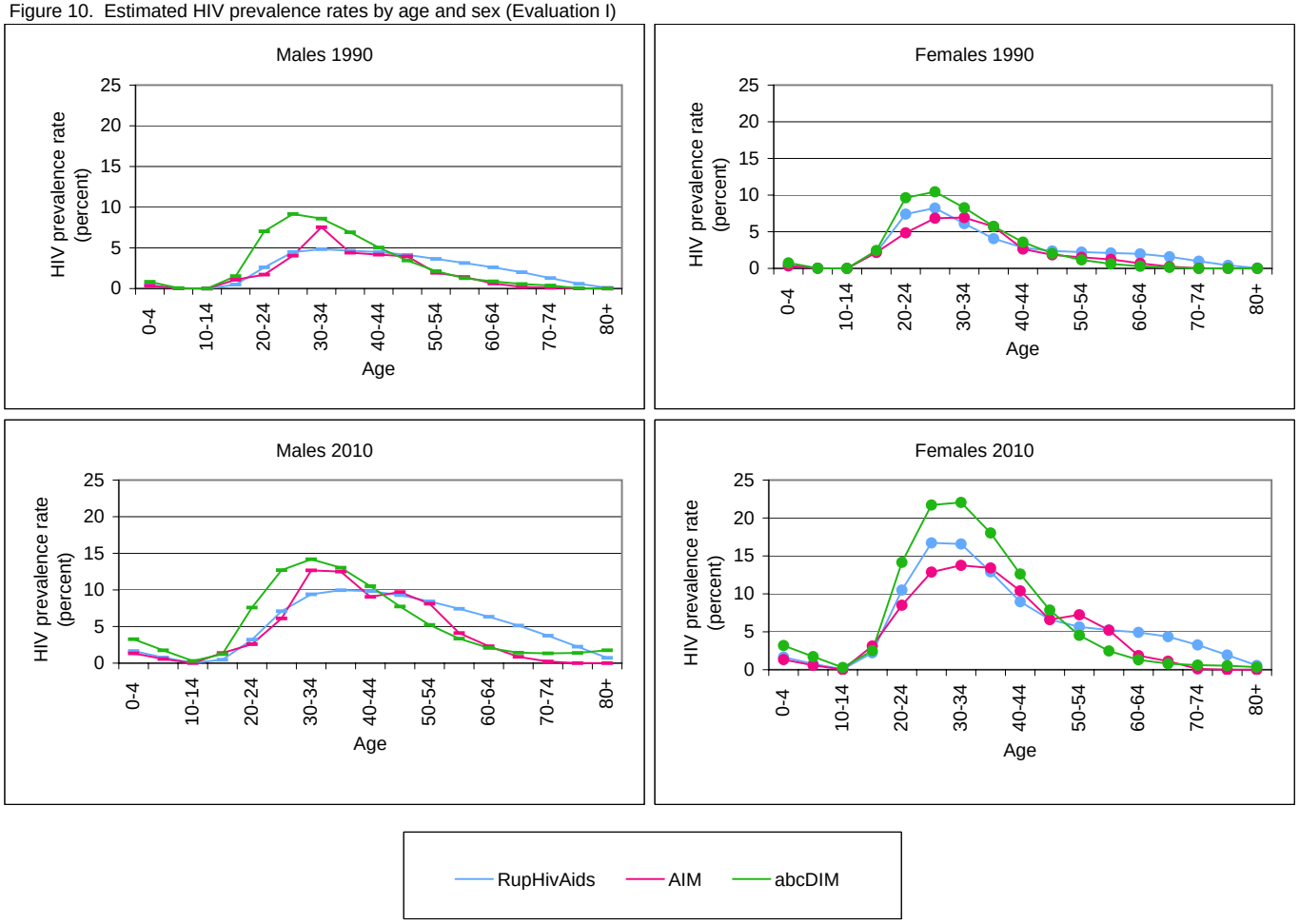
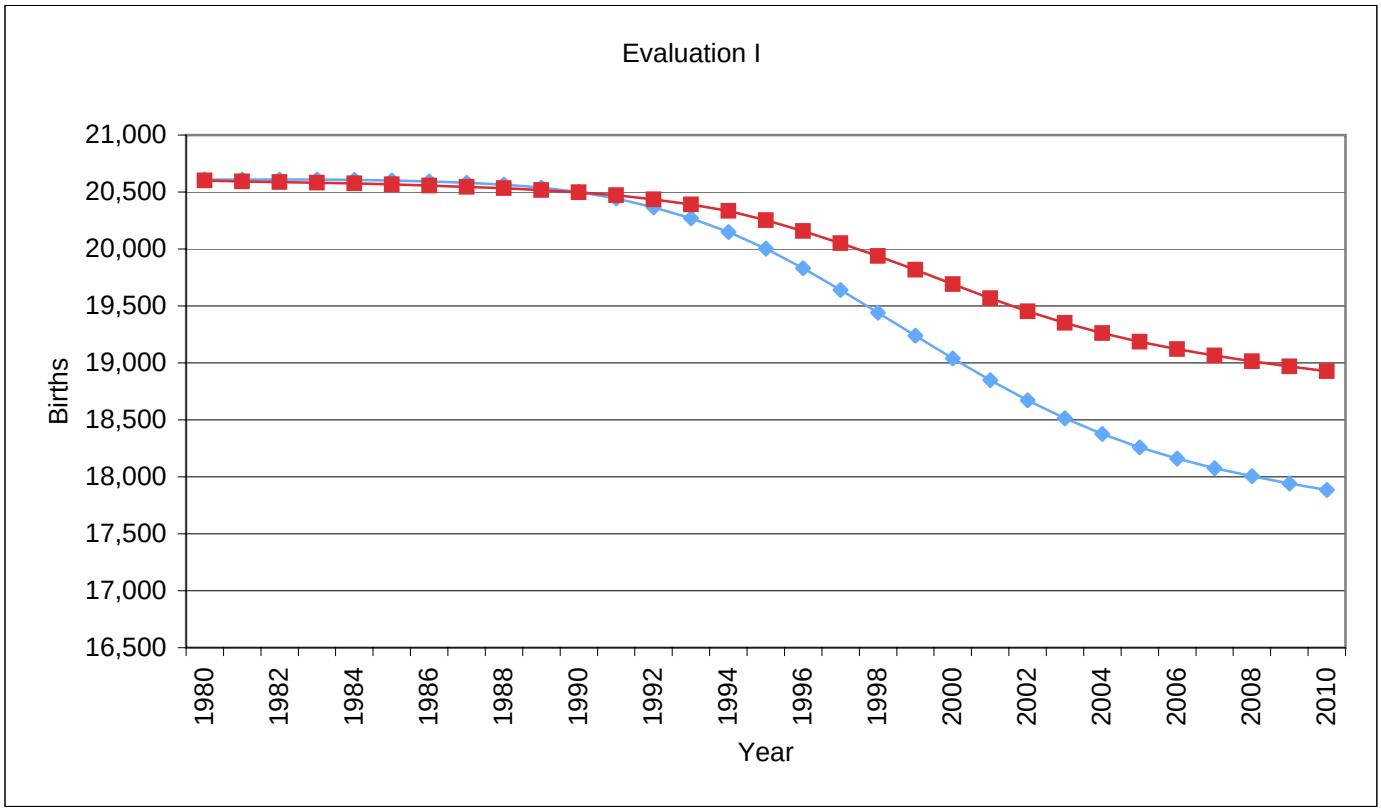


Figure 11. Projected births (Evaluation I and II)



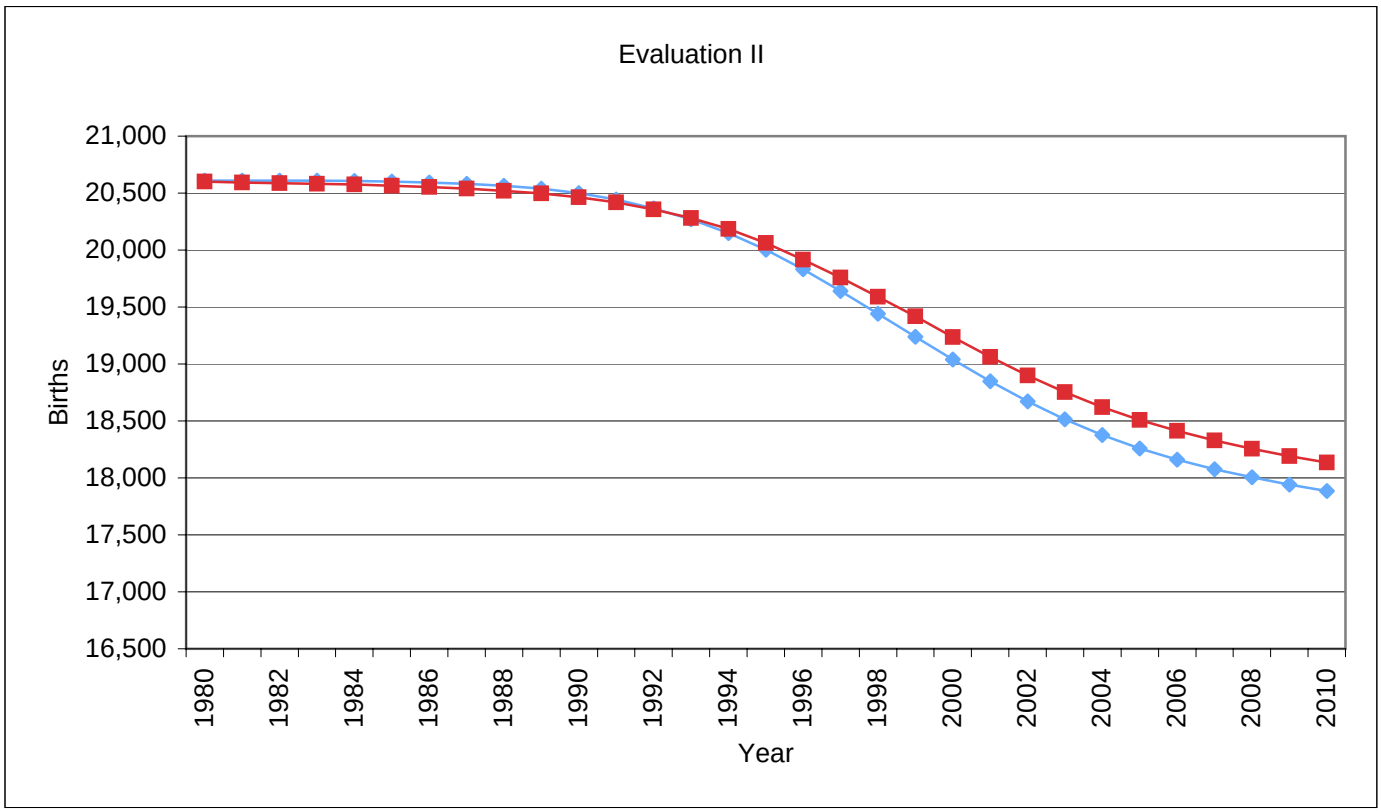


Figure 12. Estimated infected births (Evaluation I)

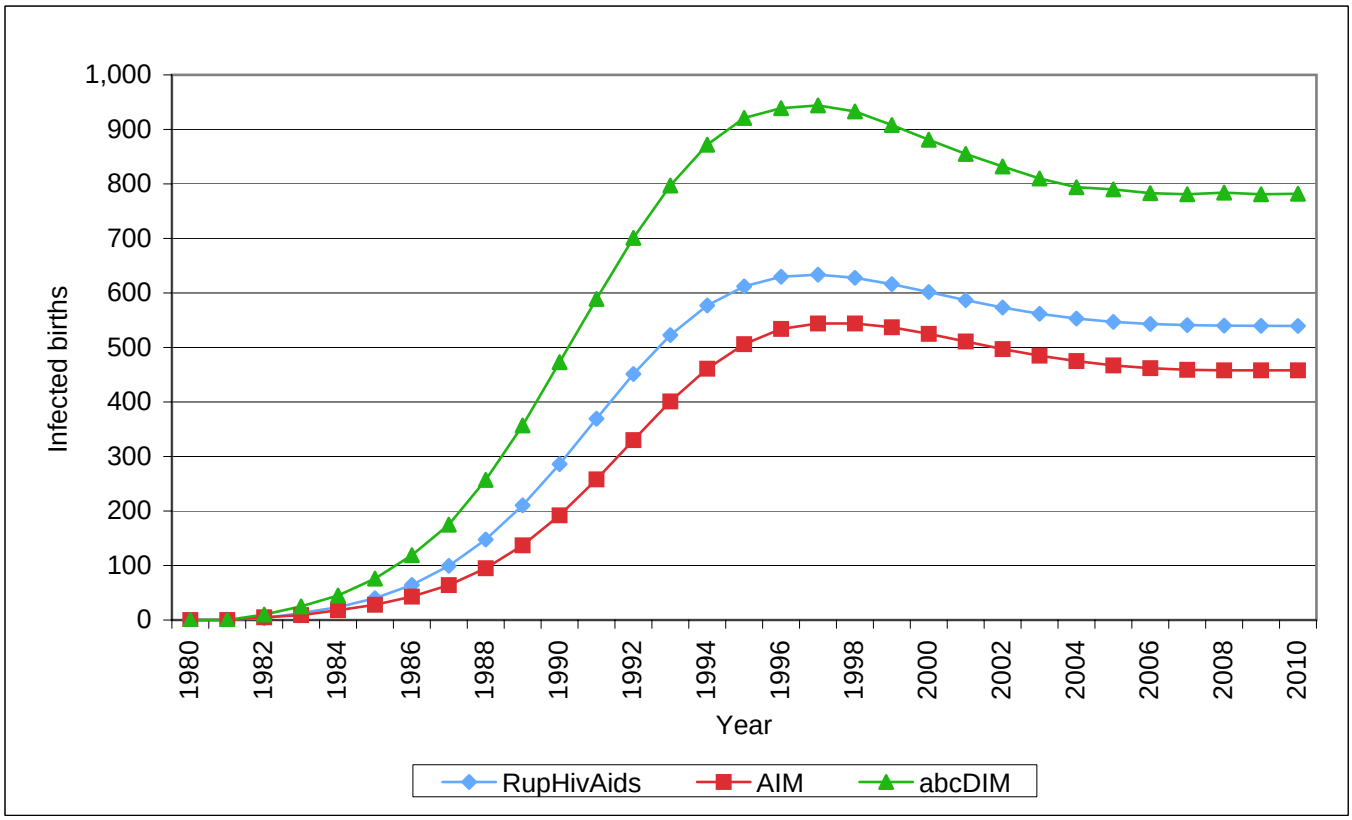


Figure 13. The ratio of infected births to infected women ages 15 to 49 (Evaluation I)

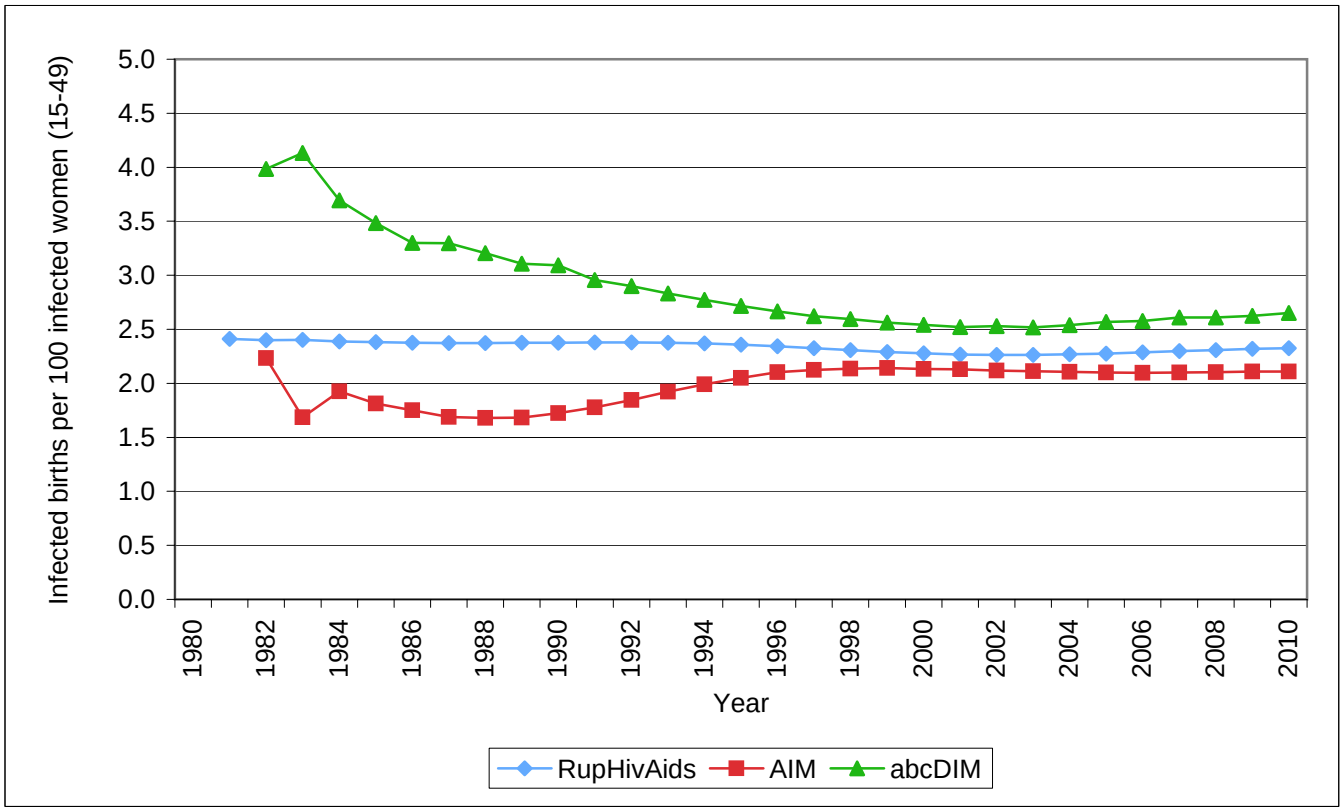


Figure 14. AIDS age-specific death rates by sex for 1990 and 2010 (Evaluation I)

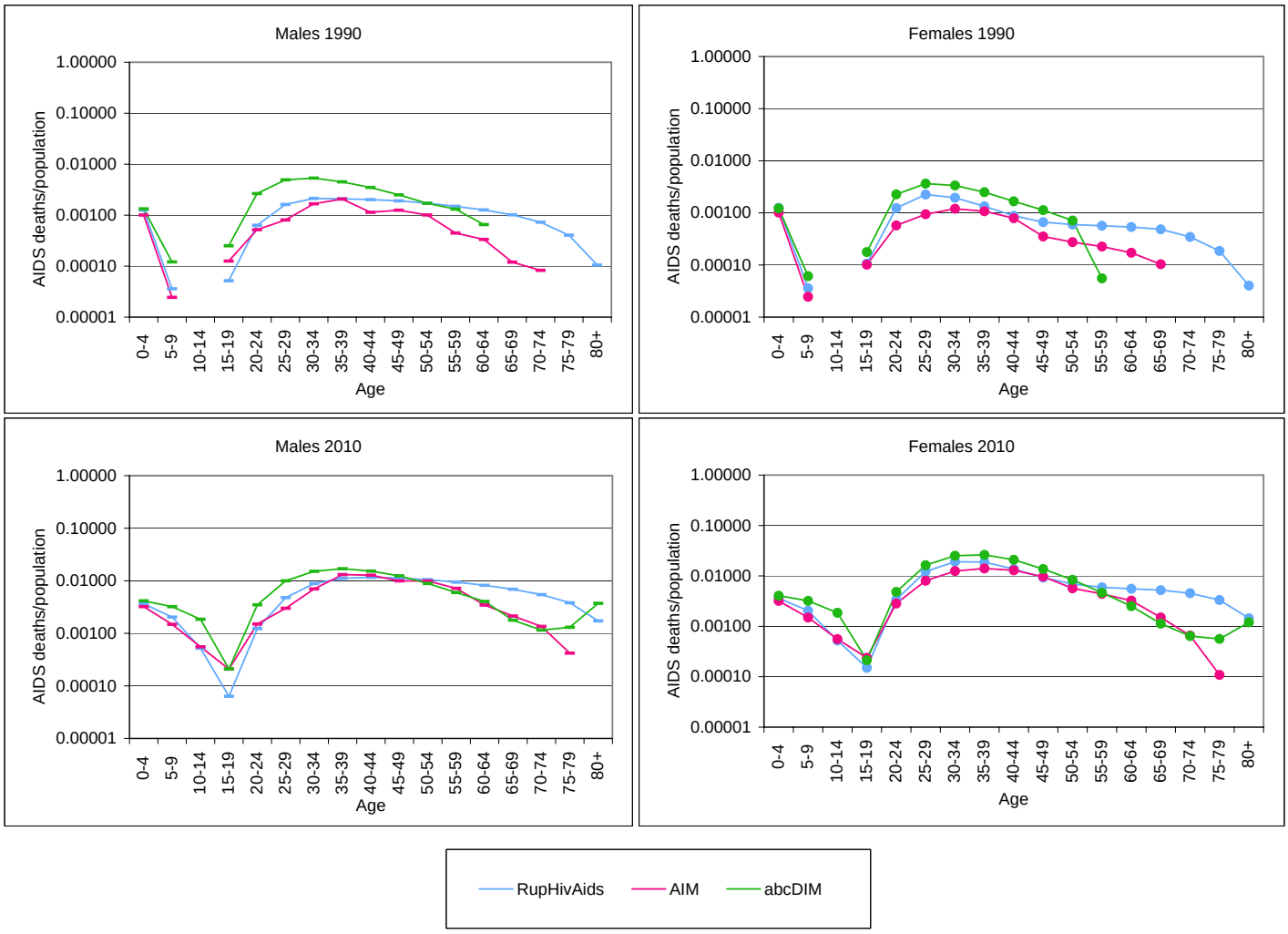


Figure 15. Ratio of AIDS deaths to non-AIDS deaths (Evaluation I)

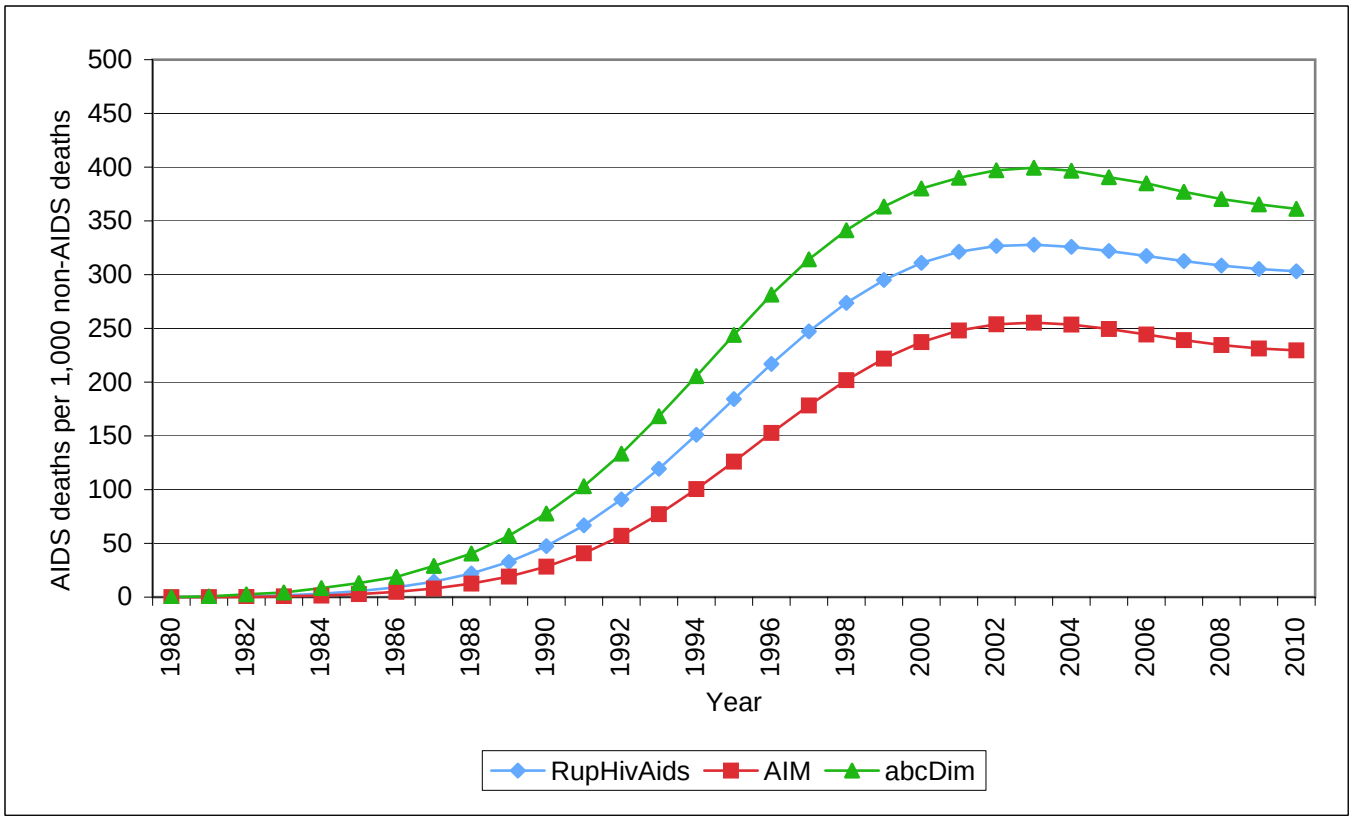


Figure 16. Estimated population sex ratio (Evaluation II)

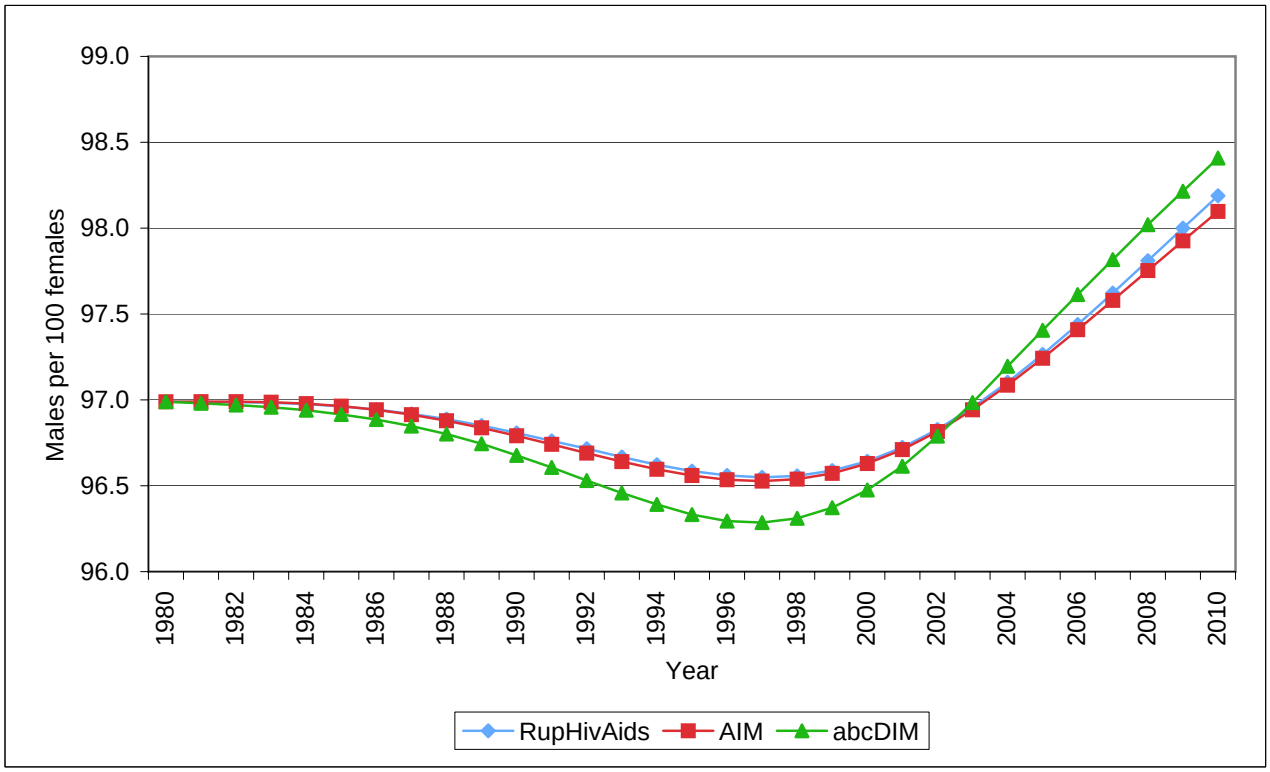


Figure 17. Estimated HIV incidence by sex and age for 1990 and 2010 (Evaluation II)

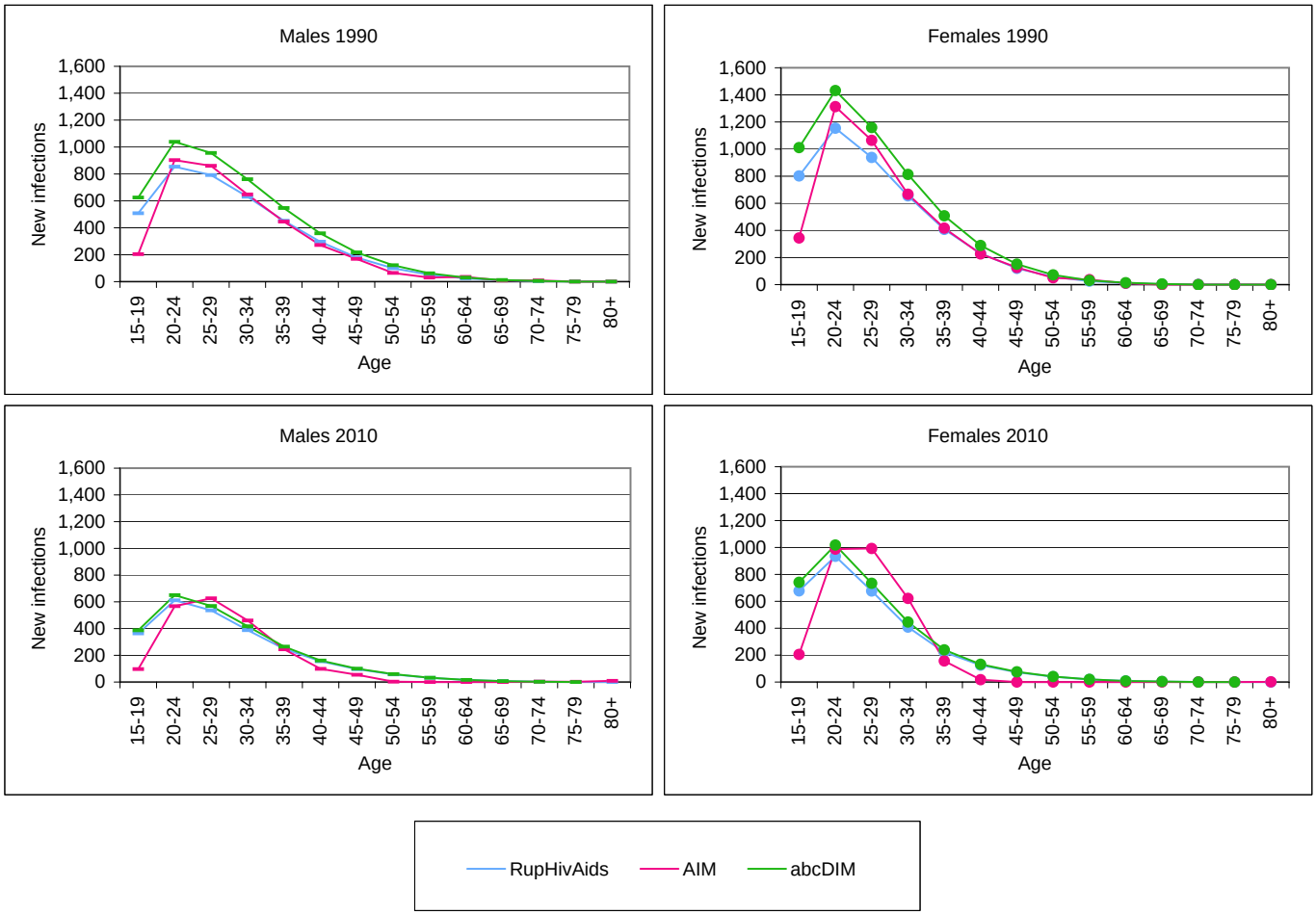


Figure 18. Estimated HIV prevalence rates by age and sex (Evaluation II)

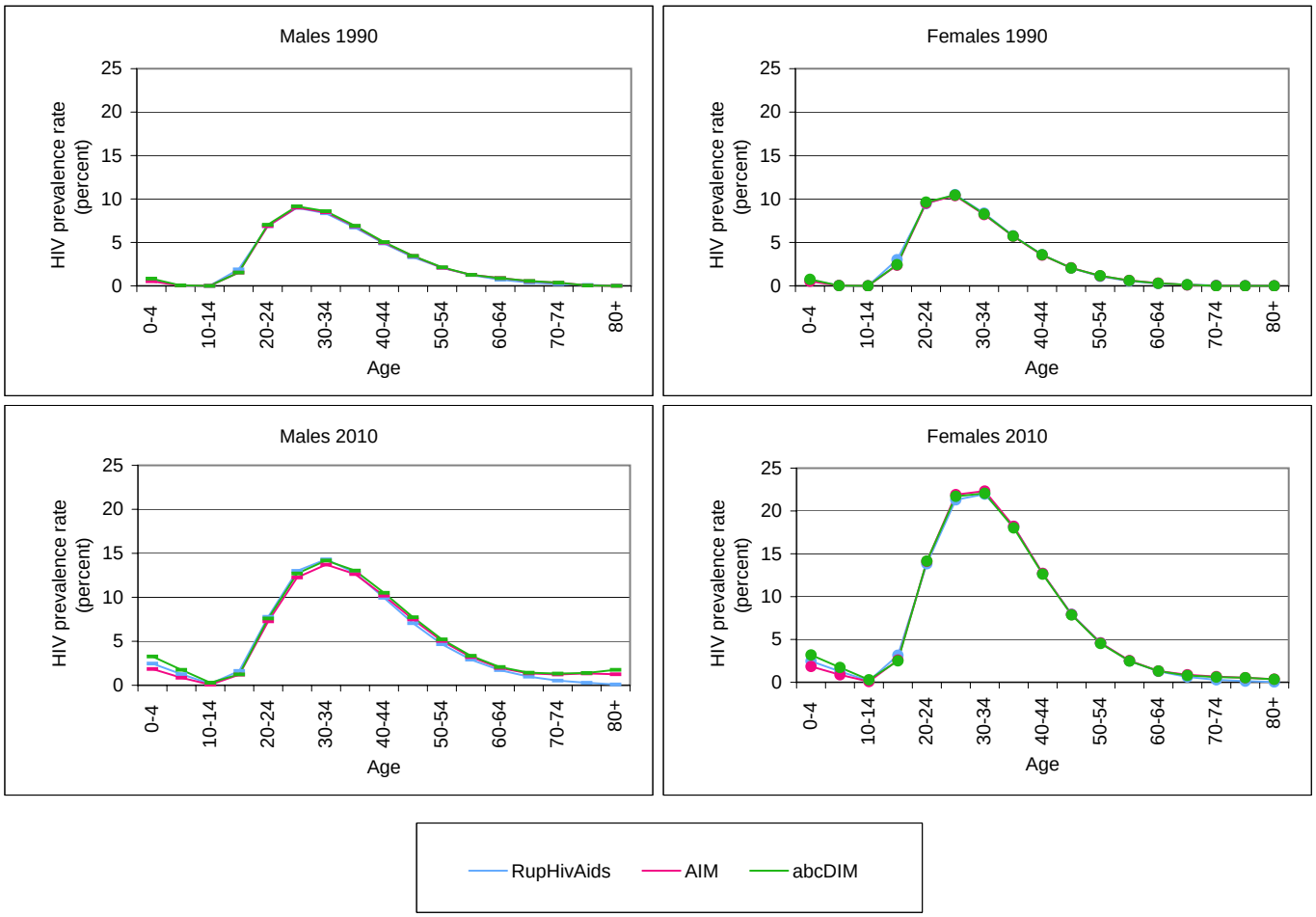


Figure 19. Ratio of infected births to infected women ages 15 to 49 (Evaluation II)

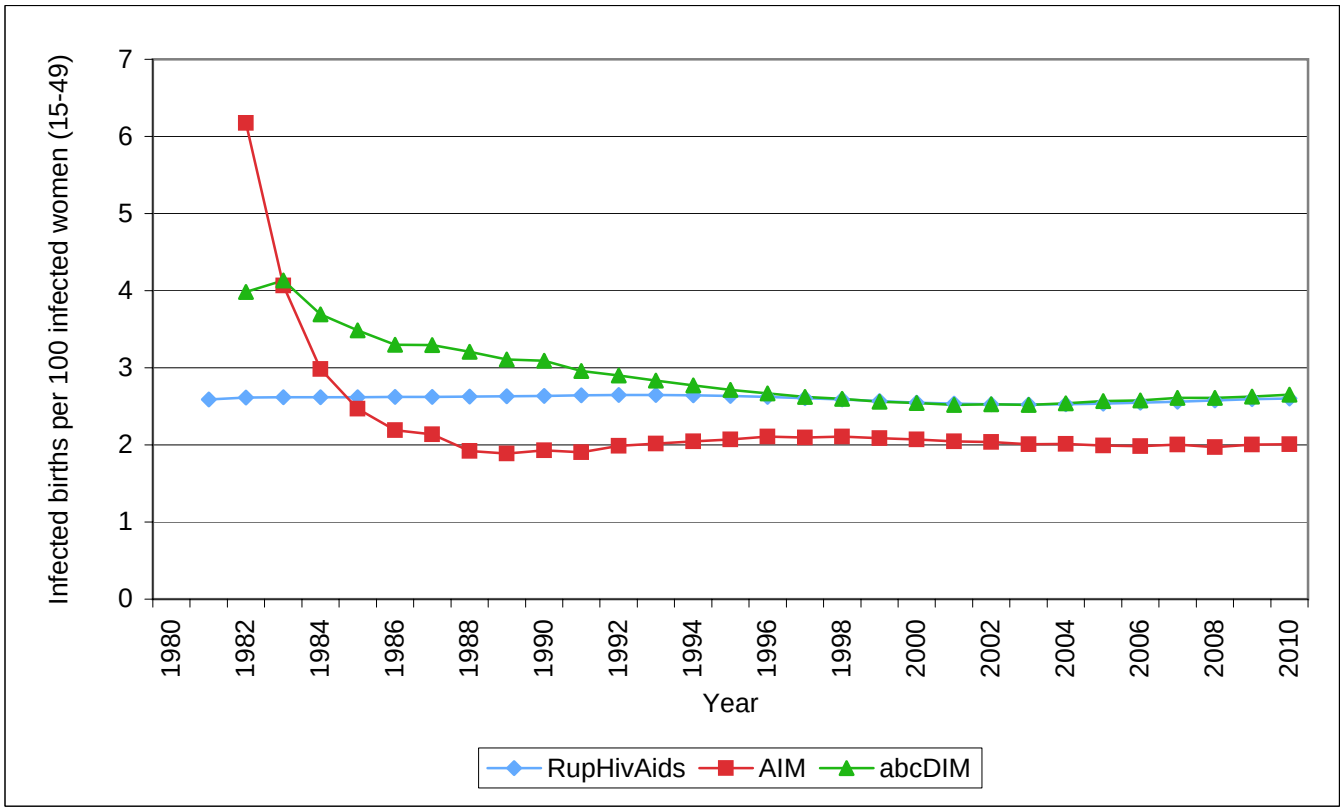


Table 11. Cumulative proportion converting to AIDS or AIDS death Weibull curve distributions (Evaluation II)

Years since infection	RupHivAids		AIM	
	Cumulative proportion converting to AIDS		Cumulative proportion dying of AIDS	
	Males	Females	Males	Females
Median years	7.69	8.45	8.69	9.45
0	0.00000	0.00000	0.00000	0.00000
1	0.00651	0.00564	0.00500	0.00400
2	0.03138	0.02661	0.02400	0.02100
3	0.07742	0.06506	0.05900	0.05100
4	0.14409	0.12071	0.11100	0.09500
5	0.22832	0.19162	0.17800	0.15200
6	0.32517	0.27445	0.25700	0.22000
7	0.42853	0.36497	0.34500	0.29700
8	0.53205	0.45857	0.43700	0.37900
9	0.62997	0.55070	0.52800	0.46300
10	0.71778	0.63742	0.61500	0.54500
11	0.79262	0.71566	0.69500	0.62300
12	0.85333	0.78347	0.76600	0.69500
13	0.90026	0.83999	0.82500	0.75900
14	0.93485	0.88532	0.87300	0.81400
15	0.95915	0.92034	0.91100	0.86000
16	0.97543	0.94639	0.93900	0.89700
17	0.98584	0.96507	0.96000	0.92600
18	0.99219	0.97798	0.97400	0.94800
19	0.99588	0.98657	0.98400	0.96500
20	0.99792	0.99208	0.99100	0.97700

NOTE: The AIM assumption is divided by 100 for comparison purposes.

Figure 20. AIDS age-specific death rates by sex for 1990 and 2010 (Evaluation II)

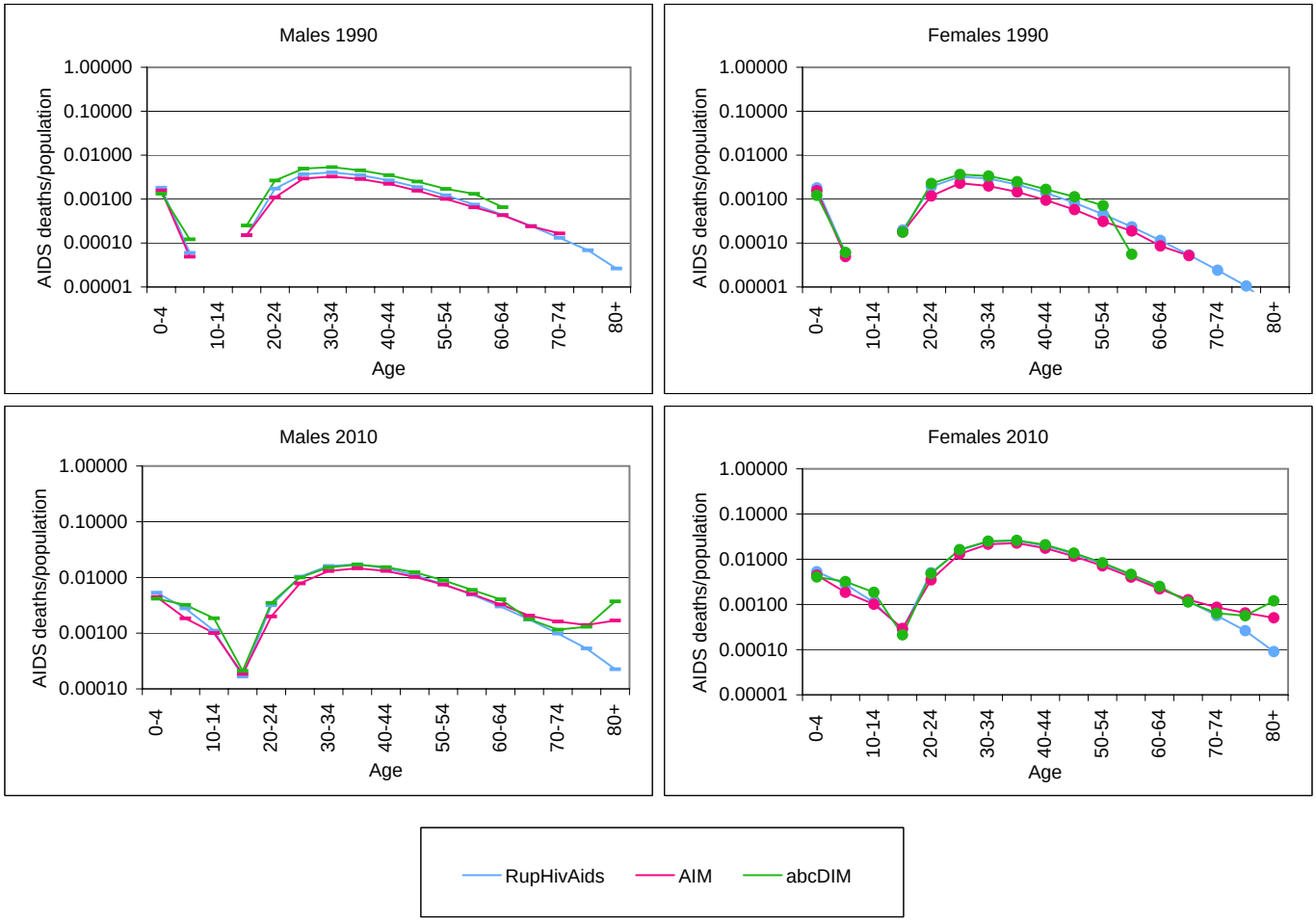


Figure 21. Non-AIDS age-specific death rates by sex for 1990 and 2010 (Evaluation II)

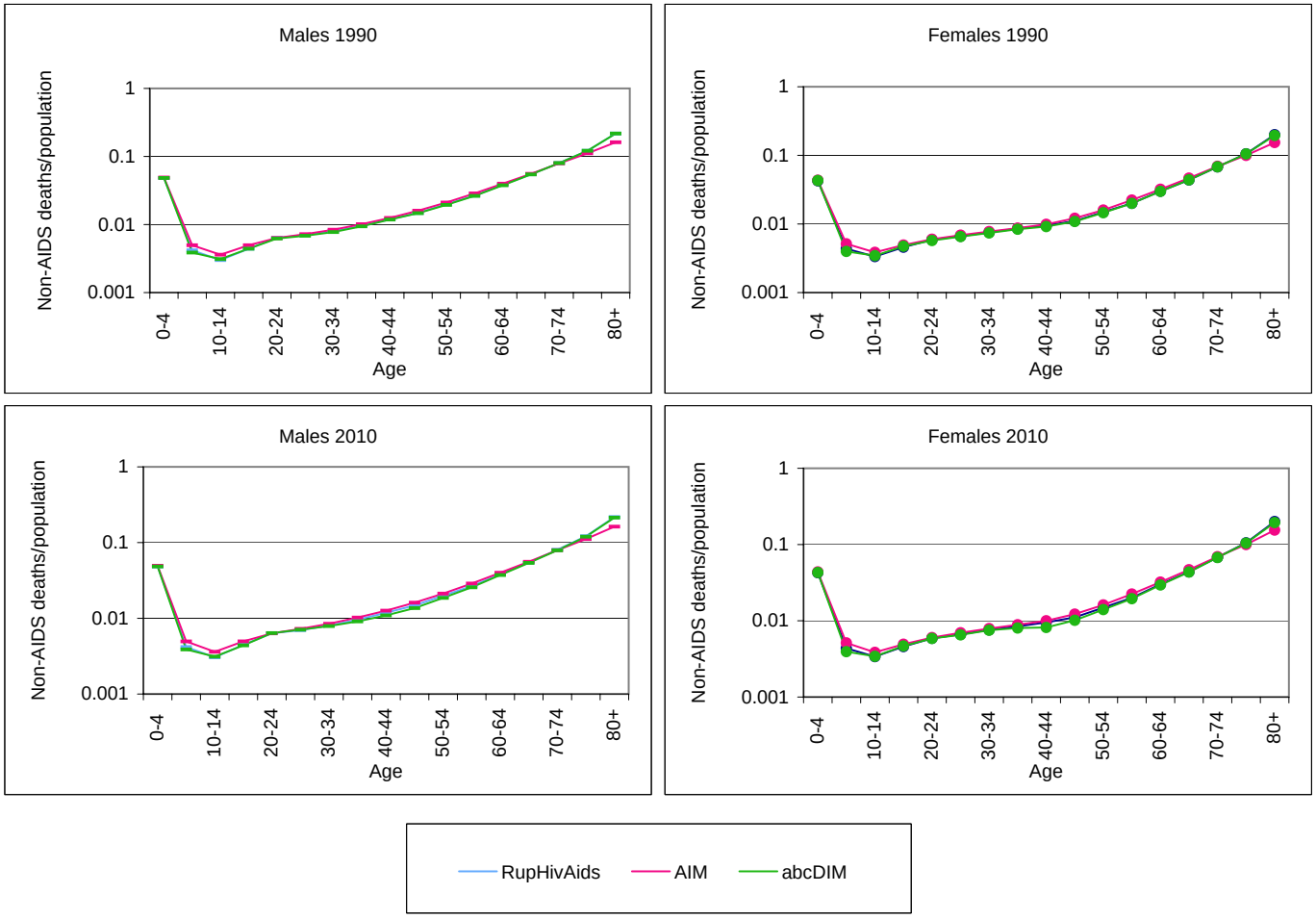


Figure 22. Iterative process of developing population projections that include the impact of HIV/AIDS