Demographic Research a free, expedited, online journal
of peer-reviewed research and commentary
in the population sciences published by the
Max Planck Institute for Demographic Research
Konrad-Zuse Str. 1, D-18057 Rostock · GERMANY
www.demographic-research.org

DEMOGRAPHIC RESEARCH
SPECIAL COLLECTION 1, ARTICLE 7
PUBLISHED 19 September 2003, PAGES 207-246
www.demographic-research.org/special/1/7/
DOI: 10.4054/DemRes.2003.S1.7

Research Article

"Moving" and Marrying: Modelling HIV Infection among Newly-weds in Malawi

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This special collection is edited by Susan Watkins, Eliya M. Zulu, Hans-Peter Kohler and Jere Behrman. The papers in this special collection were presented at the conference "Research on Demographic Aspects of HIV/AIDS in Rural Africa", held at the Population Studies Center, University of Pennsylvania, October 28 2002.

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Research Article

"Moving" and Marrying: Modelling HIV Infection among Newly-weds in Malawi

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Abstract

We use a microsimulation model to estimate the proportions of rural Malawian brides and grooms who are already HIV positive when they marry. The model, a demographic model of reproduction and mortality overlaid with a model of disease transmission, incorporates behavioural input data derived from the second round of the Malawi Diffusion and Ideational Change Project, which was conducted in three areas of rural Malawi in 2001. We estimate that HIV infection is present in between 13 and 20 per cent of couples. Although young women are more likely to be HIV positive than men of the same age, as a result of their low ages at marriage only around two per cent of brides are estimated to be HIV positive.

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1. Introduction

The relationship between marriage, sex and AIDS is perceived in a somewhat similar manner throughout much of eastern and southern Africa, where the HIV pandemic is now well-established (see, for example, Whyte 1997 for Uganda and Setel 1999 for Tanzania). Marriage is considered a highly desirable state. In Malawi, where HIV prevalence for adults is estimated to be 15 per cent, virtually all marry, and if they divorce, which many do, most remarry. In 1990, when participants in focus groups were asked why they married, they gave two reasons: referring to the gendered division of labour they said that they needed someone on whom to depend for economic subsistence, and that they married because they had reached an age where their sexual desires made it advantageous to have a regular sexual partner rather than satisfying themselves "here and there" (FAO *et al*. 1990). Now they say the same things, but they often add a third reason: that in the era of AIDS — "this dangerous disease of nowadays" — those who are not married will nonetheless seek sexual partners and thereby place themselves at risk of infection (Schatz 2000; Schatz 2002). This concern is echoed by parents, who urge their daughters and sons to marry rather than "move around", the common phrase for promiscuity (Kaler 1999; Kaler 2001).

That marrying is now being popularly advocated as an AIDS prevention measure led us to wonder what proportions of Malawian newly-weds might already be HIV positive when they married. In that case, and leaving aside the issue of faithfulness within marriage, marrying would provide no protection for an infected spouse and additionally would pose a danger to an uninfected one.

We address this question by means of a microsimulation model. The model incorporates realistic behavioural processes such as those of sexual initiation, subsequent sexual activity, and first marriage, with parameters taken from a study of ever-married women of childbearing age and their husbands conducted in three rural areas of Malawi (south, centre and north). The model also incorporates biological processes such as those of the transmission and natural histories of HIV and other STDs, the latter being included because they facilitate HIV transmission (Fleming and Wasserheit 1999, Røttingen, Cameron and Garnett 2001). We first simulate the proportions of new marriages in three areas of rural Malawi in which the bride, the groom, or both are already HIV positive. We next vary our input parameters to demonstrate their individual contributions to the simulated outcomes. Finally we reconcile our simulated findings on age-specific gender differences in HIV prevalence with comparable observational data from rural Zimbabwe.

2. Expectations

We expect to find differences between the three regions of Malawi in the simulated HIV statuses of brides and grooms because we expect to find regional differences in patterns of premarital sexual activity and the timing of first marriage, in part because of the likelihood that the regions' distinctive lineage/kinship systems influence marriage. Rumphi District, in the north, follows a patrilineal system of kinship and lineage: residence is ideally patrilocal, inheritance is traced through sons, and bridewealth is required, implying later marriage. Balaka District, in the south, follows the matrilineal system, ideally with matrilocal residence and with token gifts at marriage, although both patrilocal and matrilocal residence occur. Mchinji District, located in the central region, follows a less rigid matrilineal system whereby residence may be matrilocal or patrilocal, and, again, only token gifts at marriage. In addition to this variation in lineage/kinship systems, the three districts differ according to the predominant ethnicity, religion and language; particularly this last-mentioned difference, in language, suggests that the attitudes and behaviours in the three communities may also be distinct. Moreover, although each of the three districts lacks electricity and running water and average annual incomes are low (the World Bank gives a national average of US$160 [http://www.worldbank.org/data/countrydata/aag/mwi_aag.pdf]), both income and wealth, as well as levels of education, are highest in the north and lowest in the south.

In contrast, we have no prior expectations concerning the differences between the simulated prevalence of HIV among brides and grooms. Comparable "real" data could be obtained only if all prospective brides and grooms were tested for HIV on the morning of their wedding, and we are unaware of relevant published data from studies of rural Malawi, or indeed elsewhere in sub-Saharan Africa. Studies of the general population, classified by sex, age, and marital status, tend to reveal a higher prevalence among the ever-married than the never-married, and among young women than young men (see for example, Glynn *et al*. 2001 for urban Kenya and Zambia, and Gregson *et al*. 2002 for rural Zimbabwe), but one cannot extrapolate such findings to brides and grooms because the populations are not comparable. The proportions infected among newly-weds is affected not just by premarital sexual behaviour and the age difference between premarital sexual partners but by the timing of marriage for both women and men, which subsumes the duration from sexual initiation to marriage.

3. Microsimulation

Microsimulation is a stochastic computer-dependent technique for simulating a set of individual histories according to predetermined probabilistic rules (Santow 2001). The aim

of any microsimulation is to show the implications of a particular set of conditions, given a particular process or web of interdependent processes. In that regard, a microsimulation resembles an experiment that for reasons of ethics, expense, and time could not be conducted on an actual human population. Various characteristics of the microsimulation method make it a particularly appropriate tool in the present application. Among these characteristics are that direct observation of the outcome of interest — the HIV status of Malawian brides and grooms — is not feasible; that the outcome results from the interplay of complex processes to which probabilities and probability distributions can be attached; and that this interplay is sufficiently complicated that solution by analytical means is impossible because any mathematical formulation becomes intractable long before the equations become realistic.

A microsimulation, or Monte Carlo, model operationalizes a flow chart representing the process through which individuals experience events and changes of status (such as, in the present application, forming a sexual relationship, or contracting HIV), drawing on a set of real or hypothetical probability distributions (such as the age-specific probability of forming a sexual relationship, or the probability of contracting HIV from a single act of unprotected sexual intercourse). Whether or not an individual experiences a particular event is determined stochastically in a manner analogous to coin tossing (hence the name "Monte Carlo", because of the analogy with gaming) — heads the event occurs, tails it doesn't — with the proviso that coin tossing implies an underlying probability of one-half of obtaining a head (because a head is as likely as a tail if the coin is fair), whereas in a microsimulation the underlying probability of an event is pre-set by the analyst. This underlying input probability might, for example, be pre-set to 0.10. In the course of simulating an individual's history we come to a decision junction concerning whether or not an event occurs. The computer program generates a random probability (a random number from a uniform distribution between zero and one). If it is no greater than 0.10 the event is said to occur; if it exceeds 0.10 the event is said not to occur. In the case of HIV infection, at each coitus with an infectious partner a random probability is chosen and compared with the pre-set underlying infection probability. Infection is said to occur at this particular coitus if the randomly drawn probability is less than or equal to the input probability.

A microsimulation model simulates individual life histories one at a time, with the sample size being set by the analyst. Because of the random variation introduced by the Monte-Carlo method the collection of simulated life histories will exhibit a degree of heterogeneity akin to that in a real population: there will be "average" people, for example, but there will be outliers as well. The resulting data set is analyzed as though it had been derived from "real" people through prospective observation, interview, and continuous monitoring of STD and HIV status. Nevertheless, much more will be known about each simulated individual than could ever be known of a real one, however complex the process of data collection: we have perfect information (having set it ourselves) on the probability

distributions that govern individuals' biology and behaviour, and perfect information on every outcome and change of status, whether these be biological or behavioural.

4. Sexual behaviour and marriage

Our microsimulations use behavioural input parameters drawn from the Malawi Diffusion and Ideational Change Project (MDICP), which is described in more detail below. We rely primarily on survey data collected by the MDICP, but when that is not available (for example, for coital frequency) or there is reason to doubt the veracity of survey responses, we also draw on a set of qualitative studies conducted in the project area. These include a comparison of semi-structured interviews on marriage and divorce with the MDICP survey data (Schatz 2000; Schatz 2002a and 2002b); semi-structured interviews with married couples (Watkins and Zulu 1999; Zulu and Chepngeno 2002; Tawfik 2000 and 2003); semi-structured interviews with the elderly (Kaler 1999); interviews with rural STI workers (Smith 2001); unstructured interviews with young men about their sexual partnerships; and observational field journals kept by local interviewers recording conversations they overheard about AIDS, sexual partnerships and faithfulness (Watkins 1999-2003).

In 1998 the MDICP conducted a survey (Malawi 1) that interviewed 1541 ever-married women of childbearing age (15-49) and 1065 husbands of the currently married women. The target sample size was 1500 ever-married women and 1000 of their husbands, divided equally across the three regions. The target for husbands was lower because it was expected that many of them would have been away, due to extensive internal migration in Malawi and because some of the female respondents would be separated/divorced or widowed; in addition, because of polygyny more than one woman can be married to the same man.

The sampling procedures are described in detail elsewhere (Watkins et al. 2003; www.pop.upenn.edu/Social_Networks). In brief, an administrative area (Traditional Authority) was selected in each of three districts to correspond to a previous survey for which we had access to the data, in order to permit longitudinal comparison. In each Traditional Authority, we conducted a census of the households and the number of eligible respondents. The sampling fraction was inversely proportional to the size of the village. Although the sample was not designed to be representative of the national population of Malawi, responses to MDICP questions show close correspondence with comparable questions asked of rural respondents to the Malawi Demographic and Health Survey (Watkins et al. 2003).

In 2001 a follow-up survey (Malawi 2) sought more detailed information on premarital sexual activity, and collected detailed marriage histories that provide information not just

on the timing of marriages but the age differences between spouses. Information on the latter is critical to our simulation of couples but is not available from DHS-style surveys.

We cannot derive empirical evidence about the sexual behaviour of present-day teenagers from this survey because, since it was a follow-up of the ever-married sample first interviewed three years earlier, there is essentially no information on women currently younger than 20 or men currently younger than 25. Moreover, since only ever-married people were interviewed, we place little weight on the reporting of the youngest people interviewed since they are a specially selected group who must have married young. As a result, the following account derives mainly from the testimony of people now aged at least 25. Nevertheless, a comparison across cohorts did not reveal any evidence of a systematic shift in sexual or nuptial behaviour over the recent past.

The general picture from the survey data and supported by the qualitative data is that girls become sexually active earlier than boys and also marry earlier. Their first sexual partner tends to be older than they are themselves, and their first husband to be older again. Men are more likely to report premarital sex than women, but premarital sex is common for both. Men are also more likely than women to report that during their first sexual relationship they had concurrent sexual relations with someone other than their regular partner although the proportions are not particularly high. Both men and women, however, evinced a considerable lack of trust in the sexual faithfulness of their first sexual partner. The first sexual partnership tended to be short, and condom use was negligible. Fewer men than women reported marrying their first sexual partner (although women may be more likely to omit early relations that did not lead to marriage), and once sexually active, men were slower than women to marry.

Within this general picture, however, there is considerable regional variation (see Table 1). Both sexual debut and marriage are earliest in the south (Balaka), intermediate in the central region (Mchinji), and latest in the north (Rumphi). The likelihood that people marry their first sexual partner also increases from south to north; correspondingly, the duration from first sex to first marriage is longer in the south than the north. Thus, for example, two-fifths of women in the south, but two-thirds of women in the north, reported that they married at the same age as they first had sexual relations; corresponding figures for men are one-fifth and one-third. Note that although, in general terms, the later people first have sex, the sooner they marry thereafter, there is considerable heterogeneity within the three regions. Even in the north, where sexual debut is comparatively delayed and marriage comparatively hastened, two-fifths of men are still unmarried five years after first having sex, a proportion that does not clearly distinguish the region from the other two.

It is not just the duration from first sex to first marriage that bears on the probability that brides and grooms will be HIV positive at marriage, but people's behaviour over that interval. In each region, condom use is rare: over 90 per cent of people reported never

Table 1: *Sexual activity and marriage, people aged 30-39, Malawi 2*

	South (Balaka)		Centre (Mchinji)		North (Rumphi)	
	Women	Men	Women	Men	Women	Men
Had sex by (%):						
14th birthday	29	19	11	9	3	8
17th birthday	72	55	61	50	37	30
20th birthday	91	84	91	77	77	53
Median age at 1st sex (years)	15.5	16.2	16.3	17.0	18.0	19.5
1st sexual partner (not spouse) (%):						
older	36	6	28	3	28	13
same age	54	47	58	44	39	32
younger	5	48	10	49	3	55
DK	5	0	3	2	31	0
Married 1st sexual partner (%)	51	21	65	19	78	38
1st sexual partner (including spouse) (%):						
older	59	5	64	3	81	11
same age	36	39	30	39	11	20
younger	3	57	5	59	2	70
DK	3	0	2	3	7	0
Condom use during 1st partnership (non-marital) (%)						
never	94	92	100	93	64	96
missing data	4	1	0	1	28	0
Length of 1st partnership (non-marital) reported in (%):						
years	57	57	64	64	73	69
months	40	42	32	35	23	28
days	3	1	3	2	4	2
Average length 1st partnership (yrs)	1.0	1.2	1.2	1.7	1.5	1.4
Ever unfaithful to 1st partner (%)	4	18	5	11	3	15
1st partner was unfaithful (%):						
know or suspect	23	18	32	20	20	21
"can't know"/DK	45	41	46	52	25	36
probably not	32	41	22	28	56	44
Age at marriage minus age at first sex (%)						
0 years	40	20	56	17	68	35
0, 1, or 2 years	69	34	74	30	85	48
more than 5 years	12	44	6	50	4	41
Married by (%):						
16th birthday	35	5	19	2	11	2
21st birthday	84	50	90	23	76	17
25th birthday	94	84	99	74	95	56
Median age at first marriage (yrs)	17.1	21.0	18.0	23.0	18.9	24.3
(N)	**(208)**	**(131)**	**(167)**	**(155)**	**(166)**	**(133)**

having used a condom with their first partner. First sexual partnerships appeared to be shortest in the south, where around two-fifths of people reported the partnership's duration in months, and to be longest in the north, where around one-quarter reported the duration in months. As for whether a respondent suspected her or his first partner to have been unfaithful, there are indications that the extremes are defined by the northern and central regions. Around half the northern respondents had the confidence to declare that their first partner had probably not been unfaithful, compared with only about one-quarter of the central respondents. These differences are consistent with the implications of the regional differences in lineage and kinship systems.

Women's premarital partners are casual partners and steadier boyfriends (we use the term "peers"). Men's premarital partners include not just casual partners and steadier girlfriends but bar girls, the commercial sex workers of the rural areas, who work out of bars or discos in the small towns. Our focus-group interviews with bar girls show a considerable amount of geographical mobility by the bar girls, both to other small towns and to the larger cities where HIV prevalence is much higher. There is also a considerable amount of temporary mobility by men, who leave the villages to work in a city.

The survey did not inquire about coital frequency, but qualitative studies suggest that marriage marks a change from sporadic to regular sex; indeed, one motivation for marriage is that it provides a regular sexual partner (Schatz 2000; Tawfik 2003; Hickey 1995). Married couples recalled that they initially had sex every day, although as they grew older frequency declined. In contrast, what appears to be most typical of premarital sex is that partners are not able to have sex frequently with each other. For men, if the partner is a bar girl relations may be infrequent because of the cost: bar girls depend on their clients for their living. There are also financial transactions with casual partners, but these are small (a soda, a bottle of lotion, a small amount of money). Cost does not seem to inhibit coital frequency among peers as much as other barriers. The partners may not see each other because they are at different schools, or they meet while one is visiting elsewhere, for example when one partner has travelled to a nearby town to visit a relative or to buy or sell goods. Although it is likely that young males and females from the same or neighboring villages do have sex with each other, this is hindered by their desire to avoid their relationship becoming known to parents and other relatives. In addition, some respondents were concerned that frequent sex would result in pregnancy.

5. The burden of sexually transmitted diseases

UNAIDS/WHO (www.who.int/emc-hiv/fact_sheets/pdfs/Malawi EN.pdf) estimates that 15 per cent of Malawian adults (aged 15-49) were HIV positive at the end of 2001. Between 1992 and 2001 the median prevalence of HIV among women attending antenatal

facilities outside major urban areas reportedly increased from six per cent (range 2-14%, 10 sites) to 16 per cent (range 4-36%, 16 sites). HIV prevalence peaks among antenatal women at ages 25-29 but, as expected, is higher among specially selected groups, such as commercial sex workers.

HIV/AIDS is now the best known sexually transmitted disease in Malawi, being named without probing by 85 per cent of female respondents and 92 per cent of male respondents to a 1996 survey, but the levels of awareness of gonorrhoea, syphilis and buboes (chancroid) are also high: for example, 57 per cent of women and 73 per cent of men spontaneously named syphilis (National Statistical Office, Malawi and ORC Macro 1997). Indeed, sexually transmitted infections, in particular syphilis, have been documented in Malawi since colonial times (Chirwa 1999; King and King 1992), although information on the prevalence of sexually transmitted infections within the general population — either then or now — is scanty. Among respondents to the 2000 Malawi Demographic and Health Survey, eleven per cent of women and eight per cent of men reported having had a sexually transmitted infection during the previous year, the gender difference between the overall proportions stemming largely from the proportions who reported a genital sore or ulcer (eight per cent of women and four per cent of men). The finding, quoted by UNAIDS, that a median of 46 per cent of STI clinic patients tested at seven sites outside the major urban areas in 1995 were HIV positive (range 37-55%) serves merely to underscore the interrelationship between HIV and the older sexually transmitted infections. The only readily available government statistics are for people attending STD clinics in cities; at rural clinics there is some attempt at syndromic diagnosis, but clinicians do not have the equipment for distinguishing between STDs (Interview with Dr. Agabu, STD Controller for the National AIDS Control Program, 13 February 2001).

According to our interviews with rural STI workers in the south (Smith 2001), both women and men present with genital ulcers (suggesting syphilis, genital herpes, or chancroid), urethral discharge (gonorrhoea, chlamydia, or bacterial vaginosis), and buboes (chancroid) and that women additionally present with lower abdominal pain, a sign of pelvic inflammatory disease and hence of gonorrhoea and/or chlamydia (Arya 1998). Gonorrhoea is said to be the most commonly observed STD in people seeking treatment, followed by syphilis, but given the absence of serological testing and the difficulties of distinguishing between syphilis, chancroid and herpes on the basis of symptoms alone it is only too likely that the latter two diseases are also present in the population.

The burden of STD infection is illustrated by a single graphic semi-structured interview conducted in the central region (Chimbiri 2001). The respondent's cousin had suffered from painful (burning) pimple-like sores inside and outside the vagina and the cousin's husband complained of pains in his legs (possibly genital herpes in each case); a relative had boils on the vagina and the armpits (syphilis and/or chancroid); some people had rashes all over their bodies that looked like scabies and were said to be a sign of AIDS

(possibly syphilis); and the respondent herself experienced pain during sexual intercourse (gonorrhoea and/or chlamydia). The interviewer believed the respondent was HIV positive.

6. The model

As described earlier, our choice of microsimulation is dictated by our desire to replicate the complexity of the behavioural and epidemiological processes that in the real world shape the phenomena under study, which is possible only from the perspective of the individual. Other researchers of the AIDS epidemic have also turned, and for the same reason, to microsimulation, although approaches differ depending on the researchers' aims. Possibly the earliest model, that of Auvert (1991), was constructed at a time of rapid development of aggregate-level AIDS models (United Nations 1991). More recently, the models of Morris and colleagues, (for example, Morris and Kretzschmar 2000), incorporate rich characterizations of sexual networks but define probabilities of disease transmission per partnership rather than per coitus and lack a demographic dimension. The STDSIM model of Van der Ploeg *et al*. (1998) was constructed to model the evolution of HIV prevalence in response to intervention programmes, such as the treatment of a range of STDs. The SOCSIM model of Wachter and colleagues (for example, Wachter 2001) is a descendant of earlier demographic models that has now been adapted to examine aspects of the AIDS epidemic. As is the case with STDSIM, fertility schedules are exogenous to the simulation, that is, the childbearing of individuals is governed stochastically by input schedules constructed or selected by the user rather than derived as simulation output. We take a different approach, as outlined below.

6.1 Modelling behaviour

Our microsimulation model, which is described in greater detail in the Appendix, was originally developed as a comprehensive model of human reproduction and mortality. Only after the baseline model had been validated by comparing simulated age patterns of childbearing with the Brass fertility polynomial (Brass and Coale 1968: see the Appendix) was the model extended so that coitus carried not just a risk of pregnancy to (fecund) women but a risk of disease transmission and acquisition to all women, whether fecund or not, and also to all men. Accordingly, fertility and disease transmission are endogenous to the simulation and simulated disease outcomes are consistent with simulated fertility outcomes. This is a novel feature of our model. We focus in this description on the present application of the model, which is one of many potential applications.

The first step in simulating an individual woman is to determine her age at marriage according to the region-specific marriage model. Next we determine her husband's age at marriage on the basis of a simulated age gap between spouses. Having determined when a marriage takes place, we go back and separately simulate the sexual activity of the two individuals up to that point. In an attempt at verisimilitude, if it transpires that a groom simulated for a particular bride has the visible symptoms of AIDS (determined stochastically according to the time since the elective groom's infection with HIV), a "search" for another groom is undertaken. Up to five such searches are conducted.

Some preliminary work was necessary to transform the observed marriage data summarized in Table 1 into suitable input for the microsimulation model. Three distinct Coale-McNeil marriage models (Coale and McNeil 1972) were fitted to the observed region-specific data, using a minimum-chi-squared criterion (upper panel of Table 2a). In preliminary testing of the model we confirmed that simulated distributions of age at first marriage for men closely resembled the directly observed distributions derived from the Malawi 2 data.

To increase the heterogeneity in simulated behaviour we adopt a two-stage approach to modelling behaviours such as premarital sexual activity. In the first stage, we determine whether or not an individual has what we dub a "propensity" to undertake that behaviour. By this we mean that some individuals have a tendency, or propensity, to behave in a particular way, but others do not and will never so behave. For example, women in the south are assigned a propensity of 0.90 to engage in sex before marriage (see Table 2a). When simulating an individual history we select a random probability, and if it exceeds 0.90 then that individual does not have sex before marriage. If the random probability is no greater than 0.90, then the individual has the propensity to have premarital sex, although whether or not she actually does so depends on further Monte-Carlo experimentation. This is the second stage in the process.

Premarital sexual activity is simulated slightly differently for women and men. Each of the three variants of the model (south, centre, north) incorporates a distinct propensity for women to have sex before marriage (see Table 2a). At each age, women with this propensity have a pre-set age-specific probability of embarking on an affair, and if one transpires, the duration of the relationship is determined stochastically according to the model input. Their partner's age is determined from reported age differences between partners, and the partner's sexual and disease histories are simulated up to the point at which the affair is said to commence. Coital frequency within the affair is set to half the marital level. (More detail is given in the Appendix: suffice it to say here that marital coital frequency is itself derived in the simulation as a function of mean age-specific fecundability and cycle length by drawing on a model originally proposed by Glass and Grebenik [Bongaarts and Potter 1983].) Subsequent relationships may follow, and a relationship that is simulated to continue into the first marriage is said to be with the first husband.

Table 2a: *District-specific input parameters related to sexual debut and first marriage, women only*

	South	Centre	North
First marriage			
Minimum age, a_o	13	14.5	14.2
Compression factor	0.50	0.40	0.50
Age differences between spouses at ages:			
a_o	3.2	5.0	5.5
a_o+15	2.5	3.2	3.5
Sex outside marriage			
Propensity	0.90	0.80	0.70
Probability at age:			
13	0.10	0.10	0.10
15	0.20	0.20	0.20
17	0.30	0.30	0.30
Average duration (mths)	12	12	12
Median age diff (years)	4	4	4
Coital frequency relative to marriage	0.50	0.50	0.50

Table 2b*:* *District-invariant input parameters related to premarital sexual behaviour, men only*

Premarital sex with	**Peers**	**Bar girls**
Propensity	0.80	0.80
Monthly probability of sex at age 15	0.10	0.05
Monthly probability of sex at age 20+	0.50	0.40
Monthly coital frequency	1-8	1-4

Table 2c: *District-invariant input parameters related to extramarital sexual behavior, women and men*

	Women	Men
Extramarital affairs		
Propensity	1.00	1.00
Annual probability by marriage duration	0.05 at 1 year rising to 0.20 at 5 years	0.10 at 1 year rising to 0.20 at 5 years
Average duration (mths)	6	6
Median age diff (years)	3	3
Monthly coital frequency	0.50 relative to marr	2-10
Sex with bar girls (men only)		
Propensity		0.75
Monthly probability of sex		0.4 before age 25 falling to 0.1 at 60
Monthly coital frequency		3-8

Sources: MDIC2 questions on marriage history and premarital partnerships, and qualitative interviews by Hickey (1998) [centre], Schatz (2000) [south and north], Tawfik (2000) [south]

The input parameters governing men's premarital sexual behaviour does not vary by region (Table 2b). Their median age at premarital sexual debut is set at 17 years, and four-fifths of them have the propensity to have casual relationships with their peers and to visit bar girls. Those with either propensity (by chance some will have both) have a comparatively low probability at age 15 of sexual activity in any month, but this rises steadily to age 20 and above. Their coital frequency is selected from within pre-determined limits.

Although the possibility that married individuals engage in extramarital sexual relations has no bearing on their HIV status at first marriage, we allowed for this possibility in order to be able to simulate HIV prevalence in the general population (see Table 2c). In simulations in which married people have affairs, they all have the propensity to do so although the annual probability is rather small and affairs short-lived. These patterns of extramarital relations are consistent with our qualitative data and with Tawfik (2003): although many men and women are unfaithful, coital frequency in extramarital partnerships is comparatively low, as it is for the unmarried. In addition, some husbands visit bar girls. Two variants of the simulations incorporating extramarital sex ("medium" and "high") differ according to husbands' propensity to visit bar girls.

In these initial simulations marriage may end through the death of a spouse but in the present application we make no allowance for remarriage or for divorce.

In order to establish baseline results, we assume no condom use, and no use of contraception more generally.

Each simulation incorporates background mortality at West level 11 (Coale and Demeny 1983) implying an expectation of life at birth of 45.0 years for females and 42.1 for males. These correspond to pre-AIDS mortality levels in Malawi, where life expectancies for both sexes combined are estimated to have risen modestly, from 43 in the late 1970s, to 45 in the early 1980s, and to 46 in the late 1980s (UN 2001: 310**;** see also Doctor 2002). AIDS brings super-mortality to the simulated populations as it does in real life.

6.2. Introducing disease

Not every person has premarital sex, but those who do are at risk of becoming infected before marriage if at least one of their sexual partners is infectious with an STD or HIV. To introduce infection into the simulated population we posit the existence of a group of women external to the simulated population among whom certain proportions are infectious with various diseases, not just HIV. These women — in the real world, bar girls and casual partners or girlfriends — form the "reservoir of infection" from which disease is introduced into the population at large: they infect men, and these men in turn infect other women.

The model allows for the possibility of infection with three discharge (non-ulcerative) STDs (gonorrhoea, chlamydia and bacterial vaginosis), and three ulcerative STDs (syphilis, chancroid and herpes). It seemed important to include representatives of each of these types of disease as they differ according to their effects on HIV transmission, as we go on to describe. In addition, each group of diseases exhibits a degree of heterogeneity in terms of various characteristics: not only of their transmission probabilities but their duration of infectiousness, the likelihood (as with herpes) of spontaneous recurrence, and their conferring of immunity to subsequent infection (significant with syphilis but not, for example, with gonorrhoea).

The uppermost panel of Table 3 shows the proportions of men's sexual partners (peers and bar girls) who are said to be infectious with these three discharge STDs, three ulcerative STDs, and with HIV. Uncontroversially, bar girls are assigned higher proportions infectious (two to three times) than peers. The proportion of bar girls who are HIV positive is set to 0.75, midway between the prevalence of 0.70 observed among Lilongwe prostitutes in 1994 (UNAIDS) and the 0.80 among Blantyre bar girls in 1993 (Kishindo 1995).

In assigning values to the proportions of women who are infectious with other diseases we were guided very broadly by the available regional literature (for example Cameron *et al*. 1989, Kimani *et al*. 1996, Kreiss *et al*. 1986) and also by considerations of the natural histories of each of the diseases. Our task is complicated by the fact that many relevant studies quote serological evidence of past infection whereas what is relevant for disease

transmission (and hence important for our model) is current infectiousness, yet HIV is the only disease in which the two coincide.

Table 3: *Model input parameters related to STDs and HIV*

	Gonorrhoea	Chlamydia	BVaginosis	Syphilis	Chancroid	Herpes	HIV
Proportion infectious among							
men's casual partners	0.20	0.20	0.20	0.05	0.20	0.20	0.20
bar girls	0.40	0.40	0.50	0.10	0.40	0.60	0.75
Infection/unprotected coitus							
Male-to-female	0.5000	0.1000	0.1000	0.1500	0.1000	0.0100	0.0030
Female-to-male	0.2000	0.0500	0.0500	0.1500	0.0500	0.0050	0.0015
Increased susceptibility (relative risk) to HIV if infectious with							
	2.0	2.25	1.5	2.5	2.0	2.75	
Increased infectiousness of HIV if infectious with							
	2.0						
Increased susceptibility if HIV+ to							
				2.0	2.0	2.0	
Increased infectiousness if either recently infected or symptomatic							
							3.0
Proportion recently infected among							
men's casual partners							0.40
bar girls							0.40
Mean infectious period (months)							
	6.0	6.0	6.0	12.0	3.0	1.0	
Weibull shape parameter	4.0	4.0	4.0	4.0	4.0	4.0	
Mean duration of episode (months)							
	12.0	12.0	8.0	60.0	4.0	∞	
Weibull shape parameter	4.0	4.0	4.0	4.0	4.0	NA	
Mean survival with HIV (yrs)							7.5
Weibull shape parameter							5.0
Mean survival with AIDS (yrs)							1.0
Weibull shape parameter							1.0

Sources: Ambroziak and Levy (1999), Anderson (1999), Fleming and Wasserheit (1999), Gray et al. (2001), Holmes et al. (1998), Low-Beer et al. (1998), Musher (1998), Røttingen et al. (2001); Rowley and Berkley (1998), Schroeter et al. (1971), Sparling (1998a, 1998b), Stamm (1998), Wasserheit (1992)

Our general strategy in selecting the biomedical input parameters in the remainder of the table has been to compare quoted figures in as many sources as we could locate, to put more weight on overview articles or chapters than single studies, and to be conservative. Our state of knowledge has not changed radically over the decade since Wasserheit (1992:66) observed that "Our overall understanding of the natural history of STDs such as syphilis, chancroid, or HPV infection is still relatively embryonic". Indeed, the biomedical literature on STD transmission and the natural histories of STDs is less complete, and less satisfying, than an outsider from the social sciences might initially have expected. It is therefore not our intention to give the impression that each parameter is well-known, well-substantiated, and uncontroversial.

Transmission probabilities per single act of unprotected coitus provide a case in point (second panel of Table 3). Syphilis, for example, has been studied for longer than the other STDs, and old studies of untreated syphilis (which for ethical reasons could not be conducted today) provide invaluable data on the disease's natural history. Nevertheless, the generally quoted per-coitus transmission probability of 0.30, which was derived from just one study (Schroeter 1971), is almost certainly too high since the figure actually refers to the probability of transmission during a one-month period. This would be the same as a per-coitus probability only if there were only one sexual act during the month: we make the conservative assumption, for the purposes of our model, that there were two, giving a per-coitus risk of transmission of a little more than 0.15, the value we use. We might add, perhaps, that the syphilis transmission probability at least was quoted for a particular time period. In contrast, transmission probabilities have often been quoted "per partnership" without reference to either coital frequency or length of partnership (for example Brunham *et al*. 1994).

The most striking feature of this panel is that the transmission probability of HIV is orders of magnitude smaller than that of the classic STDs. The most frequently cited probability of male-to-female transmission of HIV per single unprotected coitus is 0.003 (Anderson 1998). In contrast, the probability of transmission of gonorrhoea, for example, is around 0.5 (Rowley and Berkley 1998).

The third panel of the table demonstrates the rationale for including STDs in our simulation model, which is that, since STD-infectious individuals are at increased risk of acquiring HIV, STDs facilitate HIV transmission. Drawn from Røttingen, Cameron and Garnett (2001), the relative risks are preferred to comparable ones given by Fleming and Wasserheit (1999) not only because the Røttingen figures are more recent but because they tend to be more conservative.

Individuals who are infectious with both gonorrhoea and HIV appear to pose twice the risk of HIV acquisition to their uninfected partners as would otherwise be expected (fourth panel of the panel). HIV-positive individuals also have perhaps twice the risk of acquiring an ulcerative STD although they appear to be at no greater risk of acquring a discharge

STD (fifth panel): the relevance of this latter effect for HIV transmission is that these individuals may infect other partners with an ulcerative STD, rendering them in turn more susceptible to HIV infection.

The biological plausibility of such synergies is well accepted (Fleming and Wasserheit 1999, Røttingen, Cameron and Garnett, 2001). Nevertheless, for various reasons uncertainty surrounds their exact strength: not all studies control adequately for sexual behaviour although concurrent STD and HIV infection may merely be a marker for risky sexual activity; many are case-control studies, which cannot untangle the temporal sequence of disease acquisition; and there is a possibility of multiple infections. For example, Wasserheit (1992) cites estimates of the relative risk of acquiring HIV (the co-factor effect) for gonorrhoea-infectious women ranging from 3.5 (derived from the only prospective study) to 8.9 (note, in passing, that this figure has now been down-graded to 2.0 (Røttingen, Cameron and Garnett 2001). Nevertheless, extensive prior testing of the microsimulation model showed that the likelihood of HIV sero-conversion is fairly insensitive to the exact magnitude, within reasonable limits, of the hypothesized co-factor effects. For example, in a set of simulations that differed only in terms of the increased susceptibility to HIV of people with infectious gonorrhoea, the life-time risk of contracting HIV ranged from 0.44 with a co-factor of 3.5, the lower limit of the cited range, to 0.52 with a co-factor of 8.9, the upper limit. The reasons for this comparative insensitivity are that the base-line probability of HIV transmission is tiny, and that for most STDs the duration of infectiousness during which the synergies operate (shown further down the table) is relatively short.

Viral load, the chief predictor of HIV transmission, is high in the early stages of infection and again after the infected individual has progressed to the symptomatic stage (Ambroziak and Levy 1999, Quinn *et al*. 2000). We therefore incorporate a trebling of infectiousness during the six months following seroconversion and also when the individual has progressed to AIDS (sixth panel).

It is necessary to take account not just of an individual's infection with a particular disease but of the disease's subsequent course. Since we assume no treatment of STDs in the present simulations, the following brief account refers to their natural histories. Episodes of some infections (gonorrhoea and chlamydia, for example) are typically short, and the duration of infectiousness is even shorter. An individual thus infected cannot be re-infected until the particular episode has run its course although infection provides no immunity against further bouts (Anderson 1999, Sparling 1999a). The course of syphilis, on the other hand, is very varied, with around two-thirds of individuals apparently acquiring a degree of immunity and never progressing beyond the post-secondary latent stage (no clinical symptoms but historical or serological evidence of past infection) (Miller 1989, Sparling 1999b, Wicher and Wicher 1983). Once infected with genital herpes (HSV-2), however, individuals remain infected for life and experience periodic relapses, during

which they are infectious, most frequently in the first year or two after initial infection, and less frequently thereafter (Corey and Wald 1999). We incorporate these aspects of our six STDs into the model.

The properties of the non-HIV diseases we include in our simulations imply that, even when couples are faithful after marriage, it is possible for a disease to travel from one to the other and then back again: a husband can infect his wife with gonorrhoea, for example, and if she remains infectious for long enough she can re-infect him once his initial infection has passed. It is also possible, except for genital herpes and HIV, for an infection to die out from a marriage if spouses are faithful to one another.

7. HIV prevalence among newly-weds

We are at last in a position to simulate the proportions of HIV positive brides and grooms in the three regions of rural Malawi. The three regional simulations differ according to women's propensity to have sex before marriage, according to first-marriage patterns for women, and to the age differences between spouses. Nevertheless, the regional simulations have most input data in common: the same age-specific probabilities that women (with a propensity to do so) start an affair; the same age difference between premarital partners, duration of the affair and coital frequency; and the same premarital sexual behaviour among men.

The next three tables contain the results of three simulations, one for each region, each of 10,000 couples. For each region we present characteristics of newly-weds first from the point of view of the bride (left-hand block of columns), and then from the point of the groom (right-hand block). For brides, we show the percentages of marriages that occur at each bridal age and the corresponding mean age of their grooms; thus in the southern (Balaka) simulations of Table 4, 15.0 per cent of brides marry at age 15 and their grooms have an average age of 19. The next four columns show, respectively, the percentages of new couples whose members are both HIV negative (labelled --), where only the bride is HIV positive (labelled b-), where only the groom is HIV positive (labelled –g), and where both are HIV positive (labelled bg). For example, among marriages when the bride is aged 15, 94.2 per cent of couples are seroconcordant HIV negative; in 0.1 per cent of couples only the bride is HIV positive; in 5.7 per cent of couples only the groom is HIV positive; and in no couples are both bride and groom HIV positive. The right-hand panel, for the grooms, is comparably designed, but shows the proportions of grooms who marry at each age, the average ages of their brides, and the HIV status of the couple according to the age of the groom. At the foot of each table we show the overall HIV status of newly-weds irrespective of their age.

Table 4: *Simulated HIV status of brides (b) and grooms (g), South (Balaka), N=10,000*

	Brides						Grooms					
	% of first marri-	Mean age of	HIV status (percent)				% of first marri-	Mean age of	HIV status (percent)			
Age	ages	grooms	--	b-	-g	bg	ages	brides	--	b-	-g	bg
13	3.4	17.2	96.6	0.0	3.4	0.0	0.1	13.3	100.0	0.0	0.0	0.0
14	9.1	18.1	96.7	0.0	3.3	0.0	0.4	13.8	100.0	0.0	0.0	0.0
15	15.0	19.0	94.2	0.1	5.7	0.0	2.2	14.4	100.0	0.0	0.0	0.0
16	14.9	19.9	91.2	0.4	8.3	0.1	4.4	14.9	99.1	0.0	0.9	0.0
17	14.7	20.8	87.4	0.6	11.8	0.1	8.3	15.5	98.1	0.2	1.6	0.0
18	11.9	21.8	84.3	1.0	14.5	0.2	10.9	16.1	96.7	0.1	3.2	0.0
19	8.9	22.6	82.9	1.6	15.3	0.1	12.3	16.7	92.5	0.3	7.1	0.0
20	6.8	23.6	76.7	3.1	19.6	0.6	12.2	17.3	89.8	0.3	9.8	0.1
21	4.7	24.4	75.4	3.8	20.4	0.4	11.2	18.0	84.3	1.3	14.1	0.4
22	3.3	25.4	76.4	3.7	19.3	0.6	10.0	18.6	80.3	2.2	17.2	0.3
23	2.2	26.3	70.4	6.6	21.6	1.4	7.3	19.3	79.5	2.3	18.1	0.1
24	1.5	27.1	78.2	6.8	15.0	0.0	6.4	20.2	73.2	2.3	24.2	0.3
25	1.1	28.4	67.9	3.7	26.6	1.8	4.6	21.0	75.2	2.9	21.8	0.0
26	0.8	29.3	66.7	7.4	22.2	3.7	3.0	21.7	74.7	4.5	19.8	1.0
27	0.5	30.0	75.0	10.4	14.6	0.0	2.1	22.7	73.0	3.5	21.5	2.0
28	0.4	31.3	57.1	5.7	34.3	2.9	1.5	23.7	72.0	7.7	17.5	2.8
29	0.3	32.9	76.9	3.8	15.4	3.8	1.0	24.9	73.0	6.0	21.0	0.0
30	0.2	32.9	62.5	12.5	25.0	0.0	0.6	25.9	70.9	5.5	21.8	1.8
31	0.1	34.5	64.3	7.1	28.6	0.0	0.5	26.5	65.4	5.8	28.8	0.0
32	0.1	34.0	42.9	14.3	42.9	0.0	0.4	27.6	65.7	0.0	31.4	2.9
33	0.1	35.8	60.0	20.0	20.0	0.0	0.2	28.7	55.6	16.7	27.8	0.0
34	0.1	39.3	66.7	16.7	16.7	0.0	0.1	31.2	58.3	8.3	33.3	0.0
Total		21.4	86.5	1.4	11.9	0.2		18.1	86.5	1.4	11.9	0.2

Note that the proportions of HIV-positive couples do not inevitably rise, or fall, steadily with age but in some cases demonstrate irregularity. This results from stochastic variation, and is particularly marked at ages when comparatively few couples marry. For example, simulated HIV prevalence among brides jumps from 7.1 per cent at age 31 to 14.3 per cent at age 32, but only about ten women (0.1 per cent of 10,000) marry for the first time at each of these ages.

Table 4 presents our results for the matrilineal/matrilocal south. In accordance with the input data (Table 2a), marriage is early, especially for brides but also for grooms: almost 80 per cent of brides and 40 per cent of grooms are younger than 20. The proportion of marriages in which the bride and groom are both infected (bg column) is very low throughout. The proportion of couples in which the bride is HIV positive (b- column + bg column) tends to rise with age as one would expect, but remains low. The proportion of couples in which the groom is positive (-g + bg) once again tends to rise with age, as expected, but faster and to considerably higher levels. For example, only about four per cent (3.1+0.6) of 20-year-old brides are HIV positive, but 20 per cent (19.6+0.6) of their grooms, with an average age of 23.6. Brides are unlikely to be infected because they marry very young. Many, indeed, will be virgins at marriage, and even those who are not simply have had little time in which to contract HIV. Their grooms, in contrast, are somewhat older, and some have had sex with peers and bar girls.

Overall, HIV infection is present in 13.5 per cent (100-86.5) of new couples: in 1.6 (1.4+0.2) per cent of brides and 12.1 (11.9+0.2) per cent of grooms. Seroconcordant HIV-positive couples are rare. That the overall percentages of HIV-positive brides and grooms are so much lower than some of the age-specific percentages stems once again from marriage patterns: most brides and many grooms marry at ages when few people have already been infected.

Tables 5 and 6 show the results of comparable simulations of the central and northern regions respectively. Similar patterns appear as for the south, but at different levels. Grooms marry later in the central and northern regions than in the south and are far more likely to be infected.

Salient features of the three simulations reveal themselves most clearly in a summary table, Table 7, which is derived from the previous three detailed tables. A striking feature of each regional simulation is that the proportion of infected brides is markedly smaller than the proportion of infected grooms. We should perhaps have expected this result: at each age, young men “move around” before marriage much more than young women, and with riskier partners; and they are older when they marry. Nevertheless, we could not have predicted that the difference — around two per cent of brides compared with between twelve and nineteen per cent of grooms — would be so great.

Table 5: *Simulated HIV status of brides (b) and grooms (g), Centre (Mchinji), N=10,000*

	Brides						Grooms					
	% of first marri-	Mean age of grooms	HIV status (percent)				% of first marri-	Mean age of brides	HIV status (percent)			
Age	ages		--	b-	-g	bg	ages		--	b-	-g	bg
13	0.0	-	-	-	-	-	0.0	-	-	-	-	-
14	2.6	20.2	88.7	0.4	10.9	0.0	0.0	-	-	-	-	-
15	8.0	20.7	88.0	0.3	11.7	0.1	0.0	15.4	100.0	0.0	0.0	0.0
16	20.9	21.6	88.1	0.4	11.5	0.0	0.4	15.2	100.0	0.0	0.0	0.0
17	19.0	22.4	84.6	0.7	14.6	0.1	1.4	15.7	97.1	0.0	2.9	0.0
18	15.4	23.3	81.1	1.1	17.6	0.1	4.1	16.1	95.9	0.5	3.6	0.0
19	12.2	24.1	79.2	1.0	19.1	0.7	7.4	16.6	93.0	0.6	6.3	0.1
20	7.5	25.0	79.9	1.5	18.0	0.5	10.5	17.0	90.2	0.8	8.9	0.1
21	5.1	25.9	73.3	1.6	23.6	1.4	13.3	17.5	86.8	0.4	12.7	0.1
22	3.4	26.7	73.0	3.3	22.2	1.5	13.6	17.9	82.7	0.9	16.1	0.3
23	2.2	27.7	75.8	2.4	20.4	1.4	12.3	18.4	81.2	0.6	17.9	0.3
24	1.2	28.2	68.4	11.1	17.1	3.4	10.5	19.0	77.9	1.2	20.5	0.4
25	0.8	29.2	65.0	7.5	27.5	0.0	8.5	19.5	75.2	0.8	23.4	0.6
26	0.7	30.8	61.8	10.3	25.0	2.9	6.1	20.3	72.4	2.5	23.9	1.2
27	0.3	31.1	69.7	0.0	30.3	0.0	4.0	20.9	71.4	2.0	25.3	1.3
28	0.2	31.6	78.3	4.3	17.4	0.0	2.8	21.1	68.6	5.8	25.2	0.4
29	0.1	32.5	90.0	0.0	10.0	0.0	2.0	22.2	78.0	4.2	16.8	1.0
30	0.1	33.8	53.8	23.1	23.1	0.0	1.2	23.2	72.6	3.4	23.1	0.9
31	0.0	35.7	66.7	0.0	33.3	0.0	0.6	24.5	61.9	6.3	30.2	1.6
32	0.0	35.8	50.0	0.0	50.0	0.0	0.5	25.0	76.0	8.0	14.0	2.0
33	0.0	37.2	50.0	0.0	50.0	0.0	0.2	26.2	80.0	0.0	20.0	0.0
34	0.0	38.4	100.0	0.0	0.0	0.0	0.2	26.0	80.0	6.7	13.3	0.0
Total		23.3	82.3	1.2	16.0	0.4		18.5	82.3	1.2	16.0	0.4

Table 6: *Simulated HIV status of brides (b) and grooms (g), North (Rumphi), N=10,000*

	Brides						Grooms					
	% of first marri-	Mean age of	HIV status (percent)				% of first marri-	Mean age of	HIV status (percent)			
Age	ages	grooms	--	b-	-g	bg	ages	brides	--	b-	-g	bg
13	0.0	-	-	-	-	-	0.0	-	-	-	-	-
14	2.1	20.4	91.2	0.0	8.8	0.0	0.0	-	-	-	-	-
15	6.3	21.3	88.1	0.5	11.4	0.0	0.0	14.6	100.0	0.0	0.0	0.0
16	15.1	21.9	86.4	0.1	13.4	0.1	0.3	15.0	100.0	0.0	0.0	0.0
17	15.0	22.8	81.5	0.3	18.1	0.1	1.0	15.5	95.7	0.0	4.3	0.0
18	14.8	23.7	81.1	0.8	17.9	0.2	2.2	16.1	96.2	0.5	3.3	0.0
19	12.7	24.5	79.0	1.4	19.5	0.2	4.7	16.6	93.0	0.2	6.8	0.0
20	9.8	25.4	78.1	1.7	19.9	0.3	7.7	17.1	89.2	0.5	10.2	0.0
21	6.7	26.2	75.6	2.8	21.3	0.3	9.8	17.5	84.4	0.5	15.0	0.1
22	5.4	27.0	72.6	5.0	21.5	1.0	11.9	18.0	82.4	1.0	16.5	0.1
23	3.7	28.0	71.9	5.6	21.2	1.4	12.4	18.6	80.4	1.3	18.1	0.2
24	2.6	28.8	66.5	5.2	27.8	0.4	11.4	19.2	78.0	0.9	20.7	0.4
25	2.0	29.7	68.1	4.8	26.6	0.5	9.9	19.8	75.6	1.9	22.1	0.4
26	1.2	30.7	73.5	6.8	19.7	0.0	7.9	20.5	74.8	2.8	22.3	0.1
27	0.8	31.0	77.9	6.5	14.3	1.3	6.0	21.2	73.9	2.1	23.7	0.3
28	0.5	32.2	67.3	3.8	25.0	3.8	4.6	22.1	72.5	4.1	22.5	0.9
29	0.4	33.6	61.8	8.8	20.6	8.8	3.5	23.0	72.8	3.9	21.8	1.5
30	0.3	34.3	78.8	3.0	18.2	0.0	2.3	23.4	66.1	5.9	27.1	0.9
31	0.2	34.5	63.2	21.1	10.5	5.3	1.5	24.7	75.9	4.3	18.4	1.4
32	0.1	37.7	42.9	14.3	42.9	0.0	1.0	25.2	74.7	4.2	20.0	1.1
33	0.1	36.5	33.3	0.0	66.7	0.0	0.7	26.3	56.1	7.6	34.8	1.5
34	0.1	38.1	75.0	0.0	25.0	0.0	0.4	26.8	76.2	0.0	21.4	2.4
Total		24.4	79.9	1.7	18.1	0.3		19.4	79.9	1.7	18.1	0.3

Table 7: *Summary regional findings, simulated HIV status of brides (b) and grooms (g) by region, N=10,000*

Region	Mean age (yrs) of brides	grooms	HIV status (per cent) – –	b –	– g	bg
South	18.1	21.4	86.5	1.4	11.9	0.2
Centre	18.5	23.3	82.3	1.2	16.0	0.4
North	19.4	24.4	79.9	1.7	18.1	0.3

Variation in two factors contributes to the simulated differences in HIV prevalence between brides and grooms within each region, and to the differences between the regions: the first-marriage patterns of women, and the age difference between spouses. (The regional variation in women's propensity for premarital affairs is too small to produce a noticeable effect, as we show later on). This nuptiality-related variation is revealed in Figure 1, which presents the proportions of brides and grooms at each age in the southern and northern regions. (The figures come from Tables 4 and 6; we do not show the marriage curves for the central region because they are very similar to those from the north.) The graph illustrates both the young bridal ages in either region and the greater differences between men's than women's regional marriage patterns.

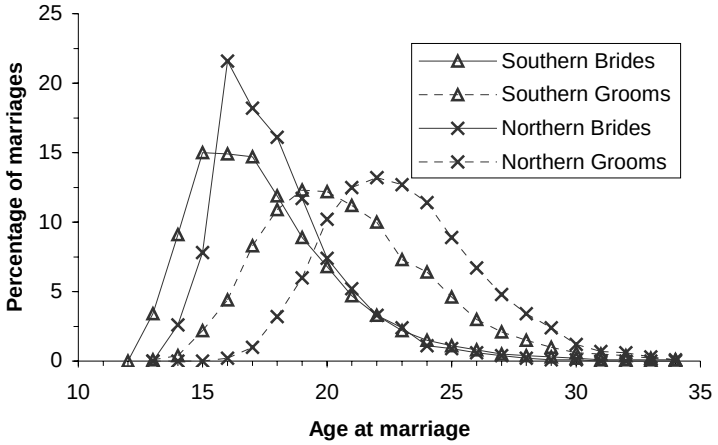

Figure 1: *Distributions of ages at marriage, by sex and region*

In order to determine the relative importance for the HIV status of brides and grooms of the timing of the first marriage among women and the age difference between spouses we next performed some simulations in which these factors were varied independently. Taking the extreme northern and southern simulations we ask, essentially, what would happen to the HIV status of newly-weds in the south if women married according to the southern pattern but the age differences between spouses were as great as in the north, and what would happen to HIV status in the north if women married according to the northern pattern but the age differences between spouses were shrunk to the levels exhibited in the south. Our findings are summarized in Table 8.

Table 8: *Effect of women's marriage pattern and age difference between spouses on simulated HIV status of brides and grooms, by region, N=10,000*

Marriage pattern	Age difference between spouses	HIV status (per cent) – –	b –	– g	bg
South	South	86.5	1.4	11.9	0.2
South	North	82.9	1.4	15.3	0.4
North	South	84.0	1.4	14.1	0.5
North	North	79.9	1.7	18.1	0.3

Notes: Women's minimum age at marriage is 13 in the South, 14.2 in the North; at this bridal age, grooms are 3.2 years older than brides in the South, and 5.5 years older in the North (see Table 2a for details)

Varying the age difference between spouses has no effect on the HIV status of brides because they still marry according to the appropriate regional pattern, but it has a pronounced effect on the HIV status of grooms. Were southern men to delay their marriages, relative to the ages of their brides, to the extent practised in the north, the proportion of HIV-positive grooms would rise from twelve per cent (11.9+0.2) to sixteen per cent (15.3+0.4). Correspondingly, were northern men to marry brides closer to themselves in age the proportion of HIV-positive grooms would fall from eighteen per cent (18.1+0.3) to fifteen per cent (14.1+0.5).

Insofar as we may have mis-specified men's propensity to have premarital affairs with casual partners or to seek the sexual services of bar girls, our results will be distorted. Holding constant women's propensity for premarital sex, and using the regional nuptiality patterns, we next performed a series of simulations in which we varied men's premarital sexual activity. The results are summarized in Table 9. (Note that holding constant women's propensity to be sexually active before marriage has only a slight effect on HIV status: compare row 1 of Table 9 with row 1 of Table 8; row 4 of Table 9 with row 4 of Table 8.)

Table 9: *Effect of men's propensity for premarital sexual activity on simulated HIV status of brides and grooms, by region, N=10,000*

	Propensity for sex with		HIV status (per cent)			
Region	Peers	Bar girls	– –	b –	– g	bg
South	80	80	87.1	1.3	11.2	0.4
	80	40	91.4	0.8	7.7	0.1
	40	40	93.1	0.8	6.0	0.1
North	80	80	79.7	1.8	18.0	0.5
	80	40	86.4	1.2	12.2	0.2
	40	40	89.3	1.3	9.2	0.2

Notes: Women's propensity for premarital sex fixed at 0.80

Unsurprisingly, reducing men's premarital sexual activity reduces the likelihood that they will be HIV positive at marriage. Also unsurprisingly, given their higher levels of infection, reducing contacts with bar girls is more efficacious in this regard than reducing contacts with peers. For example, in the south, halving men's propensity to visit bar girls reduces the proportion of HIV-positive grooms from twelve (11.2+0.4) per cent to eight per cent (7.7+0.1); reducing their contacts with peers reduces the proportion of HIV-positive grooms from eight per cent to six (6.0+0.1) per cent. Interestingly, reducing men's premarital sexual activity in this way also has the effect of reducing the proportion of HIV-positive brides. This occurs because unmarried men, whose HIV infections have been reduced, are the premarital partners of some of our prospective brides.

Earlier drafts of this paper frequently elicited expressions of unease because the very low HIV prevalences simulated for brides, both in absolute terms and in comparison with those for grooms, seemed inconsistent with the reported findings of population-based studies. Glynn *et al*. (2001), for example, report considerably higher HIV prevalence among young women than young men (aged 15-19 and 20-24) in the urban centres of Kisumu, Kenya, and Ndola, Zambia. Likewise, Gregson *et al*. (2002) report higher HIV prevalence among women than men in rural Manicaland, Zimbabwe, until ages 25-29, and higher HIV prevalence among men than women from ages 30-34 onward. However, findings pertaining to a general population, disaggregated by age, sex, and even marital status, are not comparable to findings pertaining to a population of brides and grooms at the time of marriage.

We next use our simulation model to demonstrate that a much smaller proportion of infected brides than infected grooms is not necessarily inconsistent with a higher prevalence of HIV among young women than young men. Since we are now looking beyond marriage we incorporate the possibility that married women and men engage in extramarital sexual activity. The model also allows for women to have extramarital affairs after widowhood but

no allowance is made for remarriage, or for divorce. Our findings are summarized in Table 10.

Table 10: *Age-specific prevalence of HIV (%) among women and men, northern simulation and rural Zimbabwe compared*

	Northern simulation		Rural Manicaland, Zimbabwe	
Age	**Women**	**Men**	**Women**	**Men**
15	0	0	1	0
16	1	0	4	0
17	2	1	6	1
18	5	2	7	1
19	8	4	17	2
20	12	7	14	4
21	17	11	24	4
22	22	15	30	7
23	26	19	27	12
24	31	23	38	17
25	34	27	38	21
26	37	30	40	28
27	38	34	41	29
28	39	36	36	28
29	39	38	45	26
30	38	40	39	57
31	37	41	41	49
32	35	42	42	47
33	33	42	39	54
34	30	41	37	47

Notes: See Table 2c for simulation input concerning extramarital sexual activity

We show the age-specific prevalences of HIV among the general population of the northern simulation, which produced two per cent of HIV-positive brides but 18 per cent of HIV-positive grooms. Age for age, the prevalence of HIV among women exceeds that among men until age 29 but at this point prevalence among women begins to fall while among men it continues to rise. That the simulations produce so few infected brides is consistent with women's low prevalence of HIV at the young ages at which they typically marry: 30 per cent of women have married by the age of 17, for example, and 70 per cent by the age of

20. That so many grooms are infected is consistent with their marrying at much later ages, when HIV infection has had a much greater opportunity, largely through casual affairs and commercial sex, to enter the bachelor population. That at each single year of age so many more young women — as distinct from brides — than young men are HIV positive highlights the primary mode of transmission, at least at these young ages, to women: from a typically older husband to a typically younger wife. Once married, women's coital frequency rises, and the simulations show that non-negligible proportions of new husbands are HIV positive.

The table also shows comparable figures for rural Manicaland, Zimbabwe. The data come from an unpublished tabulation kindly provided by Simon Gregson, but the basic elements are discernible in Figure 2 of Gregson *et al*. (2002). In this case, the prevalence of HIV among women exceeds that of men until age 30; from that age on, HIV prevalence among men exceeds that among women. The general resemblance between the simulated and the population data is striking.

8. Conclusions

This paper grew out of our curiosity concerning the merits of the belief, gaining currency both in Malawi and elsewhere in the region, that marrying protects against HIV/AIDS. We focus on the HIV status of newly-weds because if HIV infection is already present, whether in wife, husband, or both, the notion that marriage is protective is clearly ill-founded: an infected partner is doomed, and an uninfected partner is at high risk.

We estimate that HIV infection is already present in between 13 and 20 per cent of Malawian newly-weds. Turned on their heads, these figures imply that for at least 80 per cent of new, first-time couples, HIV infection is absent. Such couples have weathered the epidemiological perils of premarital sex and will remain seronegative so long as they restrict their sexual attentions to one another. In further work we propose to examine the further evolution of HIV infection as couples are, or are not, faithful to one another, and to incorporate divorce and remarriage, which are known to be common.

Gregson *et al*. (2002) suggest for rural Zimbabwe that knowledge of high levels of HIV in young single people could encourage couples who are planning to marry to seek voluntary counselling and testing. This could provide an effective intervention also in Malawi. The transition from the unmarried to the married state could provide an ideal opportunity for couples to take stock of their situations and to modify their behaviour accordingly; and to do so with particular relief if they find that they are among the majority of young Malawian couples who are as yet uninfected.

9. Acknowledgements

We are grateful to Agnes Chimbiri, Claire Hickey, Amy Kaler, Enid Schatz and Linda Tawfik, who made available to us transcripts of semi-structured interviews from projects in rural Malawi with which they were associated or which they directed. We have benefited from comments on earlier drafts by Jere Behrman, Agnes Chimbiri, Shelley Clark, Patrick Gerland, Herb Smith, Linda Tawfik, and two anonymous reviewers, and from discussions with Richard White and Simon Gregson; we are especially grateful to the latter for providing us also with an unpublished tabulation from a study in rural Zimbabwe.

This research was partially supported by the National Institutes of Health – National Institute on Aging, Grant number AG12836, awarded to the Population Aging Research Center (PARC), B.J. Soldo, PI.

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Appendix

A. 1. A model of human reproduction

The basic model is a conventional woman-based microsimulation model of human fertility, differing from earlier models (for example, Santow 1978) primarily in terms of the heterogeneity of various input parameters and distributions but also in the greater complexity and realism of the physiological processes that are taken into account and the ease with which the user can incorporate variations in such factors as nuptiality, breastfeeding practices, and infant and child mortality.

The simulation takes individuals through their lives, decisions being constantly made, conditional on their past experience and current status, about what will happen next.

For biological parameters, individuals are generally assigned a characteristic probability of an event (for example, that a conception will end in spontaneous foetal loss). For behavioural parameters, individuals are generally assigned a propensity for a particular type of behaviour and a probability that the behaviour will occur in any given month (for example, there is a propensity to marry and those who do marry have a probability of marrying by a given age).

Marriage, which in the absence of pre-marital sexual relations can be equated with exposure to the risk of conception, is incorporated by means of the Coale-McNeil double-exponential marriage model (Coale and McNeil 1972) according to which the distribution of women's ages at marriage is determined by the minimum age at marriage, a compression factor related to the speed with which the population marries (the lower the compression factor the more swiftly marriages occur), and the proportion of women ultimately marrying. All women are assumed to have reached menarche before they marry.

The model allows for the possibility of premarital sexual relations: women are assigned a propensity to have sex before marriage, and for those women with such a propensity their age at embarking on such a relationship and its duration are determined stochastically by reference to a user-defined schedule of age-specific probabilities and a user-defined average duration. Extramarital relationships are simulated in a similar manner except that the schedule of probabilities of entering such a relationship is duration-specific rather than age-specific. In each case, coital frequency is set as a proportion of what it would have been if the individual were married.

A tiny proportion (2.5 per cent) of women are congenitally infecund, and the age at which individual women become ultimately infecund (which in most cases is equivalent to menopause) was derived from Pittenger (1973).

Menstrual cycles vary both within and between women (Short *et al*. 1991). Across ages, fecundability, the probability of conception in a menstrual cycle, is allowed to vary between women according to a series of beta distributions (Jain 1969). Within women,

fecundability varies according to age, rising to plateau in the early twenties and then declining to reach a low level in the forties. Thus, each woman, whether her characteristic fecundability is low or high, demonstrates throughout her reproductive life the age pattern observed in real data, but at a characteristic (low or high) level. The present application of the model makes no allowance for induced abortion, but women are randomly assigned a characteristic probability of spontaneous foetal loss, which is distributed across the simulated population according to another beta distribution (Santow and Bracher 1989). Durations of gestation are determined according to known distributions, as are durations of post-partum amenorrhoea following a foetal loss (Santow 1978).

Breastfeeding and related post-partum amenorrhoea are taken into account in the case of live-birth pregnancies. Women who breastfeed (the proportion breastfeeding being set externally) either do so until the menses return, or their duration of breastfeeding is selected randomly from a predetermined range; in either case, the relation between breastfeeding and the return of fecundity is derived from a study of fully breastfeeding women (Short *et al*. 1991) and incorporated in the manner used by Bracher (1992) in a microsimulation of the effect on birth spacing of different strategies for the adoption of post-partum contraception.

The model also allows for the possibility of post-partum abstinence of varying durations, and terminal abstinence. In the present application sexual activity is resumed post partum within 15 days of stopping breastfeeding.

Background (that is, non-AIDS-related) mortality is incorporated according to the Princeton West model life tables (Coale and Demeny 1983), the precise level being set externally. Naturally, the death of an unweaned child terminates breastfeeding.

For computational efficiency, and in order to determine the order in which events occur, the model works with a time unit of a day although results are tabulated in much larger time units than this.

The basic model of human reproduction is “female-dominant” in the sense that men are taken into account only implicitly: fecundability and sterility, for example, are actually attributes of couples rather than women although treating them as attributes only of women does not invalidate the model.

The model held up well in a series of validation exercises. For example, schedules of single-year age-specific fertility rates simulated with the nuptiality pattern described above and with either no breastfeeding or breastfeeding of maximum intensity and duration were extremely similar to schedules predicted from Brass's simple fertility polynomial (Brass and Coale 1968) with childbearing beginning at 16.75 years and total fertility rates of 10.5 and 8.4 respectively (see Figure A1).

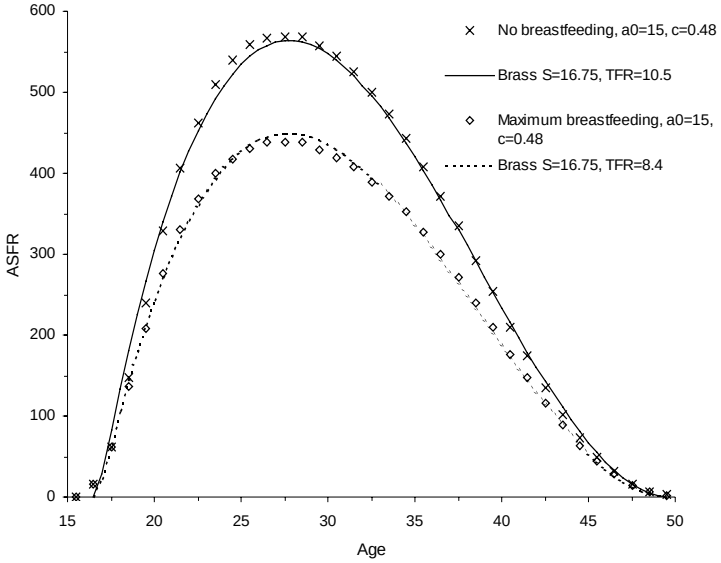

Figure A1: *Simulated fertility schedules under different assumptions about breastfeeding behaviour*

A.2. Introducing disease

Including disease in the model greatly complicates its formulation because we wish to maximize the realism of the way in which disease enters the simulated population and because, relatedly, we now need to take both men and coital frequency explicitly into account.

No method for introducing disease is completely satisfactory. The method we choose posits the existence of a group of women external to the simulated population among whom certain proportions are infectious with various diseases, including HIV. These women, with whom some of the simulated men have sexual relations before and after they marry, form the reservoir of infection from which disease enters the general population.

Within the model we take into account men's premarital and extramarital sexual behaviour and their ages at marriage. The ages of brides and grooms are not independent and men's marriages cannot be simulated in isolation from the marriages of the women they marry. Our choice was to retain the model's female dominance and to simulate a groom's age at marriage as a function of his bride's by assuming a gamma distribution for the age difference between spouses. The shape of this distribution is user-defined and may be allowed to vary according to the age of the bride.

We simulate a groom's disease status at the time of his marriage by tracking him from his sexual debut, derived from another gamma distribution, up to that point. The median age at male sexual debut is user-defined, as are propensities to engage in premarital sexual activity with women certain user-defined proportions of whom are infectious with a range of sexually transmitted diseases, including HIV. There are also user-defined probabilities of having intercourse in any month, and user-defined ranges of monthly coital frequencies.

Although the probability of conception within a menstrual cycle varies according to the timing and frequency of coital acts relative to the timing of ovulation, fecundability is well represented as a "monthly" probability of conception, which is the way it is both measured and incorporated into models (not necessarily microsimulation models). In contrast, each coital act, whatever its timing within the cycle, carries with it a probability of the transmission of disease. Such probabilities are typically higher than the probability of conception. For example, the probability of unintended pregnancy ranges from 17 to 30 per cent per mid-cycle coital act and falls below one per cent during the menses, but the probability of gonococcal transmission from infected male to uninfected female is 50 per cent per coital act, irrespective of when in the cycle it occurs (Hatcher *et al*. 1998).

Models that allow for disease transmission are therefore considerably complicated by the need to take account of coital frequency. We do this by means of an expression, which draws on a model originally proposed by Glass and Grebenik, that gives mean fecundability as a function of the length of the menstrual cycle and the distribution of coital frequency within the cycle (Bongaarts and Potter 1983). Turning the expression around, we derived

the distribution of coital frequency as a function of mean fecundability and cycle length. Next, taking a woman's value of the beta-distribution-based fecundability at any given age, and the length of her menstrual cycles, we determine stochastically her coital frequency during that cycle. Substituting this value into the original expression we obtain a new value for her probability of conception in this month. The two-fold advantages of this procedure are, first, that it allows variation in the monthly probability of conceiving even for two women with the same mean fecundability and the same cycle lengths, and secondly and more critically, that it establishes a consistent relationship between probabilities of conception and of disease transmission. In other words, simulated disease outcomes are consistent with simulated reproductive outcomes.

Because coitus always carries a risk of infection if one of the partners is infected the model incorporates sexual activity even when the chance of conception is zero. Thus we take account of the fact that a sexually active woman may be infected while she is pregnant, or during the post-partum period before she starts to ovulate again. Indeed, a menopausal woman is at risk of infection if she is sexually active, as is a woman who is congenitally infecund.

Apart from infection with HIV, the model allows for the possibility of infection with any or all of three discharge diseases, namely gonorrhoea, chlamydia and bacterial vaginosis, and three ulcerative diseases, namely syphilis, chancroid and genital herpes (HSV-2). Each STD has its own characteristic natural history, differing from others in terms of its transmissibility, duration of infectiousness, probability of spontaneous recovery and recurrence, development of natural immunity, its effects on reproductive capacity, and its co-factor effects with HIV. The model takes into account salient features of each of these natural histories. It is important to note that in doing so, what is critical for disease transmission is not whether an individual is infected but whether an infected individual is infectious. With the exception of HIV, the duration of infectiousness is typically considerably shorter than the duration of infection. The model allows for the possibility of cycles of infection and re-infection within one sexual partnership whether it be marriage or a more casual relationship. In the model, as in life, HIV-positive individuals are always infectious, but they are most infectious in the early and terminal stages of their disease.

In the present application all diseases are assumed to be untreated. In particular, we assume no anti-retroviral therapy in the case of infection with HIV.

We assume a probability of vertical transmission of 0.3 and a monthly probability of 0.01 that a breastfed child of an HIV-positive mother will seroconvert.

Individuals infected with HIV progress to full-blown AIDS according to a Weibull model with a mean of 7.5 years. Once the individual has AIDS, sexual activity ceases and death ensues according to a Weibull model with a mean of one year.