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Research Article

Masculine sex ratios, population age structure and the potential spread of HIV in China

M. Giovanna Merli

Sara Hertog

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M. Giovanna Merli[1]

Sara Hertog[2]

Abstract

There is much speculation regarding the contribution of China's changing demography to the spread of HIV/AIDS. We employ a bio-behavioral macrosimulation model of the heterosexual spread of HIV/AIDS to evaluate the roles that China's unique demographic conditions -- (1) masculine sex ratios at birth and (2) a population age structure that reflects rapid fertility decline since the 1970's -- play in altering the market for sexual partners, thereby potentially fueling an increase in behaviors associated with greater risk of HIV infection. We first simulate the relative contributions of the sex ratio at birth and the population age structure to the oversupply of males in the market for sexual partners and show that the sex ratio at birth only aggravates the severe oversupply of males which is primarily a consequence of the population age structure. We then examine the potential consequences of this demographic distortion for the spread of HIV infection and show that, to the extent that males adapt to the dearth of suitable female partners by seeking unprotected sexual contacts with female sex workers, the impact of the oversupply of males in the sexual partnership market on the spread of HIV will be severe.

[1] Sanford School of Public Policy and Department of Sociology, Duke University. Address all correspondence to giovanna.merli@duke.edu.
[2] United Nations Population Division. The views expressed in this paper do not necessarily reflect those of the United Nations.

1. Introduction

At the end of 2007, China's HIV/AIDS epidemic was classified as "low level", with an estimated 700,000 people living with HIV, corresponding to 0.05 percent of the adult population (UNAIDS 2008). While until now HIV in China has been concentrated among relatively well-defined population subgroups, such as users of injected drugs, former plasma and blood donors and female sex workers and their clients (State Council AIDS Working Committee Office 2007; Wu, Rou, and Cui 2004), new evidence suggests that HIV is spreading from these traditional high-risk groups to the general population through heterosexual contact. The proportion of HIV infections resulting from heterosexual transmission is growing, such that these accounted for half of all new cases in 2005 (MOH, UNAIDS and WHO 2006, Kerr 2005). Heterosexual transmission between high-risk groups and the general population is especially evident in the southern regions of the country, where China's HIV epidemic first took root (Gill, Huang, and Lu 2007; MOH, UNAIDS and WHO 2006; Lin et al. 2008).

The extent to which HIV will continue to spread to the general population in China depends largely on the levels and distribution of sexual activity. Results of an empirically grounded compartmental model suggested that in China, overall levels of sexual activity (identified by the rate of partner change) and the fraction of the population with multiple partners would have to be significantly higher than those currently observed in order for HIV prevalence to exceed one percent at any time during a 50-year simulation cycle (Merli et al. 2006). These results, however, do not imply that concerns about continued spread of HIV in China's general population are unwarranted. On the contrary, there are good reasons to suspect that sexual activity in China could contribute to a larger, more widespread HIV epidemic in the future. For example, China's increasingly liberal social and economic environment includes increasing prevalence of higher-risk sexual behaviors, such as casual or concurrent partnerships and commercial sexual activity (Farrer 2002; Sigley and Jeffreys 1999, Parish, Mojola, and Laumann 2007). In addition, as will be explored in this paper, it has been suggested that China's unique demographic conditions have the potential to further influence the sexual landscape in such a way as to place an increasing proportion of the population at risk for HIV infection.

Two features of China's demographic profile are hypothesized to potentially shift the distribution of the sexually active population towards higher rates of partner change and more widespread adoption of risky behaviors in the future: (1) highly masculine sex ratios at birth; and (2) the population age structure that reflects the rapid, widespread fertility decline which began in the early 1970's. Both features are likely to contribute to an oversupply of men relative to women in the marriage and sexual partnership markets in coming decades. When men and women prefer exclusively partners of the same age, the availability of sexual partners is a function of both the sex ratio at birth and the relative survival of males and females in the cohort. In China, where social norms tend toward men partnering with younger women, partner availability is further determined by the age structure of the population, which reflects shrinking cohorts as a result of the country's very rapid fertility transition (Tuljiapurkar, Li, and Feldman 1995; Goodkind 2006). Owing to their inability to find a suitable partner, unattached males are anticipated to adopt risky sexual behaviors, namely multiple partnerships and patronage of commercial sex, thereby increasing the potential for HIV spread in the population.

In this paper, we explore the implications of these two demographic conditions for changes in the market for sexual partnerships, alterations in individual sexual behaviors elicited by these changes, and implications for the potential heterosexual spread of HIV. We employ a mathematical model used previously to assess the role of sexual transmission for the spread of HIV in China (Merli et al. 2006). By uniting a population projection with an epidemiological model of HIV transmission, the model allows us to simulate concurrently three related processes over time: population change, the sexual partnership market, and the HIV epidemic. Input parameters draw upon a diverse set of empirical data sources variously describing China's demographic characteristics, patterns and trends in partnership formation and sexual behavior, and the epidemiology of HIV/AIDS. Although mathematical models of HIV transmission dynamics have been largely unsuccessful in accurately reproducing epidemic curves (Leclerc and Garenne 2007) and have proven inadequate to accurately predict the course of the Chinese epidemic (Merli et al. 2006), they are useful for understanding the dynamic relationship between macro-demographic changes and micro-behavioral adaptations and their implications for the spread of HIV.

We first simulate the relative contributions of the sex ratio at birth and the population age structure to the oversupply of males in the market for sexual partners and show that the sex ratio at birth only aggravates the oversupply of males, which exists primarily as a consequence of the population age structure. We then examine the potential consequences of this demographic distortion for the spread of HIV infection by simulating a range of possible HIV prevalence outcomes consistent with behavioral adaptations hypothesized as potential male responses to the projected dearth in availability of female partners. Results suggest that, to the extent that males adapt to the shortfall of suitable female partners by seeking contacts with female sex workers, the impact of the oversupply of males in the sexual partnership market on the spread of HIV will be severe.

2. Sex ratios at birth, age-sex structure distortions and sexual behavior

China's sex ratios at birth, the number of males born for every 100 females have risen sharply since the early 1980s as an expression of strong son preference, low fertility desires and the quantitative constraints imposed by the one child policy (Zeng et al. 1993; Gu and Roy 1995; Coale and Banister 1994; Cai and Lavely 2003; Banister 2004). This reported shortage of girls is produced by the widespread practice of sex selective abortion, made possible by the availability, as of the late 1980s, of ultrasound machines which permit identification of the sex of the fetus in utero, and by underreporting of daughters in censuses and surveys (Zeng et al. 1993; Merli 1998, Merli and Raftery 2000; Cai and Lavely 2003; Scharping 2003, 2007). The sex ratio at birth recorded in China's 2000 population census (short form) was 116.9 male births per 100 female births (Banister 2004), a rise from 107.6 in 1982 and 111.0 in 1990 and an indication of a growing imbalance.

Today and in the coming decades, the children born into this climate of strong son preference are reaching adulthood. According to the United Nations population projections for China, there were 106 men aged 15-49 for every 100 women in that same age group in 2000 and that ratio is expected to increase to over 115 men for every 100 women by 2030 (United Nations 2009). Male cohorts born into the imbalanced sex ratios at birth today are hypothesized to encounter a shortfall of female partners upon entering the marriage market. It is expected that the marriage sex ratio will be further distorted by the age structure of the population given fixed social norms that males be older than their female partners coupled with prolonged fertility decline that has reduced the size of successive birth cohorts. According to both the United Nations and the 2000 China Health and Family Life Survey (CHFLS), the first population-based nationally representative sexual behavior survey of 20-64 year olds ever conducted in China (Parish et al. 2003; Parish, Mojola, and Laumann 2007), estimates of the singulate mean age at marriage (SMAM) for China indicate that males tend to marry females who are approximately an average of two years their junior. This norm, combined with China's dramatic fertility decline from more than 6 children per woman in the early 1970s to well below the replacement level of 2.1 children per woman today means that men who reach sexually active ages after 2000 come from earlier and larger birth cohorts than their younger female partners. Thus, it is expected that China's age structure contributes to the oversupply of men in the market for sexual partners over and above what results from the masculine sex ratio at birth alone.[3] It has been

[3] The sex ratio of the adult population is also a function of differentials survival of male and female. Since the 1980s in China, the mortality rate of female infants has been higher than that for male infants (Banister and Hill 2004). The unadjusted sex mortality ratio for infants in the 2000 census was 72 male infant deaths per

estimated that the imbalance in the sex ratio at birth alone in the 1990 census would result in a surplus one million men annually unable to find wives after the year 2010 (Tuljapurkar, Li, and Feldman 1995). Hudson and den Boer (2004:176) figure that by 2020 China will be home to between 29 and 33 million surplus males between the ages of 15 and 34, which would account for between 14 and 16 percent of the total projected number of males age 15-34 for that year by the U.S. Bureau of the Census.

The implications of the marriage squeeze hypothesis consistent with variations in the size of cohorts entering the marriage market have drawn the attention of scholars and the media alike. The media, in particular, are prone to accept such general statements as “unbalanced numbers inexorably produce unbalanced behaviors” (cited in Thompson 1974:153; e.g. CNN World News 2007). Various scenarios of social dislocations as a consequence of an oversupply of men have been described. Dominant among these is the suggestion that a deficit of female partners will contribute to men’s social isolation, drive them to adopt high-risk sexual behaviors such as patronage of commercial sex, or to seek their partners among increasingly younger pools of women (Tucker et al. 2005; Hudson and den Boer 2004; Hesketh and Zhu 2006). Economic models of marriage and prostitution also posit a link between surplus males and a market for commercial sex. These models portray mate selection as a market process (Edlun and Korn 2002), assume that women seek wealth from their male partners, that men value traits associated with female fertility, that the cost of reproductive sex for men is higher than that of commercial sex, and that wives and prostitutes are drawn from the same pool of female partners available to men. According to these models, a masculine sex ratio on entrance to the marriage market can make prostitution more

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100 female infant deaths, a result of post-natal discrimination against females. However, Goodkind (2006) finds that post-natal discrimination does not significantly affect the relative number of projected adult males and females at peak marital ages and that the effect of gender differences in infant mortality on the sex ratio of the adult population is much smaller than that of the age structure and of the imbalance in the sex ratio at birth. Sex differences in migration are an additional demographic factor responsible for altering the market for sexual partners and produce male surpluses in the sexual partnership market in migration destination communities. For example, the disproportionately masculine flows of labor migration from the countryside into cities and towns which have taken place over the last three decades in China (Liang and Ma 2004) are expected to exacerbate the dearth of female partners for male migrants in urban areas (but, by the same token, they might relax the partnership market in the sending rural areas), lead male migrants to adopt HIV-related risk behaviors, such as multiple partnerships and patronage of commercial sex (Tucker et al. 2005; Li et al. 2004), injecting drug use (Yang, Derlega, and Luo 2005), and increase their vulnerability to STD infection (Li et al. 2004; Yang 2005). In fact, China’s masculine migration flows and sex ratios at birth are often combined in the same narrative of surplus males even though the precise relationship between sex ratios at birth and internal migration is not discussed (Tucker et al. 2005). While in other work (Merli et al. 2009) we have addressed the role of migration in altering the urban and rural partnership markets and driving up the prevalence of risky sexual behaviors with implications for the spread of HIV/AIDS, in the present paper our treatment of migration is limited to its incorporation into the simulation model to preserve demographic realism.

profitable relative to marriage. With a smaller pool of women relative to men, reproductive sex becomes scarcer and sex with prostitutes more desirable.

Yet accommodations of surplus males to the dearth of suitable female partners are mostly limited to the realm of hypotheses. Direct empirical support for the link between unbalanced sex ratios and the prevalence of specific risky sexual behaviors is not available, except perhaps as suggested by the results of ecological analyses of urban populations which reveal a positive association between masculine sex ratios in the adult population and the prevalence of sexually transmitted diseases (STDs) and HIV (Over 1998; Aral et al. 2006) or by circumstantial associations between highly masculine sex ratios of the adult population and the growth of prostitution highlighted by historical studies of 1930's Shanghai (Hershatter 1997: 40) and late 19th century's American Far West (Courtwright 1991:474). In the absence of a solid empirical basis to ground the types of behavioral adaptations to be simulated, we have translated the adaptations to sex imbalances in the partnership market suggested or hypothesized in the literature into inputs driving simulations of the spread of HIV/AIDS.

3. Data and methods

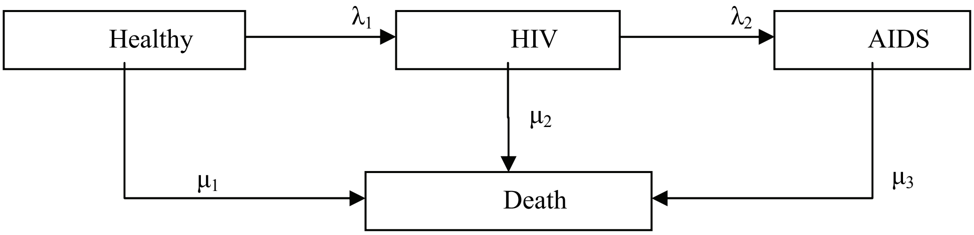
3.1 Model structure

We use an existing deterministic model, built upon a two-sex cohort component population projection, first developed by Palloni and Lamas (1991) to simulate the heterosexual spread of HIV. For the purposes of these analyses, the original model has been modified to represent the Chinese pattern of sexual relations (Merli et al. 2006), to accommodate multiple scenarios of sexual activity and sexual mixing (Hertog 2007), and, in the present paper, to estimate the number of surplus males unable to find a partner as a result of age-sex demographic imbalances.

The model defines six distinct populations: urban males, urban prostitute females, urban non-prostitute females, rural males, rural prostitute females and rural non-prostitute females. Males and non-prostitute females are allocated into homogenous "sexual activity classes" defined by the number of non-prostitute partners acquired in a year. For this application, the model considers only two sexual activity classes: monogamous and non-monogamous. Both monogamous and non-monogamous males may have contact with prostitutes in addition to their non-prostitute partner(s). Prostitute females do not have regular non-commercial partners in addition to their clients.

With each projection cycle, the model simulates the transitions of each population sub-group between three states (Healthy, HIV-infected but asymptomatic, and symptomatic AIDS) and from those states to death (Figure 1). The transition rates are determined by a set of demographic, biological and behavioral parameters and are described by a set of differential equations, presented in detail elsewhere (Palloni and Lamas 1991; Palloni 1996). New entrants (births) are allocated into sexual activity classes according to the distribution specified at the outset, independent of the distribution of sexual activity among parental generations.

Figure 1: States and flows in the Palloni and Lamas macrosimulation model



The shape of the probability distribution of urban and rural females entering into prostitution with each projection cycle is drawn from a Coale-McNeil marriage function and the proportion of a female cohort who will eventually engage in prostitution can be approximated by the proportion of prostitutes in the female population. Prostitution is an absorbing state—women do not transition back into the general population of non-prostitute females.

Partnerships are simulated according to the size of the population sub-groups and the preferences of each cohort with respect to the number and ages of partners. With each projection cycle and for each cohort defined by single year of age, the total number of partnerships preferred by urban and rural non-prostitute females defines the availability of female partners. Similarly, the number of non-commercial partnerships desired by urban and rural males of a given age is determined with each projection cycle according to the distribution of males by sexual activity class. The number of desired partnerships fulfilled for a given cohort of males is determined by the number of available female partners within the partner age preferences of the cohort. The number of desired (non-commercial) partnerships *unfulfilled* then is the difference between males' total number of non-commercial partnerships desired and the number of female partnerships available within males' age preferences for partners. In this model, all commercial sex partnerships desired by males are fulfilled.

3.2 Model inputs

Baseline parameter values are displayed in Tables 1 and 2. Simulated scenarios reflect a variety of values selected for the demographic parameters associated with the sex ratio at birth and behavioral parameters associated with partner age preference, the frequency of contacts with prostitutes and protective behaviors related to the use of condoms with prostitutes.

3.2.1 Demographic inputs (Table 1)

The baseline population is defined according to the age- and sex-specific population distributions in China's rural and urban areas as enumerated in the 2000 Census. Of the 1.24 billion inhabitants enumerated in China's 2000 national population census, 63% resided in rural areas, while the remaining 37% lived in China's cities and urban towns, which combined comprise the "urban" population for the simulation model.

Table 1: Model inputs: Demographic

	Urban (City andTown)	Rural
Population[a]		
Total	458,770,983	783,841,243
Males	235,264,707	405,011,262
Females	223,506,276	378,829,981
Total Fertility Rate (TFR)[a]	0.94	1.43
Sex Ratio at Birth[a]	116.5	121.7
Life Expectancy at Birth (years)[a]		
Males	74.0	69.0
Females	78.3	72.4
Annual migration rate from (%)	0.66	0.87
Median age at sexual debut[b]		
Males	22	22
Females	22	22
Mean age difference b/w partners (years)[b]	1.8	1.8
Women who are prostitutes (%)[c]	2.0	2.0

[a] Unadjusted rates from 2000 census
[b] From CHFLS
[c] Horizon Market Research and Future Group Europe 2002; Yuan et al. 2002

Demographic rates, including fertility, age- and sex-specific non-AIDS mortality and internal migration between rural and urban areas are based on the *unadjusted* estimates obtained from China's 2000 census. The decision not to adjust the fertility data could be readily disputed. China's TFR recorded in the 2000 census (short form) of 1.35 children per woman (0.938 in urban areas and 1.43 in rural areas) is believed to be too low. Adjusted estimates range from 1.4 to 1.8 (Retherford et al. 2005). These adjustments generally account for the number of children, especially female children, underreported in the census as a consequence of policies that hold family planning officials responsible for achieving pre-set targets and quotas within their jurisdiction (Goodkind 2004; Merli, Qian, and Smith 2004; Merli and Raftery 2000). An adjustment of the TFR would necessitate an adjustment of the age sex distribution of the population for the truly missing children and a downward adjustment of the sex ratio at birth if underreporting of female children is especially severe (Goodkind, forthcoming). In line with a larger number of underreported female births relative to male births, Goodkind and West (2007)'s adjustment brought the 2000 census sex ratio at birth down from 116.9 to 114. Because of the wide range of adjustment procedures and underlying assumptions and because the published adjustments are made on total population counts while our simulations would require separate adjustments for urban and rural areas, our preferred strategy is to accept the unadjusted census figures as the baseline. We are of course aware that an underreported TFR and an overreported sex ratio at birth in the 2000 census due to underreporting of baby girls will affect the size of the cohorts initiating sexual activity about 20 years later. Most relevant to our analysis, we might overestimate the size of the male cohorts relative to the female cohorts in the same age groups since it is unrealistic to assume that births are no more underreported for one sex than the other.

For the baseline simulation scenario, we project sex imbalances in availability of sexual partners, assuming constant fertility, a constant sex ratio at birth (116.5 in urban areas and 121.7 in rural areas), constant non-AIDS mortality, constant migration flows between rural and urban areas and an age schedule of sexual debut drawn from the CHFLS.[4] We assume an enduring social norm that males be two years older than their female partners on the average, according to the age differences between sexual

[4] Alternatively, we could have used an age-specific marriage schedule in order to define the available pool of sexual partners. However, we feel that the use of the age schedule of sexual debut is more appropriate because we are interested in measuring the impact of the sex ratio at birth on the availability of sexual partners for those who desire a sexual partner, not only on the availability of marital partners, an outcome that may be more directly determined by the inability to find a partner due to the imbalanced sex ratio. However, the projected availability of sexual partners is also empirically derived. It reflects the existing patterns of age at first sex and age difference between partners and the accommodation of partners to the supply and demand of potential mates at that time. In their study of the demography of the U.S. marriage market, Goldman, Westoff, and Hammerslough (1984) note that this problem cannot be avoided and, although it blurs the distinction between supply and demand, it is the only possible way to proceed.

partners reported in the CHFLS. This gap is consistent with the average age difference between partners indicated by the singulate mean age at marriage (SMAM) in 1999 of 24.8 years for men and 23.1 years of age for women (United Nations World Population Database), and with a SMAM for those marrying by age 30 in 2000 of 25.2 for men and 23.2 for women, an age difference at peak marital ages that endured throughout the 1990s (Goodkind 2006).

Population movement between rural and urban areas is driven by the annual rural-to-urban and urban-to-rural migration rates approximated based on information on destination for 78,756,500 floating intercounty migrants and on information on origin and destination for 65,634,248 intracounty migrants enumerated in the 2000 census. In the five years leading up to the 2000 census, approximately 0.66% of the total urban (city and town) population migrated annually to a rural area, while 0.87% of the total rural population migrated to an urban location each year.[5] The age and sex distribution of migrants corresponds to that reported in the 2000 census micro data as presented by Liang and Ma (Table 4, 2004).

We set the number of female sex workers in China at 6 million women ages 15-39 (Horizon Market Research and Futures Group Europe 2002). This widely cited estimate lies approximately in the middle of a range of estimates of 1 to 10 million female sex workers in China (Huang et al. 2004; Schafer 2003; Yuan et al. 2002). In our model, female prostitutes are found in both urban (cities and towns) and rural areas (counties), consistent with evidence from numerous studies of female sex workers that suggest the widespread availability of commercial sex across urban and rural China (Hong and Li 2007; Wang et al. 2009). Six million female prostitutes corresponds to about 2.2 percent of the total female population between ages 15 and 39, and 1 percent of the *total* female population of all ages. This figure falls in the middle of a range given by Lim (1998) who estimated that in Indonesia, Malaysia, the Philippines and Thailand between 0.25 and 1.5 percent of the *total* female population worked as a prostitute. The 15-39 age range of prostitutes in our simulations is wider than that taken from a review of studies based on samples of sex workers in entertainment establishments where the mean age of female prostitutes oscillated between 23 and 25, with most in their late-

[5] These rates were calculated by dividing the migration flows from urban to rural areas and from rural to urban areas by the total population in the area of origin (PCO 2002, Tables 7-1 (a, b, c) and Table 1-7. These census tables are believed to most accurately represent the actual rural-urban migration flows in 2000 (Zai Liang, personal communication, July 17, 2007). Because the published census tabulations present the distribution of intercounty migrants by place of destination but not by place of origin, we applied the published distribution of intracoutny migrants by place of origin to the destination row totals of intercounty migrants. We also know from other sources (Liang and Ma 2004, Table 4) that, of the 78.7 million intercounty migrants, only 58.8 million migrated to their destination between 1995 and the 2000 census. Since the published tabulations of the 2000 census do not contain information which allows apportioning intercounty migrants by duration, we assumed that all intercounty migrants have migrated in the five year leading to the 2000 census.

teens and early- to mid-twenties (Hong and Li 2008). The broader width of our simulated age range of female prostitutes is informed by recent studies which employed sampling approaches intended to reach the most hidden pockets of this population who are not establishment-based (e.g. road-side sex workers) and whose age is as high as the upper thirties and early forties (Huang et al. 2004; Ding et al. 2005; Merli et al. 2008).

3.2.2 Behavioral inputs

The sexual behavior inputs are drawn primarily from the CHFLS and are presented in top half of Table 2. The CHFLS was conducted in 2000 and collected 3,821 completed interviews from 5,000 individuals sampled from registers of households and temporary migrants held by urban neighborhoods and rural townships across China (Parish et al. 2003).

In our simulated scenarios, membership in a sexual activity class is determined by the number of non-prostitute partners drawn from CHFLS data for two groups: individuals in the monogamous class reported only one non-prostitute partner in the year leading up to the survey, while individuals assigned to the non-monogamous class reported more than one non-prostitute partner in the previous year (2.29 partners on average). According to the CHFLS, 10.5% of adult males and 2.6% of adult females belonged to the non-monogamous sexual activity class at the time of the survey. For the purposes of simulation, non-prostitute partners are assumed to be selected from the pool of available partnerships in the population, without regard to sexual activity class (i.e., proportionate mixing between classes) (Garnett and Anderson 1993).

In addition to the number of non-prostitute partners, a number of other behavioral factors influence the risk of HIV transmission faced by members of each of the sexual-activity classes. Other behavioral inputs derived from the CHFLS include the annual average per-partner coital frequency (85 coituses per partner per year for monogamous and 89 for non-monogamous) and the average proportion of an individual's coituses that are condom protected (10.3% of coituses with non-prostitute partners are protected among monogamous compared to 14.0% among non-monogamous). Reports of coital frequency in the CHFLS are consistent with values reported by 7,074 married volunteers age 18-62 interviewed in 1989-1990 (Liu et al. 1997). Condom use reported in the CHFLS was more frequent among respondents with multiple partners, consistent with more frequent condom use with non-regular partners than with regular partners.

Table 2: Model inputs: Behavioral and biological

	Sexual activity class	
	Monogamous	Non-monogamous
Parameters that vary by sexual activity class		
Percent of adult population in class (age 20-49)		
Males	89.5	10.5
Females	97.4	2.6
Mean number of non-prostitute partners per year	1	2.29
Mean coital acts per non-prostitute partner	85	89
Percent of coital acts condom protected	10.3	14.0
Percent of men who patronize prostitutes	0.01	37.7
Mean num. of prostitutes per man who patronizes prostitutes	1.0	1.4
Percent of coital acts with prostitutes condom protected	20.6	28.0
Percent infected with Chlamydia		
Men	2.9	2.0
Women	3.1	1.3
Prostitutes	32.0	na
Parameters that do not vary by sexual activity class		
Percent of adults infected with HIV at baseline		
Men	0.05	
Women	0.05	
Prostitutes	0.05	
Mean incubation from HIV to AIDS - Adults (years)	8	
Mean incubation from HIV to AIDS - Infants (years)	2	
Mean survival with AIDS - Adults (years)	1	
Mean survival with AIDS - Infants (years)	1	
Probability of vertical transmission (%)	30	
Condom efficacy (%)	80	
Per-contact transmission probability		
Male-to-female	0.0015	
Female-to-male	0.0009	
Chlamydia cofactor	2.25	
Increased infectiousness if recently infected of symptomatic	3	

Sources: CHFLS; UNAIDS 2004; van den Hoek et al. 2001; Downs and De Vincenzi 1996; Ambroziak and Levy 1999; Bracher, Santow, and Watkins 2003; Fleming and Wasserheit 1999; Chau, Yip, and Cui 2003; Churat et al. 2000.

Patronage of commercial sex was very uncommon among monogamous men in the CHFLS, with only 0.01% of monogamous men reporting a female commercial sex partner in the year leading up to the survey. Among men with more than one non-prostitute partner in the year, 37.7% reported having purchased the services of a prostitute. Unfortunately, because information on condom use with prostitutes is missing for about 80 per cent of men who reported having paid for sex in the previous year in the CHFLS, we assumed the proportion of condom protected sexual acts with prostitutes to be twice that with non-prostitute partners, to reflect typically higher condom use with prostitutes than with regular partners.

3.2.3 Biological inputs

The biological inputs which drive the simulations are shown in the bottom half of Table 2. At the outset of the simulation, we seed the Chinese population with approximately 700,000 HIV cases according to the age distribution of HIV cases recorded for the Thai population (UNAIDS 2004). This number corresponds to the most recent estimates for China, equivalent to an adult prevalence rate of 0.05%. The population of prostitutes is also seeded with HIV according to the same low HIV prevalence. Except for the very small fraction infected, the remainder of the simulated population begins the simulation period with no HIV and is introduced to the risk of infection during the simulation period only through heterosexual contacts with infected partners.

We assume a default baseline per-coitus probability of male-to-female HIV transmission of 0.0015 and a probability of female-to-male transmission of 0.0009. These are the frequently cited probabilities of transmission of HIV per single unprotected coitus estimated from a highly controlled study design of 525 HIV-discordant European couples (Downs and De Vincenzi 1996). Infectivity of HIV is higher among infected individuals who have recently acquired HIV or in individuals who have symptomatic AIDS because of the higher viral load in these two stages (Ambroziak and Levy 1999; Pilcher et al. 2004). For the simulations, we posit that HIV is trebly infectious during the first year after seroconversion and again after progression to AIDS (Mastro and de Vincenzi 1996; Ambroziak and Levy 1999).

HIV infectivity also depends on the existence of other STDs, both ulcerative (syphilis, chancroid, and genital herpes) and discharge (gonorrhoea, chlamydia, and bacterial vaginosis) diseases. These other STDs enhance the infectiousness of HIV by increasing its concentration in genital ulcer exudates or in seminal plasma, or by increasing HIV shedding in the genital tract (Fleming and Wasserheit 1999). STD-infected individuals also have an increased susceptibility to HIV. In our simulated population, HIV is 2.25 times more infectious in individuals with chlamydia.

To reflect the significant prevalence of chlamydia in the Chinese population as measured for the 3,426 CHFLS respondents who provided a urine sample, for each male and female sexual-activity group and for prostitutes, we enhanced average HIV infectivity per coital act by the chlamydia infectivity cofactor. At the onset of the simulation period, males and non-prostitute females are assigned a unique chlamydia prevalence estimated from the CHFLS, which is assumed constant throughout the simulation period. The chlamydia prevalence value assigned to prostitutes was drawn from epidemiological studies of prostitute populations in southern China (van den Hoek et al. 2001). We further assumed that partnerships are formed randomly without regard to chlamydia infection status. The average HIV infectivity enhanced by co-infection with chlamydia for each group was then determined by the probability of HIV transmission per coital act, that group's own chlamydia prevalence, the chlamydia prevalence among partners, and the chlamydia infectivity cofactor. Computational examples of the average HIV infectivity with co-infection of chlamydia were first illustrated by Bracher, Santow, and Watkins (2003) and were also presented in Merli et al. (2006).

Condom use and condom efficiency protect against HIV by reducing infectivity per sexual act (Saracco et al. 1993; Seidlin et al. 1993; Ahmed et al. 2001). For these simulation scenarios, we assume that condoms are 80 percent effective at preventing HIV transmission.

3.3 Scenarios

We simulated scenarios with variable demographic and behavioral parameters in order to assess the effect of demographic conditions on the availability of suitable female partners for males and associated HIV prevalence and the effect of behavioral adaptations to the shortfall of available female partners on the spread of HIV.

Our simulated scenarios and corresponding parameters are summarized in Table 3. The first scenario (Scenario A) was implemented by applying the baseline demographic and behavioral parameters. This scenario is driven by the sex ratio at birth, fertility, non-AIDS mortality, internal migration rates observed in the 2000 census and held constant throughout the simulation period, and by levels of multiple partnerships and other sexual behaviors as measured in the CHFLS. In the second scenario (Scenario B), we simulated conditions of absolute monogamy by constraining preferences for the number of partners to one for each adult in the population. In Scenario C, we decomposed the number of male partnerships unfulfilled into: (1) the contribution of the masculine sex ratio at birth; and (2) the contribution of the population age structure. This decomposition was achieved by using two sets of sex ratio at birth values throughout the simulation period: the urban and rural sex ratio at birth values in the 2000 census and biologically normal values of 106 males per 100 females. The fourth and fifth scenarios considered men's behavioral adaptations to the dearth of female partners in the baseline scenario and simulated a relaxation of the age preference for female partners (Scenario D) and, in Scenario E, an increase in the number of annual contacts with prostitutes for men who face a shortfall of regular female partners to equal half the number of contacts they would have had with their (forgone) regular non-prostitute partners. The last scenario (Scenario F) introduced a protective behavioral adaptation by raising to 80 percent the percentage of contacts with prostitutes which are condom protected for men who had replaced their forgone regular partners with prostitutes.

Table 3: Simulated scenarios and corresponding parameters

	Sex ratio at birth (urban /rural)	Mean number of non-prostitute partners per year (monogamous/ non-monogamous)	Age difference between spouses	Percentage men who go to prostitutes (monogamous / non-monogamous)	Mean number of contacts with prostitutes per year for men who go to prostitutes (monogamous /non-monogamous)	Percent coital acts with prostitutes condom protected (monogamous/ non-monogamous)
A. Baseline	116.5/121.7	1/2.29	1.8	0.01/37.7	1/1.4	20.6/27.9
B. Absolute monogamy	116.5/121.7	1/1	1.8	0.01/37.7	1/1.4	20.6/27.9
C. Normal sex ratio at birth in 2000 (106)	106/106	1/2.29	1.8	0.01/37.7	1/1.4	20.6/27.9
D. Behavioral adaptation: Relax age differences between spouses (years)	116.5/121.7	1/2.29	5	0.01/37.7	1/1.4	20.6/27.9
E. Behavioral adaptation: Increase contact rates with prostitutes	116.5/121.7	1/2.29	1.8	varies	42.5/44.5	20.6/27.9
F. Behavioral adaptation: 80% condom use with prostitutes	116.5/121.7	1/2.29	1.8	varies	42.5/44.5	80/80

4. Results

Our scenario outcomes, presented separately for the urban and rural populations, include the number of males' desired partnerships unfulfilled and the associated adult HIV prevalence rates. The results are given in tabular form in Tables 4 and 5 and are plotted in Figures 2-4 over a 50-year horizon.

Outcomes of simulated Scenario A based on the baseline parameters consistent with the demographic, behavioral and biological inputs described in Tables 1 and 2 are shown in Figure 2 (solid lines) and the top row of Tables 4 and 5. There are about 20 million partnerships unfulfilled for urban men at the outset of the simulation period (corresponding to the year 2000). This number hovers around 25 million between simulation years 5 and 40 and drops to 18 million in the last decade of the simulation period. Rural men experience a greater number of desired partnerships unfulfilled than urban men. This number is 33 million at the beginning of the simulation period, rises to 35 million by year 40 before it drops to 27 million in the last year of the simulation. In both the urban and rural populations, HIV prevalence rises to just below 1 percent by the middle of the simulation period. These low prevalence rates reflect the low rate of sexual partner change reported in the CHFLS. Yet, CHFLS levels of multiple partnerships for non-monogamous men are enough to keep the HIV prevalence rate close to 1 percent. The starred lines in Figure 2 describe the oversupply of men and associated HIV prevalence curve consistent with Scenario B which simulates conditions of absolute monogamy in which everyone desires only one partner. Relative to the baseline Scenario A, the numbers of desired partnerships unfulfilled in this scenario are significantly smaller in both urban and rural areas. Consistent with the very low rate of partner change of one partner per year, HIV prevalence barely rises above 0. When men desire only one partner, just over 12 million urban men are unable to find partners within their age preference at the outset of the simulation period. The number of unattached men peaks at 15 million around simulation year 40 and then declines to about 11 million by the end of the simulation period (Table 4). A similar pattern is simulated for rural men, although the increasing trend over time is more pronounced and the number of unfulfilled partnerships for males is higher. Here we posit that 18 million rural men are unable to secure partners in 2000 and that this number increases to 25 million around year 40 until, by the last year of the simulation, 19 million rural males are left without partners within the preferred age range. Under this scenario of absolute monogamy, twenty years into the simulation period, we estimated that about 13 million urban men and 20 million rural men between the ages of 18 and 49 would be unable to secure a marital partner (assuming constant age preferences for partners). This estimate agrees with the frequently cited 30 million surplus males projected for 2020 (Hudson and de Boer 2004).

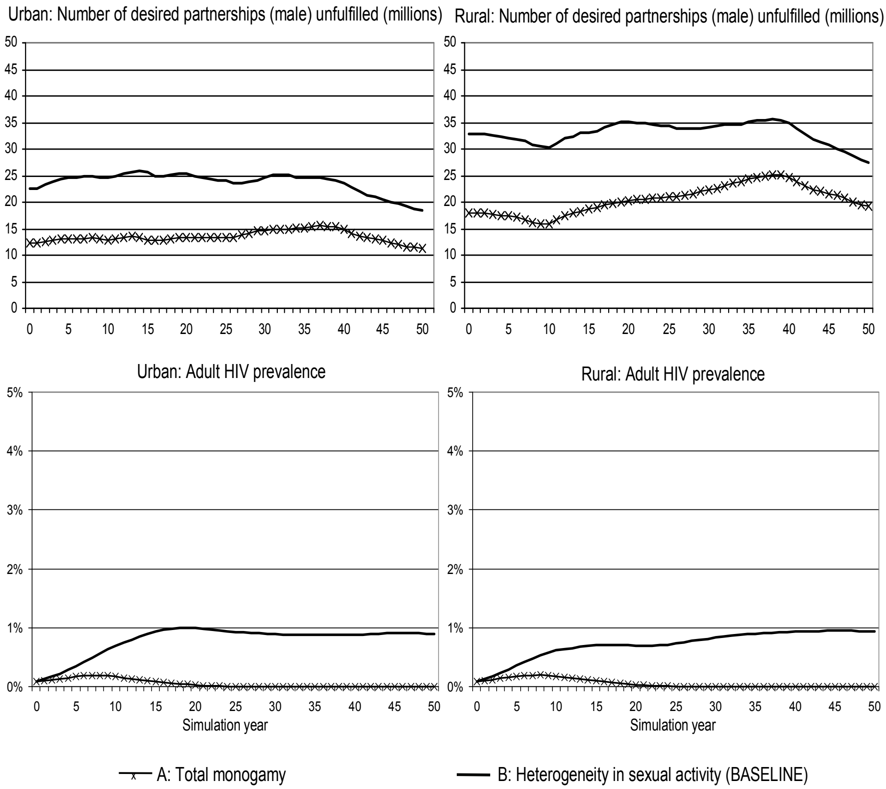
Table 4: Number of unfulfilled male partnerships according to different scenarios by year of projection (millions)

	Year 0		Year 10		Year 20		Year 30		Year 40		Year 50	
	Urban	Rural	Urban	Rural	Urban	Rural	Urban	Rural	Urban	Rural	Urban	Rural
A. Baseline	22.50	32.77	24.71	30.34	25.27	35.13	24.73	34.17	23.66	34.86	18.34	27.32
B. Absolute monogamy	12.36	18.01	12.94	15.99	13.30	20.27	14.73	22.43	14.82	24.52	11.24	19.22
C. Normal sex ratio at birth in 2000 (106)	22.49	32.76	24.68	30.34	25.31	35.10	23.44	30.73	20.08	25.95	13.10	15.01
D. Behavioral adaptation: Relax age differences between spouses (years)	21.92	30.75	23.68	29.43	24.18	33.78	23.83	33.52	21.52	32.36	17.50	26.49
E. Behavioral adaptation: Increase contact rates with prostitutes	22.50	32.77	24.75	30.38	24.83	34.76	23.56	32.69	21.68	32.38	16.74	25.35
F. Behavioral adaptation: 80% condom use with prostitutes	22.50	32.77	24.72	30.34	25.16	35.04	24.55	33.92	23.43	34.54	18.19	27.13

Table 5: Simulated adult HIV prevalence (% aged 18-49) according to different scenarios by year of projection

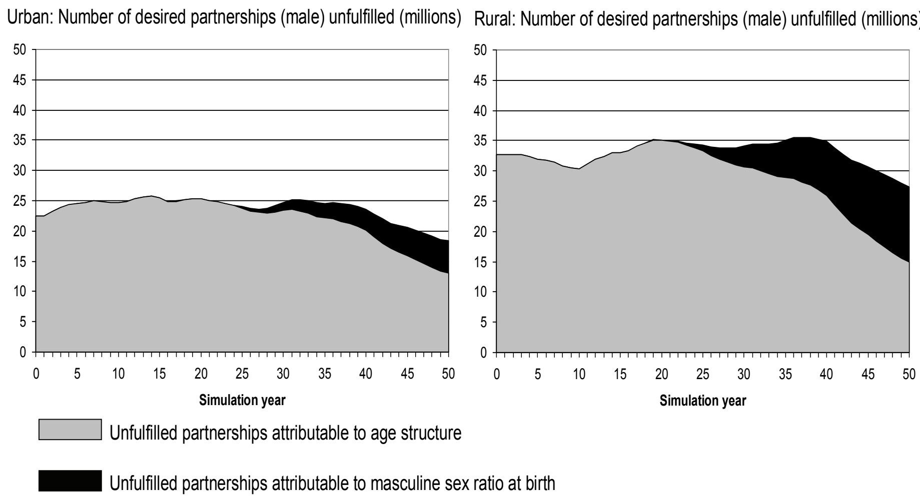
	Year 0		Year 10		Year 20		Year 30		Year 40		Year 50	
	Urban	Rural	Urban	Rural	Urban	Rural	Urban	Rural	Urban	Rural	Urban	Rural
A. Baseline	0.09	0.09	0.62	0.70	0.70	1.00	0.84	0.89	0.93	0.89	0.94	0.90
B. Absolute monogamy	0.09	0.09	0.18	0.17	0.03	0.03	0.00	0.00	0.00	0.00	0.00	0.00
C. Normal sex ratio at birth in 2000 (106)	0.09	0.09	0.81	0.90	0.89	1.24	1.02	1.09	1.16	1.12	1.24	1.24
D. Behavioral adaptation: Relax age differences between spouses (years)	0.09	0.09	0.63	0.73	0.74	1.08	0.89	0.98	1.04	1.06	1.06	1.11
E. Behavioral adaptation: Increase contact rates with prostitutes	0.09	0.09	1.00	1.00	2.25	2.49	3.70	3.79	4.26	4.27	3.82	3.96
F. Behavioral adaptation:80% condom use with prostitutes	0.09	0.09	0.72	0.79	0.97	1.29	1.20	1.31	1.27	1.24	1.19	1.16

Figure 2: Simulated unfulfilled partnerships and adult HIV prevalence under monogamy and heterogeneity in sexual activity



The rural-urban difference in the number of partnerships unfulfilled for males is consistent with differences in demographic conditions between urban and rural areas. In China, where the social norm of male preference for female partners about two years their junior has endured over time and across data sets (Goodkind 2006), the age structure of the population is an important determinant of the sex ratio imbalance in the partnership market. In Figure 3, similar to what was previously noted by Tuljiapurkar et al. (1995) and Goodkind (2006), the age structure of the population largely drives the number of male partnerships unfulfilled, primarily in the first half of the simulation period, while the contribution of the masculine sex ration at birth becomes more important in the second half of the period, especially in rural areas, as those born under the masculine sex ration at birth of 121.7 (Table 1) since 2000 become sexually active.[6] Of the 27.3 million unfulfilled male partnerships in the rural population in the 50th year simulated with baseline inputs (Scenario A), 15 million (55 percent of the total) can be attributed to the age structure (compare Scenario A and Scenario C in Table 4) and the remaining 12.3 million (45 percent) to the masculine sex ration at birth. In urban areas, where the sex ration at birth is lower, of the 18.3 million unfulfilled male partnerships, 13.1 million (71 percent) are attributable to the age structure while only 5.2 million (29 percent) can be attributed to the masculine sex ratio at birth.

Figure 3: Contribution of age structure and masculine sex ratio at birth to the simulated number of unfulfilled partnerships

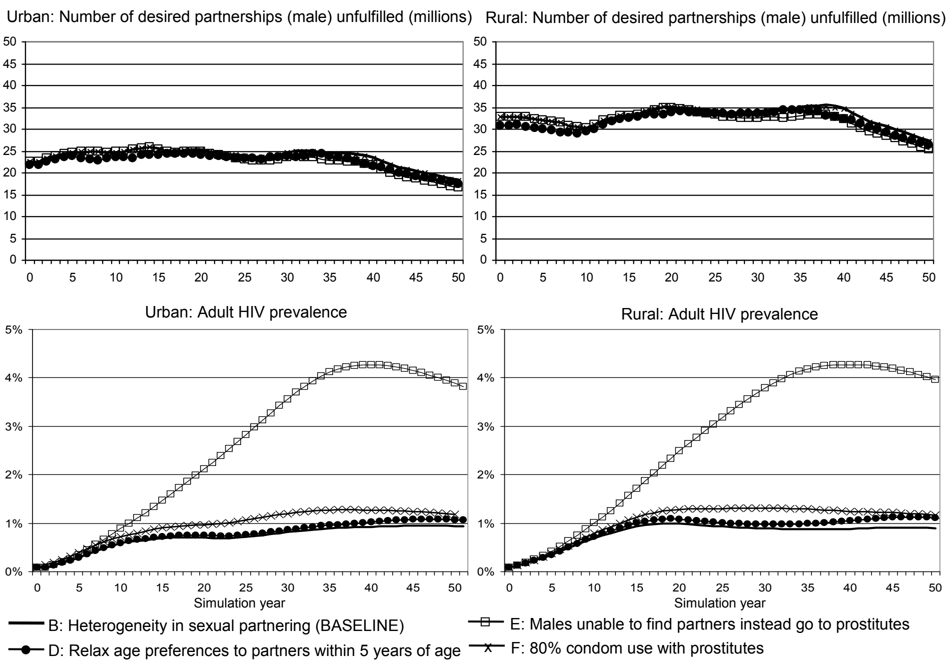


In Figure 4 we considered the implications of potential adaptive behaviors adopted by men who are unable to attain their desired number of regular female partners. Consistent with the experience of other countries where the marriage market adapted to imbalances in the sex structure with a relaxation in age preferences between partners (Bhrolcháin 2001), scenario D describes the consequences of allowing men to increase

[6] This decomposition assumes no abnormally masculine sex ration at birth before 2000. Sex ratios at birth, however, started rising in China in the late 1980s. Thus the contribution of the age structure to the oversupply of men in the partnership market is overestimated at least by the fraction attributable to the higher than normal sex ration at birth between the late-1980s and 2000, a period which saw a rise in the sex ration at birth from its biologically normal value of 106 to 116.9, as reported in the 2000 census short form.

their available pool of female partners by relaxing their age preferences and seeking partners up to five years their junior (as opposed to an average of two years in baseline scenario A). Because the dearth of suitable female partners is severe, relaxing norms about age differences between partners only yields small declines in the number of desired male partnerships unfulfilled in both rural and urban areas, ranging from a difference of half a million to a difference of 2 million fewer partnerships unfulfilled in urban areas and from less than half a million to 2.5 million in rural areas. Age differences between partners have also been shown to have an effect on the dynamics of the epidemic because they facilitate the intergenerational chain of HIV transmission (Anderson 1992; Palloni 1996; Morris 1997). Yet the rise in HIV prevalence simulated under relaxed age preferences for partners is very small, from just below 1 percent to just above 1 percent, and is due to increased exposure to HIV infection implied by the higher number of fulfilled partnerships in Scenario D.

Figure 4: Simulated unfulfilled partnerships and adult HIV prevalence with behavioral adaptations



Scenario E in Figure 4 simulates the spread of HIV if surplus men unable to attain their desired number of regular partnerships replaced those forgone partnerships with prostitute partners. Under this scenario, men have sex with prostitutes with half the frequency as with non-prostitute partners and the proportion of their condom protected contacts with prostitutes is twice that with regular partners. Simulated HIV prevalence is highly sensitive to the adoption of this risky behavior. The greater percentage of men seeking contacts with prostitutes associated with changes in the simulated fraction of men with desired partnerships unfulfilled in each simulation cycle (because in this scenario men unable to find a regular partner turn to prostitutes instead), combined with a much higher frequency of annual contacts with prostitutes (42.5/44.5), indicates the potential for an explosive epidemic in both the urban and rural populations. Scenario F evaluates the impact of an exogenous policy intervention aimed at increasing the frequency of condom use in sexual acts with prostitutes. This scenario assumes that such a program would lead to the use of condoms in 80 percent of sexual acts between prostitutes and their patrons, with 80 percent effectiveness. This figure is in line with the program for 100-per-cent condom use implemented by the Thai Ministry of Health in the early 1990s (Rojanapithayakorn and Hanenberg 1996). A major decline in the size of the epidemic is seen with this policy intervention, even with high levels of male patronage of commercial sex and frequent contacts with prostitutes. The epidemic is cut to about one fourth of that simulated in the absence of any targeted intervention, close to its size prior to the adoption by surplus males of risky behaviors in response to the deficit of female partners.

5. Summary and discussion

Although injected-drug use and contaminated blood products have been until recently the major drivers of HIV transmission in China, heterosexual transmission is contributing an increasingly important share of infections (recently accounting for up to 50% of new infections). An assessment of conditions that may put an increasing fraction of individuals at risk of HIV infection through heterosexual transmission is timely.

China’s recent demographic history is characterized by a very rapid fertility transition to below replacement fertility and by increasingly masculine sex ratios at birth. These factors combine to produce a growing age-sex imbalance in the adult population, giving rise to concerns about the ensuing squeeze in the marriage and sexual partnership markets, further exacerbated by an enduring cultural preference that men partner with younger women. These unique demographic features, by conditioning the adult population composition in terms of sex and age, may raise the proportion of people who engage in sexual behaviors that place an increasing proportion of the population at risk for HIV infection, such as multiple sexual partnerships and patronage of prostitution.

We have employed a mathematical simulation model that unites a population projection with an epidemiological model of HIV transmission to concurrently represent three related processes over time: population change, the sexual partnership market, and the HIV epidemic. Model parameters were extracted from diverse data sets including China's most recent census completed in 2000 and the CHFLS. By utilizing inputs specific to the Chinese context in a macrosimulation model describing the heterosexual spread of HIV in a population, we were able to evaluate the effects of China's macro-demographic conditions on the marriage and sexual partnership markets, and their implications for the adoption of sexual behaviors associated with HIV transmission and spread.

Our simulations have shown that a substantial number of sexual partnerships desired by men remain unfulfilled as a consequence of both the masculine sex ratios at birth and the population age structure. When combined with normative partnering of males with female partners on average two years their junior, the latter implies an increasingly restrictive sexual partnership market that penalizes men as they choose younger female partners from cohorts smaller than their own. Our results attributed much of the surplus male phenomenon to the population age structure. This implies that severe male deficits will be unavoidable in China even with a hypothetical normalization of the sex ration at birth after 2000. Also, allowing men to partner with younger women will provide only few additional partnering options for men. Our simulations suggested that the magnitude of the age-sex distortion in China's adult population leaves little room to fulfill partnerships by choosing partners from among a broader range of age groups. Hence changes in preferences for age difference between partners which have proven effective in relaxing the marriage squeeze at other times in other societies are not likely to be effective in China. Similarly, while large age differences between partners have been associated with severe HIV epidemics elsewhere, increases in the age difference between partners is unlikely to fuel the spread of HIV in China. However, to the extent that surplus males adapt to the dearth of suitable female partners by seeking contacts with female sex workers, the impact of China's oversupply of adult males on the spread of HIV will be severe. Simulations confirm that the progression of HIV in the population is highly sensitive to increases in the fraction of men who patronize commercial sex combined with a high frequency of unprotected sexual contacts with female sex workers. Protective behaviors associated with higher frequency of condom use with prostitutes have the potential to offset the negative effects of this particularly dangerous behavioral adaptation to the dearth of suitable female partners.

Our results illustrate the implications of demographic imbalances unique to the Chinese context for the potential spread of HIV in China. They are not meant to be predictive of the future of HIV prevalence in the world's largest population. Although the mathematical model we employ is a useful tool to concurrently describe the process of population change, the sexual partnership market, and the spread of HIV over time, the model and the data which inform its parameters have several limitations. First, simulation outcomes are very sensitive to the assumptions considered, first among which is the level of sexual activity. The CHFLS may understate the level of sexual activity owing to an understatement of stigmatized behavior, a feature generally common to surveys of sexual behavior, especially among women (Buvé et al. 2001; Mensch, Hewett, and Erulkar 2003; Curtis and Sutherland 2004). In previous work we have shown the sensitivity of simulated HIV prevalence to changes in the levels of sexual activity, with a larger epidemic produced by a hypothetical higher rate of partner change consistent with levels of sexual activity observed in the U.S., which are higher than those in China (Merli et al. 2006). But understated levels of sexual activity also have implications for the simulated number of unfulfilled partnerships. If, for example, Chinese women are more likely than their male counterparts to understate the number of their regular partners, which, in our model, represent the number of desired male partners, the number of males' desired partnerships unfulfilled will be overestimated. In our behavioral adaptation scenario where men replace their forgone regular partnerships with prostitutes, this would imply that the effect of age-sex demographic imbalances on the spread of HIV will be overestimated.

Second, the model suffers from the limitations characteristic of a macrosimulation model. All partnerships are formed anew each year as reflected in the aggregate sizes of the population subgroups and the numbers of desired partnerships fulfilled. Thus, unlike a microsimulation which follows a partnership formed between two individuals through their lives and enables one to realistically carry over the partnership squeeze through successive cohorts, a macrosimulation model which deals only with groups and proportions simply enables us to compare the number of partnerships men would like to have to the number of partnerships made available by women in a given year.

Third, our treatment of the prostitute population is perhaps the least realistic feature of the model. With the current model structure and specifications, we are not able to represent the process of population renewal and the cycling of women out of this population. The model also restricts female sex workers' partnering behavior to commercial sex partners. In the real world of female sex work in China, some women work as prostitutes for only a limited period of time, others cycle in and out of prostitution as their economic circumstances change, and their sexual lives are often characterized by concurrent relationships with paying clients and regular male partners (Merli et al. 2008, Xia and Yang 2005). While we recognize that this is an unrealistic representation of the lives of these women, we do not yet have a set of rules and appropriate empirical data that will allow us to realistically depict the often temporary, cyclical nature of prostitution in women's lives, or their sexual relationships with different types of partners.

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