Demographic shifts and the spread of HIV in China

Sara Hertog
shertog@ssc.wisc.edu

M. Giovanna Merli
gmerli@ssc.wisc.edu

Department of Sociology and Center for Demography and Ecology

University of Wisconsin, Madison

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Introduction

An estimated 650,000 people are currently living with HIV/AIDS in China and the number of infections is expected to rise in the coming years as the virus spreads to previously unaffected risk groups. While China's HIV epidemic first took root among injecting drug users (IDU) and commercial plasma donors, heterosexual contact is an increasingly important mode of transmission. IDU and former commercial blood and plasma donors currently contribute about 55% of all infections, while 44% of infections are among sex workers, their clients and partners of HIV-infected individuals. In 2005, 49% of new HIV infections were believed to be the result of heterosexual contact (China Ministry of Health and UNAIDS 2006), fuelling existing concern that HIV will become an endemic disease in China sustained by heterosexual transmission (Brady et al. 2001; Kaufman and Jing 2002; UN Team Group on HIV/AIDS in China 2002).

The extent to which HIV will spread via heterosexual transmission in China, the world's largest population, depends highly on the level and distribution of sexual activity there. Merli, Hertog, Wang and Li (2006) used a macrosimulation model to explore the implications of the observed regime of sexual relations for the spread of HIV in China. To represent the level and distribution of sexual activity, they drew relevant behavioral input parameters from the first sexual behavior survey ever conducted using a probability sample of the Chinese population, the Chinese Health and Family Life Survey (Parish et al. 2003). Similar to the findings from other studies that have utilized mathematical models to project the spread of HIV (May and Anderson 1987; Hyman and Stanley 1988; Anderson, Gupta and Ng 1990; Anderson 1992a), Merli and colleagues identified the rate of sexual partner change, fraction of the population with multiple partners, patterns of sexual mixing between risk groups, patronage of commercial sex, and the average per-coitus HIV transmission probabilities as crucial determinants of the size and shape of the epidemic. In addition, their results suggest that levels of sexual activity must cross a certain threshold for a given input parameter to have a sizeable impact on the simulated epidemic curve and this threshold becomes somewhat easier to cross when a small degree of mixing is allowed between high-activity and low-activity groups. Hertog (forthcoming) confirms this interaction between rate of partner change and patterns of sexual mixing by showing that at low levels of partner change, assortative mixing, when sexual contacts between groups are rare and infections remain concentrated among the most sexually active group, may contribute to a higher reproductive rate of infection and a greater prevalence overall, while at the same level of sexual activity, disassortative, or "random" mixing, fails to sustain an epidemic through sexual transmission. Merli and colleagues conclude that in China, the overall levels of sexual activity identified by the rate of partner change and the fraction of the population with multiple sexual partners would have to be significantly higher than those *reported* in the CHFLS for the model to predict HIV prevalence driven by heterosexual transmission above 1% at any time during the 50-year simulation period.

Does this suggest that fears of a generalized HIV epidemic driven by heterosexual transmission in China are misplaced? Two observations suggest that it is incorrect to accept this statement. First, it is possible that levels of sexual activity in the Chinese population are higher than those reported in the CHFLS. Underreporting of stigmatized behavior is a feature common to all surveys of sexual activity, especially among women (Buve´ et al. 2001; Mensch et al. 2003; Curtis and Sutherland 2004). Second, one must not ignore the potential for increasing sexual activity and widespread adoption of high-risk behaviors, given ongoing transformations in sexual norms and behaviors that accompany China's rapid pace of social and economic change.

The Chinese state's retreat from many realms of economic and social life as well as China's opening towards a more liberal model under Western and Japanese influence are evident in leisure pursuits, the media, travel, consumerism, personal contacts, and the availability of new social spaces. These changing conditions are transforming norms about relationships and sexual lives and are giving rise to multiple forms of sexual relationships (Farrer 2002; Sigley and Jeffreys 1999) with important implications for the adoption of risk behaviors and the spread of sexually transmitted diseases (STDs). That a growing number of people are engaging in risky sexual behaviors is suggested by soaring STD prevalence (Chen et al. 2000; Cohen et al. 2000; Gong et al. 2002; Chen et al. 2007). Following the virtual eradication of STDs under Mao, today China reports a nationwide primary and secondary syphilis incidence of 5.67 cases per 100,000 that is substantially higher than the 2.7 cases per 100,000 in the U.S. (Chen et al. 2007). Similarly, an analysis of CHFLS data on Chlamydia infection estimated prevalence in China that is as high as or higher than among the urban populations of developed countries (Parish et al. 2003).

Given the increasing role of sexual behavior in the transmission of HIV in China, two types of demographic shifts have been identified as particularly relevant for the spread of infection: the increasingly masculine imbalance in the sex ratio at birth and the massive internal migration flows seen in China, especially since the early 1990s. Both demographic phenomena are expected to produce an oversupply of men relative to women in the marriage and partnership markets. Owing to their inability to find a suitable female partner, unattached males are expected to add to the share of those who display risky sexual behaviors, namely multiple partnerships and patronage of commercial sex, behaviors which may expose them to the risk of HIV infection and bring HIV to previously unexposed populations.

In this paper, we implement a bio-behavioral macrosimulation model of the spread of HIV to first assess the extent of the oversupply of males in the partnership market and then to examine potential consequences of these sex ratio imbalances for the adoption of high risk behaviors. We simulate a range of possible HIV prevalence outcomes consistent with behavioral adaptations to changes in the availability of partners associated with both imbalances in the sex ratio at birth and rural-to-urban migration flows. Baseline behavioral inputs are drawn primarily from the Chinese Health and Family Life Survey (CHFLS), while potential behavioral adaptations to these demographic shifts are informed by hypotheses elaborated in the literature.

Do masculine sex ratios and the experience of migration condition sexual behavior?

The numerical imbalance in the sex ratio of the adult population is a function of the sex ratio at birth, the relative survival of males and females in each cohort, sex differences in migration and, in the presence of social norms regarding age differences between partners, the age structure of the population (Tuljiapurkar et al. 1995; Guillot 2000; Goodkind 2006). In China, surplus males in the partnership market refer to the excess males relative to females in the adult population given male preferences for younger female partners in a population which has experienced a continuous decline in fertility.

This oversupply of males is exacerbated by the increasing trends in the sex ratio at birth and the massive internal migration flows that have engulfed China since the early 1990s.

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 a 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 fetus'sex in utero, and by underreporting of daughters in censuses and surveys (Zeng et al. 1993; Cai and Lavely 2003). The sex ratio at birth recorded in China's 2000 population census was 116.9 (Banister 2004), a rise from 107.6 in 1982 and 111 in 1990.

Today and in the coming decades, the children born into cohorts with imbalanced sex ratios are reaching adulthood, initiating sexual activity and marrying. 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 109 men for every 100 women by 2030 (United Nations 2004). In the presence of social norms that males be older than their female partners, this rising imbalance is expected to alter the market for sexual partners and produce a shortage of suitable female partners. Given that Chinese tend to marry partners within five years of age to their own, it has been estimated that the imbalance in the sex ratio at birth in the 1990 census would result in a surplus one million men unable to find wives annually after the year 2010 (Tuljapurkar, Li and Feldman 1995). Hudson and den Boer (2004:176) surmise that by

2020 China will be the home to between 29 and 33 million surplus males between the ages of 15 and 34, accounting for between 14 and 16 percent of the total male population in that age range (our calculations based on U.S. Census Bureau projected number of 15-34 males in China in 2020).

Conditions of male surplus in China have drawn the attention of academics and the media alike. The media, in particular, are prone to accept such general statements as "unbalanced numbers inexorably produce unbalanced behaviors" (cited in Thomson 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 an oversupply of males will condition sexual behavior. These discussions generally infer that an increasing number of men who would otherwise marry but are unable to do so due to a dearth of suitable female partners will resort to high-risk sexual activities, such as patronage of commercial sex, multiple casual partnerships, or they may search partners among increasingly younger pools of women (Tucker et al. 2005; Hudson and den Boer 2004; Hesketh and Zhu 2006). These contemporary concerns echo claims of Chinese social reformers of the early 1930s, who maintained that masculine sex ratios in Shanghai pushed up the demand for, patronage and supply of commercial sex. At that time, Shanghai exhibited population sex ratios of 135, 156 and 164 males per 100 females respectively in the Chinese-run sector of the city, the international settlement and the French concession and an estimated 100,000 prostitutes amounting to one in 13 women (Hershatter 1997: 40).

The second demographic shift widely regarded as relevant for the spread of HIV in China is the massive flow of labor migration from the countryside to Chinese cities and towns. According to the 2000 census, there were 79 million floating migrants (i.e. those without a legal permanent household registration) in China,[1] which is double the size estimated in 1995 and four times that of 1990 (Liang and Ma 2004). The official estimate of China's rural migrants in urban areas in 2003 was 140 million, equivalent to 30% of the rural labor force (Huang and Zhang 2005). Mainly a result of the well established association between mobility and the spread of HIV in other societies (Hunt 1989; Pison et al. 1993; Nunn et al. 1995; Lurie et al. 1997), Chinese rural migrants have often been identified as a source of social ills and as bridges of HIV infection between the urban and rural populations (Hong et al. 2006; Tucker et al. 2005; Anderson et al. 2003; du Guerny et al. 2003; Bates et al. 2002; Kaufman and Jing 2002; Zhang and Ma 2002; Tucker et al. 2005). Surplus males are often identified as migrants, and their risky behaviors linked to the unavailability of suitable female partners (Tucker et al. 2005). Attributed partly to experiences of social exclusion, long separations from their families and institutional barriers which keep them in a position of second class citizens within the host cities (Solinger 1999), upon arrival to the urban destinations, rural migrants, most of them unmarried, are expected to adopt risky sexual behaviors. These contemporary descriptions do not differ greatly from the social historians' narratives of Chinese immigration to America in the 19th and early 20th centuries and of the American frontiers in the latter half of the 19th century, though the masculinity of the sex ratios were much more extreme than those observed and projected in contemporary China. These masculine sex ratios among Chinese immigrants to the U.S. -- the U.S. census of 1890 reported 102,620 Chinese men and 3,868 Chinese women-- or sex ratios of 125 or higher

[1] This figure excludes those who have migrated to their place of current residence within 6 months prior to the census (Liang and Ma 2004).

in the American frontiers were inevitably linked to the establishment of prostitution, the high density of brothels in the Chinatowns of American cities (Lyman 1968) and the ubiquity of prostitutes in the American far west. In Virginia City, Nevada in 1870, one of every 50 residents was a prostitute. In 1880 Leadville, Colorado there was one brothel each 148 inhabitants (cited in Courtwright, 1991:474).

Studies of Chinese rural migrants' adaptations as a means of coping with the experience of social isolation have posited multiple sexual partnerships, patronage of commercial sex (Tucker et al. 2005), especially among the most mobile migrants (Li et al. 2004), injecting drug use (Yang, Derlega and Luo 2005), and a higher vulnerability to STD infection (Li et al. 2004; Yang 2005) compared to non-migrants. However, the empirical record regarding the link between migration and risk behaviors is mixed. Available evidence is not sufficient to establish whether migrants adopt sexual behaviors that put them at risk of HIV and STD infection after reaching their destination. According to data from the CHFLS, male migrants to urban areas show levels of risky sexual activity that are only marginally higher than those displayed by non-migrants (Parish et al. 2003). Of 986 sexually active male migrants recruited from venues employing migrants in Shanghai, 11.5 percent reported ever having sex with a commercial sex worker but only 3.2 percent reported engaging in commercial sex since migration to Shanghai (He et al. 2006). A study of migrant and urban workers in Eastern China failed to find any significant difference in the prevalence of syphilis (Hesketh et al. 2005). While in a large population-based sample in Southwest China, Yang et al. (2005) found that migrants had a significantly higher prevalence of HIV-related risk behaviors than non-migrants, both sexual and drug using, no difference was found between migrants and non-migrants in prevalence of HIV/STDs. More recent analyses of this population based sample in Southwest China (Yang and Xia 2006) have revealed that the difference in prevalence of risk behaviors between migrant and non migrants in Southwest China is due to a disproportionately higher prevalence of casual and commercial sex among female migrants, compared to both non-migrants and male migrants. The higher prevalence of these risk behaviors among female migrants is explained by their disproportionate representation in the service sector, especially entertainment establishments, an occupation which puts them at higher risk of engaging in commercial sex.

Most studies of Chinese migrants' sexual behavior do not rely on research designs that enable the actual measurement of changes in sexual behavior accompanying migration or suitable comparisons which address issues of selection of migrants with respect to sexual behavior. A recent study appropriately designed to study changes in sexual behavior through a survey of Mexican migrants at origin and destination in the U.S. illustrates significant changes in sexual behaviors accompanying migration with marked differences by gender and marital status. For men, sexual practices such as patronage of commercial sex workers and secondary partnerships increased significantly with migration. Among single women, migration facilitated the formation of short term relationships (Parrado and Flippen 2006).

From our brief review of historical and contemporary cases of male surpluses in China and other societies, it is clear that, despite claims that the predominance of unattached men increases the demand and patronage for commercial sex and other risky behaviors, the link is subsumed from circumstantial evidence and one cannot definitively establish whether sex imbalances in fact condition sexual behaviors.

With this review we have identified some common assumptions about conditions of male surpluses. The first posits that surplus males unable to locate a female partner are the product of imbalances in the sex ratio at birth combined with cultural norms that males be older than their female partners. The second anticipates behavioral accommodations to the dearth of suitable female partners. For example, surplus males in search of a partner may turn to younger pools of women or they may patronize prostitutes as a replacement for regular partners. Finally, migration is expected to contribute to the male surplus in local populations as male migrants add to the pools of surplus males at destination. As an adaptive response to the dearth of suitable partners and to cope with the experience of social exclusion, migrants are expected to adopt high risk behaviors such as multiple casual partnerships and commercial sex.

This review has failed to accomplish two tasks that we hoped would provide some empirical grounding to our simulations. First we were unable to quantify a range of sexual behavior adaptations associated with various degrees of imbalance in sex ratios. Second, we could not identify a precise ratio at which we may expect those behavioral adaptations to manifest. In the absence of an empirical basis to inform the simulated scenarios, we have chosen to explore the behavioral adaptations hypothesized in the literature and to translate these hypotheses into inputs driving simulations of the heterosexual spread of HIV. We aim to assess the potential influence of those hypothesized behavioral adaptations on the distribution of risky sexual behaviors in China and on the heterosexual spread of HIV.

Empirical data: Sexual behavior in China

To implement our model of the spread of HIV, we use data from the Chinese Health and Family Life Survey (CHFLS), the first population based nationally representative cross-sectional survey of 20-64 year olds ever conducted in China. The CHFLS was conducted between August 1999 and August 2000 by a team of researchers at the University of Chicago, People's University of China in Beijing and the University of North Carolina, Chapel Hill. Respondents were sampled from registers of households and temporary migrants held by urban neighborhoods and rural townships. After being administered a questionnaire covering numerous aspects of their sexual lives, survey participants were asked to provide a urine sample to test for gonorrhea and chlamydia infection. Of the 5,000 individuals who were initially selected, 3,821 completed the interview, yielding a response rate of 76 per cent, and 3,426 provided a urine sample yielding an overall participation rate of 69 per cent. Although these figures are low for China, where response rates in social and public opinion surveys were, until recently, remarkably high (Shi 1996), they are comparable to response rates achieved by the National Health and Social Life Survey (NHSLS) in the U.S. (Laumann et al. 1994) and the National Survey of Sexual Attitudes and Lifestyles in the U.K. (NATSAL 2000) (Johnson et al. 2001). Our description of Chinese sexual behavior relies on the subset of 3,821 respondents who completed the interview. Participant and data losses reflect recent problematic aspects of doing survey research in China associated with the rapid pace of socioeconomic transformations, especially in urban areas (Treiman et al. 2005).[2]

Due to the sensitive nature of most sections of the survey and to preserve confidentiality of responses, most of the questionnaire was administered by audio-computer and interviews were conducted away from the respondent's home. Evaluation of agreement on selected sexual behavior items reported by 50 husband-wife pairs and 50 respondents who were interviewed twice at an interval of two months yielded moderate to high agreement scores (Parish et al. 2003).

Model Structure

For the purposes of these analyses, we have modified an existing bio-behavioral macrosimulation model, first developed by Palloni and Lamas (1991). It is essentially a two-sex cohort component population projection designed simulate the effect of various biological and behavioral risk factors on the heterosexual spread of HIV.

Modeling begins with the creation of five distinct populations. First, the populations of urban males, urban females, rural males and rural females are defined according to sex-specific age distributions for rural and urban areas respectively. Next,

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[2] Losses include (1) those who refused to be interviewed (897); (2) those who did not provide a urine sample (340); and (3) those for whom data were not obtained (337) (Parish et al. 2003: 1267). Although no information is provided on the characteristics of the first group, we know more about the latter two groups. In the second group, those who did not provide a urine samples were only marginally different from those who did and rural respondents were more likely to give urine samples than their urban counterparts (Parish et al. 2003:1267). The third group is comprised mostly of men and some women in their early 20s who had left their place of residence and could not be located by interviewers (Parish et al. 2003: 1272). The study also suffered from incomplete enumerations of rural migrants in urban areas who were not registered in the official registration lists of migrants (Parish et al. 2003:1272).

the model defines a given fraction of the urban female population as prostitutes, who do not have regular non-commercial partners, but with whom men may seek contact in addition to their relationships with non-prostitute partners. After those five populations have been defined, the model allocates males and non prostitute females into homogenous "sexual activity classes" defined by the number of non-prostitute partners acquired in a year. For the purpose of assessing the impact of potential sexual behavioral adaptations to imbalances in the sex ratio of the population, we consider only two sexual activity groups, monogamous and non-monogamous. In our model both monogamous and non-monogamous men can form a partnership with prostitutes.

These various population subgroups defined by urban/rural residence, sex, age, and sexual activity class are simulated as they transition through three disease related states (Healthy, HIV-infected but asymptomatic, and symptomatic AIDS) and from these states to death (Figure 1). 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).

The biological and behavioral factors underlying the heterosexual spread of HIV act primarily through their influence on the rate of transition from the Healthy state to the HIV-Infected but asymptomatic state, denoted λ_1 in Figure 1. When heterosexual transmission is the sole route of HIV spread, λ_1 is a function of the proportion of infected individuals in each sexual activity class, the sexual activity of each class (the rate of sexual partner change, coital frequency and contacts with prostitutes), as well as the probability of infection per coital act (determined by the distribution of the HIV-infected population by duration of infection, prevalence of co-morbidities that enhance infectiousness of HIV and/or susceptibility to HIV infection, and condom use) and the degree of sexual mixing between partners of different ages and between members of the two sexual activity classes. Infection occurs as a result of multiple sexual acts each carrying a constant probability of infection from the infected to the uninfected partner. To account for changes in infectiousness associated with HIV progression, those in the HIV and AIDS states are further subdivided according to duration (years) since infection.

In addition to their transition through the various disease-related states, some fraction of non-prostitute urban females will enter into prostitution with each projection cycle. The shape of this probability distribution is pulled from a Coale-McNeil marriage function and the proportion of a female cohort who will eventually become prostitutes 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. While we recognize that this is an unrealistic representation of the lives of women who have sold sex – some women will work as prostitutes for only a limited period of time, while others will cycle in and out of prostitution as their economic circumstances change – we do not yet have a set of rules that will allow us to realistically depict the cyclical nature of prostitution.

Population renewal occurs with each new projection cycle when new entrants (births) are allocated into sexual activity classes according to the distribution specified at the outset, and does not take into consideration tastes and preferences of parental generations.

Model inputs

Demographic inputs

The demographic inputs driving the simulations are presented in Table 1. The initial population for the simulations is defined according to the age and sex-specific population distributions in China's rural and urban areas as enumerated in the 2000 Census. There were 1.24 billion inhabitants enumerated in China's 2000 national population census. Sixty-three percent resided in rural areas, while the remaining 37% lived in China's cities and urban towns, which we have combined to comprise the "urban" population in the simulation model.

Demographic rates, including fertility and age- and sex-specific mortality are assumed constant throughout the simulation period and are based on the *unadjusted* population data in the 2000 census. Our decision not to adjust the 2000 census data could be easily disputed. China's total fertility rate (TFR) recorded in the 2000 census (short form) of 1.35 children per woman (it is 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 (refs). These adjustments generally account for the number of children underreported in the census, especially female children, as a consequence of policies that hold family planning officials responsible for achieving pre-set targets and quotas in their jurisdiction (Goodkind 2004; Merli, Qian and Smith 2004; Merli and Raftery 2000). An adjustment of the TFR would also imply 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 births is greater relative to male births. Goodkind's adjustment of the 2000 SRB brought it down to 114 (Goodkind and West 2007), in line with a larger number of underreported, but not missing, female births than male births. Because of the wide range of adjustment procedures and the assumptions underlying them 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 for the time being, is to accept the unadjusted census figures as the baseline. We are of course aware that an underreported TFR in 2000 will affect the size of the cohorts of marriageable age 20 years later. Most relevant to our analysis, because of the underreported TFR, we may 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. Concerns of overestimation of the SRB are alleviated by the fact that our projections use values of SRB held constant at the 2000, a conservative assumption given recent trends of increasing sex ratios.

We thus 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, and an age schedule of sexual debut drawn from the CHFLS.[3] We assume an enduring social norm that males be 1.8 years older than their female partners on average, according to the age differences between sexual partners reported in the CHFLS. This gap is generally consistent with the average age difference between partners indicated by the singulate mean age at marriage in 1999 of 24.8 years for men and 23.1 years of age for women (United Nations World Population Database).

[3] 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. But the projected availability of sexual partners is also empirically derived. It reflects therefore 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 et al. (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.

We simulate population movement between rural and urban areas driven by the annual rural-to-urban and urban-to-rural migration rates approximated based on migrants enumerated in the 2000 census. These rates were calculated by dividing the migration flows as reported in Liang and Ma (Table 3, 2004) by the total population in the origin region. In the five years leading up to the 2000 census, approximately 0.89% of the total urban (city and town) population migrated annually to a rural area, while 0.52% of the total rural population migrated to an urban location each year. The age and sex distribution of migrants corresponds to that reported in the 2000 census microdata as presented by Liang and Ma (Table 4, 2004). Approximately 48% of migrants (both permanent and floating population) are female and, while both male and female migrants are between the ages of 15 and 29, male migrants were older than female migrants on average.

We set the proportion of prostitutes in the population of urban women equal to 2 percent, based on an estimated 6 million prostitutes ages 15-39 (Horizon Market Research and Futures Group Europe 2002b; Yuan et al. 2002) and on the age distribution of the female population from China's 2000 census.

Behavioral inputs

The sexual behavioral inputs are drawn primarily from the CHFLS (Table 2). 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 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 belong to the non-monogamous class. 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 was more frequent when the number of partners was high, which is consistent with more frequent condom use with non-regular partners than with regular partners.

Commercial sex was very uncommon among monogamous men in the CHFLS, with only 0.01% of monogamous men reporting a prostitute partner in the year leading up to the survey. Among non-monogamous 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, we instead 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.

Biological inputs

The biological inputs which drive the simulations are shown in the lower section of Table 2. At the outset of the simulation, we seed the Chinese population with 650,000 HIV cases of infection according to the age distribution of HIV cases recorded for the Thai population. This is the number corresponding to the most recent estimates for China, equivalent to an adult prevalence rate of 0.1%. The population of prostitutes is also seeded with HIV according to the same low HIV prevalence. Except for the very small fraction infected, everybody else begins the simulation period with no HIV and is introduced to the risk of infection during the simulation period 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 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). We posited 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). Condom use and condom efficiency protect against HIV and STDs by reducing infectivity per sexual act (Saracco et al. 1993; Seidlin et al. 1993; Ahmed et al. 2001).

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 by the CHFLS (Table 2), 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, each group was assigned a unique chlamydia prevalence figure estimated from the CHFLS and assumed constant thereafter. 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 proportional mixing between those infected with chlamydia and those not infected. 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 prevalence among partners, and the chlamydia infectivity cofactor. For example, a man with both chlamydia and a recent infection with HIV would have a probability per coital act of transmitting HIV to his female partner of 1 per cent (0.0015 x 3 x 2.25 = 0.010125), where 2.25 is the chlamydia infectivity cofactor and 3 reflects the triple infectiousness of HIV associated with a higher viral load in the first year after seroconversion. If his partner also had chlamydia, her probability of seroconversion per coital act would rise to 2.3 per cent (0.010125 x 2.25 = 0.02278). Similar calculations are presented in Bracher et al. per coital act 2003.

Scenarios

The top panels of Figures 2 through 5 show the simulated percentage of males' desired partnerships unfulfilled for 50 year horizons under several demographic scenarios. The bottom panels show HIV prevalence curves consistent with the combination of demographic, biological and behavioral inputs we have discussed but also with hypothesized behavioral adaptations of the simulated number of males who find themselves without desired sexual partnerships. Scenarios are presented separately for the urban and rural population. The first scenario simulates a very constrained population. This is a population in which everybody is monogamous. The factors determining the availability of female partners in the partnership market in this context will be the sex ratio at birth, the relative survival of males and females and the differences in age preferences for partners held by males and females. Because of this difference, the age structure of the population is a major determinant of the balance of the sexes in the partnership market. Simulation results for this scenario are marked "A: Total monogamy" and are represented by the dark purple lines. Fewer than ten percent of urban men are unable to find partners within their age preference at the outset of the simulation period (corresponding to the year 2000). Because the legacy of imbalanced sex ratios at birth was only beginning to be felt in the year 2000, the percent of urban men unable to find a partner increases over the course of the simulation period, peaking at 17.1 percent in simulation year 40 and then declining to around 16 percent by the 50th simulation year. A similar pattern is simulated among rural men seeking a single partnership, although the increasing trend over time is more pronounced due to the higher SRB observed in China's rural population. Here we simulate that 8 percent of rural men are unable to secure partners in 2000 and this percentage increases to near 18 percent of rural males without suitable partners at the end of the 50 year period.

In terms of absolute numbers of males unable to secure partners, for scenario A "Total monogamy", we simulate that 12.4 million urban men and 15.9 million rural men between the ages of 20 and 49 are unable to locate a partner at the outset (year 2000). By the 50th simulation year, 8.1 million urban men and 22.3 million rural men are without partners. Twenty years into the simulation period, we estimate that 11.2 million urban men and 20.0 million rural men between the ages of 20 and 49 would be unable to secure a marital partner (assuming constant age preferences for partners). These results are consistent with the often cited 30 million surplus males in 2020 (Hudson and den Boer 2004).

Simulated adult HIV prevalence associated with scenario A remains quite low over the course of the 50-year simulation period, below three tenths of one percent in both the urban and rural populations. This reflects the low rate of sexual partner change that results when only one single regular partnership per individual is considered.

It is unrealistic to think that all regular sexual partnerships are monogamous partnerships. Indeed, data from the CHFLS indicate that a small proportion of China's adult population (10.5% of men and 2.6% of women ages 20 to 49) had more than one sexual partner during the year leading up to the CHFLS survey date. On average, this group reporting multiple partners had 2.29 partners in the previous year. To reflect heterogeneity in desired number of partnerships, the following set of simulation results (scenario "B: Heterogeneity in sexual partnering") accounts for some proportion of the population desiring more than one sexual partner in a year's time and considers the impact of these added partnerships on the likelihood of males' desired partnerships being fulfilled as well as on the heterosexual spread of HIV. As in the previous scenario which considered only the one single partner per person, the relevant demographic rates are held constant at those unadjusted levels from the 2000 census and from the CHFLS. As expected, here we see an upward parallel shift in the proportion of desired male partnerships unfulfilled in both the rural and urban populations corresponding to the proportional increase in total number of partnerships desired by men. Reflecting the increased rate of sexual partner change simulated in this scenario, we also see a substantial increase in the simulated adult HIV prevalence. In both the urban and rural populations, HIV prevalence hovers just under one percent over the latter half of the simulation period. All remaining simulations reflect this heterogeneity in the desired number of partnerships. Thus scenario B will serve as the "baseline" to which the remaining scenarios may be compared.

The number of desired male partnerships unfulfilled in the urban and rural populations is influenced by migration of males and females between rural and urban areas, which contributes to the availability of partnerships in each population. For the third scenario "C", we simulate the availability of marital and non-marital partners and associated spread of HIV if there were no migration between urban and rural areas observed over the entire 50-year simulation period. At the rates of migration approximated based on data from the 2000 census long form (from urban cities and townships to rural areas= 0.89% and from rural areas to urban cities and townships = 0.52% and with the sex and age distribution of migrants from the 2000 census micro data = 48% female and with female migrants tending to be younger than male migrants), the simulated availability of partnerships changes only slightly when we eliminate migration. Some very small increase in the proportion of desired male partnerships unfulfilled is observed in urban areas, while a barely detectable decrease in unfulfilled male partnerships is simulated for rural areas. No marked change in the simulated adult HIV prevalence is observed for either the rural or urban population.

The number of desired male partnerships unfulfilled is a function of not only the legacy of a masculine sex ratio at birth and migration between urban and rural areas, but also the preference of males for younger female partners (or likewise of females with older male partners) combined with the age structure of the population which reflects declining fertility over the past three decades (Goodkind 2006). In order to distinguish the influence of the sex ratio at birth on the simulated surplus male partnerships and HIV prevalence, we simulate what those outcomes would be if migration were still held to zero and the sex ratio at birth in the year 2000 and beyond were 106 males per 100 females, which is the biologically normal sex ratio. The effect of this change (scenario D) is not apparent until the 20th simulation year and beyond because it is only at this point that babies born under the normal sex ratio assumption become sexually active. In the urban population, we see that under the normal SRB the proportion of desired male partnerships unfulfilled falls nearly to 15% in the 50th simulation year, compared to more than 20% under the unadjusted SRB observed in the 2000 census. Thus for simulated partnerships formed in the 50th year of the simulation period, only one quarter of the unfulfilled male partnerships are attributable to imbalanced sex ratios at birth. The remaining three quarters are mostly due to the age structure of the population given a preference for males to partner with younger females (approximately 2 years different on average as per the CHFLS).[4] In the rural population, the greater imbalance in the sex ratio at birth yields a larger contribution to unfulfilled male partnerships. Here we see that while 25% of rural male partnerships go unfulfilled in year 50 under the census SRB, only 15% of those partnerships would go unfulfilled if a natural SRB were observed in year 2000 and beyond. Thus close to 40% of unfulfilled rural male partnerships in year 50 are attributable to the imbalanced SRB. Because the simulated impact of the natural SRB does not take effect until 20 years or more into the simulation period, no measurable effect on the simulated adult HIV prevalence is evident.

Now we turn to consider the types of adaptive behaviors we might expect to see as men are unable to attain their desired numbers of regular partners. We consider two main types of adaptations: (1) the "*conventional*" where men relax their age preferences in order to increase their available pool of partners; and (2) the "*unbalanced*" behavior in which men who find themselves unable to locate regular sexual partners instead turn to patronize commercial sex in order to maintain their desired level of sexual activity. Scenario E reflects the "conventional" behavioral adaptation with men relaxing their age preferences to consider partners up to five years younger than themselves (as opposed to two years in baseline scenario B). To draw comparisons with scenario B, we have

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[4] The rise in the sex ratio at birth started in the mid-1980s. Some of the unfulfilled male partnerships we attribute here to the age structure effect are due to higher than normal sex ratios at birth prior to 2000.

restored migration rates and the simulated SRB to those approximated from the 2000 census. Age differences between partners have been shown to have an important effect on the size and shape of the epidemic because they ensure an intergenerational chain of HIV transmission (Anderson 1992; Palloni 1996; Morris 1997). Here we see that, because the dearth of available female partners is severe, relaxing age preferences yields only small decreases in the proportion of desired male partnerships unfulfilled in both rural and urban areas. The effect of this adaptation on the simulated adult HIV prevalence is small, and this small increase is due to the number of fulfilled partnerships (and thus exposure to transmission).

The "unbalanced" adaptive behavior is represented by scenario F, which considers what would happen if urban males who were unable to satisfy their desired number of regular partners, exactly replaced those foregone partnership with commercial sex workers. In this scenario men have sex with prostitutes with the same frequency as with non-prostitute partners but the proportion of their condom protected contacts with prostitutes is twice that with regular partners. Rural males are given no opportunity for contact with commercial sex workers in this scenario. As the bottom charts reflecting adult HIV prevalence show, the model outcomes are most sensitive to the adoption of this risky behavior. A larger prevalence of male patronage of prostitutes combined with high frequency of contacts indicates the potential for an explosive epidemic in the urban population. This adaptive behavior also impacts the availability of desired sexual partnerships unfulfilled through AIDS mortality as seen in the upper panel.

Risk behaviors adopted in urban areas influence the rural population, albeit with a much smaller impact, through return migration which exposes the rural population to an increased risk of coming in contact with infected individuals.

To this point we have considered only the impact of imbalanced sex ratios on partnership availability and the heterosexual spread of HIV. Now we turn to assess what role migration might play in influencing the spread of HIV. The previous set of simulations held migration rates constant at levels observed in the 2000 census throughout the simulation period. We also assumed that migrants display the same sexual risk behavior profile as non-migrants of the same age. To assess the impact of increased sexual risk taking associated with migration, scenario G simulates partnership formation and the spread of HIV if all migrants enter the highest sexual activity group (2.29 partners per year on average) following migration. This scenario effectively shifts the population distribution by sexual activity class such that a growing proportion (migrants) of the population is assigned to the non-monogamous group with each simulation cycle. Because both men and women migrate, assigning migrants to the highest sexual activity class raises both the partnerships desired by men and in the partnerships made available by women. Given the age profile of migrants (migrant women tend to be younger than men) the aggregate result is that the new female partners available outweigh the number of new male partnerships desired and we observe a net decrease in the percent of desired male partnerships unfulfilled in both urban and rural areas. This increase in the fraction of individuals in the high sexual activity class yields a dramatic rise in the simulated adult HIV prevalence. Scenario G shows simulated urban adult HIV prevalence rises to greater than 4% by the end of the simulation period, while rural adult prevalence grows to just under 3%.

Thus far we have held rates of migration constant across all of the simulated scenarios. However, it is not unrealistic to posit that migration rates will increase over the coming years (Landoni 2006) with potential implications for both partnership formation and the sexual spread of HIV. Scenario H reflects a doubling of annual migration rates over the first 20 years of the simulation (linearly) and held constant thereafter. In this scenario we continue to assign migrants to the most sexually active group following their moves. This assumed increased rate of migration further increases the availability of partnerships reflected in a decline in the percent of male partnerships unfulfilled in both the urban and rural populations. Increased rates of migration have little effect on the spread of HIV in the short run. In the middle years (15-30) the higher migration rates actually contribute to lower HIV prevalence in urban areas – partly because rural-to-urban migrants increase the pool of available non-infected partners by creating "mixing" between the higher-prevalence urban and lower-prevalence rural populations. When prevalence and rates of partner change are relatively low, this proportionate mixing pattern may contribute to a lower reproductive rate of infection and a smaller prevalence overall. However, over the long run, increased sexual activity resulting from the higher rates of migration and a resulting shift of the population into the non-monogamous sexual activity class simulated in scenario H yields adult HIV prevalence that is around one percentage point higher in both urban and rural areas.

Discussion and Conclusions

We have assessed the implications of projected conditions of surplus males for the spread of HIV in China. This paper is part of a larger effort to assess the potential for spread of HIV in the world's largest population in the wake of rapid transformations in sexual norms and behaviors. Our larger project features both mathematical modeling of the spread of HIV and original collection of sexual behavior and sexual networks data (now in preparation) in Shanghai, China.

The first motivation for this paper was provided by two sets of findings from our published work which relies on simulations of the spread of HIV. In simulations to assess the role of sexual transmission for the spread of HIV/AIDS in China (Merli et al. 2006) we have identified the most crucial behavioral parameters that drive the simulations of the potential course of the epidemic in China: the average rate of partner change and the size of the fraction of the highly sexually active population, patterns of sexual mixing between sexual activity classes, the extent of male patronage of prostitution combined with the frequency of contacts with prostitutes. Further work by Hertog (forthcoming) undertaken to evaluate the sensitivity of the spread of HIV to the interaction between the rate of partner change and sexual mixing patterns has shown that assortative mixing, when sexual contacts between groups are rare and infection remains concentrated in the highest sexual activity classes, is associated with higher endemic HIV prevalence, especially when the population average rate of partner change is low, as observed in China from presently available data on sexual behavior. Under low average rates of partner change, the epidemic is driven and sustained by the sexual partnerships of those with the highest rates of partner change.

These findings have encouraged us to further explore conditions that may affect the distribution of sexual activity in the Chinese population, the rate of partner change and the extent of male patronage of prostitutes. The empirical understanding of patterns of sexual mixing is a major objective of our upcoming data collection in Shanghai.

The male surplus in the marriage and partnership market, produced by several decades of higher than normal sex ratios at birth and by internal migration flows and much discussed by the media as well as in the academic literature on China is expected to increase the fraction of the highly sexually active population and of the population with high risk behaviors. One objective of the present work was to assess the implications of conditions of male surpluses for the spread of HIV in China.

A second objective was to provide some concrete grounding to the discussion surrounding the role played by demographic shifts of the kind described here for the spread of HIV in China. The literature on the subject is filled with assumptions about expected social outcomes associated with conditions of male surplus, most of which stand on shaky terrain. Our findings have enabled us to evaluate the validity of these assumptions about the potential impact of these demographic shifts on the spread of HIV offering in some cases confirmation and in other important qualifications.

Our results suggest that through their effect on the most crucial behavioral parameters for the spread of HIV, surplus males' adaptive risky behaviors would significantly increase the potential for spread of infection, especially through increased contacts with prostitutes and rising the fraction of individuals in the high sexual activity class.

The latter mechanism especially applies to the case of migrants. Migrants are expected to contribute to the male surpluses at destination. Some have speculated with limited empirical evidence that Chinese migrants are more likely to display risky sexual behaviors (multiple sex partners and commercial sex) than non-migrants in their destinations because the process of migration itself changes migrants' patterns of social interaction and contributes to greater sexual promiscuity. We have shown that the increase in the fraction of highly sexually active individuals through migration drives up HIV prevalence dramatically. However, because both men and women migrate and women migrants are younger than male migrants, assigning migrants to the high sexual activity class raises both partnerships desired by men as well as the available partnerships by women. The number of newly available female partners now exceeds the newly available supply of male partners with an ensuing relaxation of the partnership squeeze. While migration is a major demographic determinant of the spread of HIV, it does not necessarily exacerbate the problem of surplus males. Migration, however, is a complex phenomenon, and migrants' partnering patterns at destination are not really known. The behavioral change upon arrival at destination we have attributed to migrants is consistent with the expectations in the literature. To the extent that migration will induce a transfer of membership from a low to a high sexual activity class, as shown by our chosen scenario, the spread of HIV will be severe because of the scale of migration.

Other plausible scenarios describing migrants' behavioral adaptations to new conditions at destination could be explored with our model, after making some adjustment to model structure and specifications. Rural women are more likely to migrate when they are young and are expected to return home when they reach marriageable age

(Fan 2003). Because of inequalities in education and job training, female migrants are at an economic disadvantage in cities and do not fare as well as their male counterparts. They are channeled overwhelmingly into low-status occupations and are disproportionately concentrated in the service and entertainment sectors (Fan 2000; 2003) where the opportunities to engage in prostitution are abundant. Yang and Xia (2006) find that female migrants, relative to their male counterparts and to non-migrants, are more likely to engage in risk behaviors such as commercial sex and multiple partnerships. This knowledge about the determinants of commercial sex work in China (recent field work I conducted in Shanghai confirms the relationship between female migration, occupational segregation by gender and prostitution) will, in future work, inform a more dynamic modeling of the prostitute population which will enable us to model the process of renewal of the prostitute population and to cycle women out of this population.

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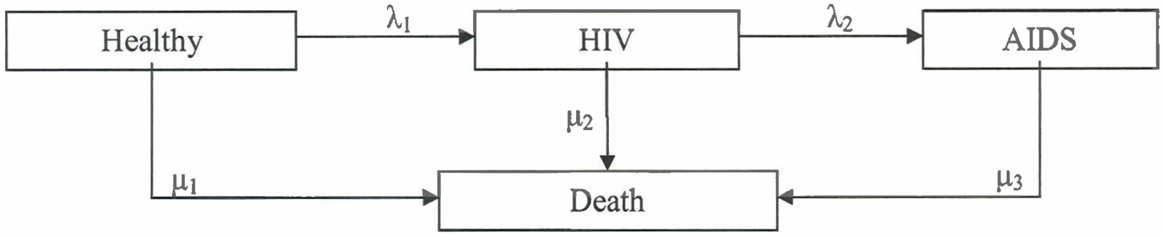

Figure 1: States and flows in the Palloni and Lamas macrosimulation model

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 (SRB)[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 (%)[b]	0.892	0.522
Women who are prostitutes (%)[c]	2.0	0.0
Median age at sexual debut[d]		
Males	22	22
Females	22	22
Mean age difference b/w partners (years)[d]	1.8	1.8
Women who are prostitutes (%)[c]	2.0	0.0

[a] Unadjusted rates from 2000 census

[b] Approximated based on migration flows presented in Table 3, Liang and Ma (2004)

[c] Horizon 2002; Yuan et al. 2002

[d] From CHFLS

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	0.1	
Women	0.1	
Prostitutes	0.1	
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	0.15	
Female-to-male	0.09	
Chlamydia cofactor	2.25	
Increased infectiousness if recently infected of symptomatic	3	

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

Figure 2: Simulated unfulfilled partnerships and adult HIV prevalence (Baseline)

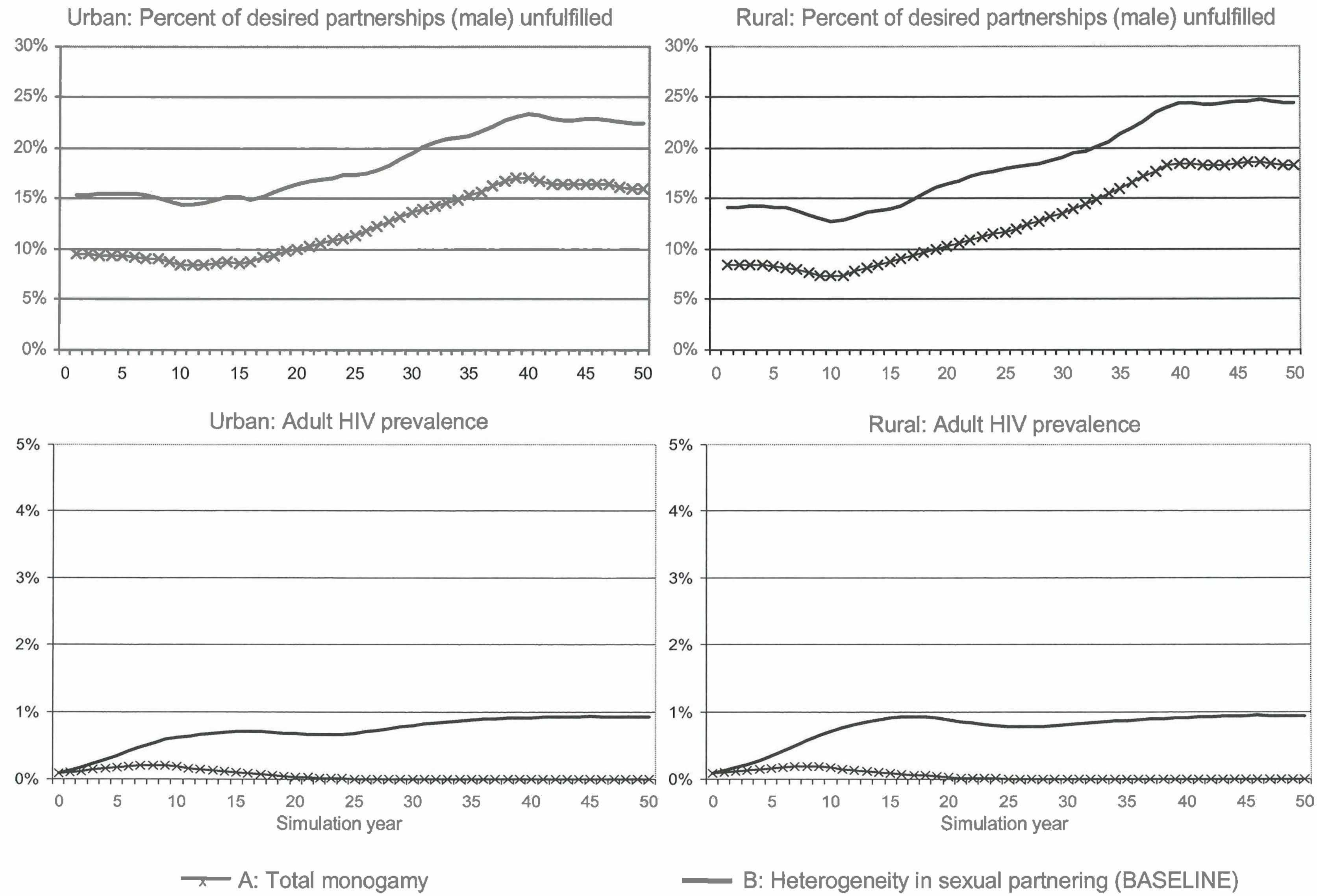

Figure 3: Simulated unfulfilled partnerships and adult HIV prevalence in the absence of migration and with “natural” SRB

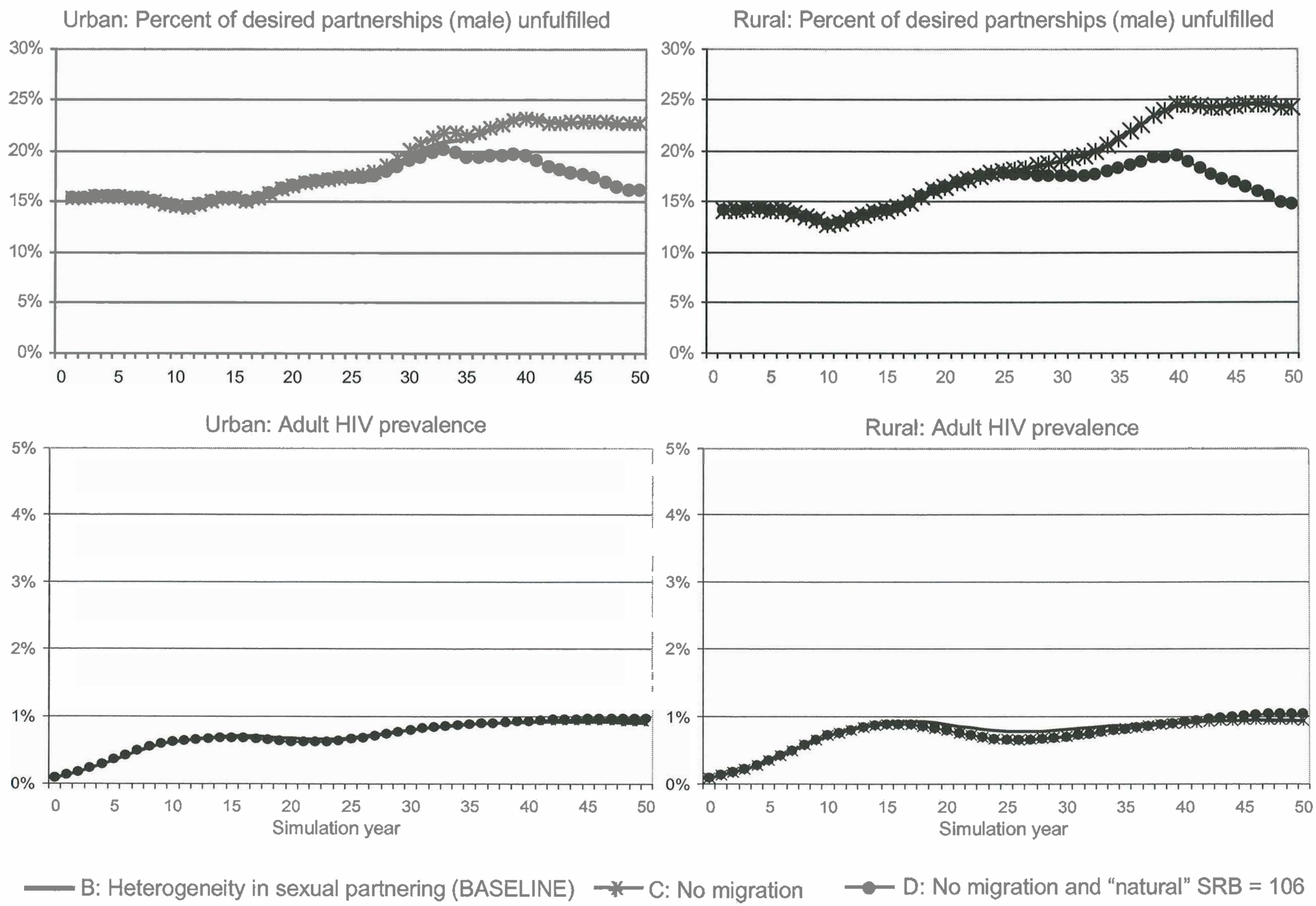

Figure 4: Simulated unfulfilled partnerships and adult HIV prevalence with adaptive behaviors

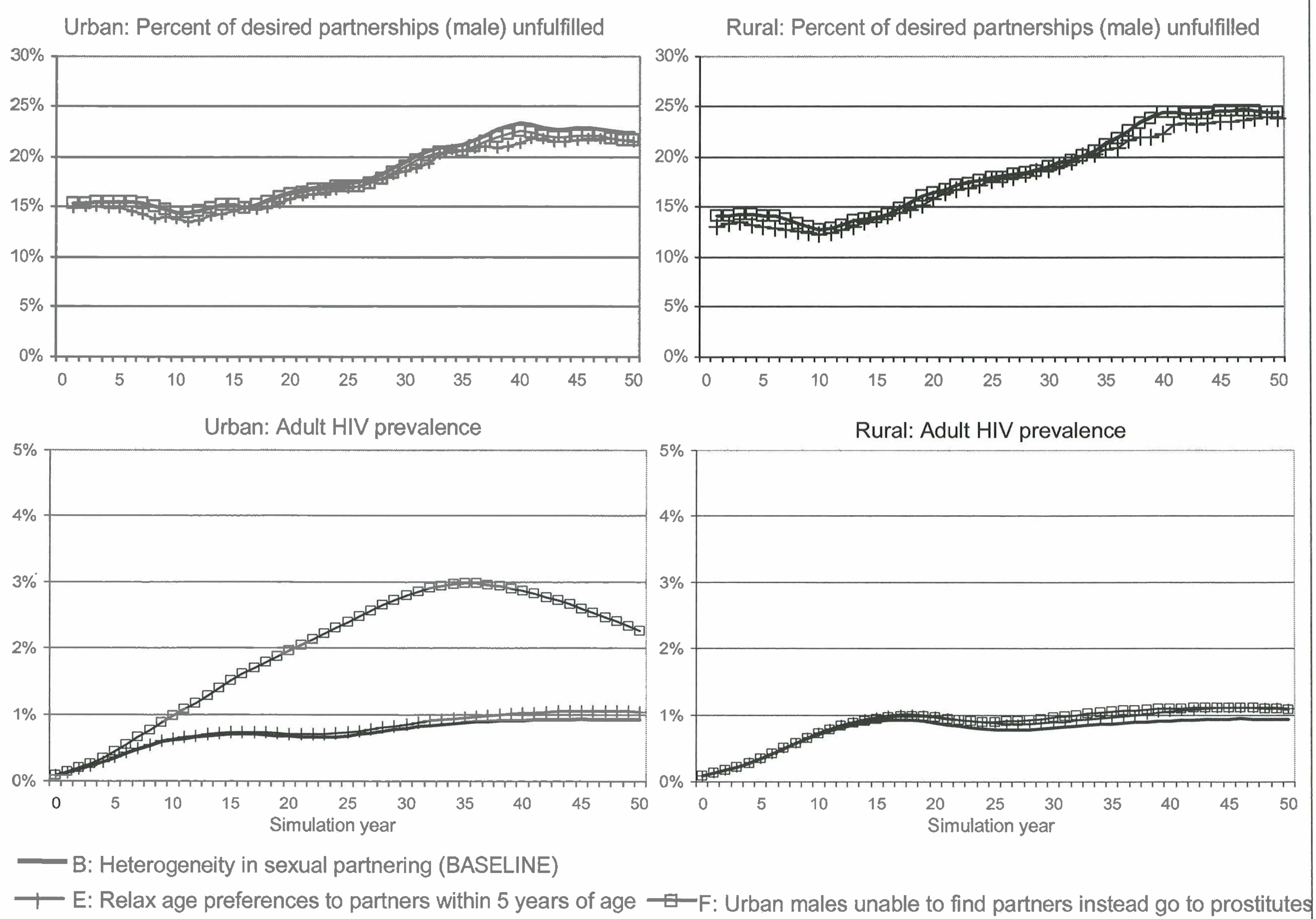

Figure 5: Simulated unfulfilled partnerships and adult HIV prevalence with risky behaviors among migrants and increasing migration