# Demographic Consequences of HIV Epidemics and Effects of Different Male Circumcision Intervention Designs: Suggestive Findings from Microsimulation

# ABSTRACT

Three randomized controlled trials in South Africa, Kenya and Uganda have demonstrated that male circumcision reduces female-to-male HIV transmission, estimating an incidence rate ratio of roughly 0.55 comparing circumcised to uncircumcised men. Using a microsimulation model this work investigates the demographic consequences of an HIV epidemic and the *population-level* effects of different male circumcision intervention designs. Sixteen different male circumcision interventions are applied to virtual populations to (1) understand the relationship between demographic and disease processes in HIV epidemics, (2) characterize the relationship between coverage and effectiveness of male circumcision interventions, (3) compare interventions targeted at different age groups, and (4) demonstrate approximate equity in intervention outcomes for both sexes resulting from male circumcisions that directly affect only males. The results broadly confirm that male circumcision can reduce the incidence and prevalence of HIV, but that eradication of an HIV epidemic through male circumcision alone is unlikely. Alternative intervention designs produce very different effects. The best equilibrium results are obtained when the majority of men become circumcised at ages before sexual debut, but initially targeting sexually active males yields a more immediate impact of the intervention. Finally, age rather than sex appears to be the dimension along which there is potential for inequities in intervention effect.

# KEY WORDS

‘male circumcision’, microsimulation, model, HIV, AIDS, intervention, evaluation, disease, Africa.

# BACKGROUND AND MOTIVATION

During 2007 roughly 2.5 million people were infected with HIV and just over two million died from AIDS, bringing the estimated total living with HIV around the globe to around 33 million (UNAIDS 2007a). Two thirds of those infected live in sub-Saharan Africa where adult prevalence is roughly 5%. Following three successful randomized controlled trials conducted in South Africa, Kenya and Uganda (Auvert et al. 2005; Bailey et al. 2007; Gray et al. 2007a) male circumcision has become one of the most promising potential new interventions. All three of these trials measured incidence rate ratios on the order of 0.55 comparing circumcised to uncircumcised young men in widely different populations in east and southern Africa. These results confirm and support a large number of observational, meta-analytical and biomedical studies conducted over the past 15-20 years that have suggested that male circumcision is associated with reductions in female-to-male transmission of several sexually transmitted infections, including HIV and other infections that may facilitate infection with HIV (see for example: Donoval et al. 2006; McCoombe and Short 2006; Moses et al. 1994; Siegfried et al. 2005; Van Howe 1999; Weiss, Quigley and Hayes 2000; Weiss et al. 2006).

As an intervention, male circumcision is attractive because it is comparatively cheap and only has to be applied *once* to each ‘user’ (Buve, Delvaux and Criel 2007). However important questions remain about the population-level benefit of circumcising individual men. Given the individual-level protection found in the clinical trials, it is obvious that the number of new infections averted will increase as the proportion of circumcised men increases, but beyond this simple assertion the complex dynamic nature of HIV epidemics makes it hard to predict exactly how intervention coverage is related to HIV incidence and prevalence (Garenne 2006). The overall aim of the work presented here is to investigate the relationship between reductions in individual-level female-to-male transmission of HIV at different ages *and* population-level indicators of an HIV epidemic – incidence and prevalence – differentiated by sex and age.

This investigation builds on a small body of mathematical modeling studies that have begun to examine aspects of this relationship. Orroth and colleagues use the STDSIM model (van der Ploeg et al. 1998) to carefully model the relationship between risk behaviors, the fraction of men who are circumcised and the prevalence of other sexually transmitted infections *and* the prevalence of HIV in the Four Cities study populations (Carael and Holmes 2001) to test the hypothesis that the joint variation in these three predictors largely explains the observed differences in HIV prevalence across the Four Cities (Orroth et al. 2007). The results strongly suggest that by lowering the likelihood of female-to-male transmission and simultaneously reducing the incidence and prevalence of ulcerative sexually transmitted infections that facilitate infection with HIV, male circumcision can result in significant reductions in HIV transmission, and hence in the prevalence of HIV. Williams and colleagues (2006) use a dynamical compartmental simulation model to investigate the impact of male circumcision interventions of varying coverage on the HIV epidemic in sub-Saharan Africa. Their results demonstrate that high-coverage male circumcision interventions that reduce female-to-male transmission by 60% can significantly reduce incidence and prevalence of HIV and AIDS-related deaths, and that such an intervention would be equivalent to an intervention, such as a vaccine, that reduces transmission in both directions (female-to-male and male-to-female) by about 37%. Podder and colleagues

(2007) and Nagelkerke and colleagues (2007) have built mathematical models of HIV epidemics that address fundamental properties of the epidemic process in a general sense and the potential effects of male circumcision interventions in different contexts, respectively. The results of Podder et al. suggest that it will not be possible to extinguish an HIV epidemic using male circumcision alone, but that such an outcome could result from very effective combinations of male circumcision and other interventions. Finally, modeling work by Gray and colleagues (2007b) and Kahn and colleagues (2006) address *inter alia* the cost effectiveness of male circumcision interventions. The stochastic simulation model of Gray et al. is the only one to explicitly investigate the possible effect of behavioral disinhibition – an increase in risk taking behavior following circumcision resulting from the incorrect belief that circumcision is highly effective in preventing infection for individual men. Their results confirm those of the other models to the effect that male circumcision can significantly reduce HIV prevalence, adding that this may be achieved in a cost-effective way. Gray et al. caution that behavioral disinhibition could largely counteract these positive effects of the intervention and that additional work should be undertaken to develop a more predictive understanding of the possible effects of behavioral disinhibition, although empirical studies to date have not witnessed significant behavioral disinhibition (Agot et al. 2007).

Together these models support the empirical evidence and demonstrate at the population level the potential for male circumcision to significantly diminish the HIV epidemics affecting sub-Saharan Africa in a cost-effective and reasonably equitable way, with caution raised around the issue of behavioral disinhibition and the fact that male circumcision alone is not likely to extinguish an HIV epidemic. Missing is a detailed understanding of how male circumcision affects people of either sex at different ages, and critically how different male circumcision intervention designs affect the outcomes. This investigation seeks to begin filling some of these gaps by using a microsimulation modeling approach to investigate the following hypotheses:

1. As the coverage – the proportion of uncircumcised males who are circumcised as part of the intervention – of a male circumcision intervention increases, the magnitude of the effect will increase in a non-linear way such that substantial effects are only obtained with high population coverage of male circumcision.

2. The age at which males are circumcised will affect both the eventual overall magnitude of the population-level reductions in HIV incidence and prevalence and the duration of the lag between intervention and detectable effect. At-birth through pre-adolescent age interventions will have the greatest impact with a longer lag as the circumcision age is made younger. The best result in terms of short lag, greatest impact, cheapest cost and simplest logistics over the long term will be obtained through a sequenced intervention that simultaneously circumcises infants and young men until the first cohort of infants are young men, at which time the 'young man' circumcisions can stop.

3. In the absence of increased unsafe sexual practices (such as sex before circumcisions have fully healed), females benefit from intervention to roughly the same extent as males with a negligible lag, disputing the notion that an intervention that only directly targets men is unjustified in Africa where the individual and population-level implications of HIV are often

worse for women (Hankins 2007) .

# METHODS

There is strong empirical evidence that HIV has an impact on standard demographic processes, increasing mortality in young adults, an otherwise healthy age group, and adversely affecting fertility (Ford and Hosegood 2005; Garenne et al. 2007; Gregson et al. 2007; Hunter et al. 2003; Kahn et al. 2007; Lewis et al. 2004; Nyirenda et al. 2007; Terceira et al. 2003; Timaes and Jasseh 2004; Wachter, Knodel and Vanlandingham 2002; Zaba and Gregson 1998; Zaba et al. 2007). However directly measuring the population-level demographic impacts of the HIV epidemic is challenging because the influence of HIV cannot be easily isolated from a host of other exogenous and endogenous changes – civil war, famine, family planning programs or changes in healthcare infrastructure, for example – that simultaneously fuel and respond to the epidemic (Evans and Miguel 2007; Fortson 2008). Using a model it is possible to hold everything else constant and simulate only the influence of an HIV epidemic on a population. While it will never be true that HIV is the only force of change affecting a population, understanding how an HIV epidemic affects a population by itself makes it possible to compare how interventions affect both the epidemiology of the epidemic and the demography of the population.

In the context of HIV modeling, the deterministic, compartmental models most often used in both demographic and epidemiological population-level modeling studies either focus on accurately modeling the population demography at the expense of dynamically modeling HIV transmission (e.g. Heuveline 2003) or they focus on dynamic HIV transmission at the expense of realistic demography (e.g. Hallett et al. 2007). Considering both demography and HIV transmission and interactions between the two is central to this investigation, and consequently we propose a microsimulation model as an alternative approach. By modeling interactions between specific individuals the microsimulation model ensures consistency between the important demographic and disease processes. For a thorough review of the advantages and disadvantages of microsimulation models see van Imhoff and Post (1998).

## Simulator

The Structured Population Event History Simulator (SPEHS) (Clark 2001c, 2006) is used to evaluate the hypotheses presented above. SPEHS is an individual-level, two-sex, polygynous union-capable, age-structured, stochastic population microsimulation model with a one-month time step.

Following is an intuitive description of the demographic and disease processes represented by SPEHS. An exhaustive, detailed description of the simulator with mathematical expressions, parameter values and technical specifics is provided in the supplemental material and the authors can be contacted directly to address further questions. The simulator and all of the simulated data presented below are available on request.

## Population – Epidemic Model

The simulator contains entities corresponding to *individual people*, *individual unions* (both marital and extra-marital) between men and women, *fertility histories* for women, and *pregnancies* for women. Together with the union-mediated *links* between spouses or partners and between parents and children this is sufficient to model the vital and pairing dynamics of a whole population.

Simulated time is incremented in units of one month, and during each month, every entity is exposed to the risk of the events for which it is eligible. Event hazards governing the monthly probability of occurrence of each event are compared to random numbers to decide which events occur during a given month. These occurrences and their repercussions are recorded – often changing the eligibility of the affected entities for future events – and the process is repeated until the desired number of months have been simulated.

## Demographic Events

Mortality is modeled by exposing each individual to a monthly risk of dying that varies by age and sex. For HIV positive individuals, the risk of dying also varies with the duration since the individual was infected, accounting for the long latent period of HIV infection and the relatively shorter period of AIDS morbidity and increased mortality. Fertility is modeled through the inter-birth interval model of fertility presented by Bongaarts and Potter (1983). At any time a fecund woman can be identified as waiting for conception, pregnant, recovering from a birth or miscarriage. A woman's monthly risk of conceiving varies depending on her current 'waiting' state, her age, time since infection if she is HIV positive, and the number of sexual intercourse events she experiences in the month, which is calculated as a function of the number and types of her unions. The risk of miscarrying increases as time since infection for HIV positive women.

Model parameters dictating fertility and mortality are calculated from 38 years of demographic surveillance data collected by anthropologists from a sample of about 15,000 members of the Tonga tribe of the Gwembe Valley in Southern Zambia between 1957 and 1995 (see for example: Clark 2001b; Clark et al. 1995; Colson 1960, 1971; Scudder 1962; Scudder and Colson 1980). The demography of the Gwembe Tonga is fairly typical of a high fertility, high mortality sub-Saharan African population. Model parameters directly estimated from the Gwembe Tonga dataset (Clark 2001b) include baseline mortality and marital union formation and dissolution. The estimated mortality parameters yield an average life expectancy of approximately 50 years for men and 52 years for women before the introduction of HIV into the population. Parameters dictating fertility are calculated such that the total fertility rate is approximately 6.9 births per woman prior to the introduction of HIV into the population. The model yields an annual crude growth rate of approximately 3.8% per annum before HIV is introduced.

## Unions

Acknowledging the possibility that polygynous marital unions may play an important role in HIV transmission in Africa (Reniers 2008), the explicit modeling of both monogynous and polygynous marital unions is one of the unique strengths of the SPEHS model. Nuptiality is modeled such that males and unmarried females have a monthly probability of forming a union that depends on female age, male age, male wife count and the HIV status of the individual women and men. As HIV positive individuals approach and enter the AIDS phase of their illness their propensity to form new unions diminishes. The monthly hazard of divorce for current unions depends on the duration of the union, the number of children produced within the union, and each partner's age and duration of HIV infection (Porter et al. 2004). Nuptiality parameters are calculated from the Gwembe data set.

Non-marital unions allow intercourse to occur between unmarried individuals and outside of marriage and are feasible between any female and any male regardless of current union status, a fact that allows varying levels of concurrent partnerships to develop. The risk of forming a non-marital union varies with each partner's age and 'sexual propensity'. Sexual propensity is a normally distributed variable assigned to individuals at birth intended to recognize heterogeneity in sexual desire – that some individuals have a greater preference for sex than others – and to allow assortative mixing on this dimension.

Unfortunately little information has been available for parameterizing the frequency and duration of non-marital unions, although it is accepted that HIV transmission within less formal often overlapping unions is an important factor contributing to the HIV epidemic (Kretzschmar and Morris 1996; Morris and Kretzschmar 1997). In SPEHS non-marital unions are formed such that on average the males are 7.5 years older than the females (SD 3.0 years), an average age differential supported by empirical data from Zimbabwe (Hallett et al. 2007). All non-marital unions have a fixed monthly hazard of termination of 0.45. The aggregate frequency of forming non-marital unions is set at a level such that enough HIV transmission is induced to create a robust HIV epidemic. Recall that the individual frequency of non-marital unions depends on age, sex and sexual propensity. This approach is not satisfying, but until very recently data about sexual behavior in sub-Saharan Africa has been sparse and unreliable. A number of recently completed and current studies have sought to improve knowledge on this topic (for example, Gregson et al. 2002; Mensch, Hewett and Erulkar 2003), and we anticipate that this is an area where HIV models, including ours, will improve in the future.

Within both types of union the partners are at risk of sexual intercourse. Each union is subjected to a daily hazard of intercourse over the roughly 26 non-menstruating days of the month. This hazard is modulated by union type and the HIV status of both partners, with 'sicker' people less likely to have sex. For each woman waiting to conceive, the total number of intercourse events from all unions during a month is used together with her age and HIV status to calculate a probability of conception, again older women and women who have been infected for a longer time are less likely to conceive. *Importantly, these same intercourse events are used to calculate a monthly probability of transmission from infected to uninfected partner for HIV discordant couples. This ensures that the transmission and conception dynamics are linked in a realistic way.* Parameters controlling the frequency of sexual intercourse and likelihood of conception are back-calculated using the non-contracepting inter-birth intervals (Bongaarts and Potter 1983) and the *M & m* model (Coale and Trussell 1974) such that the modeled fertility patterns reproduce observed fertility in the Gwembe Tonga data.

## Effects of HIV

An HIV disease progression (DP) indicator is used to govern the progress of an infected individual's HIV infection. The DP indicator is a lop-sided U- shaped curve of values that roughly models viral load over the course of HIV infection such that transmissibility is very high during a two to three month acute infection stage, then very low for a five to eight year latent phase and increasing over the final years of AIDS until death. In sum, the average duration from infection to death for adults 20 and older is 8.3 years for females and 8.1 years for males. For children, the latent phase with very low DP value is much shorter, about 18 months.

Transmission of HIV between adults occurs only through heterosexual sexual intercourse from an infected individual to their partner, and probability of transmission depends on the duration since infection of the infected partner according to the DP indicator curve. Averaged over this entire period from acute HIV infection until death, transmission is approximately nine per thousand sexual intercourses for male-to-female transmission and six per thousand for female-to-male transmission, similar to that reported by Wawer et al. in Uganda (2005). Individuals can be infected more than once but their DP indicator starts at the date of their first infection; that is re-infection has no impact on the disease process.

Infected mothers transmit the virus to their newborns at birth with an average transmission probability of about 0.3 over the course of an infected woman's disease (for Africa and similar settings in Latin America: Newell 2003; Newell et al. 2004; Orio et al. 2007). Again, the specific transmission probability applied to a given birth is scaled by the mother's DP indicator allowing her transmission probability to track the progress of her disease and reflect her viral load, and hence her potential to transmit at each time following her own infection.

The influence of HIV on other behavioral processes such as union formation and frequency of sexual intercourse is also adjusted via the DP indicator to roughly model additional morbidity as the disease progresses. For a detailed description of the behavioral effects of HIV, see (Clark

2001c).

## Running the Simulator

To run the simulator we first begin with a small population of 15 males and 15 females and run the model without HIV for about 1,500 until a stable population of around 4,400 individuals is created. At this time HIV is introduced into the population through a random monthly incidence of 15 infections per 10,000 adults aged 15 to 49, mimicking a situation in which people leave the population, become infected, and return in small numbers. This level of random incidence remains throughout the epidemic, although after the epidemic has taken hold it contributes very little to the total number of new infections.

Because the model is stochastic the realization of each simulation is different, and while the general shape of the epidemic is similar every time, there can be a great deal of variation in the initial rate at which the epidemic grows and the time scale over which the epidemic reaches its peak. As a result of these stochastic processes, the model must be run many times to generate stable and reliable results.

## Male Circumcision Intervention Scenarios

The principle purpose of this investigation is to understand the potential epidemiological and demographic outcomes of different male circumcision intervention strategies. To illuminate these, four different intervention strategies are tested corresponding to interventions circumcising males of four different age groups:

- **‘at-birth’** – a specified proportion of uncircumcised males become circumcised at their birth (in addition to a baseline proportion of ‘routine’ circumcisions presumed to be already occurring in the population).

- **‘teenage’** – a specified proportion of uncircumcised males become circumcised between the ages of 10 and 13.

- **‘young-adult’** – a specified proportion of uncircumcised males between the ages of 18 and 24 become circumcised, and

- **‘mixed’** – a specified proportion of uncircumcised male infants are circumcised at the time of birth for the duration of the intervention period in addition to circumcising the same proportion of young-adults for the first 15 years of the intervention period.

Each of these interventions is tested at coverage levels circumcising 10, 25, 50, and 75% of the uncircumcised male population. When directly comparing the interventions it should be kept in mind that the ‘mixed’ age intervention requires approximately twice the number of circumcisions during the first 15 years as it is targeting two age groups during this period. The individual-level reduction in susceptibility to HIV infection conferred by circumcision is taken from the South African trial (Auvert et al. 2005), the only one of the three trials that had reported when this work was done. The HIV incidence rate ratio reported by that trial controlling for various behavioral factors is 0.39 comparing circumcised to uncircumcised men. To reflect this in the simulator, the monthly probability of HIV infection is multiplied by 0.4 if the male partner is circumcised.

To evaluate the impact of each of these 16 intervention scenarios at each level of coverage we first simulate a ‘control’ HIV epidemic for 80 years in order to observe the natural course of the epidemic without intervention. This population experiences only the low, steady rate of circumcision that can be considered ‘normal’. In order not to overstate the impact of interventions a random 25% of the male population is circumcised at birth, this being slightly above the median circumcision rate for sub-Saharan African countries with severe HIV epidemics (UNAIDS 2007b; Williams et al. 2006).

Each of the 16 interventions is implemented 30 years into the epidemic, approximately the current ‘age’ of most HIV epidemics in Africa now, by rolling back the control epidemic to its state at the end of year 30 and implementing the intervention strategy for 50 years. The control epidemic and each of the 16 intervention scenarios are simulated 100 times, and the results presented below are averages over those 100 simulations.

While the principle purpose of this investigation is to compare the demographic and epidemiological merits of the intervention strategies, each of the strategies may pose different logistical benefits or challenges such as cost of implementation or potential for behavioral disinhibition. Some of these issues are discussed later, but should be more comprehensively understood and incorporated into future models and cost-benefit analyses.

# DEMOGRAPHIC IMPACTS OF HIV

This section focuses on the demographic changes that result from a moderately severe HIV epidemic with no intervention. Figure 1 displays the population-level HIV prevalence and incidence for females and males in the epidemic created by SPEHS. Female HIV prevalence peaks around 27% about 29 years into the HIV epidemic and male prevalence peaks around 21% about 38 years into the epidemic. These all-age HIV prevalence rates are higher than any empirical national epidemics but are in line with some of the most severe local epidemics that have been observed such as urban Botswana or KwaZulu-Natal province in South Africa. The trend of male HIV prevalence growing more slowly and being several percentage points lower than female HIV prevalence is consistent with most observed HIV epidemics in southern and eastern Africa (Stover 2004) and is a direct result of the fact that women are consistently paired with older men (Garnett and Anderson 1993).

Figure 2 shows population pyramids before the introduction of HIV and at fifteen-year intervals during the HIV epidemic. The initial broad-based population pyramid is characteristic of a high fertility, high mortality population that is growing rapidly, consistent with the parameter values used to run the simulator. After 15 years HIV has had little noticeable impact on the age-structure of the population, but after 30 years HIV has severely affected both mortality and fertility. Because of the reduction in fertility and increase in child mortality, a smaller proportion of the population is aged zero to four. Due to the HIV-induced transition in the population mortality the age groups with the largest share of the population are, perhaps ironically, the young-adult and child ages, roughly 30 and younger. As the epidemic stabilizes, the proportion of older adults increases slightly as the proportion of younger adults falls. Noteworthy is the substantially greater proportion of males than females between the ages of 20 and 50. This differential has the potential to cause problems in the marriage market, household structure and other organizational structures of the society that rely on near equal numbers of women and men.

Figure 3 shows the aggregate impact of HIV on expectation of life at birth and the annual crude death rate. Life expectancy for females declines from about 52 years to 21 years and from about 49 years to 24 years for males. The large decline is attributable to a substantial increase in under-five mortality from about 40 per 1,000 to 81 per 1,000, a change to which life expectancy is particularly sensitive, and to the unusual and severe burden of mortality in the young-adult age group, roughly 25 to 40 years of age. The decrease in life expectancy may be overstated by the model, even in an epidemic as large as this, because of the high mother to child transmission rate[1] (one per three births to HIV positive mothers) and the artificially short life expectancy for infants born with HIV (all die before the age of five). Nevertheless, even after removing the effect of pediatric HIV, the impact of HIV on life expectancy is still dramatic. In the mature HIV epidemic life expectancy for females is less than that of males because of the significantly younger age profile of incidence, and hence HIV induced mortality, for women, see Figure 5. Again, this is due to the age differential in partnerships that has been highlighted already.

Figure 4 shows the change in total fertility rate and the overall change in the population annual crude growth rate. The total fertility rate decreases from approximately 6.8 to around 3.9 children per woman as a result of the HIV epidemic and rebounds to slightly above 4 after the epidemic has peaked and reached equilibrium. Note that the change in TFR only captures loss of

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[1] Currently in real HIV epidemics widespread availability of AZT and Nevirapine reduces mother-to-child transmission several fold.

births due to HIV-associated infecundity and morbidity, and does not account for loss of births resulting from increased mortality to child-bearing-age women. Loss of birth from both sources, as well as loss of life from mortality is captured by the catastrophic decline in the annual crude growth rate, which decreases from 40 per 1,000 to a net loss of 5 per 1,000 as a result of the HIV epidemic.

Figure 5 shows the average age of infection with HIV through the epidemic. At the start of the epidemic when the entire population is susceptible, infection is spread across the sexually active population creating an average age of infection of around 27 years for females and 33 years for males (the now familiar age difference). However, after the epidemic has moved through the population and saturated the higher-risk adult population, new infections become concentrated in the younger population as they begin sexual activity, and the average age of infection decreases to around 19 for females and 24 for males. The epidemiological significance of this dynamic is demonstrated in the age-specific prevalence in Figure 8. This phenomenon is a nice demonstration of how, in general, the distribution of age at infection will be a product of two attributes of the population: the sexual behavior of the population – particular the age of sexual debut and sexual mixing patterns – and the severity of the HIV epidemic. As illustrated, the distribution of age at infection and the way it shifts as the epidemic progresses is critical for understanding the demographic changes wrought by an HIV epidemic and for planning effective intervention programs.

# INTERVENTION RESULTS

The following describes results of the male circumcision HIV intervention scenario simulations described above. Generally, the model results show that with broad coverage male circumcision interventions may substantially reduce the burden of a severe HIV epidemic, but alone male circumcision is not likely to be the 'silver bullet' that ends the epidemic.

Figure 6 shows the change in male all-age HIV prevalence as a result of each intervention scenario. Figure 7 shows the percentage reduction in HIV incidence for females and males in each intervention scenario at different stages in the HIV epidemic, and Figure 8 shows male *age-specific* HIV prevalence to demonstrate how the benefit of the intervention is distributed across age.

## Target Age and Coverage of Circumcision Intervention

Figure 6 shows the change in male all-age HIV prevalence in each of the intervention scenarios. As anticipated the reduction in prevalence varies substantially based on the proportion of males who become circumcised, from as little as an absolute reduction of one half of 1% when circumcising 10% of the uncircumcised males to as much as three to six percentage points when circumcising 75% of the uncircumcised males. Clearly there is a nonlinear relationship between coverage and prevalence, while there appears to be little relationship between coverage and the lag between the start of the intervention and onset of its effect on prevalence.

The age group to target depends on the goals of the intervention, with clear tradeoffs between the different interventions with respect to the timing of the reductions in prevalence. This is demonstrated even more clearly in Figure 7, showing the percentage reduction in male and female HIV incidence in each intervention scenario. To see the differential impact of the interventions at different times after they are initiated, the reduction in incidence associated with each intervention is calculated for the first five years of the intervention, the next 10 years, then years 15 through 29 and finally years 30 through 49. Figure 7 shows that in years 30 to 49 of the intervention the most effective interventions reduce male HIV incidence by as much as 25% when circumcising 75% of the uncircumcised men, while there is a 15% reduction in male incidence when circumcision reaches 50% of the eligible male population. Circumcising 25% only leads to a 7% reduction in incidence, and circumcising 10% reduces incidence by around 3%.

This figure also illustrates that some of the interventions perform better than others at different stages in the epidemic. For creating an immediate reduction in HIV prevalence, interventions targeting young males between the ages of 18 and 24 are the most effective, with these being the *only* intervention strategies that show an appreciable reduction in incidence in the first five years of the intervention. However, by 30 to 49 years after the start of the intervention, the reduction in incidence from the young-adult intervention is much less than that in the other designs.

In contrast, the intervention targeting newborn infants has no impact at all until 15 to 24 years after the intervention is introduced, but after 50 years this intervention has reduced prevalence as much as the teenage and mixed interventions, and more than the adult intervention. The intervention targeting young teenage boys (ages 10-13) is a middle ground between these, having a less immediate reduction in prevalence, but having the maximum possible effect over time.

The mixed intervention, which circumcises both young adults for the first 15 years and infants for the duration of the intervention, combines the positive aspects of each of the interventions and has the best overall positive impact on male HIV prevalence. This comprehensively good result comes at the cost of rolling out an intervention that initially requires roughly twice the number of circumcisions as the others because it targets two age groups simultaneously.

Recalling from Figure 5 that the average age of HIV infection for males is 23 at the time when these interventions are beginning, it is clear that the reason the young-adult intervention targeting men aged 18 to 24 is less effective over time is simply because some men become infected with HIV before they become circumcised. This sensitivity to the age at infection highlights the importance of understanding the transmission dynamics that fuel local epidemics when planning intervention programs in specific communities.

Finally the degree to which the choice of target age group matters depends on the coverage of the intervention. For example, compare the percentage reduction in male HIV incidence in years 30 to 49 across the different targeted age groups when circumcising only 10% of uncircumcised males. Each of the interventions reduces incidence by between two and 3%, fairly similar results. However, when circumcising larger proportions of the population, the young-adult intervention performs considerably worse than the others during this same stage of the epidemic – years 30 to 49.

## Impact of Male Circumcision on Female HIV Epidemic

As hypothesized, Figure 7 shows that male circumcision intervention programs substantially reduce female HIV incidence even though the model does not include any direct protective benefit for females. Overall at most time points and in most scenarios, the reduction in female HIV incidence lags a few percentage points behind the reduction in male HIV incidence. However, this is not an absolute rule and it is not possible to quantify a regular relationship between reduction in male incidence and female incidence. If any generalization is to be made, it is that as the coverage of the intervention increases, the gap between the reduction of incidence for males and females decreases (proportionally, not in absolute terms). For example, considering the teenage intervention from 15 to 29 years, when circumcising 10% of males, the reduction in incidence is 36% less for females than males, when circumcising 25%, the reduction is 19% less for females, when circumcising 50% the reduction is 14% less for females, and when circumcising 75% the reduction is only 9% less for females than males. Just from observing Figure 7, this relationship does not hold for all intervention scenarios at all stages of the epidemic.

One interesting finding is that the reduction in female incidence is much closer to the reduction in male incidence for the young-adult intervention than in the other scenarios, sometimes the reduction for females being greater than that for males. This should not be confused to mean that the young-adult intervention reduces incidence in females more than the other interventions, as this is clearly not the case, only that the reduction is more similar to that of males at the same intervention level. This observation is not easily explained, but is likely tied to nuanced trends in the sexual mixing and partner change dynamics, as well as the stage of the male and female epidemics.

## Age-Specific HIV Prevalence Reductions

Figure 8 shows the age-specific male HIV prevalence for five-year age groups between ages 15 and 44 comparing the benefits of the different age-targeted interventions, all with a coverage level of 50%. Absent consideration of the interventions, observing how the age-specific prevalence changes over time in the control epidemic sheds important light on how the epidemic spreads through the population. The time evolution of these age-specific prevalence curves reveals that the simple epidemic prevalence trend in Figure 6 is not sufficient to summarize the complexities of HIV transmission. Initially when the population is naive to HIV, prevalence increases most rapidly amongst the older age groups, but after the at-risk population has been saturated and HIV mortality sets in, prevalence decreases rapidly at these ages, especially ages 35 to 39 and 40 to 44. From then on, the perpetuation of the epidemic relies on replenishing the at-risk individuals from younger age groups as they become sexually active. In these young age groups, the epidemic grows more gradually, but does not peak and decline; rather it plateaus and maintains an equilibrium level of HIV prevalence. At equilibrium everyone who will be infected is infected relatively young and consequently dies comparatively young leaving few susceptible to infection at older ages. In sum, the burden of disease shifts from older to younger age groups as the epidemic progresses, and layered on top of this is the female/male age differential in the effects that we have pointed out many times already.

These observations are important for anticipating the burden of HIV on healthcare and welfare systems and more broadly on social and economic institutions such as family structures and labor markets, not to mention planning both direct and indirect HIV intervention and support programs. Furthermore, simply understanding the transition in age-specific burden of disease can help predict otherwise complex intervention outcomes.

None of the interventions have important impacts for males at ages greater than about 35 because, as described immediately above, these age groups experience a natural decline in incidence as the epidemic matures. Looking at younger ages, the largest reductions in male prevalence are in the 20-24 age range with similar but slightly smaller reductions in the 15-19 and 25-29 age groups. The lag between initiation of intervention and noticeable effect varies considerably with the targeted age group, and reflects the general pattern described above.

# DISCUSSION

Taken as a whole the results presented here support the notion that male circumcision can affect the course of an HIV epidemic to reduce incidence and prevalence. The maximum change in prevalence observed in our simulations is about 30% when 75% of uncircumcised males are circumcised (about a six percentage point reduction in male prevalence from about 20% to about 13%). Although this is far from eradicating the epidemic, it is a substantial change and warrants further investigation.

Realistic interventions will have to balance cost with effect and choose how to both target and time circumcisions. The simulation scenarios we investigated provide some information to guide future work on these issues by exploring the relationship between coverage and magnitude of effect, age-targeting and timing of effect, and in a general sense, the equity of results with respect to sex and age.

Results from the four age-targeted intervention scenarios demonstrate that both the eventual magnitude and the timing of the effects of male circumcision are sensitive to the ages at which males are circumcised. Circumcising males at birth produces results with a large effect that is equal to the best of the other scenarios, but changes in incidence and prevalence only begin to appear after the first cohort of circumcised infants has aged to sexual maturity (about 15 years) and the maximum effect is only apparent after about 60 years! This result clearly draws into question the utility of only conducting at-birth circumcisions, especially considering the rapidly changing landscape of HIV epidemiology and the prospect of more effective preventative methods within the next one or two decades. Other alternatives include circumcising young boys before they reach adolescence, circumcising young men as they become sexually active and circumcising adult men. There is an obvious advantage to circumcising young males before they have extensive exposure to infection, and consequently we pursued two intervention scenarios that circumcised teenagers and young men. Results of the teen intervention that circumcises boys aged 10 to 13 indicate that the effects are felt with a relatively short lag of five to 10 years and that the final magnitude of the effects is equal to the largest produced by any of the other scenarios. This is a good intervention that leads to large reductions in incidence and prevalence in a relatively short period of time. The adult intervention scenario targeted men aged 18 to 24, and this intervention reduced HIV incidence and prevalence immediately, but in the long term these reductions were substantially less than for any of the other intervention scenarios – a little over half the total reduction in prevalence compared to the others. Finally, the 'mixed' intervention designed to have both an immediate effect and produce large effects in the long term worked well. Infant males were circumcised throughout this intervention, and young adult males 15 to 24 were circumcised for the first 15 years of the intervention, requiring approximately twice the number of circumcisions as the other interventions during this period. This produced the strong effects associated with the infant scenario over the long term, and while the population was waiting for that, the young adult circumcisions produced an immediate effect.

In all of the intervention scenarios HIV incidence and prevalence were reduced for both males and females, and as a result of those reductions for females, the incidence and prevalence in young children was also reduced. The benefit for females is typically slightly less than that for males, by a few percent in each case, although there are scenarios for which the female benefit is equal to or even slightly greater than the male (early during the adult scenario).

Examining the effects on prevalence by age for each scenario at 50% coverage revealed that changes in prevalence are strongly differentiated by age. Age groups for which the epidemic has already peaked by the time the intervention is initiated benefit the least, while age groups for which the epidemic either does not peak or has not yet peaked benefit significantly. *In terms of equity, it appears that age rather than sex is the real dimension along which there is likely to be significant inequity with male circumcision interventions*.

The model results presented here suggest that for optimal epidemiological outcomes, interventions should focus on two components: circumcising populations currently at risk of HIV infection, and in the long term focusing on circumcising boys before they begin sexual activity. In this context the average age at infection becomes an extremely important demographic feature of the epidemic system. Maximally effective male circumcision interventions must affect a near majority of males before they become sexually active and are infected. Combined with the overall incidence rate, the average age at first intercourse has a strong effect on the age structure of prevalence and the pace with which different age groups go through the epidemic. This affects the timing of the peak of the epidemic in each age group, and hence affects which age groups will benefit significantly from a male circumcision intervention when it is rolled out at different times during the growth and stabilization of an epidemic.

The average age at infection is even more important in another way. The dominant impact of male circumcision interventions (as with any partially preventative intervention) is to delay infection rather than to prevent it (Garenne 2006), and through this delay to reduce the number of secondary infections and hence the overall transmission of the disease. This effectively slows the epidemic, reduces equilibrium incidence and prevalence, and crucially, shifts the average age at infection to older ages. This allows women to advance further through their reproductive careers before they are affected by HIV, and thereby reduces some of the most important effects of an HIV epidemic on the demography of the population by allowing fertility to rebound, which in turn affects the population growth rate, age structure, etc. in positive ways. The insight to be gained here is that male circumcision interventions are likely to have the greatest demographic impact (including effects on fertility, growth and age structure) in populations that have low average ages of infection; as the average age at infection increases, the overall impact of the intervention is likely to decrease. This finding is again relevant when considering combined interventions that include male circumcision and other interventions that delay infection.

Our results should be interesting to the community of demographers, epidemiologists, economists and politicians who participate in deciding if and how to roll out male circumcision interventions. In keeping with our theory-building approach to this investigation, our results do not relate to any specific population and should not be used directly in decision making. They do, however, strongly support the notion that male circumcision interventions can be very helpful in reducing the spread of HIV and motivate additional investigation in a number of areas.

The simulator used to produce the results presented here can be improved in many ways. The current simulator's ability to represent and manipulate a detailed representation of reality is both a strength and a weakness. Used in the way described above, the detail allows us to illuminate complex relationships and dynamics in the epidemic system but does not allow detailed representation or prediction for a specific population because the simulator has not been fit or calibrated completely to a given population. Moreover, given the high degree of freedom and large number of parameters that govern the simulator, any parameterization is necessarily very specific and possibly not representative of any real population, and furthermore, multiple parameterizations may yield the same outcome, making it difficult to figure out exactly how to create a desired change in the outcome. Our primary aim for the near future is to work on methods that will allow us to reduce the degrees of freedom and number of parameters, and most importantly, calibrate and/or fit the simulator to real populations of various sizes. We are interested in developing measures of uncertainty in model outputs, and it appears possible to address both aims using Bayesian melding methods (Alkema, Raftery and Clark 2007; Poole and Raftery 2000).

More specific to the questions addressed here, the HIV epidemic that is generated by the current parameterization of the simulator is young, fast and severe. This results mainly from the specifics of the pairing dynamic in the non-marital pairing market, and we must examine and understand this better and bring to bear new findings in the literature that may shed light on key parameter values that govern non-marital mixing in the African settings that concern us. Acknowledging that, the present findings remind us that the specific character of an HIV epidemic can strongly affect the ability of a given intervention to modify the epidemic, and cautions that one-size-fits-all solutions are almost certainly not going to work well in the specific contexts where they are applied. Consequently, using a modeling approach like this to test an intervention design in a specific population before it is implemented is worth considering.

Beyond methodological development and model improvement, we hope to continue using an improved version of the simulator to examine the impact of individual-level behavioral disinhibition on the population-level effectiveness of male circumcision interventions and transmission-targeted interventions in general. Where male circumcision is concerned, we have continuing interest in better modeling the precise mechanism of protection (protects 60% of those circumcised completely or all of those circumcised 60% of the time; any effects on male-to-female transmission; etc.), different types of circumcision (partial, traditional, medical), and more realistic intervention designs that may include HIV screening and specific targeting of males (for example, single men only). Further work should also focus on quantifying and comparing the costs and logistics associated with various interventions. For example the at-birth intervention is conducted at a time when most of the recipients (newborn infants) are already in contact with the healthcare system, and the school system could be used disseminate an intervention targeting you teenagers. Recruitment for an intervention targeting young adults may be more difficult and hence expensive. Finally, given the simulator's ability to model the possibly interacting effects of multiple simultaneous interventions, we are also interested in exploring more complex intervention scenarios that combine different types of interventions at different times during an epidemic. Related to that we hope to add important additional sexually transmitted infections to the model, especially those that might affect the transmission of HIV, including HSV, ulcerative STIs, etc. (Wasserheit 1992).

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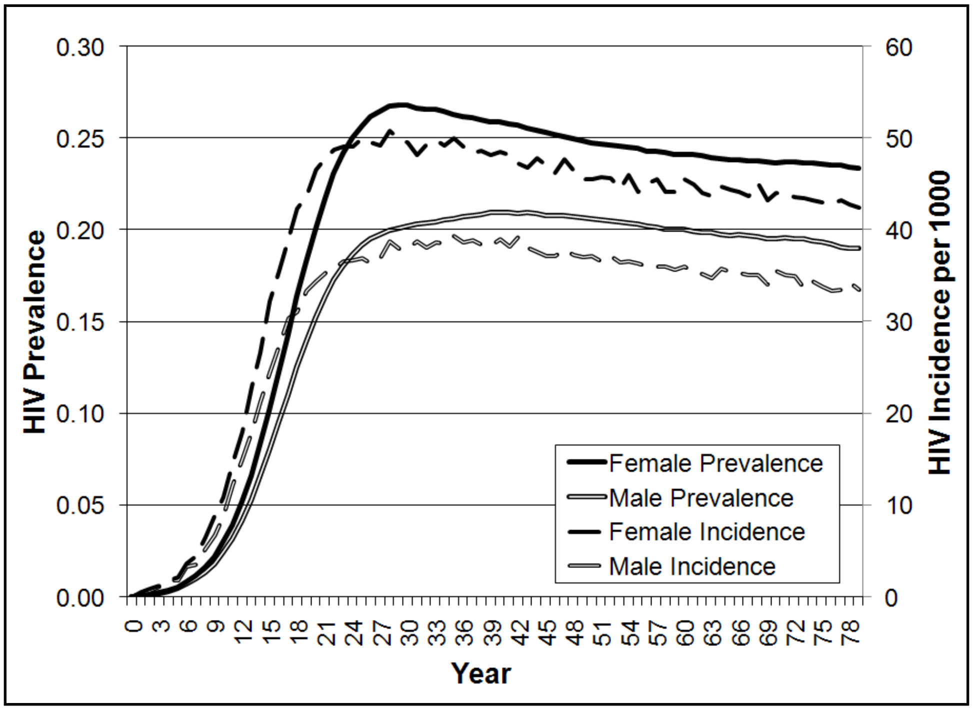
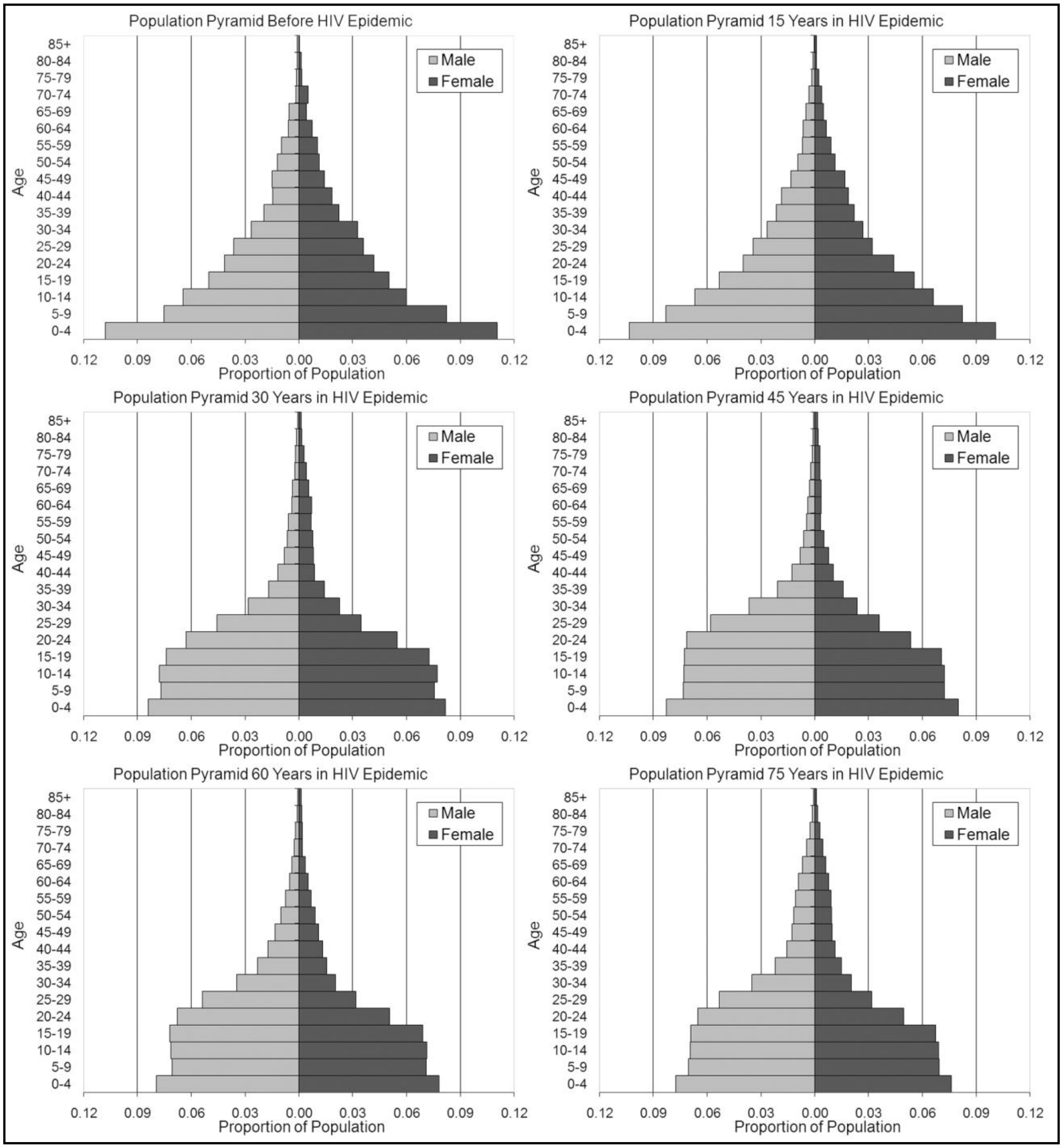
# FIGURES

**Figure 1: Simulated HIV Prevalence & Incidence – No Intervention**



HIV prevalence and incidence in simulated population with no interventions. HIV introduced into stable population in year 0. Solid lines are female, hollow lines are male, continuous lines are prevalence, dashed lines are incidence. Incidence rises before prevalence, and there is a peak and gradual decline to equilibrium incidence and prevalence for both sexes. Females experience a greater impact of HIV.

**Figure 2: Population Pyramids during an HIV epidemic**



Population Pyramid Before HIV Epidemic

Population Pyramid 15 Years in HIV Epidemic

Population Pyramid 30 Years in HIV Epidemic

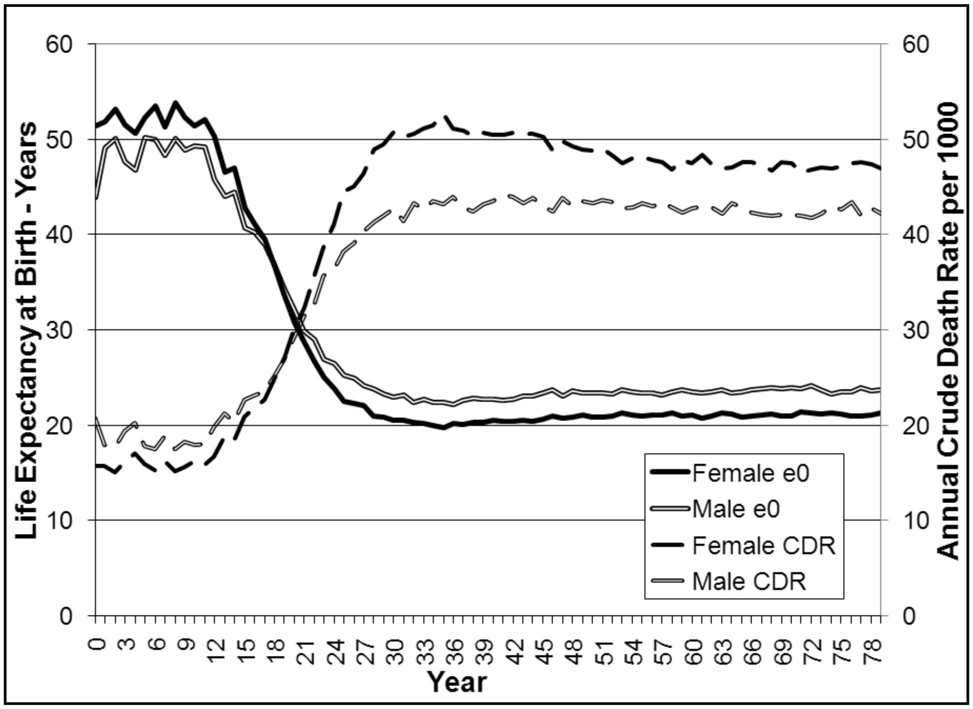
Population Pyramid 45 Years in HIV Epidemic

Population Pyramid 60 Years in HIV Epidemic

Population Pyramid 75 Years in HIV Epidemic

Population pyramids at various stages of an HIV epidemic with no intervention. HIV affects primarily the bottom and top of the population pyramid to diminish both. The result is a new step-shaped population pyramid with comparatively fewer young children and older adults.

**Figure 3: Life Expectancy at Birth and Crude Death Rate**



Changes in the expectation of life and the crude death rate as an HIV epidemic unfolds with no intervention. Life expectancy falls precipitously as the epidemic is growing and settles at a new equilibrium value that is almost 30 years less. The sex differential between female and male life expectancy reverses. The trend in the crude death rate mirrors changes in life expectancy in the opposite direction with the same consequences for the sexes.

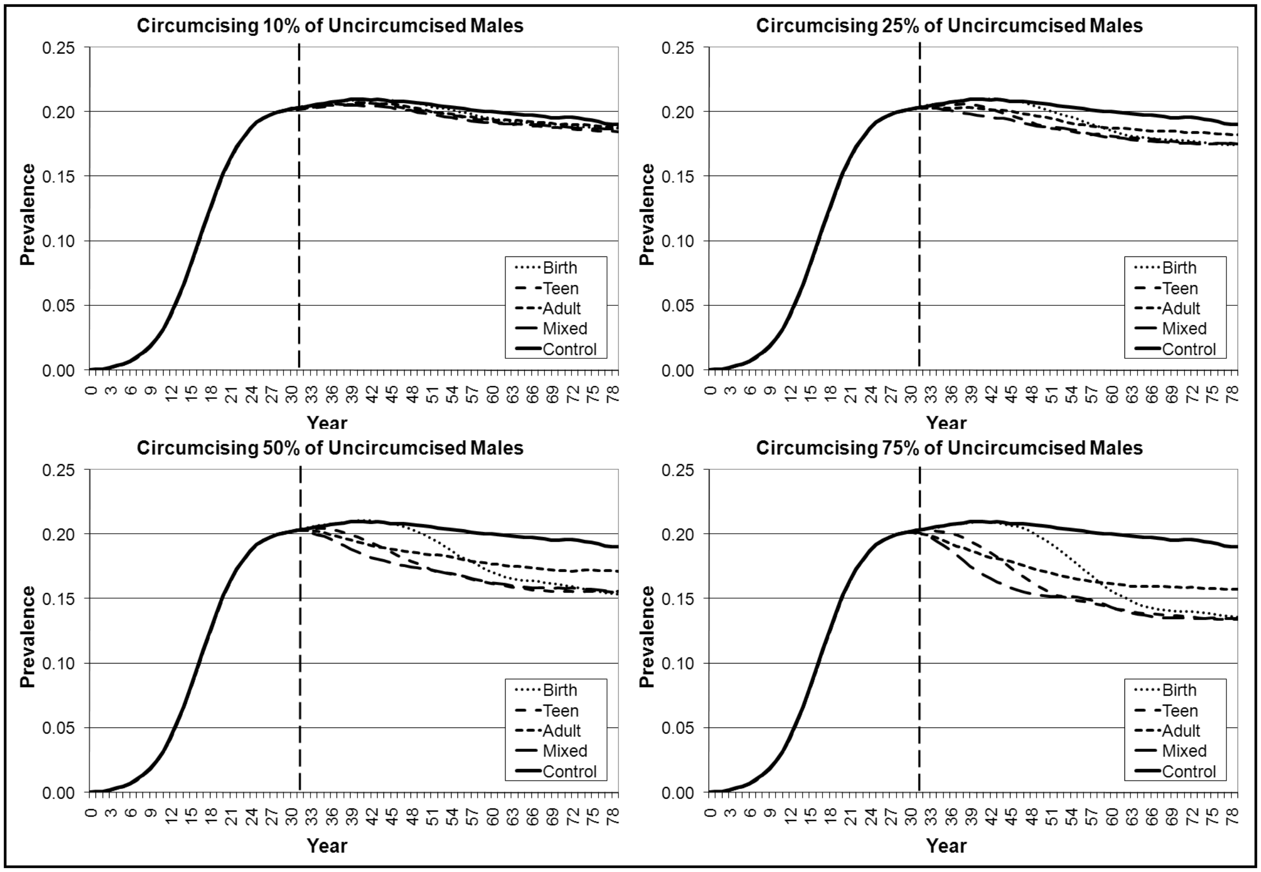
**Figure 4: Crude Growth Rate and Total Fertility Rate**

Changes in the crude growth rate and total fertility rate as an HIV epidemic progresses without intervention. The crude growth rate captures mortality and morbidity effects on population growth beyond the fertility-related effects captured by the total fertility rate. Both the total fertility and crude growth rates fall sharply as the epidemic grows to eventually stabilize at much lower levels. In the case of this comparatively severe epidemic the equilibrium crude growth rate is negative, something that is obviously not true for less severe epidemics.

**Figure 5: Change in Average Age of HIV Infection**

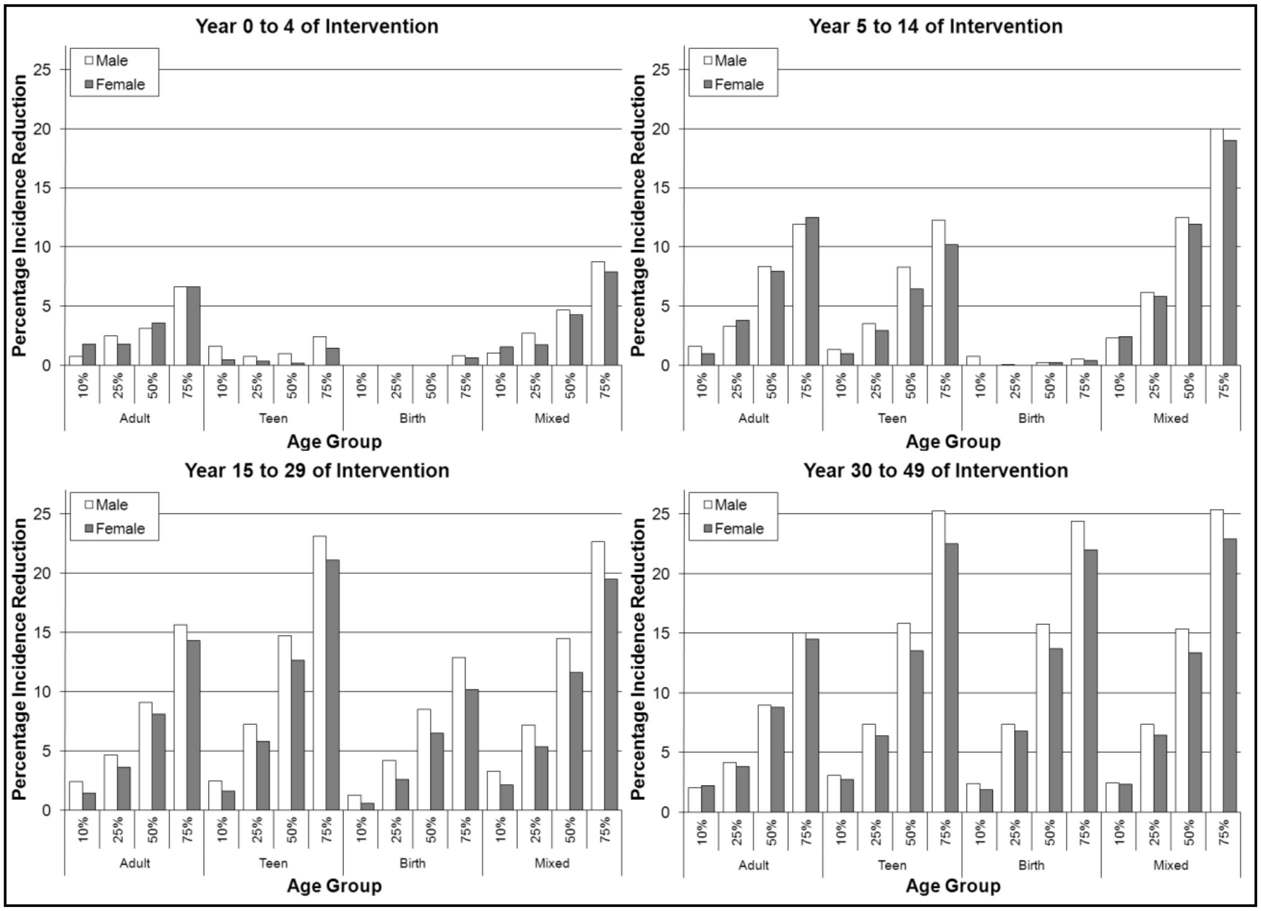
Changes in the average age at infection for females and males as an HIV epidemic grows without intervention. For females as the epidemic grows the average age at infection falls sharply to a much lower equilibrium level, and for males the same thing happens after a short period of increase. This dynamic is key to driving the age-dependent behavior and impacts of the epidemic and is a result of the epidemic spreading and ‘burning’ through the population, and importantly on the fact that women are on average several years younger than men in sexually active relationships. Although the shape of the trends are similar in less severe simulated epidemics, the large magnitude of the changes shown here are a direct consequence of the comparative severity of this simulated epidemic.

**Figure 6: Male HIV prevalence in Male Circumcision Intervention Scenarios**



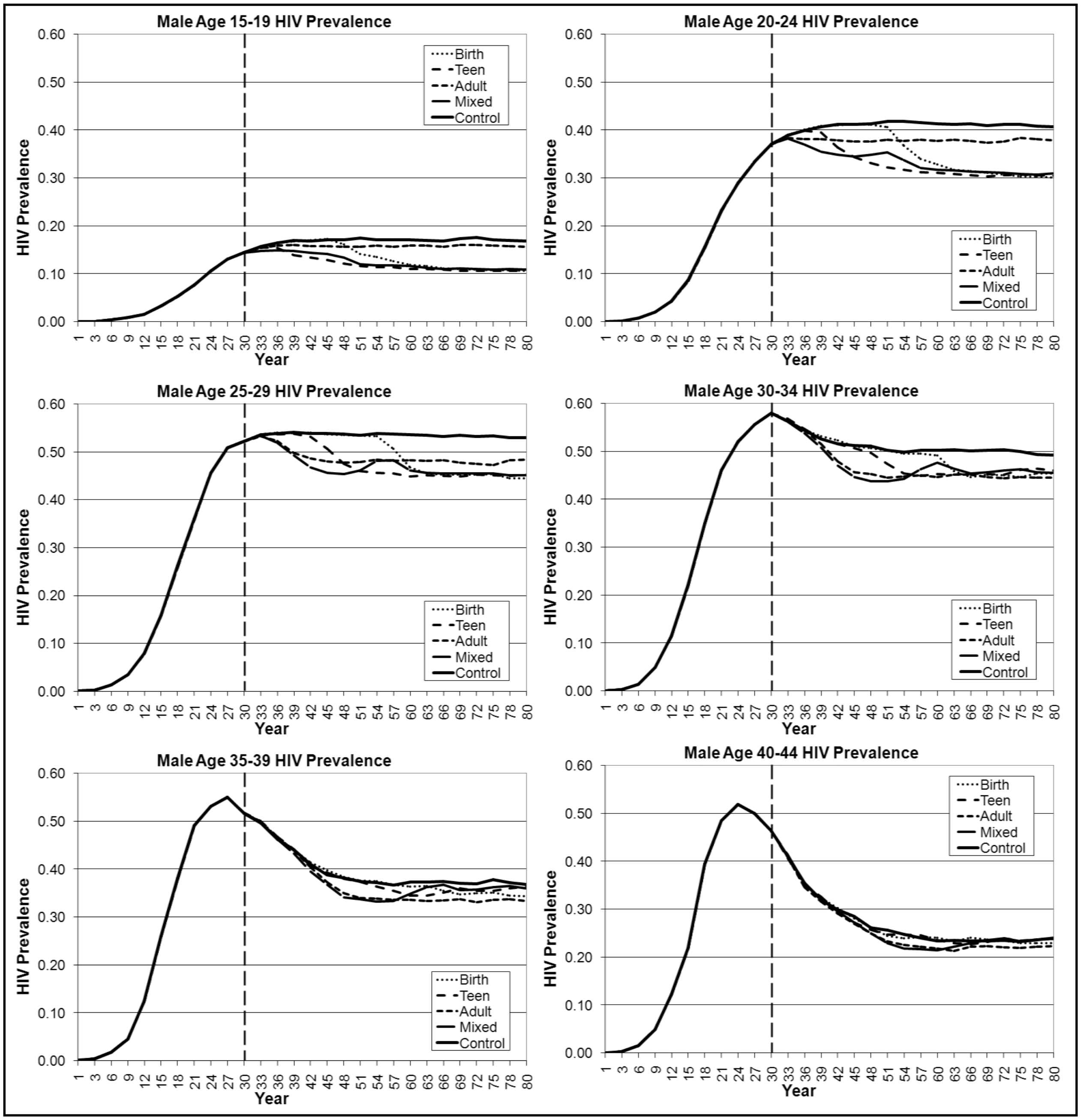
Prevalence of HIV among males of all ages during HIV epidemics affected by different male circumcision interventions, all starting in year 30 (vertical line). Each of the four panels displays a different coverage of intervention with either 10, 25, 50 or 75% of uncircumcised males being circumcised as part of the intervention, and within each panel each line represents a different intervention design. The relationship between coverage of intervention and effect is clearly nonlinear with an increasingly larger effect as the coverage of the intervention increases. The 'adult' intervention consistently performs poorly, while all other intervention designs eventually reach a similar level of effect. The best intervention in terms of timing and magnitude of effect is the 'mixed' intervention.

**Figure 7: Percentage Reduction in Female and Male HIV Incidence**



Percent reduction in the incidence of HIV for females and males in HIV epidemics affected by various male circumcision interventions. The four panels display different periods of the HIV epidemic during the interventions. Each plot portrays the percent reduction in HIV incidence (bars) comparing the intervention to no intervention for women and men by intervention design (horizontal axis), and within each intervention, coverage of male circumcision. The 'adult' and 'mixed' interventions clearly have the fastest effect, while all intervention designs except 'adult' eventually yield an equilibrium reduction in incidence of about the same magnitude, depending on intervention coverage. Males enjoy a slightly greater reduction in incidence but the differences between levels of reduction for females and males are small.

**Figure 8: Change in Male Age Specific Prevalence Circumcising 50% of Uncircumcised Males**



Changes in HIV prevalence for males of various ages during an HIV epidemic affected by different male circumcision interventions, all interventions begin in year 30 (vertical line). Each panel corresponds to a different age group, and within each panel the lines corresponds to different intervention designs. The largest reductions in prevalence affect man aged 20-30 with lower levels of effect at both younger and older ages. Older men are affected much less with the oldest age group experiencing essentially no effect at all. The time trend in prevalence reductions is similar for each intervention design regardless of age group; the big difference is in the magnitude of effect that varies substantially with age.

# SUPPLEMENTAL MATERIAL: THE STRUCTURED POPULATION EVENT HISTORY SIMULATOR (SPEHS)

SPEHS is a heuristic tool designed to provide insight into the behavior of an HIV epidemic. The structure of the model captures the main time-sex-age-dependent dynamics of a polygynous, reproducing population engaging in some non-marital sexual contacts and infected with HIV. The parameters that govern the dynamics of the model are taken from a variety of sources because no one source can provide all of them, although all of the demographic parameters are taken from or adapted from a high fertility, high mortality, population in Southern Zambia that was observed for nearly 40 years (Clark 2001b). Consequently the simulator does not model or reflect any one *real* population, but rather reflects populations of the general type on which the parameters were measured. The results it produces illuminate how a population-disease system of this type works and how changing one or more of its parameters or components affects the whole system. Its primary advantage is an ability to assess the population-level effects of making individual-level changes, and it does this in a fully two-sex, dynamic framework in which fertility and the transmission of sexually transmitted disease, and effects of interventions on either or both, are properly linked through intercourse events occurring to pairs of individual males and females.

## Simulation Model

SPEHS is a simple state transition machine. At the beginning of each month of simulated time each entity's eligibility to experience events that can affect it is assessed, and if the entity is eligible, it is exposed to the risk of that event occurring. The entities are described below. The probability of occurrence for each type of event is determined by a set of parameters and may vary depending on the specific attributes and current state of the entity at risk for the event. These parameters and the relationships that transform them into probabilities of occurrence are described below. This straightforward approach has the advantage of simplicity in that it avoids the logical complexity of scheduling and rescheduling events when conditions change. The disadvantage is an increase in computation required to run the simulator, but with careful attention to optimizing algorithms the overall computational load is manageable.

SPEHS is implemented using the Microsoft Access 97™ (Access) relational database management system and the programming languages and tools associated with it[2]. The data generated by SPEHS are stored and manipulated in a relational database managed by Access. The logic of SPEHS is implemented using the Structured Query Language (SQL) and Microsoft Visual Basic™ for applications (VBA).

## Entities and Structure of SPEHS

SPEHS models the interactions of four entities: 1) **lives** that correspond to individual people, 2) **unions** that correspond to relationships between men and women that are of either type *union* or *affair*, 3) **fertility events** that are events that mark transitions in a woman's reproductive life (conception, birth, miscarriage, recovery after miscarriage, recovery after birth), and 4) **pregnancies**. Each of these entities has a corresponding table in a SPEHS database – *tblALives*, *tblAUnions*, *tblAFertilityEvents* and *tblAPregnancies* – that contains (or describes) individual

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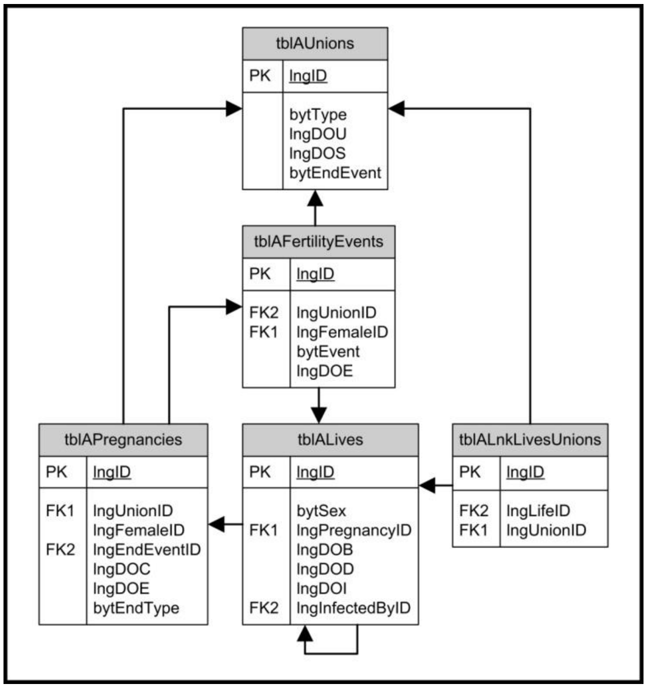
[2] This unusual choice of technology is the result of the lead author's extensive experience with relational databases for managing data collected at demographic surveillance system sites and the fact that work on the original simulator began in the late 1990s while he was a graduate student without easy access to more sophisticated and/or powerful technologies.

instances of the relevant entity. There is one additional table *tblALnkLivesUnions* that mediates a many-to-many link between tblALives and tblAUnions which allows the database to keep track of who the partners are for each union. Except for fertility events, the entities have 'start' and 'stop' dates that mark their beginning and end, and consequently provide the temporal information necessary to record the dynamics of the simulated population. Naturally, fertility events simply have a date that marks when the event occurred. Months are numbered consecutively so that dates take the form of an integer number.

Figure 9 displays an entity relationship diagram for SPEHS. The diagram indicates how the tables and attributes (fields) of each table are related to each other. The lines connecting the tables represent relationships between the tables in which the primary key (PK) attribute of a parent table is related to the foreign key (FK) attribute of a child table. The FK attribute of the child table can only contain values that exist in the PK attribute of the parent table. Arrowheads point to the parent table. For example the line connecting tblALives to tblALnkLivesUnions indicates that each life can be linked to many life-union links through the values of the PK in tblALives (lngID) and values of the FK in tblALnkLivesUnions (lngLifeID), but that each life-union link can be linked to only one life.

**Figure 9: Entity Relationship Diagram for SPEHS[3]**



Each table in SPEHS defines a number of attributes and each record (row) in a table contains a combination of attribute values that together describe a unique instance of the entity to which the table corresponds. The tables and their attributes are defined below.

**Table 1: tblAFertilityEvents: Contains Fertility Events Occurring to Women**

| Attribute Name | Description |
|---|---|
| lngID | Unique ID for each fertility event |
| lngUnionID | Unique ID of the union associated with this event |
| lngFemaleID | Unique ID of the female associate with this event |
| bytEvent | Fertility event type: 0=birth, 1=miscarriage, 2=conception birth, 3=conception miscarriage, 4=end breastfeeding, 5=recovered after miscarriage, 7=woman born (still a child and not yet reproducing) |
| lngDOE | Date of this event |

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[3] The prefixes to attribute names, 'lng', 'byt' etc, indicate the datatype used to store values of the attribute; 'lng' refers to a long number, etc

**Table 2: tblALives: Contains Individual People**

| Attribute Name | Description |
|---|---|
| lngID | Unique ID for each life |
| bytSex | Sex: 0=female, 1=male |
| lngPregnancyID | Unique ID for the pregnancy that gave rise to this life |
| lngDOB | Date of birth |
| lngDOD | Date of death: null=still alive |
| lngDOI | Date of infection with HIV: null=uninfected |
| lngInfectedByID | Unique ID of the life from which HIV most recently acquired |

**Table 3: tblALnkLivesUnions: Contains Links between People and Unions**

| Attribute Name | Description |
|---|---|
| lngID | Unique ID for each life-union link |
| lngLifeID | Unique ID for the life associated with this link |
| lngUnionID | Unique ID for the union associated with this link |

**Table 4: tblAPregnancies: Contains Pregnancies**

| Attribute Name | Description |
|---|---|
| lngID | Unique ID for each pregnancy |
| lngUnionID | Unique ID of the union associated with this pregnancy |
| lngFemaleID | Unique ID of female to which this pregnancy belongs |
| lngEndEventID | Unique ID of the fertility event that ends this pregnancy |
| lngDOC | Date of conception |
| lngDOE | Date of end |
| bytEndType | End event type: 0=miscarriage, 1=birth, 2=pregnant |

**Table 5: tblAUnions**

| Attribute Name | Description |
|---|---|
| lngID | Unique ID for each union |
| bytType | Union type: 0=marriage, 1=affair |
| lngDOU | Date of union |
| lngDOS | Date of separation |
| bytEndEvent | End event type: 0=separation, 1=death, 2=end affair |

## Events and Transition Probabilities

Table 6 displays the 17 events that SPEHS models. Along with each event is a brief description of the entities that are eligible for each event, and in what condition they must be to be eligible for each event. The probability that each event occurs is described by an expression, and the timescale over which the probability is defined and the values of the parameters that it requires are also defined.

When unions are formed, mixing is random within male marriage-parity, male-age, female-age classes. Forming affairs is a two stage process involving first becoming eligible to enter into an affair and then seeking a partner for the affair. When affairs are formed between eligible males and females, mixing is random within male-age, female-age classes.

**Table 6: Transition Probabilities**

| ID | Event | Eligible | Probability | Time-scale | Parameter Values |
|---|---|---|---|---|---|
| 1 | Death | Everyone who is alive | $D_{ASPR} = 1 - \; 1 - {}_{U}D_{ASP} \; \cdot \; 1 - \; V_R \; ^{Hm}$<br>D: monthly probability of death<br>U: signifies underlying probability of death<br>A: age (months)<br>S: sex<br>H: HIV status<br>P: period<br>R: duration since infection with HIV<br>$V_R$: viral load at duration R since infection, $V_0 = 0$<br>Hm: modifies effect of being HIV+ on mortality | month | ${}_{U}D_{ASP}$: Table 8 for all P<br>$V_R$: Table 7<br>Hm: 3.0 |
| 2 | Conception | Fecund females who are having sex | $F_{AREP} = F \cdot F_a \cdot F_h \cdot F_c$<br>$F = 0.3 \cdot \left[ 1 - \frac{M - n \;\cdot\; M - n - 1}{M^2 - M} \right]$<br>$F_a = 2.174 \cdot N_A \cdot e^{m_P \cdot W_A}$<br>$F_h = 1 - \; V_R \; ^{Hf}$<br>$F_c = 1 - E_P$<br>F: monthly probability of conception - *fecundability*<br>M: number of days during month when intercourse can happen<br>n: number of intercourse events during the month<br>R: duration since infection with HIV<br>$V_R$: viral load at duration R since infection, $V_0 = 0$<br>Hf: modifies effect of viral load on fecundability<br>$E_P$: effectiveness of contraception<br>$N_A$: scale factor for age-specific modification of fecundability<br>$W_A$: underlying schedule of age-specific modifications to fecundability<br>$m_P$: coefficient to scale $W_A$ values<br>P: period | month | M: 26<br>n: determined by events 4 and 5<br>$V_R$: Table 7<br>Hf: 0.5<br>$N_A$: Table 9<br>$W_A$: Table 9<br>$E_P$: 0.0 for all P |

## Table 6: Transition Probabilities

| ID | Event | Eligible | Probability | Time-scale | Parameter Values |
|---|---|---|---|---|---|
| 3 | Miscarriage | All women who have conceived | $G_{RP} = \left(\frac{k_P}{1+k_P}\right) + \left(1 - \frac{k_P}{1+k_P}\right) \cdot V_R^{Hk}$<br>G: probability that a conception leads to a miscarriage<br>$k_P$: ratio of conceptions that lead to a miscarriage to conceptions that lead to a birth; average number of miscarriages per birth<br>R: duration since infection with HIV<br>P: period<br>$V_R$: viral load at duration R since infection, $V_0 = 0$<br>Hk: modifies effect of being HIV+ on probability of miscarriage | month | $k_P$: 0.33 for all P<br>$V_R$: Table 7<br>Hk: 0.75 |
| 4 | Intercourse within marriage | Married couples | $X_{A_m A_f R_m R_f} = {}_U X_{A_m A_f} \cdot 1 - V_{R_m}^{Hn} \cdot 1 - V_{R_f}^{Hn}$<br>X: probability of intercourse<br>U: signifies underlying probability of intercourse<br>A: age<br>$_m$: male<br>$_f$: female<br>R: duration since infection with HIV<br>$V_R$: viral load at duration R since infection, $V_0 = 0$<br>Hn: modifies effect of being HIV+ on probability of intercourse | day | ${}_U X_{A_m A_f}$: Table 11 for all P<br>$V_R$: Table 7<br>Hn: 0.8 |
| 5 | Intercourse within affairs | Couples engaged in an affair | $X_{A_m A_f I_m I_f R_m R_f} = \left( {}_U X_{A_m A_f} + 1 - {}_U X_{A_m A_f} \cdot \left( \frac{I_m + I_f - 2}{2 \cdot \beta - 2} \right) \cdot \alpha_P \right) \cdot 1 - V_{R_m}^{Hn} \cdot 1 - V_{R_f}^{Hn}$<br>X: probability of intercourse<br>U: signifies underlying probability of intercourse<br>A: age<br>P: period<br>$_m$: male<br>$_f$: female<br>I: sexual activity propensity category<br>α: sexual activity slope (maximum of addition due to affair status of union)<br>β: number of sexual activity categories<br>R: duration since infection with HIV<br>$V_R$: viral load at duration R since infection, $V_0 = 0$<br>Hn: modifies effect of being HIV+ on probability of intercourse | month | ${}_U X_{A_m A_f}$: Table 11<br>$V_R$: Table 7<br>Hn: 0.8<br>I: quintiles of *N*(3,1.2)<br>$\alpha_P$: 0.2 for all P<br>β: 5 |

**Table 6: Transition Probabilities**

| ID | Event | Eligible | Probability | Time-scale | Parameter Values |
|---|---|---|---|---|---|
| 6 | Vertical transmission of HIV | Newborns born to HIV+ mothers | $H_{R_f} = {}_U H + 1 - {}_U H \cdot V_{R_f}{}^{Hv}$<br>H: probability of transmitting the HI virus from mother to child during childbirth<br>U: signifies underlying probability of transmitting<br>R: duration since infection with HIV<br>$V_R$ : viral load at duration R since infection, $V_0$ = 0<br>$_f$: female<br>Hv: modifies effect of being HIV+ on probability of vertical transmission | birth | ${}_U H$ : 0.2<br>$V_R$ : Table 7<br>Hv: 0.75 |
| 7 | Horizontal transmission of HIV | partner in intercourse event with HIV+ person | ${}_{M \rightarrow F} T_{R_m P} = V_{R_m} \cdot {}_U T_m \cdot 1 - b_P$<br>${}_{F \rightarrow M} T_{R_f P} = V_{R_f} \cdot {}_U T_f \cdot 1 - b_P$<br>T: probability of transmitting the HIV virus during an intercourse event<br>R: duration since infection with HIV<br>$V_R$ : viral load at duration R since infection, $V_0$ = 0<br>$_m$: male<br>$_f$: female<br>$b_P$: effectiveness of barrier to transmission<br>P: period | inter-course | ${}_U T_m$ : 0.9 (Wawer et al. 2005)<br>${}_U T_f$ : 0.6 (Wawer et al. 2005)<br>$V_R$ : Table 7<br>$b_P$: 0 for all P |
| 8 | Random transmission of HIV | Adults aged 15-49 | $J = 0.00015$ , for all periods<br>J: random probability of acquiring HIV “from the outside” | month | |
| 9 | Become eligible to enter into an affair | Adults aged 10-79, male and female | $G = {}_{\max} G_P \cdot \left( \frac{I - 1}{\beta - 1} \right)^{\gamma_P}$<br>G: probability of being eligible for entering into an affair<br>I: sexual activity propensity category<br>β: number of sexual activity categories<br>$_{\max}$G: maximum probability of being eligible to enter into an affair<br>γ: modifies the factor that diminishes the maximum probability of being eligible to enter into an affair<br>P: period | month | ${}_{\max} G_P$: 0.2 for all P<br>I: quintiles of *N*(3,1.2)<br>β: 5<br>$\gamma_P$: 2.5 for all P |

**Table 6: Transition Probabilities**

| ID | Event | Eligible | Probability | Time-scale | Parameter Values |
|---|---|---|---|---|---|
| 10 | Enter into an affair | Adults aged 10-79 who have become eligible to enter into an affair | $A_P = AA^{\varepsilon_P} \cdot IA^{\lambda_P}$<br>$AA = \frac{{}_{\max}AA_P}{{}_{\max}N_{L_AB_A\sigma_{AP}A_mA_f}} \cdot N_{L_AB_A\sigma_{AP}A_mA_f}$<br>$N_{L_{AP}B_{AP}\sigma_{AP}A_mA_f} = \frac{1}{\sigma_{AP}\sqrt{2\pi}} e^{\left(-\frac{\Delta_{L_{AP}B_{AP}A_mA_f}{}^{2}}{2\sigma_{AP}{}^{2}}\right)}$<br>$\Delta_{L_AB_AA_mA_f} = A_f - {}_{\omega}A_f{}^{2} - A_m - L_{AP} \cdot {}_{\omega}A_f + B_{AP}{}^{2}{}^{0.5}$<br>${}_{\omega}A_f = \frac{L_{AP} \cdot A_m - B_{AP} + A_f}{1 + L_{AP}}$<br>$IA = \frac{{}_{\max}IA_P}{{}_{\max}N_{L_IB_I\sigma_{IP}I_mI_f}} \cdot N_{L_IB_I\sigma_{IP}I_mI_f}$<br>$N_{L_{IP}B_{IP}\sigma_{IP}I_mI_f} = \frac{1}{\sigma_{IP}\sqrt{2\pi}} e^{\left(-\frac{\left(\Delta_{L_{IP}B_{IP}I_mI_f}\right)^{2}}{2\sigma_{IP}{}^{2}}\right)}$<br>$\Delta_{L_{IP}B_{IP}I_mI_f} = \left(\left(I_f - {}_{\omega}I_f\right)^{2} - \left(I_m - \left(L_{IP} \cdot {}_{\omega}I_f + B_{IP}\right)\right)^{2}\right)^{0.5}$<br>$\omega I_f = \frac{L_{IP} \cdot \left(I_m - B_{IP}\right) + I_f}{1 + L_{IP}}$<br>Each associativity component is distrubuted as a normal distribution about a line defined by male value $= B + M \cdot$ female value ; the axis of the normal distribution is perpendicular to the line, and the distance from any point female value, male value to the line is the value at which the normal probability is calculated. Both normal distributions have mean 0 and variance given by σ.<br>A: probability of entering into an affair<br>AA: age-associative component of the probability of entering into an affair<br>IA: sexual activity-associative component of the probability of entering into an affair | month | $\varepsilon_P$: 1.0<br>$\lambda_P$: 0.5<br>$L_{AP}$ : 1.0 for all P<br>$B_{AP}$ : 7.5 for all P<br>$\sigma_{AP}$ : 3.0 for all P<br>${}_{\max}AA_P$ : 1.0 for all P<br>$L_{IP}$ : 1.0 for all P<br>$B_{IP}$ : 7.5 for all P<br>$\sigma_{IP}$ : 3.0 for all P<br>${}_{\max}IA_P$ : 1.0 for all P |

**Table 6: Transition Probabilities**

| ID | Event | Eligible | Probability | Time-scale | Parameter Values |
|---|---|---|---|---|---|
| | | | ε: exponent modifying the contribution of AA to A<br>λ: exponent modifying the contribution of IA to A<br>A: age<br>P: period<br>I: sexual activity propensity category<br>L: slope of maximum associativity, change in maximum associativity with age or sexual activity propensity<br>B: offset of maximum associativity, non age or sexual activity propensity dependent offset in age or sexual activity propensity that yields greatest probability of forming an affair<br>σ: variance in normal distribution around line of maximum associativity<br>ω: denotes value of female age of sexual activity that is closest to the line of maximum associativity | | |
| 11 | Becoming male | All births | $Q_P = 0.5122$ , for all P<br>Q: probability that a birth is male<br>P: period | at birth | |
| 12 | End an affair | All affairs | $W_P = 0.45$ , for all P<br>W: probability that an affair ends<br>P: period | month | |
| 13 | Become fecund again following a miscarriage | Females whose last fertility event is a miscarriage | ${}_{m}\Omega_{dP} = \frac{1}{1 + e^{\left(-{}_{m}\rho_{p} \cdot \left(d - {}_{m}t_{0P}\right)\right)}}$<br>${}_{m}\Omega$: probability of becoming fecund after a miscarriage, *recovering*<br>${}_{m}\rho_{P}$: “rate constant” of logistic defining probability of recovery, higher ρ means less variance in the duration from miscarriage to recovery<br>d: duration since miscarriage<br>${}_{m}t_{0P}$: mean duration of recovery<br>P: period | month | ${}_{m}\rho_{P}$: 1.5 for all P<br>${}_{m}t_{0P}$: 4 for all P |
| 14 | Become fecund again following a birth | Females whose last fertility event is a birth | ${}_{b}\Omega_{\delta P} = \frac{1}{1 + e^{\left(-{}_{b}\rho_{p} \cdot \left(d - {}_{b}t_{0P}\right)\right)}}$<br>${}_{b}\Omega$: probability of becoming fecund after a birth, *recovering*<br>${}_{b}\rho_{P}$: “rate constant” of logistic defining probability of recovery, higher ρ means less variance in the duration from birth to recovery<br>d: duration since birth<br>${}_{b}t_{0P}$: mean duration of recovery after a birth<br>P: period | month | ${}_{b}\rho_{P}$: 1.5 for all P<br>${}_{b}t_{0P}$: 12 for all P |

**Table 6: Transition Probabilities**

| ID | Event | Eligible | Probability | Time-scale | Parameter Values |
|---|---|---|---|---|---|
| 15 | End union | All unions | $S_{A_mA_fCDPR_mR_f} = \text{OtoP PtoO } {}_US_{A_mA_fCP} \cdot T_D + \left( \frac{1 - \text{OtoP PtoO } {}_US_{A_mA_fCP} \cdot T_D}{2} \right) \cdot V_{R_m}{}^{Hs} + V_{R_f}$<br>S: probability of separating<br>U: signifies underlying probability of death<br>A: age<br>P: period<br>$_m$: male<br>$_f$: female<br>T: odds ratio modifying underlying probability of separating associated with duration D of union<br>OtoP: odds ratio to probability conversion<br>PtoO: probability to odds ratio conversion<br>D: duration of union<br>C: number of children born within the union<br>R: duration since infection with HIV<br>$V_R$ : viral load at duration R since infection, $V_0 = 0$<br>Hs: modifies the effect of being HIV+ on the probability of separating | month | ${}_US_{A_mA_f\Delta\Gamma P}$ : Table 15,<br>Table 16 and<br>Table 17 for all P<br>$T_D$ : Table 10 for all P<br>$V_R$ : Table 7<br>Hs: 0.75 |
| 16 | Form union | All males and unmarried females | $Y_{A_mA_fWPR_mR_f} = {}_UY_{A_mA_fWP} \cdot 1 - V_{R_m}{}^{Hu} \cdot 1 - V_{R_f}{}^{Hu}$<br>Y: probability of forming a union<br>U: signifies underlying probability of death<br>A: age<br>P: period<br>$_m$: male<br>$_f$: female<br>W: number of wives the man already has<br>R: duration since infection with HIV<br>$V_R$ : viral load at duration R since infection, $V_0 = 0$<br>Hu: modifies the effect of being HIV+ on the probability of forming a union | month | ${}_UY_{A_mA_fWP}$ : Table 12,<br>Table 13 and<br>Table 14 for all P<br>$V_R$ : Table 7<br>Hu: 0.75 |
| 17 | Circumcision | Un-circumcised males in specific age range(s) | $C_{L,E} = 1 - 1 - L^{1/\min(1,E)}$<br>C: monthly probability of becoming circumcised during intervention<br>L: Target level of circumcision intervention<br>E: Duration of exposure period for intervention | month | C: Section 0 |

**Table 7: Disease Progression Indicator**

| | DP Indicator | |
|---|---|---|
| Months Since Infection | Child | Adult |
| 1 | 0.4418 | 0.1159 |
| 2 | 0.3992 | 0.0189 |
| 3 | 0.3646 | 0.0174 |
| 4 | 0.3367 | 0.0176 |
| 5 | 0.3144 | 0.0179 |
| 6 | 0.2969 | 0.0181 |
| 7 | 0.2834 | 0.0184 |
| 8 | 0.2736 | 0.0187 |
| 9 | 0.2671 | 0.0190 |
| 10 | 0.2636 | 0.0193 |
| 11 | 0.2633 | 0.0196 |
| 12 | 0.2662 | 0.0200 |
| 13 | 0.2727 | 0.0203 |
| 14 | 0.2832 | 0.0206 |
| 15 | 0.2986 | 0.0210 |
| 16 | 0.3199 | 0.0214 |
| 17 | 0.3484 | 0.0218 |
| 18 | 0.3860 | 0.0222 |
| 19 | 0.4351 | 0.0226 |
| 20 | 0.4988 | 0.0230 |
| 21 | 0.5811 | 0.0234 |
| 22 | 0.6874 | 0.0239 |
| 23 | 0.8241 | 0.0244 |
| 24 | 1.0000 | 0.0248 |
| 25 | | 0.0253 |
| 26 | | 0.0259 |
| 27 | | 0.0264 |
| 28 | | 0.0270 |
| 29 | | 0.0275 |
| 30 | | 0.0281 |
| 31 | | 0.0287 |
| 32 | | 0.0294 |
| 33 | | 0.0300 |
| 34 | | 0.0307 |
| 35 | | 0.0314 |
| 36 | | 0.0321 |
| 37 | | 0.0329 |
| 38 | | 0.0337 |
| 39 | | 0.0345 |
| 40 | | 0.0353 |
| 41 | | 0.0362 |
| 42 | | 0.0371 |
| 43 | | 0.0380 |
| 44 | | 0.0389 |
| 45 | | 0.0399 |
| 46 | | 0.0409 |
| 47 | | 0.0420 |
| 48 | | 0.0430 |
| 49 | | 0.0442 |
| 50 | | 0.0453 |
| 51 | | 0.0465 |
| 52 | | 0.0478 |
| 53 | | 0.0490 |

**Table 8: Monthly Probability of Dying**

| Age | Female | Male |
|---|---|---|
| 0 | 0.009975 | 0.011362 |
| 1-4 | 0.001884 | 0.002163 |
| 5-9 | 0.000683 | 0.000785 |
| 10-14 | 0.000414 | 0.000475 |
| 15-19 | 0.000329 | 0.000378 |
| 20-24 | 0.000308 | 0.000354 |
| 25-29 | 0.000324 | 0.000372 |
| 30-34 | 0.000368 | 0.000423 |
| 35-39 | 0.000444 | 0.000511 |
| 40-44 | 0.000562 | 0.000646 |
| 45-49 | 0.000736 | 0.000846 |
| 50-54 | 0.000993 | 0.001141 |
| 55-59 | 0.001370 | 0.001573 |
| 60-64 | 0.001926 | 0.002210 |
| 65-69 | 0.002747 | 0.003150 |
| 70-74 | 0.003962 | 0.004538 |
| 75-79 | 0.005759 | 0.006585 |
| 80-84 | 0.008407 | 0.009589 |
| 85-89 | 0.012274 | 0.013952 |
| 90-94 | 0.017840 | 0.020183 |
| 95-99 | 0.025671 | 0.028860 |
| 100-104 | 0.036349 | 0.040540 |
| 105-109 | 0.050338 | 0.055614 |
| 110-114 | 0.067830 | 0.074163 |
| 115+ | 0.088649 | 0.095896 |

Source: Clark (2001a)

**Table 9: Fecundability Age Modification Parameters**

| Age | $N_A$ | $W_A$ |
|---|---|---|
| 20-24 | 0.460 | 0.000 |
| 25-29 | 0.431 | -0.279 |
| 30-34 | 0.395 | -0.667 |
| 35-39 | 0.322 | -1.042 |
| 40-44 | 0.167 | -1.414 |
| 45-49 | 0.024 | -1.671 |

Source $N_A$: Coale and Trussell (1974)

**Table 10: Duration-specific Odds Ratios Modifying Probability of Separation**

| Years | No Children | One or Two Children | 3+ Children |
|---|---|---|---|
| 0 | 1.0000 | 1.0000 | 1.0000 |
| 1-4 | 1.0000 | 1.0000 | 1.0000 |
| 5-9 | 0.5788 | 0.6673 | 0.4319 |
| 10-14 | 0.3439 | 0.4003 | 0.2220 |
| 15-19 | 0.2070 | 0.2612 | 0.2385 |
| 20-24 | 0.2135 | 0.1680 | 0.1816 |

| | |
|---|---|
| 54 | 0.0504 |
| 55 | 0.0517 |
| 56 | 0.0531 |
| 57 | 0.0546 |
| 58 | 0.0561 |
| 59 | 0.0577 |
| 60 | 0.0593 |
| 61 | 0.0610 |
| 62 | 0.0627 |
| 63 | 0.0645 |
| 64 | 0.0663 |
| 65 | 0.0682 |
| 66 | 0.0702 |
| 67 | 0.0722 |
| 68 | 0.0744 |
| 69 | 0.0765 |
| 70 | 0.0788 |
| 71 | 0.0811 |
| 72 | 0.0835 |
| 73 | 0.0860 |
| 74 | 0.0886 |
| 75 | 0.0913 |
| 76 | 0.0940 |
| 77 | 0.0969 |
| 78 | 0.0998 |
| 79 | 0.1029 |
| 80 | 0.1060 |
| 81 | 0.1093 |
| 82 | 0.1126 |
| 83 | 0.1161 |
| 84 | 0.1197 |
| 85 | 0.1234 |
| 86 | 0.1273 |
| 87 | 0.1312 |
| 88 | 0.1353 |
| 89 | 0.1396 |
| 90 | 0.1440 |
| 91 | 0.1485 |
| 92 | 0.1532 |
| 93 | 0.1581 |
| 94 | 0.1631 |
| 95 | 0.1683 |
| 96 | 0.1736 |
| 97 | 0.1792 |
| 98 | 0.1849 |
| 99 | 0.1909 |
| 100 | 0.1970 |
| 101 | 0.2033 |
| 102 | 0.2099 |
| 103 | 0.2167 |
| 104 | 0.2237 |
| 105 | 0.2309 |
| 106 | 0.2384 |
| 107 | 0.2461 |
| 108 | 0.2541 |
| 109 | 0.2624 |
| 110 | 0.2710 |

| | | | |
|---|---|---|---|
| 25-29 | 0.2657 | 0.2202 | 0.1502 |
| 30-34 | 0.3546 | 0.1944 | 0.1577 |
| 35-39 | 0.3546 | 0.2577 | 0.2134 |
| 40-44 | 0.3546 | 0.2577 | 0.2262 |
| 45+ | 0.3546 | 0.2577 | 0.2139 |

Source: Clark (2001a)

| | |
|---|---|
| 111 | 0.2798 |
| 112 | 0.2890 |
| 113 | 0.2984 |
| 114 | 0.3082 |
| 115 | 0.3183 |
| 116 | 0.3287 |
| 117 | 0.3395 |
| 118 | 0.3507 |
| 119 | 0.3623 |
| 120 | 0.3742 |
| 121 | 0.3865 |
| 122 | 0.3993 |
| 123 | 0.4125 |
| 124 | 0.4261 |
| 125 | 0.4403 |
| 126 | 0.4548 |
| 127 | 0.4699 |
| 128 | 0.4855 |
| 129 | 0.5016 |
| 130 | 0.5183 |
| 131 | 0.5355 |
| 132 | 0.5533 |
| 133 | 0.5717 |
| 134 | 0.5908 |
| 135 | 0.6105 |
| 136 | 0.6308 |
| 137 | 0.6519 |
| 138 | 0.6736 |
| 139 | 0.6961 |
| 140 | 0.7194 |
| 141 | 0.7434 |
| 142 | 0.7683 |
| 143 | 0.7940 |
| 144 | 0.8205 |
| 145 | 0.8480 |
| 146 | 0.8764 |
| 147 | 0.9058 |
| 148 | 0.9362 |
| 149 | 0.9675 |
| 150 | 1.0000 |

Source: Clark (2001a)

**Table 11: Daily Probability of Coitus for Married Couples, per 1,000**

| | Male Age | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Female Age | 10-14 | 15-19 | 20-24 | 25-29 | 30-34 | 35-39 | 40-44 | 45-49 | 50-54 | 55-59 | 60-64 | 65-69 | 70-74 | 75-79 | 80-84 | 85-89 | 90-94 | 95-99 | 100-104 | 105-109 | 110-114 | 115+ |
| 10-14 | 0.2690 | 0.2826 | 0.2718 | 0.2495 | 0.2250 | 0.1965 | 0.1533 | 0.0973 | 0.0438 | 0.0153 | 0.0063 | 0.0040 | 0.0031 | 0.0018 | 0.0013 | 0.0010 | 0.0007 | 0.0005 | 0.0004 | 0.0003 | 0.0002 | 0.0002 |
| 15-19 | 0.2572 | 0.3086 | 0.3307 | 0.3182 | 0.2862 | 0.2452 | 0.1988 | 0.1519 | 0.1131 | 0.0837 | 0.0627 | 0.0462 | 0.0304 | 0.0208 | 0.0153 | 0.0111 | 0.0077 | 0.0052 | 0.0036 | 0.0027 | 0.0020 | 0.0012 |
| 20-24 | 0.1921 | 0.2786 | 0.3252 | 0.3430 | 0.3215 | 0.2734 | 0.2290 | 0.1882 | 0.1520 | 0.1233 | 0.0996 | 0.0785 | 0.0613 | 0.0471 | 0.0362 | 0.0262 | 0.0177 | 0.0116 | 0.0081 | 0.0060 | 0.0044 | 0.0031 |
| 25-29 | 0.1136 | 0.2076 | 0.2824 | 0.3084 | 0.2978 | 0.2680 | 0.2305 | 0.1954 | 0.1646 | 0.1394 | 0.1183 | 0.1003 | 0.0849 | 0.0707 | 0.0559 | 0.0407 | 0.0279 | 0.0189 | 0.0134 | 0.0098 | 0.0072 | 0.0054 |
| 30-34 | 0.0458 | 0.1427 | 0.2152 | 0.2479 | 0.2464 | 0.2303 | 0.2064 | 0.1805 | 0.1582 | 0.1404 | 0.1250 | 0.1106 | 0.0971 | 0.0829 | 0.0667 | 0.0496 | 0.0347 | 0.0246 | 0.0179 | 0.0129 | 0.0091 | 0.0068 |
| 35-39 | 0.0227 | 0.0904 | 0.1502 | 0.1872 | 0.1941 | 0.1867 | 0.1718 | 0.1549 | 0.1412 | 0.1310 | 0.1217 | 0.1113 | 0.0997 | 0.0861 | 0.0698 | 0.0526 | 0.0381 | 0.0276 | 0.0202 | 0.0139 | 0.0093 | 0.0066 |
| 40-44 | 0.0115 | 0.0585 | 0.1057 | 0.1381 | 0.1484 | 0.1472 | 0.1385 | 0.1281 | 0.1205 | 0.1156 | 0.1108 | 0.1038 | 0.0943 | 0.0819 | 0.0666 | 0.0506 | 0.0370 | 0.0271 | 0.0197 | 0.0133 | 0.0081 | 0.0050 |
| 45-49 | 0.0094 | 0.0421 | 0.0764 | 0.1008 | 0.1131 | 0.1151 | 0.1102 | 0.1037 | 0.0994 | 0.0973 | 0.0950 | 0.0903 | 0.0827 | 0.0720 | 0.0587 | 0.0446 | 0.0324 | 0.0236 | 0.0172 | 0.0114 | 0.0068 | 0.0041 |
| 50-54 | 0.0077 | 0.0323 | 0.0559 | 0.0763 | 0.0875 | 0.0909 | 0.0884 | 0.0840 | 0.0811 | 0.0799 | 0.0785 | 0.0750 | 0.0688 | 0.0599 | 0.0489 | 0.0371 | 0.0267 | 0.0192 | 0.0140 | 0.0092 | 0.0055 | 0.0033 |
| 55-59 | 0.0063 | 0.0252 | 0.0442 | 0.0603 | 0.0701 | 0.0734 | 0.0723 | 0.0693 | 0.0670 | 0.0659 | 0.0645 | 0.0615 | 0.0563 | 0.0489 | 0.0398 | 0.0301 | 0.0216 | 0.0154 | 0.0107 | 0.0072 | 0.0043 | 0.0027 |
| 60-64 | 0.0052 | 0.0206 | 0.0363 | 0.0495 | 0.0573 | 0.0601 | 0.0600 | 0.0582 | 0.0564 | 0.0551 | 0.0537 | 0.0508 | 0.0463 | 0.0399 | 0.0323 | 0.0243 | 0.0173 | 0.0119 | 0.0082 | 0.0050 | 0.0033 | 0.0022 |
| 65-69 | 0.0042 | 0.0169 | 0.0295 | 0.0402 | 0.0465 | 0.0493 | 0.0498 | 0.0488 | 0.0475 | 0.0462 | 0.0447 | 0.0421 | 0.0381 | 0.0325 | 0.0261 | 0.0194 | 0.0136 | 0.0093 | 0.0058 | 0.0037 | 0.0025 | 0.0018 |
| 70-74 | 0.0035 | 0.0138 | 0.0239 | 0.0316 | 0.0370 | 0.0396 | 0.0409 | 0.0405 | 0.0395 | 0.0383 | 0.0368 | 0.0345 | 0.0309 | 0.0262 | 0.0208 | 0.0154 | 0.0107 | 0.0071 | 0.0043 | 0.0028 | 0.0021 | 0.0015 |
| 75-79 | 0.0028 | 0.0113 | 0.0193 | 0.0251 | 0.0284 | 0.0314 | 0.0331 | 0.0333 | 0.0326 | 0.0315 | 0.0300 | 0.0279 | 0.0249 | 0.0209 | 0.0165 | 0.0120 | 0.0082 | 0.0050 | 0.0033 | 0.0023 | 0.0017 | 0.0012 |
| 80-84 | 0.0023 | 0.0093 | 0.0158 | 0.0201 | 0.0226 | 0.0246 | 0.0266 | 0.0272 | 0.0269 | 0.0260 | 0.0247 | 0.0226 | 0.0199 | 0.0166 | 0.0129 | 0.0092 | 0.0057 | 0.0037 | 0.0025 | 0.0019 | 0.0014 | 0.0010 |
| 85-89 | 0.0019 | 0.0076 | 0.0129 | 0.0165 | 0.0183 | 0.0197 | 0.0211 | 0.0219 | 0.0220 | 0.0215 | 0.0202 | 0.0183 | 0.0158 | 0.0128 | 0.0097 | 0.0067 | 0.0043 | 0.0028 | 0.0021 | 0.0015 | 0.0011 | 0.0008 |
| 90-94 | 0.0016 | 0.0062 | 0.0106 | 0.0135 | 0.0150 | 0.0159 | 0.0169 | 0.0173 | 0.0175 | 0.0172 | 0.0163 | 0.0145 | 0.0122 | 0.0096 | 0.0071 | 0.0049 | 0.0033 | 0.0023 | 0.0017 | 0.0013 | 0.0009 | 0.0007 |
| 95-99 | 0.0013 | 0.0051 | 0.0087 | 0.0111 | 0.0123 | 0.0133 | 0.0138 | 0.0137 | 0.0137 | 0.0135 | 0.0126 | 0.0112 | 0.0092 | 0.0071 | 0.0051 | 0.0037 | 0.0026 | 0.0019 | 0.0014 | 0.0010 | 0.0008 | 0.0005 |
| 100-104 | 0.0010 | 0.0042 | 0.0071 | 0.0091 | 0.0102 | 0.0113 | 0.0117 | 0.0111 | 0.0108 | 0.0107 | 0.0099 | 0.0086 | 0.0073 | 0.0055 | 0.0039 | 0.0028 | 0.0021 | 0.0015 | 0.0011 | 0.0008 | 0.0006 | 0.0004 |
| 105-109 | 0.0009 | 0.0034 | 0.0058 | 0.0074 | 0.0085 | 0.0096 | 0.0100 | 0.0094 | 0.0090 | 0.0089 | 0.0081 | 0.0070 | 0.0058 | 0.0044 | 0.0031 | 0.0023 | 0.0017 | 0.0013 | 0.0009 | 0.0007 | 0.0005 | 0.0004 |
| 110-114 | 0.0007 | 0.0028 | 0.0048 | 0.0061 | 0.0070 | 0.0081 | 0.0085 | 0.0081 | 0.0078 | 0.0076 | 0.0068 | 0.0058 | 0.0048 | 0.0036 | 0.0025 | 0.0019 | 0.0014 | 0.0010 | 0.0008 | 0.0006 | 0.0004 | 0.0003 |
| 115+ | 0.0006 | 0.0022 | 0.0040 | 0.0052 | 0.0053 | 0.0070 | 0.0077 | 0.0067 | 0.0065 | 0.0068 | 0.0059 | 0.0043 | 0.0042 | 0.0027 | 0.0020 | 0.0015 | 0.0011 | 0.0008 | 0.0006 | 0.0004 | 0.0003 | 0.0002 |

Source: Clark (2001a)

**Table 12:** **Monthly Probability of Union Formation for Couples whose Male Member is not Married, per 1,000**

| | Male Age | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Female Age | 10-14 | 15-19 | 20-24 | 25-29 | 30-34 | 35-39 | 40-44 | 45-49 | 50-54 | 55-59 | 60-64 | 65-69 | 70-74 | 75-79 | 80-84 | 85-89 | 90-94 | 95-99 | 100-104 | 105-109 | 110-114 | 115+ |
| 10-14 | 1.2601 | 6.9981 | 10.5183 | 9.3525 | 4.4742 | 2.6871 | 1.3529 | 0.7115 | 0.3518 | 0.0634 | 0.0026 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 15-19 | 1.6454 | 16.0307 | 59.1912 | 38.1234 | 14.4844 | 6.6721 | 4.2361 | 2.5845 | 1.1012 | 0.1343 | 0.0109 | 0.0033 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 20-24 | 1.5201 | 10.0149 | 34.7435 | 39.9519 | 19.8630 | 11.1167 | 7.0864 | 4.8703 | 1.6341 | 0.3603 | 0.1609 | 0.0839 | 0.0065 | 0.0005 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 25-29 | 0.6002 | 3.9290 | 8.9836 | 16.4355 | 16.4668 | 12.1145 | 9.1894 | 5.2192 | 2.8563 | 1.7269 | 1.2090 | 0.6479 | 0.3636 | 0.2040 | 0.1145 | 0.0643 | 0.0361 | 0.0202 | 0.0114 | 0.0064 | 0.0036 | 0.0020 |
| 30-34 | 0.3641 | 1.3652 | 3.7736 | 7.1308 | 10.8162 | 10.0830 | 7.8645 | 6.4737 | 4.8178 | 4.2365 | 3.0290 | 1.2422 | 0.6952 | 0.3891 | 0.2178 | 0.1219 | 0.0682 | 0.0382 | 0.0214 | 0.0120 | 0.0067 | 0.0037 |
| 35-39 | 0.2887 | 1.0207 | 2.0696 | 3.5502 | 4.4025 | 5.6693 | 5.5923 | 7.0434 | 6.7674 | 3.9201 | 3.5192 | 1.2725 | 0.5664 | 0.2521 | 0.1122 | 0.0499 | 0.0222 | 0.0099 | 0.0044 | 0.0020 | 0.0009 | 0.0004 |
| 40-44 | 0.2798 | 0.9240 | 1.5825 | 1.3285 | 1.6645 | 2.6305 | 5.1051 | 4.4105 | 3.7573 | 3.9758 | 1.8604 | 0.7610 | 0.6923 | 0.6297 | 0.5728 | 0.5210 | 0.4740 | 0.4311 | 0.3922 | 0.3567 | 0.3245 | 0.2952 |
| 45-49 | 0.2639 | 0.8722 | 1.2915 | 1.2941 | 1.0599 | 2.3002 | 2.3616 | 2.0006 | 1.9775 | 2.2943 | 1.1369 | 0.1884 | 0.1787 | 0.1695 | 0.1607 | 0.1525 | 0.1446 | 0.1372 | 0.1301 | 0.1234 | 0.1170 | 0.1110 |
| 50-54 | 0.1997 | 0.6571 | 1.0483 | 0.6729 | 0.7962 | 1.0393 | 1.0001 | 1.2768 | 0.9435 | 0.6587 | 0.5223 | 0.0786 | 0.0349 | 0.0155 | 0.0069 | 0.0030 | 0.0014 | 0.0006 | 0.0003 | 0.0001 | 0.0001 | 0.0000 |
| 55-59 | 0.1703 | 0.4748 | 0.5102 | 0.4172 | 0.4094 | 0.4373 | 0.6566 | 0.4173 | 0.3642 | 0.1100 | 0.0539 | 0.0261 | 0.0007 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 60-64 | 0.0918 | 0.3642 | 0.5540 | 0.2031 | 0.1990 | 0.5178 | 0.2064 | 0.0746 | 0.0363 | 0.0191 | 0.0029 | 0.0011 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 65-69 | 0.0072 | 0.0403 | 0.0243 | 0.0435 | 0.0419 | 0.0417 | 0.0929 | 0.0256 | 0.0119 | 0.0017 | 0.0001 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 70-74 | 0.0006 | 0.0045 | 0.0011 | 0.0093 | 0.0088 | 0.0034 | 0.0418 | 0.0088 | 0.0039 | 0.0002 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 75-79 | 0.0000 | 0.0005 | 0.0000 | 0.0020 | 0.0019 | 0.0003 | 0.0188 | 0.0030 | 0.0013 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 80-84 | 0.0000 | 0.0001 | 0.0000 | 0.0004 | 0.0004 | 0.0000 | 0.0085 | 0.0010 | 0.0004 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 85-89 | 0.0000 | 0.0000 | 0.0000 | 0.0001 | 0.0001 | 0.0000 | 0.0038 | 0.0004 | 0.0001 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 90-94 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0017 | 0.0001 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 95-99 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0008 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 100-104 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0003 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 105-109 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0002 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 110-114 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0001 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 115+ | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |

Source: Clark (2001a)

**Table 13: Monthly Probability of Union Formation for Couples whose Male Member is Married with One Wife, per 1,000**

| | Male Age | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Female Age | 10-14 | 15-19 | 20-24 | 25-29 | 30-34 | 35-39 | 40-44 | 45-49 | 50-54 | 55-59 | 60-64 | 65-69 | 70-74 | 75-79 | 80-84 | 85-89 | 90-94 | 95-99 | 100-104 | 105-109 | 110-114 | 115+ |
| 10-14 | 0.1508 | 2.0450 | 3.8902 | 3.4658 | 1.9351 | 1.8919 | 1.3677 | 0.8158 | 0.3498 | 0.0492 | 0.0021 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 15-19 | 0.2380 | 2.9289 | 20.3337 | 14.2712 | 6.6793 | 4.7785 | 2.9986 | 1.5600 | 0.7000 | 0.1015 | 0.0051 | 0.0004 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 20-24 | 0.2091 | 2.8888 | 11.5952 | 14.5505 | 10.6349 | 6.9031 | 4.3676 | 2.3071 | 1.1206 | 0.1937 | 0.0360 | 0.0047 | 0.0001 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 25-29 | 0.1550 | 1.2457 | 3.7204 | 8.2208 | 6.4271 | 7.3832 | 5.2513 | 3.3799 | 1.8811 | 0.8299 | 0.2355 | 0.0712 | 0.0117 | 0.0019 | 0.0003 | 0.0001 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 30-34 | 0.1010 | 0.7987 | 2.5043 | 4.2014 | 5.7841 | 6.2091 | 5.7464 | 4.7193 | 3.9895 | 2.7697 | 1.3456 | 0.1415 | 0.1175 | 0.0976 | 0.0811 | 0.0673 | 0.0559 | 0.0464 | 0.0386 | 0.0320 | 0.0266 | 0.0221 |
| 35-39 | 0.0995 | 0.7083 | 1.3438 | 2.3645 | 4.0990 | 5.4166 | 5.9052 | 5.3899 | 5.3496 | 4.2629 | 1.5545 | 0.2124 | 0.1582 | 0.1179 | 0.0878 | 0.0655 | 0.0488 | 0.0363 | 0.0271 | 0.0202 | 0.0150 | 0.0112 |
| 40-44 | 0.0975 | 0.6346 | 0.9609 | 1.4669 | 2.3464 | 4.1005 | 4.1249 | 4.9273 | 4.7375 | 3.4923 | 1.6967 | 0.3657 | 0.2747 | 0.2064 | 0.1551 | 0.1165 | 0.0875 | 0.0658 | 0.0494 | 0.0371 | 0.0279 | 0.0209 |
| 45-49 | 0.0963 | 0.6182 | 0.8746 | 0.8114 | 1.2398 | 1.6658 | 2.5128 | 3.0095 | 3.2059 | 2.7546 | 2.4452 | 2.0327 | 0.8385 | 0.3459 | 0.1427 | 0.0588 | 0.0243 | 0.0100 | 0.0041 | 0.0017 | 0.0007 | 0.0003 |
| 50-54 | 0.0957 | 0.6154 | 0.8386 | 0.6740 | 0.2329 | 0.2894 | 0.5260 | 1.7897 | 2.3369 | 2.7079 | 3.2049 | 3.1175 | 0.2724 | 0.0238 | 0.0021 | 0.0002 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 55-59 | 0.0845 | 0.5927 | 0.8032 | 0.5954 | 0.0928 | 0.0727 | 0.6362 | 1.5408 | 2.1483 | 2.7871 | 3.0989 | 2.7639 | 0.9261 | 0.3103 | 0.1040 | 0.0348 | 0.0117 | 0.0039 | 0.0013 | 0.0004 | 0.0001 | 0.0000 |
| 60-64 | 0.0525 | 0.3874 | 0.5679 | 0.3874 | 0.0541 | 0.0577 | 0.5446 | 1.3725 | 1.1920 | 1.5326 | 1.8215 | 1.0262 | 0.8161 | 0.6490 | 0.5162 | 0.4105 | 0.3264 | 0.2596 | 0.2065 | 0.1642 | 0.1306 | 0.1039 |
| 65-69 | 0.0017 | 0.0795 | 0.1336 | 0.0806 | 0.0021 | 0.0009 | 0.0499 | 0.2309 | 0.8831 | 0.5638 | 0.6701 | 0.0069 | 0.0897 | 0.2199 | 0.2128 | 0.1542 | 0.1028 | 0.0664 | 0.0424 | 0.0269 | 0.0170 | 0.0108 |
| 70-74 | 0.0001 | 0.0163 | 0.0314 | 0.0168 | 0.0001 | 0.0000 | 0.0046 | 0.0388 | 0.6542 | 0.2074 | 0.2465 | 0.0000 | 0.0099 | 0.0745 | 0.0877 | 0.0579 | 0.0323 | 0.0170 | 0.0087 | 0.0044 | 0.0022 | 0.0011 |
| 75-79 | 0.0000 | 0.0034 | 0.0074 | 0.0035 | 0.0000 | 0.0000 | 0.0004 | 0.0065 | 0.4846 | 0.0763 | 0.0907 | 0.0000 | 0.0011 | 0.0252 | 0.0361 | 0.0218 | 0.0102 | 0.0043 | 0.0018 | 0.0007 | 0.0003 | 0.0001 |
| 80-84 | 0.0000 | 0.0007 | 0.0017 | 0.0007 | 0.0000 | 0.0000 | 0.0000 | 0.0011 | 0.3590 | 0.0281 | 0.0334 | 0.0000 | 0.0001 | 0.0085 | 0.0149 | 0.0082 | 0.0032 | 0.0011 | 0.0004 | 0.0001 | 0.0000 | 0.0000 |
| 85-89 | 0.0000 | 0.0001 | 0.0004 | 0.0002 | 0.0000 | 0.0000 | 0.0000 | 0.0002 | 0.2660 | 0.0103 | 0.0123 | 0.0000 | 0.0000 | 0.0029 | 0.0061 | 0.0031 | 0.0010 | 0.0003 | 0.0001 | 0.0000 | 0.0000 | 0.0000 |
| 90-94 | 0.0000 | 0.0000 | 0.0001 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.1970 | 0.0038 | 0.0045 | 0.0000 | 0.0000 | 0.0010 | 0.0025 | 0.0012 | 0.0003 | 0.0001 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 95-99 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.1460 | 0.0014 | 0.0017 | 0.0000 | 0.0000 | 0.0003 | 0.0010 | 0.0004 | 0.0001 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 100-104 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.1081 | 0.0005 | 0.0006 | 0.0000 | 0.0000 | 0.0001 | 0.0004 | 0.0002 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 105-109 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0801 | 0.0002 | 0.0002 | 0.0000 | 0.0000 | 0.0000 | 0.0002 | 0.0001 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 110-114 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0593 | 0.0001 | 0.0001 | 0.0000 | 0.0000 | 0.0000 | 0.0001 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 115+ | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0440 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |

Source: Clark (2001a)

**Table 14: Monthly Probability of Union Formation for Couples whose Male Member is Married with Two or More Wives, per 1,000**

| | Male Age | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Female Age | 10-14 | 15-19 | 20-24 | 25-29 | 30-34 | 35-39 | 40-44 | 45-49 | 50-54 | 55-59 | 60-64 | 65-69 | 70-74 | 75-79 | 80-84 | 85-89 | 90-94 | 95-99 | 100-104 | 105-109 | 110-114 | 115+ |
| 10-14 | 0.1465 | 1.6665 | 3.4168 | 8.7284 | 4.7795 | 5.0931 | 3.3263 | 1.9732 | 1.6880 | 1.5675 | 1.0926 | 0.8604 | 0.1997 | 0.0464 | 0.0108 | 0.0025 | 0.0006 | 0.0001 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 15-19 | 0.2208 | 1.9745 | 12.9314 | 12.1498 | 15.6442 | 10.7600 | 6.0094 | 4.9408 | 3.5948 | 2.4192 | 2.7874 | 0.9874 | 0.2312 | 0.0541 | 0.0127 | 0.0030 | 0.0007 | 0.0002 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 20-24 | 0.1627 | 1.9429 | 5.7266 | 19.3232 | 15.5571 | 13.1123 | 8.3011 | 5.5632 | 5.1073 | 3.0247 | 1.3867 | 0.9343 | 0.2188 | 0.0512 | 0.0120 | 0.0028 | 0.0007 | 0.0002 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 25-29 | 0.0970 | 0.6908 | 4.2097 | 11.0412 | 14.4341 | 9.3499 | 7.4035 | 6.8708 | 5.4316 | 2.8063 | 1.3968 | 0.4053 | 0.0949 | 0.0222 | 0.0052 | 0.0012 | 0.0003 | 0.0001 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 30-34 | 0.0343 | 0.5819 | 3.5501 | 7.6283 | 8.2551 | 6.5485 | 5.8604 | 6.1619 | 5.1966 | 4.9165 | 2.7798 | 1.6062 | 0.3761 | 0.0881 | 0.0206 | 0.0048 | 0.0011 | 0.0003 | 0.0001 | 0.0000 | 0.0000 | 0.0000 |
| 35-39 | 0.0339 | 0.5991 | 3.2278 | 5.9458 | 5.5605 | 4.9392 | 5.5863 | 7.4057 | 7.0450 | 6.8407 | 8.4079 | 4.1835 | 0.9796 | 0.2294 | 0.0537 | 0.0126 | 0.0029 | 0.0007 | 0.0002 | 0.0000 | 0.0000 | 0.0000 |
| 40-44 | 0.0340 | 0.5875 | 3.0835 | 5.3262 | 4.7545 | 4.1913 | 5.6773 | 7.5449 | 10.3895 | 13.0299 | 11.7675 | 7.8667 | 1.8420 | 0.4313 | 0.1010 | 0.0236 | 0.0055 | 0.0013 | 0.0003 | 0.0001 | 0.0000 | 0.0000 |
| 45-49 | 0.0300 | 0.5190 | 2.9126 | 5.0123 | 4.2967 | 3.3432 | 3.4745 | 5.0729 | 10.4113 | 15.6114 | 11.4707 | 4.6267 | 1.0833 | 0.2537 | 0.0594 | 0.0139 | 0.0033 | 0.0008 | 0.0002 | 0.0000 | 0.0000 | 0.0000 |
| 50-54 | 0.0222 | 0.3877 | 2.0252 | 3.9395 | 2.8779 | 2.0817 | 1.4255 | 2.6116 | 7.0655 | 8.4296 | 5.7600 | 2.0536 | 0.4809 | 0.1126 | 0.0264 | 0.0062 | 0.0014 | 0.0003 | 0.0001 | 0.0000 | 0.0000 | 0.0000 |
| 55-59 | 0.0131 | 0.1997 | 1.0249 | 1.2736 | 1.4278 | 0.6915 | 0.5972 | 1.1653 | 2.1035 | 2.3329 | 1.5228 | 0.4957 | 0.1161 | 0.0272 | 0.0064 | 0.0015 | 0.0003 | 0.0001 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 60-64 | 0.0052 | 0.0692 | 0.1404 | 0.2245 | 0.1931 | 0.1509 | 0.1177 | 0.1940 | 0.2790 | 0.2885 | 0.1899 | 0.0758 | 0.0087 | 0.0010 | 0.0001 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 65-69 | 0.0000 | 0.0090 | 0.0190 | 0.0304 | 0.0261 | 0.0204 | 0.0159 | 0.0262 | 0.0377 | 0.0390 | 0.0257 | 0.0103 | 0.0009 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 70-74 | 0.0000 | 0.0012 | 0.0026 | 0.0041 | 0.0035 | 0.0028 | 0.0022 | 0.0035 | 0.0051 | 0.0053 | 0.0035 | 0.0014 | 0.0001 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 75-79 | 0.0000 | 0.0002 | 0.0003 | 0.0006 | 0.0005 | 0.0004 | 0.0003 | 0.0005 | 0.0007 | 0.0007 | 0.0005 | 0.0002 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 80-84 | 0.0000 | 0.0000 | 0.0000 | 0.0001 | 0.0001 | 0.0001 | 0.0000 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 85-89 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 90-94 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 95-99 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 100-104 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 105-109 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 110-114 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 115+ | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |

Source: Clark (2001a)

**Table 15: Monthly Probability of Separation for Couples with No Children, per 1,000**

| | Male Age | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Female Age | 10-14 | 15-19 | 20-24 | 25-29 | 30-34 | 35-39 | 40-44 | 45-49 | 50-54 | 55-59 | 60-64 | 65-69 | 70-74 | 75-79 | 80-84 | 85-89 | 90-94 | 95-99 | 100-104 | 105-109 | 110-114 | 115+ |
| 10-14 | 4.8640 | 11.9495 | 19.6445 | 21.7634 | 22.2397 | 17.2825 | 12.6332 | 5.3521 | 1.7739 | 0.3264 | 0.0456 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 15-19 | 6.9813 | 21.8029 | 38.3107 | 49.5150 | 48.7013 | 49.7730 | 35.0336 | 20.0365 | 7.2059 | 2.0382 | 0.3363 | 0.0612 | 0.0168 | 0.0046 | 0.0013 | 0.0004 | 0.0001 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 20-24 | 6.4553 | 19.4019 | 41.8820 | 60.9334 | 77.4859 | 82.6047 | 77.0527 | 46.6730 | 22.7737 | 8.0472 | 3.1024 | 0.9211 | 0.4223 | 0.1936 | 0.0887 | 0.0407 | 0.0187 | 0.0086 | 0.0039 | 0.0018 | 0.0008 | 0.0004 |
| 25-29 | 3.1451 | 11.4283 | 27.5985 | 55.8700 | 86.0012 | 113.5373 | 105.9634 | 83.3551 | 48.2920 | 29.2415 | 15.6094 | 6.7682 | 0.7655 | 0.0866 | 0.0098 | 0.0011 | 0.0001 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 30-34 | 1.0278 | 4.0209 | 15.4298 | 44.2783 | 85.3366 | 104.0665 | 111.6146 | 94.7054 | 87.7344 | 69.8536 | 48.6448 | 27.8240 | 1.3364 | 0.0642 | 0.0031 | 0.0001 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 35-39 | 0.1324 | 1.2908 | 9.1163 | 31.8141 | 57.8428 | 70.8230 | 82.6276 | 101.5697 | 108.8649 | 120.2012 | 107.4666 | 57.0986 | 1.1336 | 0.0225 | 0.0004 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 40-44 | 0.0000 | 0.5914 | 4.8969 | 15.4363 | 25.7536 | 35.8824 | 53.9494 | 88.6467 | 130.1641 | 158.9759 | 148.1869 | 79.5954 | 1.1604 | 0.0169 | 0.0002 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 45-49 | 0.0000 | 0.2425 | 1.6561 | 4.4273 | 9.1767 | 16.8549 | 33.6206 | 75.0273 | 128.1329 | 164.0586 | 146.3599 | 74.4824 | 1.0362 | 0.0144 | 0.0002 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 50-54 | 0.0000 | 0.0518 | 0.2592 | 1.1764 | 3.5430 | 6.9361 | 21.3688 | 54.8911 | 98.0601 | 123.1217 | 101.8236 | 51.2411 | 1.0130 | 0.0200 | 0.0004 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 55-59 | 0.0000 | 0.0000 | 0.0518 | 0.4146 | 0.8509 | 2.6182 | 10.7969 | 29.9575 | 50.4677 | 59.9844 | 47.1539 | 24.7528 | 1.1050 | 0.0493 | 0.0022 | 0.0001 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 60-64 | 0.0000 | 0.0000 | 0.0173 | 0.0518 | 0.1037 | 0.7266 | 3.8755 | 8.9907 | 14.8589 | 16.0133 | 13.1546 | 6.6462 | 1.0212 | 0.1569 | 0.0241 | 0.0037 | 0.0006 | 0.0001 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 65-69 | 0.0000 | 0.0000 | 0.0006 | 0.0188 | 0.0775 | 0.3841 | 0.5599 | 0.4288 | 0.4173 | 0.3642 | 0.3869 | 0.3671 | 0.0856 | 0.0169 | 0.0005 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 70-74 | 0.0000 | 0.0000 | 0.0000 | 0.0068 | 0.0579 | 0.2031 | 0.0809 | 0.0205 | 0.0117 | 0.0083 | 0.0114 | 0.0203 | 0.0072 | 0.0018 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 75-79 | 0.0000 | 0.0000 | 0.0000 | 0.0025 | 0.0433 | 0.1073 | 0.0117 | 0.0010 | 0.0003 | 0.0002 | 0.0003 | 0.0011 | 0.0006 | 0.0002 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 80-84 | 0.0000 | 0.0000 | 0.0000 | 0.0009 | 0.0323 | 0.0567 | 0.0017 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0001 | 0.0001 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 85-89 | 0.0000 | 0.0000 | 0.0000 | 0.0003 | 0.0241 | 0.0300 | 0.0002 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 90-94 | 0.0000 | 0.0000 | 0.0000 | 0.0001 | 0.0180 | 0.0159 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 95-99 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0135 | 0.0084 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 100-104 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0101 | 0.0044 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 105-109 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0075 | 0.0023 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 110-114 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0056 | 0.0012 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 115+ | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0042 | 0.0007 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |

Source: Clark (2001a)

**Table 16:** **Monthly Probability of Separation for Couples with One or Two Children, per 1,000**

| | Male Age | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Female Age | 10-14 | 15-19 | 20-24 | 25-29 | 30-34 | 35-39 | 40-44 | 45-49 | 50-54 | 55-59 | 60-64 | 65-69 | 70-74 | 75-79 | 80-84 | 85-89 | 90-94 | 95-99 | 100-104 | 105-109 | 110-114 | 115+ |
| 10-14 | 0.4195 | 1.6562 | 3.4323 | 4.5777 | 4.3008 | 3.0381 | 1.9701 | 1.2341 | 0.8706 | 0.5402 | 0.3765 | 0.1807 | 0.0354 | 0.0069 | 0.0014 | 0.0003 | 0.0001 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 15-19 | 0.6407 | 2.5977 | 6.1439 | 9.0060 | 9.2869 | 8.0048 | 6.2077 | 5.1353 | 3.9794 | 3.3267 | 2.2315 | 1.0759 | 0.3958 | 0.1456 | 0.0536 | 0.0197 | 0.0072 | 0.0027 | 0.0010 | 0.0004 | 0.0001 | 0.0000 |
| 20-24 | 0.5589 | 2.5905 | 6.6721 | 11.2431 | 13.7985 | 13.9103 | 13.4957 | 11.8221 | 10.8170 | 9.1304 | 6.2089 | 2.6414 | 0.7404 | 0.2075 | 0.0582 | 0.0163 | 0.0046 | 0.0013 | 0.0004 | 0.0001 | 0.0000 | 0.0000 |
| 25-29 | 0.3498 | 1.7459 | 5.1362 | 10.1167 | 14.7534 | 18.2415 | 19.4471 | 19.6664 | 18.4308 | 15.6520 | 10.2209 | 4.1479 | 0.6830 | 0.1125 | 0.0185 | 0.0030 | 0.0005 | 0.0001 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 30-34 | 0.1394 | 0.8650 | 2.9387 | 6.5944 | 11.7846 | 16.9745 | 21.2421 | 23.5741 | 23.5156 | 19.6362 | 12.1703 | 4.6990 | 0.6289 | 0.0842 | 0.0113 | 0.0015 | 0.0002 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 35-39 | 0.0432 | 0.3232 | 1.1649 | 3.1905 | 6.7141 | 11.6729 | 17.2169 | 22.7428 | 25.3295 | 21.3213 | 12.3768 | 4.5708 | 0.5856 | 0.0750 | 0.0096 | 0.0012 | 0.0002 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 40-44 | 0.0108 | 0.0666 | 0.3172 | 1.0661 | 2.8051 | 5.7394 | 10.6854 | 18.2499 | 23.9380 | 20.9253 | 12.2505 | 4.1342 | 0.5094 | 0.0628 | 0.0077 | 0.0010 | 0.0001 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 45-49 | 0.0000 | 0.0061 | 0.0516 | 0.2597 | 0.7747 | 2.0292 | 5.3717 | 11.3510 | 16.8416 | 17.1649 | 10.0185 | 3.4084 | 0.5156 | 0.0780 | 0.0118 | 0.0018 | 0.0003 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 50-54 | 0.0000 | 0.0000 | 0.0071 | 0.0327 | 0.1260 | 0.5752 | 1.9610 | 4.7019 | 8.0100 | 8.5681 | 5.9688 | 2.0870 | 0.5376 | 0.1385 | 0.0357 | 0.0092 | 0.0024 | 0.0006 | 0.0002 | 0.0000 | 0.0000 | 0.0000 |
| 55-59 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0164 | 0.1007 | 0.3888 | 1.1184 | 1.9887 | 2.3951 | 1.7910 | 0.8364 | 0.3077 | 0.1132 | 0.0416 | 0.0153 | 0.0056 | 0.0021 | 0.0008 | 0.0003 | 0.0001 | 0.0000 |
| 60-64 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0224 | 0.0897 | 0.1925 | 0.2504 | 0.2186 | 0.1158 | 0.0119 | 0.0012 | 0.0001 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 65-69 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0082 | 0.0872 | 0.1072 | 0.1168 | 0.1390 | 0.0835 | 0.0035 | 0.0001 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 70-74 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0030 | 0.0848 | 0.0597 | 0.0544 | 0.0884 | 0.0601 | 0.0010 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 75-79 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0011 | 0.0824 | 0.0332 | 0.0254 | 0.0562 | 0.0433 | 0.0003 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 80-84 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0004 | 0.0801 | 0.0185 | 0.0118 | 0.0358 | 0.0312 | 0.0001 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 85-89 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0001 | 0.0779 | 0.0103 | 0.0055 | 0.0227 | 0.0225 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 90-94 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0001 | 0.0757 | 0.0057 | 0.0026 | 0.0145 | 0.0162 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 95-99 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0736 | 0.0032 | 0.0012 | 0.0092 | 0.0117 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 100-104 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0716 | 0.0018 | 0.0006 | 0.0059 | 0.0084 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 105-109 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0696 | 0.0010 | 0.0003 | 0.0037 | 0.0061 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 110-114 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0676 | 0.0006 | 0.0001 | 0.0024 | 0.0044 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 115+ | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0657 | 0.0003 | 0.0001 | 0.0015 | 0.0032 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |

Source: Clark (2001a)

**Table 17: Monthly Probability of Separation for Couples with Three or More Children, per 1,000**

| | Male Age | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Female Age | 10-14 | 15-19 | 20-24 | 25-29 | 30-34 | 35-39 | 40-44 | 45-49 | 50-54 | 55-59 | 60-64 | 65-69 | 70-74 | 75-79 | 80-84 | 85-89 | 90-94 | 95-99 | 100-104 | 105-109 | 110-114 | 115+ |
| 10-14 | 0.0631 | 0.2414 | 0.5351 | 0.8781 | 1.5735 | 2.2507 | 2.7288 | 2.1565 | 1.2746 | 0.3904 | 0.0890 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 15-19 | 0.1893 | 1.2921 | 3.2518 | 5.3252 | 6.9839 | 9.4715 | 10.3889 | 9.4737 | 5.4418 | 2.3409 | 0.4944 | 0.0791 | 0.0329 | 0.0136 | 0.0057 | 0.0024 | 0.0010 | 0.0004 | 0.0002 | 0.0001 | 0.0000 | 0.0000 |
| 20-24 | 0.3785 | 2.5843 | 8.2620 | 14.1862 | 18.0000 | 21.2057 | 25.7466 | 23.3056 | 16.1001 | 6.7144 | 2.0596 | 0.3817 | 0.2275 | 0.1356 | 0.0808 | 0.0482 | 0.0287 | 0.0171 | 0.0102 | 0.0061 | 0.0036 | 0.0022 |
| 25-29 | 0.4416 | 3.3935 | 10.5535 | 20.4257 | 27.2293 | 33.6889 | 41.4260 | 42.5398 | 28.8399 | 14.2357 | 4.8665 | 1.1358 | 0.3044 | 0.0816 | 0.0219 | 0.0059 | 0.0016 | 0.0004 | 0.0001 | 0.0000 | 0.0000 | 0.0000 |
| 30-34 | 0.3785 | 2.5843 | 8.4953 | 16.1237 | 25.3149 | 38.5682 | 51.7807 | 53.0647 | 39.4534 | 21.1457 | 8.4323 | 2.1275 | 0.3374 | 0.0535 | 0.0085 | 0.0013 | 0.0002 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 35-39 | 0.1893 | 1.2921 | 3.5537 | 7.6858 | 16.1123 | 31.1739 | 48.3538 | 53.1120 | 43.2245 | 26.4033 | 12.0496 | 3.8554 | 0.4705 | 0.0574 | 0.0070 | 0.0009 | 0.0001 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 40-44 | 0.0631 | 0.2414 | 0.7406 | 2.3981 | 7.3952 | 19.2295 | 35.4408 | 47.3189 | 44.8315 | 32.6456 | 18.4232 | 6.6868 | 0.5697 | 0.0485 | 0.0041 | 0.0004 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 45-49 | 0.0000 | 0.0000 | 0.0821 | 0.5496 | 2.7661 | 9.9354 | 24.6899 | 39.6344 | 46.6790 | 41.5883 | 27.0556 | 11.6579 | 0.7571 | 0.0492 | 0.0032 | 0.0002 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 50-54 | 0.0000 | 0.0000 | 0.0136 | 0.0854 | 0.9663 | 5.6472 | 15.9991 | 30.1730 | 40.8498 | 44.0641 | 33.7383 | 16.6457 | 0.9738 | 0.0570 | 0.0033 | 0.0002 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 55-59 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.4815 | 2.9443 | 8.9521 | 16.5398 | 25.8042 | 32.1681 | 31.5665 | 16.4878 | 1.0934 | 0.0725 | 0.0048 | 0.0003 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 60-64 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.2058 | 1.2560 | 2.9680 | 5.7673 | 9.9076 | 15.9979 | 16.1116 | 10.9211 | 2.1041 | 0.4054 | 0.0781 | 0.0150 | 0.0029 | 0.0006 | 0.0001 | 0.0000 | 0.0000 | 0.0000 |
| 65-69 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0567 | 0.7439 | 0.4960 | 0.5354 | 0.6232 | 0.9893 | 1.0425 | 1.9619 | 0.7740 | 0.1349 | 0.0057 | 0.0002 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 70-74 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0156 | 0.4406 | 0.0829 | 0.0497 | 0.0392 | 0.0612 | 0.0675 | 0.3524 | 0.2848 | 0.0449 | 0.0004 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 75-79 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0043 | 0.2610 | 0.0139 | 0.0046 | 0.0025 | 0.0038 | 0.0044 | 0.0633 | 0.1048 | 0.0149 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 80-84 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0012 | 0.1546 | 0.0023 | 0.0004 | 0.0002 | 0.0002 | 0.0003 | 0.0114 | 0.0385 | 0.0050 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 85-89 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0003 | 0.0916 | 0.0004 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0020 | 0.0142 | 0.0017 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 90-94 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0001 | 0.0542 | 0.0001 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0004 | 0.0052 | 0.0006 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 95-99 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0321 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0001 | 0.0019 | 0.0002 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 100-104 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0190 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0007 | 0.0001 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 105-109 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0113 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0003 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 110-114 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0067 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0001 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 115+ | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0040 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |

Source: Clark (2001a)

## Running SPEHS

SPEHS is run from an initial population of roughly 30 young individuals, evenly split between males and females, for about 150 years to create a stable population of several thousand individuals. This stable population is used as $P_0$ for all simulation scenarios. SPEHS creates data to populate the tables displayed in Figure 9. These describe the time-evolving dynamics of the entire simulated population, allowing flexible analysis of dynamic indicators. Generational links between parents and children are maintained as well as time-dependent, union-mediated links between men and women. Together this information provides an opportunity for a wide variety of investigations.

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