Marital Partnership Selection and HIV Seroconcordance in a Generalized Epidemic Setting

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Abstract:

Serosorting, where individuals select partners of the same HIV status as themselves, is a potentially important avenue for HIV prevention. It is unknown, however, whether people in generalized epidemic settings are more likely to partner with someone of the same HIV status as themselves. The first part of this paper uses 13 years of data from a serosurveillance site in Southwestern Uganda to measure the occurrence of serosorting. Taking into account changes in population composition, we present the first quantitative evidence of serosorting in Sub-Saharan Africa. The second part of this paper uses a mixed-methods approach to investigate the direct and indirect selection mechanisms that drive serosorting. First, we use simulation models to test whether mixing on non-HIV attributes can account for the observed level of serosorting. While disassortative age-mixing increases serosorting, it does not fully explain serosorting. We find no evidence that other factors associated with partnership choices (e.g., education, ethnicity, and marital histories), have a bearing on serosorting. Ruling out indirect selection, this paper invokes qualitative evidence of a direct preference for partners of the same HIV status. The paper concludes by discussing the implications of these findings for HIV prevention programs.

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As the HIV epidemic has matured in Sub-Saharan Africa, individuals have become more aware of the causes and consequences of HIV, as well as ways to prevent infection. HIV prevention programs predominantly focus on individual sexual risk behaviors, including condom use and fidelity. What is lost in focusing on individual risk behaviors, however, is an appreciation for whom people choose as their sexual partners. Sexual risk is not determined just by the riskiness of one's behaviors, but also the riskiness of one's sexual partners. In particular, serodiscordant partnerships, where one partner is HIV-positive and the other is HIV-negative, pose an immediate and direct risk for HIV transmission. The most important type of partner someone chooses is their marital partner: people have the longest duration of exposures and the lowest rates of condom use and condom acceptability with their marital partner (Tavory and Swidler 2009; Chimbiri 2007). We do not know, however, whether people in generalized epidemics are more likely to marry someone of the same HIV status.

Serosorting, where individuals select partners of the same HIV status as themselves, is a potentially important avenue for HIV prevention (Table 1). Serosorting may be desirable for HIV-negative people as it allows them to avoid infection. At the individual level, two HIV-negative individuals are not at risk of intra-marital transmission. Two HIV-positive individuals in a partnership, however, can lead to reinfection with a different viral strain (Poudel et al. 2007) and superinfection (Redd, Quinn, and Tobian 2013), which can speed up the progression of the disease or lead to drug resistance. Despite these risks, serosorting may be desirable for HIV-positive men and women if they want to avoid infecting a future partner, fear being rejected by an HIV-negative partner, or want a partner with whom they share the experience of being HIV-positive (Reniers and Helleringer 2011). There are also network-level benefits to serosorting: a seroconcordant negative union removes two susceptible people from the marriage market, while a seroconcordant positive union removes two infected people (Reniers and Helleringer 2011). The higher the level of serosorting is, the lower the probability of subsequent serodiscordant partnerships.

The occurrence of serosorting may also be changing over time, particularly since antiretroviral therapy (ART) became available in 2005, dramatically altering the landscape of HIV risk in Uganda. ART suppresses the HIV viral load to the point that HIV transmission risk becomes nominal when HIV-positive individuals are adhering to treatment (Cohen et al. 2011).

There is no empirical evidence of serosorting in a generalized epidemic setting. Overlooking serosorting as an HIV prevention strategy may result in an underestimation of the impact of HIV policies and programs. HIV testing and counseling (HTC), for example, is evaluated based on changes to individual risk behaviors such as condom use. However, HTC programs could also result in people choosing different sexual partners, or taking HIV status into account when forming new partnerships. Measuring the current level of serosorting, and the mechanisms through which men and women serosort, is the first step towards understanding how partnership selection is already being used, and could further be promoted as an HIV prevention activity.

(Insert Table 1)

The term homophily also describes the increased likelihood of partnering with someone of similar attributes. However, we want to draw on an important conceptual difference made by Wimmer and Lewis (2010) between homophily and homogeneity, where homophily refers to the preference for partners with similar attributes, and homogeneity refers to the outcome – that is, the actual formation of partnerships among people sharing similar attributes. From a public health perspective, homogeneity is critical as it is the outcome, not the preferences, which determine actual HIV risk. Homophily can be a potential explanation for homogeneity, but homogeneity can also arise even in the absence of homophily. For example, serosorting could be due to preference for the HIV status of one's partner, or it could be driven by other sorting mechanisms that are correlated with HIV status. This paper explores both homogeneity and homophily on HIV status in a generalized epidemic setting, first looking at homogeneity on HIV status in marriage, and then, in the second part, taking into account homophily on HIV status.

The first part of this paper examines whether there is evidence of serosorting in a generalized epidemic setting. To answer this question, this paper measures whether individuals are more likely to partner with someone of the same HIV status as themselves, compared to what one would expect if people formed their partnerships at random. We use 13 years of longitudinal data on marital partnership formation and HIV status from a demographic surveillance site in rural southwestern Uganda. This site provides the ideal setting to measure serosorting as it collects annual data on residents' HIV status and marital status. Prior research on the HIV status of marital partnerships has relied on cross-sectional analyses or retrospective reporting (e.g. De Walque 2007; Pullum and Staveteig 2013), which cannot rule out the potential of seroconversions after marriage formation. To identify serosorting it is necessary to know the HIV status of a couple at the time of marital partnership formation.

The second part of this paper then evaluates direct and indirect mechanisms that could account for serosorting. Mixing on other attributes that are correlated with HIV status could lead to serosorting without a direct preference for serosorting. Serosorting can also emerge, however, as the result of direct sorting on HIV status, driven by a preference for a partner of the same HIV status. This paper uses a mixed-methods approach, including simulation modeling and qualitative in-depth interviews, to evaluate whether one or both of these mechanisms can explain the observed trends in serosorting in rural Uganda.

Evidence of Homogeneity on HIV Status

The first evidence of serosorting emerged among men who have sex with men (MSM) in the United States (Cox, Beauchemin, and Allard 2004; Eaton et al. 2007; Eaton et al. 2009; Snowden, Raymond, and McFarland 2009; Marks et al. 2010; Snowden, Raymond, and McFarland 2011). Serosorting is considered one of a range of seroadaptive behaviors, where people modify their choice in partnership and their sexual risk behaviors depending on the HIV status of a prospective partner. Snowden, Raymond and McFarland (2011) find that seroadaptive behaviors such as serosorting are more commonly reported than consistent condom use: 27.5% of HIV-negative men and 22.2% of HIV-positive men report serosorting. Considering the challenges in adopting consistent condom use to reduce HIV infection, serosorting may be more achievable HIV prevention strategy.

Quantitative data on the HIV status of couples in generalized epidemic settings have been limited to cross-sectional studies of seroconcordant and serodiscordant partnerships. Two studies of DHS surveys across Sub-Saharan Africa (SSA) find that HIV-positive individuals are more likely to be in serodiscordant than seroconcordant positive unions (De Walque and Kline 2012; De Walque 2007). This does not necessarily indicate that HIV-positive individuals are not serosorting, however. First, the prevalence of serodiscordant and seroconcordant marriages is influenced by HIV prevalence rates, and therefore the availability of HIV-positive partners in the population. Second, they are not able to distinguish couples that were serodiscordant when their union formed from seroconcordant negative couples where one partner seroconverted through extra-marital transmission. Determining whether serosorting is in fact occurring requires longitudinal data and the couples' HIV status at marriage formation, a limitation this paper overcomes using data from an open-cohort population survey in rural Uganda.

Evidence of Homophily on HIV Status

There is some evidence to suggest that people do have a preference for the particular HIV status of a prospective partner. Homophily on HIV status could result in homogeneity on HIV status through two main pathways: direct selection where people select partners because of their HIV status, or indirect selection where people choose their partners based on characteristics that are associated with HIV.

Indirection selection may be important for serosorting when HIV-positive and HIV-negative men and women lack direct knowledge of the HIV status of a prospective partner, and therefore need to rely on other indicators of HIV status. Kaler (2004) highlights partnership selection as an opportunity for individuals to respond to HIV-risk, whereby behavior and characteristics associated with higher risk influence men's notions of desirable women. For example, they see more outgoing women, bar girls, and town girls as "risk groups", and instead prefer women from "good families" or school girls and younger women, who they assume to have had fewer previous sexual partners (Kaler 2004). Watkins (2004) shows how social norms are changing, as consulting local community knowledge about potential partners' sexual histories is considered a wise decision before marriage. The preference for HIV status may also override other considerations in partnership selection: Studying youth in rural Malawi, Clark, Poulin and Kohler (2009) find that HIV-negative status is a more important factor in selecting potential partners than attractiveness or education. Nevertheless, nearly half of the young men and women interviewed in this study said they would still marry an HIV-positive partner.

Attributes that men and women perceive to be highly correlated with HIV risk are also associated with higher rates of dissolution and lower rates of remarriage in Malawi (Reniers 2008). Individuals are more likely to divorce partners they suspect of infidelity, and less likely to remarry widows compared to non-widows, as both infidelity and widowhood are characteristics associated with HIV infection. While documenting that groups with higher HIV prevalence display different marital outcomes, Reniers is not able to disentangle whether people select their partners based on attributes associated with HIV status, or on HIV status itself.

Qualitative research in Uganda, Nigeria and Malawi shows that many HIV-positive women and men desire partners who are also HIV-positive (Seeley et al. 2009; Rhine et al. 2009; Gombachika 2012). These studies identify seroconcordant positive unions as desirable due to the shared experiences of being HIV-positive, the ease of fertility decision-making, and a fear of rejection by HIV-negative partners. Respondents also identified antiretroviral therapy (ART) clinics and support groups as places where prospective partners meet.

While there is evidence to suggest that both HIV-negative and HIV-positive people may have preferences for the HIV status of their partners, researchers have not yet been able to determine if those preferences are translating into serosorting at a population level in SSA.

Setting

Data for this paper come from the Medical Research Council and Uganda Virus Research Institute (MRC/UVRI) General Population Cohort (GPC) study site in rural southwestern Uganda. The study site comprises approximately 20,000 respondents 13 years and older from 25 villages. Small-scale agriculture is the primary livelihood source, including cash crops such as bananas, coffee, and beans, and some income from fish trading. The majority of the population belongs to the Baganda tribe (73%), and a sizeable minority is of Rwandese origin (15%). HIV prevalence among study respondents 15 years and older grew from 6.2% in 2000 to 7.7% in 2005 (Shafer et al. 2008), and has remained relatively stable at that level since then. Free ART provision to eligible study respondents was initiated in 2004.

The majority of men and women in rural Uganda marry. As of 2011, over 97% of women and 99% of men 35 years and older have ever been married (MEASURE DHS 2012). In the GPC, 96% of women and 93% of men 35 years and older had ever been married – slightly below but quite similar to the national estimate. Approximately a quarter of women and a third of men have a customary marriage, while 9% of women and 8% of men have a religious marriage (MEASURE DHS 2012). Civil or informal unions make up the remainder. Due to the high cost associated with religious or civil ceremonies, many couples move in together and consider themselves to be informally married. Informally married or cohabiting couples may either remain in informal unions, or later become formally married when they have saved up enough money for a ceremony. This study uses self-reported marital status, which includes both formal and informal unions, as well as polygynous marriages. Polygyny in the GPC is slightly below the national level: 24.6% of Uganda women were in polygynous unions as of 2011 (MEASURE DHS 2012), while 21.5% of women were in polygynous unions in the GPC study in 2007 (Seeley 2012). Marriage is also unstable in Uganda (Nabaitu, Bachengana, and Seeley 1994): 13.1% of women and 5.1% of men aged 14-49 are divorced, separated or widowed (MEASURE DHS 2012).

Data

Quantitative Data

The GPC is an annual population census and serosurvey that has been conducted in the area since 1989. Details of the population cohort study and methodology are described elsewhere (Nunn et al. 1997; Nakibinge et al. 2009; Asiki et al. 2013). This paper draws on annual data from 1999 to 2011. The dataset includes information on individual demographic variables, sexual behavior, current marital status, and HIV status. Over the 13 years of observation there are 1,251 first marriages and 1,318 remarriages. Of those respondents reporting new marriages, approximately 75% marry partners within the study site, leading to 912 linked first marriages and 1,031 linked remarriages, providing a total sample of 1,943 marriages over 13 years.

Measuring serosorting using linked marital partnership data requires a known HIV status for both partners to classify the HIV status of the couple. While the serosurvey has an approximate participation rate of 83% each year, HIV status for both partners is known only for 54% of new marriages. To address this problem, two different imputation methods are used: a logical imputation and a limited-logical imputation. Since a person who tests positive will remain positive and a person who tests negative was negative in past years, it is possible to undertake a logical imputation carrying forward positive statuses and backwards negative statuses. This provides complete couples' HIV statuses for 76% of first marriages and 77% of remarriages. New marriages with missing HIV status information after imputation were dropped from the sample.

Analyses of serosorting must take into account changes in population composition, including changes in HIV prevalence. Since logical imputation can only impute positive statuses forward and negative statuses backward, it biases the population composition to include more

HIV-negative men and women in earlier years and more HIV-positive men and women in later years. To minimize the effect of imputation on population composition, a limited logical imputation is also used. In this method, a positive HIV infection is imputed forward only two-person years and a negative HIV status back two person-years. This provides full HIV status for both partners in 69% of all new marriages. All analyses in this paper are run using no imputation, logical imputation and limited-logical imputation. The findings are not substantially different, so this paper only includes the limited-logical imputation results.

Qualitative Data

The qualitative Intimacy and Risk Study was conducted from a subsample of the GPC in 2011, such that the qualitative data are nested in the quantitative data (Agol et al. 2014). The qualitative study was designed to gain a better understanding of long-term relationships so as to build HIV prevention messages and interventions that better target married men and women. An age- and gender-stratified sample of 50 married respondents was drawn from the GPC population census: five men and ten women 30 years or younger were selected, ten men and ten women between 30 and 49 years of age, and ten men and five women 50 years or older.

In-depth semi-structured interviews were conducted in the local language (Luganda) during home visits by a local interview team comprised of two women and one man. Fieldwork also included an ethnographic component, social-demographic data collection, and questions on the respondent’s family background. To encourage more open and honest responses, the spouses of sampled respondents were not interviewed. Respondents were asked about their first intimate relationship and their most recent relationship. Interviewers were guided to ask respondents questions on how their relationships started, what attracted them to their partner, how they communicate with their partner, and how they express intimacy with their partner. Each interviewer transcribed and translated their interviews into English, providing detailed notes on context, gestures, and interpretations of local terms. An MRC/UVRI supervisor read the transcribed and translated interviews, identified gaps to be filled in a second follow-up interview, and conducted quality checks on all transcripts.

Respondents were never asked explicitly about their HIV status, but many disclosed their status through the course of the interviews. Since the sample was not stratified on HIV status, most of the interviews (48/50) were among HIV-negative respondents, providing important insight into serosorting of seroconcordant negative partnerships. Among the 50 respondents, there were 19 marriages that formed after 1990, when HIV had become a concern in the community. One of the very rich parts of this data is the insight it provides on prospective partners that respondents chose not to be with or not to marry, and how HIV affects their decisions to reject partners.

The Science and Ethics Committee of the Uganda Virus Research Institute, and the National Council for Science and Technology provided ethical approval for both the GPC and the Intimacy and Risk Study. Written informed consent was obtained from all participants; where a participant was unable to sign their name their thumbprint was given and witnessed by an independent observer.

Part 1: Evidence of Serosorting

Analytic Methods

Collapsing all newly formed marriages together over 13 years, including both first marriages and remarriages, we first measure serosorting by looking at the percentage of new marriages that are seroconcordant positive, seroconcordant negative, and serodiscordant. For each gender and HIV status group, we then compare the observed proportion of seroconcordant marriages (p_o), with the expected proportion of seroconcordant marriages (p_e) if people chose their marital partners at random. The expected proportions of seroconcordant marriages are calculated separately for HIV-positive and HIV-negative men and women to get p_e^{GH} (Equation 1). G refers to gender (F for female and M for male), and H refers to the HIV status (+ and -). The numerator is the total number of expected seroconcordant marriages for an HIV status group, and the denominator is the number of observed men or women of the same HIV status group who form a new marriage. The numerator is calculated using Equations 2.1 and 2.2. The expected number of seroconcordant positive marriages is the probability of selecting an HIV-positive woman ($Pr(F^+)$) and the probability of selecting an HIV-positive man ($Pr(M^+)$), multiplied by the total number of marriages observed ($N_o^{Marriages}$ = 1310). The number of seroconcordant negative marriages is based on the same equation, but uses the probability of randomly selecting an HIV-negative man and an HIV-negative woman.

$$p_e^{GH} = \frac{N_e^{Seroconcordant\ marriages(H)}}{N_o^{GH}} \tag{1}$$

$$N_e^{Seroconcordant\ marriages(+)} = \left(Pr(F^+) * Pr(M^+) * N_o^{Marriages}\right) \tag{2.1}$$

$$N_e^{Seroconcordant\ marriages(-)} = \left(Pr(F^-) * Pr(M^-) * N_o^{Marriages}\right) \tag{2.2}$$

To calculate the expected proportions of marriages types we make the assumption of random mixing. It is assumed that those marrying in a given year were those who were at risk of marriage in that year. In reality, however, people choose their partners from a much larger pool of individuals, including those never married, formerly married, and polygynous men who may have an additional marriage. Men who currently have one wife who may in future have additional wives are not identifiable within the dataset, so the pool of polygynous men is biased to include only those with two or more wives. If there are changes in the composition of those in the unmarried (and polygynous) pool, not just those who marry, this may affect the observed proportions of marriage types. We therefore consider two variants of the null model: a null model of random mixing among those in the married pool, and a null model of random mixing among those in the unmarried pool (Figure 1). The married pool is nested within the unmarried pool as those that marry in a given year come from the unmarried pool in the previous year. The real, but unobservable, population of those who are could marry likely lies between the null models.

(Insert Figure 1)

To compare the observed level of serosorting to that in the two null models, two datasets are constructed: a longitudinal dataset of all respondents in the unmarried pool each year, and a couple-level dataset of all new marriages formed. Table 2 presents descriptive characteristics of both samples.

(Insert Table 2)

There are large differences in the population size of HIV-negative and HIV-positive individuals, biasing any direct comparisons in the level of serosorting across HIV status groups.

To compare the serosorting of HIV-negative and HIV-positive men and women, a normalized measure of homogeneity bias (H_B) is used to remove population composition effects. Equation 3 shows how H_B^{GH} is calculated for HIV-positive men and women, and HIV-negative men and women. p_o^{GH} is the observed proportion of seroconcordant marriages and p_e^{GH} is the expected proportion of seroconcordant marriages under random mixing. Both of these values are calculated for each gender and HIV status group. This measure is used in prior work on assortative mating, but under the name homophily bias (McClintock 2010). The name of the measure is changed to reflect that it measures homogeneity, not homophily.

$$H_B^{GH} = \frac{(p_o^{GH} - p_e^{GH})}{(1 - p_e^{GH})} \quad (3)$$

The numerator in homogeneity bias is the difference between the observed and the expected proportion of seroconcordant marriages. The excess proportion of marriages is divided by the maximum proportion of excess marriages. This removes the effects of group size by normalizing the measure between -1 and 1. A value of 0 indicates perfect random mixing. A positive number indicates a stronger level of seroconcordant marital partnership selection and a negative number indicates serodiscordant selection. While a value of 1 means that everyone formed seroconcordant marriages, it is not possible for all groups to obtain a value of -1 (McClintock 2010). As a result, homogeneity bias is a good measure to compare intra-group selection across groups of varying size, but not a useful measure for inter-group selection. Given the large population size differences between HIV-positive and HIV-negative men and women, this measure is necessary to make comparative assessments about the level of serosorting.

Homogeneity bias is calculated using both the unmarried and the married pool null models, but results are substantively similar, and therefore presented for only the unmarried pool.

Confidence intervals were calculated for homogeneity bias using a bootstrap method of simulating p_e^{GH} and then calculating the homogeneity bias for each simulation. We run this simulation 1000 times and construct confidence intervals from the distribution in which 95% of the simulated H_B values fall. Confidence intervals are not calculated for the observed proportion of seroconcordant marriages because the observed proportions are derived from census data, not a sample population.

Results

(Insert Figure 2)

The majority of marriages that occur each year are seroconcordant negative, accounting for 80-90% of new marriages across years (Figure 2). Seroconcordant positive couples account for less than 10% of new marriages, while serodiscordant couples represent 4-15% of new marriages each year. Seroconcordant positive marriages have been increasing since 2010.

(Insert Figure 3)

We collapse all newly formed marriages together over 13 years and present the proportion of new marriages to someone of the same HIV status, by respondents' HIV status and gender (Figure 3). Seroconcordant positive marriages are decomposed into those that one would expect to see if people were mixing randomly and the excess seroconcordant positive marriages.

The excess is simply the observed proportion of seroconcordant positive marriages minus the expected proportion. Among HIV-positive women, 45% form a seroconcordant marriage, compared with 52% of HIV-positive men. Approximately 95% of HIV-negative men and women marry someone of the same status as themselves. While both HIV-negative and HIV-positive men and women have more seroconcordant marriages than one would expect under random mixing, the excess proportion of seroconcordant marriages is larger among HIV-positive men and women. However, it is difficult to compare the excess percentage of seroconcordant marriages across the two groups as the group size of HIV-negative and HIV-positive individuals in the population affects these numbers.

Figure 4 presents homogeneity bias for each group, or the normalized excess proportion of seroconcordant marriages. Men and women of both HIV statuses have a homogeneity bias far above zero, suggesting that there is a strong selection for seroconcordant marriages. Serosorting is greater among HIV-positive men and women compared to HIV-negative men and women. However, confidence intervals that do not overlap do not necessarily imply statistical significant differences. Homogeneity biases across HIV status groups are not independent; the selection processes among HIV-positive men and women affects the availability of HIV-positive partners for HIV-negative men and women, and vice versa.

(Insert Figure 4)

Homogeneity bias was calculated using the expected proportion of seroconcordant marriages under the assumption of random mixing in the unmarried pool. Figure 5 displays the results of testing the sensitivity of this assumption by comparing the observed percentage of seroconcordant positive marriages each year with random mixing among those in the married and unmarried pools. The 95% confidence intervals are provided for each of the random-mixing models. The observed value falls outside of the confidence interval in most years, and when it does not, it is close to the boundary of the confidence interval – aside from 2009 when no seroconcordant positive marriages formed. Despite the small sample size, and the resulting volatility in the curve, both expected values remain consistently lower than the observed proportion, suggesting that more seroconcordant positive marriages occur than random mixing would suggest.

(Insert Figure 5)

This paper uses homogeneity bias to measure the strength of serosorting among HIV-negative and HIV-positive men and women in rural Uganda. The normalization of this measure allows for comparison across populations of different sizes, but this comes at the cost of interpretability. To put the degree of serosorting in context, Table 3 presents the results in this paper along with homogeneity bias on education and ethnicity in the GPC study site. Aside from ethnic homogeneity between Bagandans, serosorting among HIV-positive men and women is similar, and in many cases greater, than ethnic and educational homogeneity. However, the local context of education and ethnic marital formation in rural Uganda may not be familiar to the read. Homogeneity on race in the United States, however, is a robustly documented phenomenon (Kalmijn 1993; Kalmijn 1998; Qian 1997; Rosenfeld 2008), and the subject of prior research on homogeneity bias (McClintock 2010). The bottom of Table 3 shows the value of homogeneity bias among students in long-term non-marital relationships in the College Social Life Survey in the United Status (McClintock 2010). Overall serosorting is strong among men and women of both statuses in rural Uganda, but not as strong as racial homogeneity among Black and White college students in the United States.

(Insert Table 3)

Part 2: Serosorting Mechanisms

Analytic Methods

The first part of this paper shows that HIV-positive and HIV-negative men and women in rural Uganda are sorting into seroconcordant partnerships. The question then becomes why and how these partnerships emerge. Part two of this paper addresses this question, using a mixed-methods approach to investigate the direct and indirect selection mechanisms that lead to serosorting. Indirect selection could be occurring if marital partners are selected on attributes that are correlated with HIV status, while direct selection could be occurring if people are choosing their marital partners based on known HIV status.

To determine if marital partnership selection based on other attributes correlated with HIV could be leading to the observed levels of serosorting, we use a simple simulation model to test a series of hypothetical selection scenarios that consider whether sorting on non-HIV attributes could account for the observed level of serosorting. For example, if the only attribute that matters to people in choosing their marital partner is the age of their partner, could the observed correlation between age and HIV account for the same level of serosorting? This simulation does not rule out direct selection on HIV status, but rather provides evidence of whether indirect selection could be driving serosorting.

We evaluate four attributes that are considered important in marriage formation in SSA: age, education, ethnicity, and marital history. Table 2 describes HIV prevalence across these attributes in both the married and the unmarried pool. For ethnicity and education, there is evidence that people mix assortatively. The ethnic-mixing model looks at the HIV prevalence of the two main ethnic groups in the area, the Baganda and Ugandans of Rwandese origin. Smaller ethnic groups in the area are categorized as Other Ethnicity. The education-mixing model breaks down the population into four main education categories: no education, some primary education, some secondary education, and unknown education. Reniers (2008) suggests that marital history is also important, with widowed individuals less likely to remarry and more likely to have HIV. We therefore test whether mixing based on marital order is influencing serosorting. Finally, there is a widely documented trend in disassortative mixing on age across Southern and Eastern Africa (Gregson et al. 2002; Luke 2003), whereby women are more likely to marry men of the same age or older. In Rakai, the neighboring district to Masaka, 98.2% of females aged 15-29 were with partners of the same age or older, where the median age difference between partners was 6.3 years for HIV-positive females, and 5.7 years for HIV-negative females (Kelly et al. 2003). HIV prevalence peaks at earlier ages for women than for men (Glynn et al. 2001), creating the potential for disassortative mixing on age to account for assortative mixing on HIV. The age-mixing model simulates serosorting with HIV prevalence in 10-year age categories (15-24, 25-34, 35-44, 45-54, and 55 and older).

For each attribute, we calculate the probability that the man and woman are HIV-positive given their value on that attribute. These probabilities are determined by the HIV prevalence among people who share that same attribute in the unmarried pool the previous year. Using these probabilities, we simulate HIV status by taking a random draw from the binomial distribution.

For example, if a couple marries at time *t* and the woman has secondary education, we determine the probability that the wife in that partnership would be HIV-positive if we randomly drew from the unmarried pool of women at time *t-1* who had some secondary education.

Simulating HIV status for all men and women that marry in a given year, we calculate the number of seroconcordant positive marriages. The simulation is run 1000 times to calculate the expected proportion of seroconcordant positive marriages, given the observed attribute-mixing. The attribute-mixing model relaxes the assumption of complete random mixing under the null model, determining what marriages would exist if they were no longer formed completely at random.

We also run a logistic regression model to consider the combined effect of all four attributes. The dependent variable is whether someone is HIV-positive, and the primary predictors are their age, education, ethnic group, and whether they have been previously married. Predicted probabilities are calculated using Stata, and used in the simulation model described above to obtain the average proportion of seroconcordant positive marriages from mixing across all four attributes.

The simulation models allow me to test whether indirect selection is a possible explanation of serosorting. To test other potential mechanisms, the simulation analyses are couples with a qualitative analysis of direct sorting on HIV status. Together, these analyses provide a broader picture of how serosorting may be occurring.

To explore direct selection of HIV status, we analyze qualitative data from the 50 in-depth interviews from the Intimacy and Risk Study. In addition to interview transcripts, we also include in the analysis the ethnographic notes, contextual background information, and the interviewer's account of pauses, intonation, gestures, and implied meanings. Qualitative data analysis was managed using ATLAS.ti (Version 7). The first step of data analysis involves selective coding (Strauss 1987), systematically focusing on all accounts of relationship formation, including what respondents were looking for in a potential partner, the period leading up to the relationship, and the relationships respondents chose not to start. For recently divorced or widowed respondents, relationship formation codes include ongoing partner searches. Respondents were explicitly asked about their first and most recent relationships, but respondents often discussed other relationships within the context of their narratives of how their first and most recent relationships formed. All relationships are included in the initial coding, but relationship order is central to the analysis, as current relationships shape how respondents recall and discuss past relationships.

The second stage of open coding classifies all references to HIV/AIDS in relationship formation stories. HIV comes up in many other instances in the interview, such as fears of contracting HIV from current marital partners. Discussions of HIV outside of the context of relationship formation were only included in the analysis if they were seen to impact the formation subsequent relationships.

To understand serosorting's mechanisms, the third stage of analysis involves axial coding (Strauss 1987; LaRossa 2005), taking into account preferences for serosorting, the actions taken to achieve serosorting, as well as the context, strategies and consequences of these actions. To understand personal, generational, and structure factors that enable or hinder serosorting, we take into account past relationship experiences as well as demographic characteristics, including age and gender. From these codes, patterns in the data are identified to develop a framework for understanding the mechanisms of serosorting.

The first author was responsible for all qualitative data analysis. The interpretation of the data was verified by the coauthors from MRC/UVRI. The coauthors had designed and implemented the Intimacy and Risk Study, and were not only familiar with the setting, data collection and transcripts, but are also simultaneously analyzing the data for other research projects. They confirmed that the analysis and framework in this paper fit with their own readings of the data.

Simulation Results

One potential explanation for the observed levels of serosorting is indirect selection, where individuals choose partners on attributes that are associated with HIV. Figure 6 shows the results from each of the attribute-mixing simulations, along with the results from a multivariate model that takes into account all four attributes. Each bar shows the expected percentage of seroconcordant positive marriages under the specified attribute-mixing model, compared to the observed percentage of seroconcordant positive marriages and the percentage expected under random-mixing model. Only age-mixing is closer to the observed level of serosorting than random mixing, but it accounts for merely 30% of the observed serosorting. Ethnic-mixing and marital history-mixing are lower than random mixing – that is, fewer seroconcordant positive marriages are expected under these models. This suggests that indirect selection, at least on these most apparent attributes, is unlikely to be the driving mechanism behind serosorting in rural Uganda.

(Insert Figure 6)

Qualitative Results

Since indirect selection does not appear to explain the observed level of serosorting, it is possible that serosorting emerges from a direct preference for the HIV status of one's partner. The qualitative data analysis shows that this may in fact be the case. However, there also appear to be barriers to enacting serosorting preferences, particularly among women looking to serosort. Direct selection into serosorted marriages can be thought of as (1) people first having the knowledge about HIV and how to prevent infection, (2) which then shapes the preference for a partner of the same status, (3) then having the knowledge about HIV testing and when to go, and (4) having the agency to enforce this preference in their relationships. It seems somewhat self-evident that given a choice, HIV-negative men and women would prefer a marital partner who does not pose an immediate risk of HIV infection. However, preferences alone are insufficient for serosorting to occur. The knowledge and ability to act on one's preferences are the necessary conditions for homophily on HIV status to result in homogeneity on HIV status.

Men and women who bring up HIV in their stories of how their relationships formed either mention a desire to know the status of their partner before beginning the relationship, or indicate a clear preference for the status of their partner. In the case below, Mark, a 41-year-old married man, discusses a potential relationship he chose not to start due to his concerns about HIV. Mark discusses how strongly he felt about the need for HIV testing based on his fear that the woman he was interested in was also having sex with other men. He used to see her hanging around other men, and this made him very worried.

> *I could not use condoms…you feel as if you have lost all your feelings or having dead senses. HIV has become very unbearable because we rely on blood testing but still someone could be in the window period and infect you.* ***If a woman refuses to go for blood testing, I just give-up, however much I may love to have sex with her*** *because I cannot use condoms.*
>
> -Mark, 41-year-old married man

Preferences for the HIV status of a partner – and HIV testing in particular – are commonly described in reference to past relationship experiences. Previous relationships are essential in imparting caution and strengthening preferences for serosorting.

In most of the relationship formation stories that discuss HIV, there is a clear sequence between HIV testing and marriage – where those who feel HIV testing is important require that testing occur before they get married. Part of the need for an HIV test also comes from community norms, where local church officials are advised not to officiate formal marriage ceremonies without proof of HIV status. In one interview, Moses, a 36 year old married man who works as a motorcycle taxi driver mentions passing by a woman in a local village and falling in love with her as soon as he saw her. He then talks about how he worked up the courage to initiate the relationship:

> *I met her at home and told her point blank that I wanted to have a relationship with her. She laughed and told me that she would think about it. I started frequenting her home and within one week we had started having sex.* ***We had protected sex for two months and the third month we decided to have an HIV test to know our statuses. After knowing that we were both HIV-negative, I married her.***
>
> - Moses, 36-year-old man

The large majority of respondents have sex with their partners before marriage. What Moses' case illustrates though is the combination of prevention strategies that are being employed – first using condoms, and then using HIV testing once they are more certain of one another, with the desired HIV test results being the last step leading to marriage. In another interview, Ibrahim, a 58-year-old widowed man discusses how his previous wife had died of HIV, and he found a new wife who had also lost her husband to HIV. They went to the health center together to get tested, and it was only after learning they were both still negative that they decided to get married. HIV testing – and condom use before testing – provide the tools to help enact serosorting preferences in marriage and long-term relationships.

One of the key themes that emerges from these interviews is how differently men and women discuss how their relationships form, and how HIV influences their decisions. There are clear gender differences in men's and women's ability to dictate the terms of their relationship and enforce their preferences for serosorting and HIV testing. Historically, marriages were more likely to be arranged – with a man choosing a woman – but there has been a growing shift towards free choice for both men and women in initiating relationships. Even among more recent relationships, however, these gendered differences in agency persist. Two women whose marriages formed as the result of forced sex provide the clearest and most violent example of this power difference between men and women in relationship formation. Partnership selection is not always a decision that two people make independently; there are clear gender differences in control and agency in forming relationships. Agency in relationship formation has also been changing overtime.

While men always discuss HIV testing as a joint activity with their partners, women talk about going to test for HIV on their own. Exceptional women who do enforce clear requirements for HIV testing before they begin a relationship are perceived to be setting their standards too high so that no man will want to be with them. Rose, a 36-year-old married teacher discusses how she found her current husband, despite her colleagues thinking she never would:

> *Many men used to propose to me, but I used to tell them* ***the condition was a legal marriage and an HIV test before the relationship could take on****… this condition put off a number of suitors. Among people in the community… a female parent approached me who had a brother that wanted a partner for marriage and that partner should be willing to go for an HIV test... I was so impressed about the idea of an HIV test…We made an appointment to go for an HIV test together.* ***We***

> ***both went to the MRC clinic for the test and we both tested HIV-negative. That is how I started the relationship till date.***
>
> - Rose, 36-year-old married woman

Rose situates this desire for an HIV test as the result of finding out that her first intimate partner had been seeing another woman at the same time as her. This experience led to her decision to wait until marriage to have sex again, and to require any future husband of hers to first have an HIV test. This marital condition, as she calls it, was shaped by past experience, and then reinforced by her local priest who was stressing the importance of premarital testing at her church.

These interviews provide many cases of HIV-negative individuals discussing a clear and direct preference for having partners without HIV. One-third of relationships in this sample formed in the time of HIV/AIDS involve an explicit consideration of HIV (N=19). HIV testing is only reported in six of those relationships; three males, one between 30-49 years of age and two over 50 years of age, and three females all between 30-49 years of age, mention HIV testing in their relationship formation stories. No one under the age of 30 discusses HIV testing, despite their sexual socialization occurring in the time of HIV/AIDS. There are also many relationship formation stories in which HIV is never discussed. People who do not mention HIV may still have preferences for the status of their partner, but if they do, those preferences were not a central consideration in how their relationships formed.

Discussion

This paper provides a longitudinal quantitative analysis of couples' HIV status at marriage formation in SSA. Even after adjusting for population composition, we find evidence to suggest that marital serosorting is occurring among both HIV-positive and HIV-negative men and women (Figure 4). Exploring what mechanisms could account for serosorting, we find that disassortative age-mixing may be one mechanism leading to serosorting, but it cannot account for most of the observed serosorting (Figure 6). We do, however, find evidence of directly expressed preferences to have an HIV-negative partner among HIV-negative individuals, and that this factor is often seen as a precondition to marriage. Direct selection seems to be the most likely factor that can account for the observed levels of serosorting. However, there are barriers to serosorting, particularly with respect to women's ability to both control the process of partnership selection and enforce preferences for HIV testing with their prospective partners.

While this paper evaluates both direct and indirect mechanisms that may account for the observed level of serosorting, there are other untested potential mechanisms. First, it is possible that serosorting occurs through indirect selection on unmeasured characteristics. For example, men and women who share a proclivity towards risk may be more likely to partner with one another, and also be more likely to have HIV. This paper cannot rule out indirect selection on unobserved characteristics.

Second, in addition to direct and indirect selection, opportunistic selection may also be occurring. HIV-positive men and women may be more likely to form seroconcordant positive marriages largely because they have repeated opportunities to meet other HIV-positive people. Research on marital mixing finds that geographic proximity (Blau and Schwartz 1984; Harris and Ono 2005) and social contact networks (Blau and Schwartz 1984; Harris and Ono 2005; Clark-Ibáñez and Felmlee 2004) are key determinants of inter- and intra-racial partnership formation. Contact patterns might suggest that, based on numbers, HIV-positive men and women are less likely to find HIV-positive partners as they are less likely to meet other people of the same status as themselves compared with HIV-negative individuals. HIV clinics and support services change this scenario, providing both the physical space and social opportunities for contact among HIV-positive men and women. In this specific study site, the MRC clinic has been providing free ART since 2004, incidentally providing space and opportunity for HIV-positive men and women to meet a prospective partner. Further work should test the role of opportunistic selection in serosorting by measuring the role of physical spaces and social networks in partnership search and partnership formation processes.

There are some important limitations to this research. First, we are only able to identify the date at which the marital union was formed, but not the date of first sex within the partnership. It is possible that seroconversion occurs prior to marriage, overstating the prevalence of serosorting. However, the qualitative data show that some partners avoid unprotected sex until after they test for HIV, which would minimize the effect of seroconversions occurring before marriage. For first marriage, the gap between sexual debut and marriage is relatively small. According to the 2011 DHS survey in Uganda (MEASURE DHS 2012), women have on average a one-year gap between the age of first sex and age of first marriage, at 16.8 years of age and 17.9 years of age, respectively. Men on the other hand, have a larger gap between sexual debut and first marriage: men's average age of first sex is 18.6 years and their average age of first marriage is 22.3 years. The short gap, at least for women, suggests that premarital seroconversions are infrequent. It is also possible that sexual debut and first marriage do not occur with the same partner, narrowing the window for premarital seroconversions even further. Nevertheless, the potential for premarital seroconversions may still exist, particularly for remarriages. To determine if a large number of seroconversions were occurring before marriage, we test for differences in serosorting between lagged and non-lagged HIV status. Serosorting would be lower with lagged HIV status if premarital seroconversions were occurring. We find no such difference (results not shown), suggesting that premarital seroconversions are unlikely to explain serosorting.

One of the main limitations to the qualitative data is that only a few HIV-positive individuals were interviewed. One respondent openly disclosed she was HIV-positive, and another respondent made indirect comments that implied to the interviewer that he was HIV-positive. However, neither respondent discusses HIV in their partnership formation stories. We do not have data on HIV-positive men and women's preferences for the HIV status of their partners. Previous research in SSA using focus groups suggests that HIV-positive men and women have a preference for marrying an HIV-positive partner. However, these focus groups are all done in connection with HIV clinics or post-test clubs. HIV-positive men and women who choose to go for testing or participate in these clubs may be very different from the general population. In addition, we cannot make population-based inferences based on these data. Nonetheless, the interviews do provide insight into how serosorting may be occurring, and who may be able to serosort effectively.

Finally, this research is looking only for evidence of serosorting and the underlying mechanisms. It does not speak to the importance of serosorting for HIV transmission, nor what impact serosorting has on incidence and the HIV epidemic more broadly. Modeling studies of the MSM HIV epidemic in the US find that serosorting decreases HIV; in the absence of serosorting the modeled HIV prevalence increases from 16% to 24.5% (Cassels et al. 2009). The effectiveness of serosorting in reducing HIV transmission requires that people know their own status and the status of their partner. As a result, the effectiveness of serosorting will vary based on the overall level of HIV-testing (Wilson et al. 2010). Cassels et al. (2010) finds that with frequent testing, serosorting can reduce HIV risk. Without frequent testing, a recently infected HIV-positive person wishing to serosort may form a serodiscordant marriage unintentionally as they are unaware of their recent change in HIV status. It is exactly at this time that they pose the greatest risk, as their infectivity peaks in the months immediately following seroconversion (Boily et al. 2009; Wawer et al. 2005). Preferences for serosorting in the absence of testing can therefore be harmful, rather than protective. Further research should be done to model the effect of serosorting in a generalized epidemic to determine the level of HIV testing necessary to make serosorting effective at reducing HIV transmission in SSA (Cassels and Katz 2013). In Uganda, there is still a great need to increase HIV testing. As of 2011 only 66% of women 45% of men have ever had an HIV test (Staveteig et al. 2013), though testing in the study site is likely higher than the national average.

There has been an increase in seroconcordant positive marriages since 2010. If this increase holds, serosorting may play an even more important role in shaping future HIV transmission dynamics. What has caused the increase in serosorting is unclear. Growing HIV awareness and access to ART may change the desirability of HIV-positive partners. For example, being in a seroconcordant positive marriages means having someone to help remind you to take your pills, and who can pick up pills from the clinic for both of you. However, ART became freely accessible to study participants in 2004, yet we do not observe any changes in the proportion of seroconcordant positive marriages until 2010. We might also expect ART to be associated with a decrease in serosorting as ART-related viral suppression reduces the risk of forming a serodiscordant marriage (Cohen et al. 2011). Despite the recent increase in seroconcordant positive marriages, there is still the potential for serosorting to be even higher: approximately half of HIV-positive men and women in this study marry someone who was HIV-negative. In the absence of condom use or ART adherence, these marriages may result in HIV transmission.

There are several different ways to increase serosorting: the first is by removing uncertainty around HIV status. Widely accessible and frequently used HIV testing is the cornerstone of effective serosorting. However, prospective partners may falsely disclose their HIV status, interfering with attempts to serosort. Couples HIV testing programs and pre-marital testing present one solution to this quandary. In these programs, couples get tested together, learning their own and their partner's HIV status. As the qualitative analysis in this paper illustrates, church leaders, or other community leaders, can play an important role in shaping norms and strengthening resolve, around pre-marital testing. These programs may be particularly effective if targeted towards adolescents, none of whom (15/50) reported HIV testing in the Intimacy and Risk Study. Faith-based organizations and local governments can, and do, play an important role in promoting pre-marital testing programs (Luginaah, Yiridoe, and Taabazuing 2005; Uneke, Alo, and Ogbu 2007; Rennie and Mupenda 2008). However, these programs need to be offered as services that people can opt into, not as programs mandated by governments or religious institutions as a precondition to marriage. Attempts at mandatory couples testing are not only a potential human rights violation, it may also have adverse effects on deterring people from accessing any HIV testing services. Despite these concerns, mandatory premarital testing programs have been implemented at churches in Burundi, Democratic Republic of the Congo, Ghana, Kenya, Nigeria, Tanzania and Uganda, and some churches discourage, or even forbid, marrying serodiscordant couples (Open Society Institute 2010). Premarital testing programs can help people serosort, but they also risk being misused in ways that inhibit rather than assist men and women in making informed and empowered partnership choices.

The second way to increase serosorting is by helping people who want to serosort find partners of the same HIV status as themselves. This could be done through support groups for HIV positive individuals. Alternatively, dating services could facilitate serosorting through providing a pool of prospective partners of the same HIV status. Prior research has documented a range of such match-making services, as well as newspaper personal ads, in Ethiopia, Kenya, South Africa, Zimbabwe and India (Reniers and Helleringer 2011). In Uganda, the newspaper *Bukedde* has similar personal ads. These programs primarily target HIV-positive men and women, but could be expanded, strengthened, and promoted as a service for both HIV-positive and HIV-negative people. There is also a local cultural equivalent to matchmaking services, where family members, peers or pastors take on the role of finding and screening prospective partners. Increasing awareness about HIV, and knowledge about how serosorting can reduce the spread of HIV, among those screening for prospective partners could also help increase serosorting.

Serosorting in and of itself may be an important outcome of prevention activities that we should be measuring. HIV testing is evaluated in terms of changes in unprotected sex, but programs may also be impacting partnership formation and selection. It is possible that people are more willing to modify their choices in sexual partners than their sexual behaviors. In this sense, serosorting could be considered a prevention goal in and of itself. Ignoring serosorting in impact evaluations of HIV testing programs may bias our estimates of these programs' effectiveness, leading to an undervaluation of the benefits of HIV testing (Reniers and Helleringer 2011). This same problem may plague a range of HIV prevention evaluations that ignore couple-level outcomes. As a community of researchers, service providers, and policy makers, we may be missing important effects of these programs by only thinking about sexual behavior within partnerships rather than the partnership dyad itself. This study provides the first step in documenting the occurrence of, and direct preference for, serosorting in a generalized epidemic setting. Moving forward, we should consider how people may already be using serosorting as an HIV prevention activity, and take this behavior into account in designing and evaluating HIV prevention policies and programs.

Bibliography

Agol, Dorice, Dominic Bukenya, Janet Seeley, Elizabeth Kabunga, and Anne Katahoire. 2014. “Marriage, Intimacy and Risk of HIV Infection in South West Uganda.” *African Journal of Reproductive Health* 18 (5): 86–94.

Asiki, Gershim, Georgina Murphy, Jessica Nakiyingi-Miiro, Janet Seeley, Rebecca N. Nsubuga, Alex Karabarinde, Laban Waswa, et al. 2013. “The General Population Cohort in Rural South-western Uganda: a Platform for Communicable and Non-communicable Disease Studies.” *International Journal of Epidemiology* (January 30).

Blau, Peter M., and Joseph E. Schwartz. 1984. *Crosscutting Social Circles: Testing a Macrostructural Theory of Intergroup Relations*. San Francisco: Academic Press.

Boily, Marie-Claude, Rebecca F Baggaley, Lei Wang, Benoit Masse, Richard G White, Richard J Hayes, and Michel Alary. 2009. “Heterosexual Risk of HIV-1 Infection Per Sexual Act: Systematic Review and Meta-analysis of Observational Studies.” *The Lancet Infectious Diseases* 9 (2) (February): 118–129. doi:10.1016/S1473-3099(09)70021-0.

Cassels, Susan, and David A. Katz. 2013. “Seroadaptation Among Men Who Have Sex with Men: Emerging Research Themes.” *Curr HIV/AIDS Rep* 10: 305–313.

Cassels, Susan, Timothy W. Menza, Steven M. Goodreau, and Mathew R. Golden. 2009. “HIV Serosorting as a Harm Reduction Strategy: Evidence from Seattle, Washington.” *AIDS (London, England)* 23 (18) (November 27): 2497–2506. doi:10.1097/QAD.0b013e328330ed8a.

———. 2010. “Available Evidence Does Not Support Serosorting as an HIV Risk Reduction Strategy: Author’s Reply.” *AIDS* 24 (6): 936–938.

Chimbiri, A. M. 2007. “The Condom Is an [] Intruder’in Marriage: Evidence from Rural Malawi.” *Social Science & Medicine* 64 (5): 1102–1115.

Clark, Shelley, Michelle Poulin, and Hans-Peter Kohler. 2009. “Marital Aspirations, Sexual Behaviors, and HIV/AIDS in Rural Malawi.” *Journal of Marriage and Family* 71 (2): 396–416. doi:10.1111/j.1741-3737.2009.00607.x.

Clark-Ibáñez, Marisol, and Diane Felmlee. 2004. “Interethnic Relationships: The Role of Social Network Diversity.” *Journal of Marriage and Family* 66 (2): 293–305.

Cohen, Myron S., George M. Shaw, Andrew J. McMichael, and Barton F. Haynes. 2011. “Acute HIV-1 Infection.” *New England Journal of Medicine* 364 (20): 1943–1954. doi:10.1056/NEJMra1011874.

Cox, J., J. Beauchemin, and R. Allard. 2004. “HIV Status of Sexual Partners Is More Important Than Antiretroviral Treatment Related Perceptions for Risk Taking by HIV Positive MSM in Montreal, Canada.” *Sexually Transmitted Infections* 80 (6) (December 1): 518–523. doi:10.1136/sti.2004.011288.

Eaton, Lisa A., Seth C. Kalichman, Daniel A. O’Connell, and William D. Karchner. 2009. “A Strategy for Selecting Sexual Partners Believed to Pose Little/no Risks for HIV: Serosorting and Its Implications for HIV Transmission.” *AIDS Care* 21 (10): 1279–1288. doi:10.1080/09540120902803208.

Eaton, Lisa, Seth C. Kalichman, Demetria Cain, Chauncey Cherry, Heidi Stearns, Christina Amaral, Jody Flanagan, and Howard Pope. 2007. “Serosorting Sexual Partners and Continued Risk for HIV Transmission Among Men Who Have Sex with Men.” *American Journal of Preventive Medicine* 33 (6) (December): 479–485. doi:10.1016/j.amepre.2007.08.004.

Glynn, J. R, M. Cara\ël, B. Auvert, M. Kahindo, J. Chege, R. Musonda, F. Kaona, A. Buvé, and others. 2001. “Why Do Young Women Have a Much Higher Prevalence of HIV Than Young Men? A Study in Kisumu, Kenya and Ndola, Zambia.” *Aids* 15: S51.

Gombachika, Belinda Chimphamba. 2012. “Marriage Partner Selection by Heterosexual Couples Living with HIV from Rural Southern Malawi.” *Journal of AIDS & Clinical Research* 01 (S1).

Gregson, S., C. A Nyamukapa, G. P Garnett, P. R Mason, T. Zhuwau, M. Caraël, S. K Chandiwana, and R. M Anderson. 2002. "Sexual Mixing Patterns and Sex-differentials in Teenage Exposure to HIV Infection in Rural Zimbabwe." *The Lancet* 359 (9321): 1896–1903.
Harris, David R., and Hiromi Ono. 2005. "How Many Interracial Marriages Would There Be If All Groups Were of Equal Size and Lived in the Same Places? A New Look at National Estimates of Interracial Marriage." *Social Science Research* 34 (1): 236–251.
Kalmijn, Matthijs. 1993. "Trends in Black/White Intermarriage." *Social Forces* 72 (1): 119–146.
———. 1998. "Intermarriage and Homogamy: Causes, Patterns, Trends." *Annual Review of Sociology* 24 (January 1): 395–421.
Kelly, R. J, R. H Gray, N. K Sewankambo, D. Serwadda, F. Wabwire-Mangen, T. Lutalo, and M. J Wawer. 2003. "Age Differences in Sexual Partners and Risk of HIV-1 Infection in Rural Uganda." *Journal of Acquired Immune Deficiency Syndromes* 32 (4): 446–51.
LaRossa, Ralph. 2005. "Grounded Theory Methods and Qualitative Family Research." *Journal of Marriage and Family* 67 (4): 837–857.
Luginaah, Isaac N., Emmanuel K. Yiridoe, and Mary-Margaret Taabazuing. 2005. "From Mandatory to Voluntary Testing: Balancing Human Rights, Religious and Cultural Values, and HIV/AIDS Prevention in Ghana." *Social Science & Medicine* 61 (8): 1689–1700.
Luke, Nancy. 2003. "Age and Economic Asymmetries in Sexual Relationships of Adolescent Girls in Sub-Saharan Africa." *Studies* 34 (2): 67–86.
Marks, Gary, Gregorio A. Millett, Trista Bingham, Jennifer Lauby, Christopher S. Murrill, and Ann Stueve. 2010. "Prevalence and Protective Value of Serosorting and Strategic Positioning Among Black and Latino Men Who Have Sex With Men." *Sexually Transmitted Diseases* (January): 1. doi:10.1097/OLQ.0b013e3181c95dac.
McClintock, Elizabeth Aura. 2010. "When Does Race Matter? Race, Sex, and Dating at an Elite University." *Journal of Marriage and Family* 72 (1): 45–72.
MEASURE DHS. 2012. "Uganda Demographic and Health Survey 2011". Calverton, Maryland USA: ICF International.
Nabaitu, Januario, Cissy Bachengana, and Janet Seeley. 1994. "Marital Instability in a Rural Population in South-West Uganda: Implications for the Spread of HIV-1 Infection." *Africa: Journal of the International African Institute* 64 (2): 243. doi:10.2307/1160982.
Nakibinge, S., D. Maher, J. Katende, A. Kamali, H. Grosskurth, and J. Seeley. 2009. "Community Engagement in Health Research: Two Decades of Experience from a Research Project on HIV in Rural Uganda." *Tropical Medicine & International Health* 14 (2): 190–195.
Nunn, A. J, D. W Mulder, A. Kamali, A. Ruberantwari, J. F Kengeya-Kayondo, and J. Whitworth. 1997. "Mortality Associated with HIV-1 Infection over Five Years in a Rural Ugandan Population: Cohort Study." *British Medical Journal* 315 (7111): 767.
Open Society Institute. 2010. "Mandatory Premarital HIV Testing: An Overview". New York, NY: Open Society Institute. http://www.opensocietyfoundations.org/sites/default/files/mandatory-premarital-hiv-testing-20100513.pdf.
Poudel, Krishna C, Kalpana Poudel-Tandukar, Junko Yasuoka, and Masamine Jimba. 2007. "HIV Superinfection: Another Reason to Avoid Serosorting Practice." *The Lancet* 370 (9581) (July 13): 23–23. doi:10.1016/S0140-6736(07)61033-2.
Pullum, Thomas, and Sarah Staveteig. 2013. "HIV Status and Cohabitation in Sub-Saharan Africa". No. 35. DHS Analytical Studies. Rockville, Maryland, USA: ICF International.
Qian, Zhenchao. 1997. "Breaking the Racial Barriers: Variations in Interracial Marriage Between 1980 and 1990." *Demography* 34 (2): 263–276.
Redd, A D, T C Quinn, and A A Tobian. 2013. "Frequency and Implications of HIV Superinfection." *Lancet Infect Dis* 13: 622–628.
Reniers, Georges. 2008. "Marital Strategies for Regulating Exposure to HIV." *Demography* 45 (2) (May).

Reniers, Georges, and Stéphane Helleringer. 2011. "Serosorting and the Evaluation of HIV Testing and Counseling for HIV Prevention in Generalized Epidemics." *AIDS and Behavior* 15 (1) (January): 1–8. doi:10.1007/s10461-010-9774-0.

Rennie, S., and B. Mupenda. 2008. "Ethics of Mandatory Premarital HIV Testing in Africa: The Case of Goma, Democratic Republic of the Congo." *Dev World Bioeth* 8 (2): 126–37.

Rhine, K. A, K. Waters, F. D Oyekanmi, and R. T Suberu. 2009. "Support Groups, Marriage, and the Management of Ambiguity Among HIV-Positive Women in Northern Nigeria." *Anthropological Quarterly* 82 (2): 369–400.

Rosenfeld, Michael J. 2008. "Racial, Educational and Religious Endogamy in the United States: A Comparative Historical Perspective." *Social Forces* 87 (1): 1–31.

Seeley, Janet. 2012. "The Changing Relationships of Co-wives over Time in Rural Southern Uganda." *Journal of Development Studies* 48 (1): 68–80.

Seeley, Janet, Steven Russell, Kenneth Khana, Enoch Ezati, Rachel King, and Rebecca Bunnell. 2009. "Sex After ART: Sexual Partnerships Established by HIV-infected Persons Taking Anti-retroviral Therapy in Eastern Uganda." *Culture, Health & Sexuality: An International Journal for Research, Intervention and Care* 11 (7): 703.

Shafer, Leigh Anne, Samuel Biraro, Jessica Nakiyingi-Miiro, Anatoli Kamali, Duncan Ssematimba, Joseph Ouma, Amato Ojwiya, et al. 2008. "HIV Prevalence and Incidence Are No Longer Falling in Southwest Uganda: Evidence from a Rural Population Cohort 1989–2005." *AIDS* 22 (13) (August): 1641–1649. doi:10.1097/QAD.0b013e32830a7502.

Snowden, J. M., H. F. Raymond, and W. McFarland. 2009. "Prevalence of Seroadaptive Behaviours of Men Who Have Sex with Men, San Francisco, 2004." *Sexually Transmitted Infections* 85 (6) (October 1): 469–476. doi:10.1136/sti.2009.036269.

Snowden, Jonathan M., H. Fisher Raymond, and Willi McFarland. 2011. "Seroadaptive Behaviours Among Men Who Have Sex with Men in San Francisco: The Situation in 2008." *Sexually Transmitted Infections* 87 (2) (March 1): 162–164. doi:10.1136/sti.2010.042986.

Staveteig, Sarah, Shanxiao Wang, Sara K. Head, Sarah E.K. Bradley, and Erica Nybro. 2013. "Demographic Pattersn of HIV Testing Uptake in Sub-Saharan Africa". 30. DHS Comparative Reports. Calverton, Maryland USA: ICF International.

Strauss, Anselm L. 1987. *Qualitative Analysis for Social Scientists*. Cambridge, England: Cambridge University Press.

Tavory, I., and A. Swidler. 2009. "Condom Semiotics: Meaning and Condom Use in Rural Malawi." *American So* 74 (2): 171–189.

Uneke, C.J., M. Alo, and O. Ogbu. 2007. "Mandatory Pre-marital HIV Testing in Nigeria: The Public Health and Social Implications." *AIDS Care: Psychological and Socio-medical Aspects of AIDS/HIV* 19 (1).

De Walque, Damien. 2007. "Sero-Discordant Couples in Five African Countries: Implications for Prevention Strategies." *Population and Development Review* 33 (3): 501–523.

De Walque, Damien, and Rachel Kline. 2012. "The Association Between Remarriage and HIV Infection in 13 Sub- Saharan African Countries." *Studies in Family Planning* 43 (1) (March 1): 1–10.

Wawer, Maria J., Ronald H. Gray, Nelson K. Sewankambo, David Serwadda, Xianbin Li, Oliver Laeyendecker, Noah Kiwanuka, et al. 2005. "Rates of HIV-1 Transmission Per Coital Act, by Stage of HIV-1 Infection, in Rakai, Uganda." *Journal of Infectious Diseases* 191 (9) (May 1): 1403 –1409. doi:10.1086/429411.

Wilson, David P., David G. Regan, Kelly-Jean Heymer, Fengyi Jin, Garrett P. Prestage, and Andrew E. Grulich. 2010. "Serosorting May Increase the Risk of HIV Acquisition Among Men Who Have Sex With Men." *Sexually Transmitted Diseases* 37 (1) (January): 13–17. doi:10.1097/OLQ.0b013e3181b35549.

Wimmer, Andreas, and Kevin Lewis. 2010. "Beyond and Below Racial Homophily: ERG Models of a Friendship Network Documented on Facebook." *American Journal of Sociology* 116 (2): 583–642.

Table 1: Individual and network effects of serosorting

Partnership type	Individual-level effects	Network-level effects
Seroconcordant positive	- Risk of super-infection	+ Removes two infected individuals from the marriage market
Seroconcordant negative	+ Not at risk of intra-marital infection* *assuming absence of extra-marital partnerships	+ Removes two susceptibles from marriage market

Table 2: Background characteristics of new marriages and unmarried men and women in the GPC study (1999-2011)

		Married Pool	Unmarried Pool
Number of couples		1,310	
Number of men			7,186 (31,455 PY)
Number of women			6,691 (24,683 PY)
Marital Characteritics			N (% HIV positive)
HIV status			
	Concordant negative	1,139	
	Female-positive discordant	67	
	Male-positive discordant	50	
	Concordant positive	54	
Type of marriage			
	First marriage	623	
	Remarriage	687	
	Polygynous	240	984 (11.4%)
	Formerly married		5,047 (17.8%)
	Never married		7,846 (0.7%)
Women's Characteristics		*N (% HIV positive)*	*N (% HIV positive)*
Age			
	15-24	666 (4.8%)	3,945 (2.8%)
	25-34	283 (16.6%)	759 (27.1 %)
	35-44	188 (16.0%)	539 (31.4%)
	45-54	108 (8.3%)	439 (22.6%)
	55+	65 (4.6%)	1,009 (5.0%)
Ethnicity			
	Muganda	864 (8.2%)	3,743 (10.5%)
	Munyanrwanda	168 (10.1%)	641 (17.5%)
	Other/Unknown	278 (11.9%)	2,307 (5.6%)
Education			
	No education	106 (8.5%)	835 (4.0%)
	Some primary	867 (9.7%)	3,456 (11.7%)
	Some secondary	283 (7.4%)	1,855 (6.6%)
	Unknown	54 (13.0%)	545 (13.6%)
HIV status			
	HIV negative	1,189	6,057
	HIV positive	121	634
Men's Characteristics		*N (% HIV positive)*	*N (% HIV positive)*
Age			
	15-24	255 (3.1%)	4,346 (0.9%)
	25-34	522 (8.4%)	933 (11.3%)
	35-44	231 (14.7%)	624 (24.5%)
	45-54	133 (10.5%)	446 (20.0%)
	55+	169 (2.4%)	837 (5.3%)
Ethnicity			
	Muganda	865 (6.5%)	3,643 (5.8%)
	Munyanrwanda	162 (11.1%)	728 (9.2%)
	Other	283 (10.6%)	2,815 (5.4%)
Education			
	No education	67 (3.0%)	577 (4.5%)
	Some primary	858 (8.2%)	4,375 (6.6%)
	Some secondary	360 (7.8%)	1,775 (4.9%)
	Unknown	25 (16%)	459 (6.3%)
HIV status			
	HIV negative	1,206	6,756
	HIV positive	104	430

Note: For the longitudinal unmarried pool, time-varying characteristics are described for the sample at point of last observation

Table 3: Homogeneity bias on HIV status, ethnicity and education in Masaka, Uganda, and on race among college students in long-term non-marital relationships in the United States

	Homogeneity Bias	
	Men	Women
GPC Study		
HIV status		
HIV-negative	**0.26**	**0.33**
HIV-positive	**0.48**	**0.41**
Ethnicity		
Muganda	0.56	0.56
Munyanrwanda	0.22	0.21
Other/Unknown	-0.90	-0.94
Education		
No education	0.08	0.15
Some primary	0.43	0.44
Some secondary	0.26	0.19
Unknown	-0.08	-0.21
United States (McClintock 2010)[a]		
Long term relationships		
Race		
White	0.39	0.77
Black	0.67	0.54
Hispanic	0.29	0.29
Asian	0.50	0.43

[a] Source: College Social Life Survey, 2005 homogeneity on race in long term relationships.

Figure 1: Profile of adults exposed to the risk of marriage at time t=1 in the Unmarried Pool, Married Pool, and unobserved true population

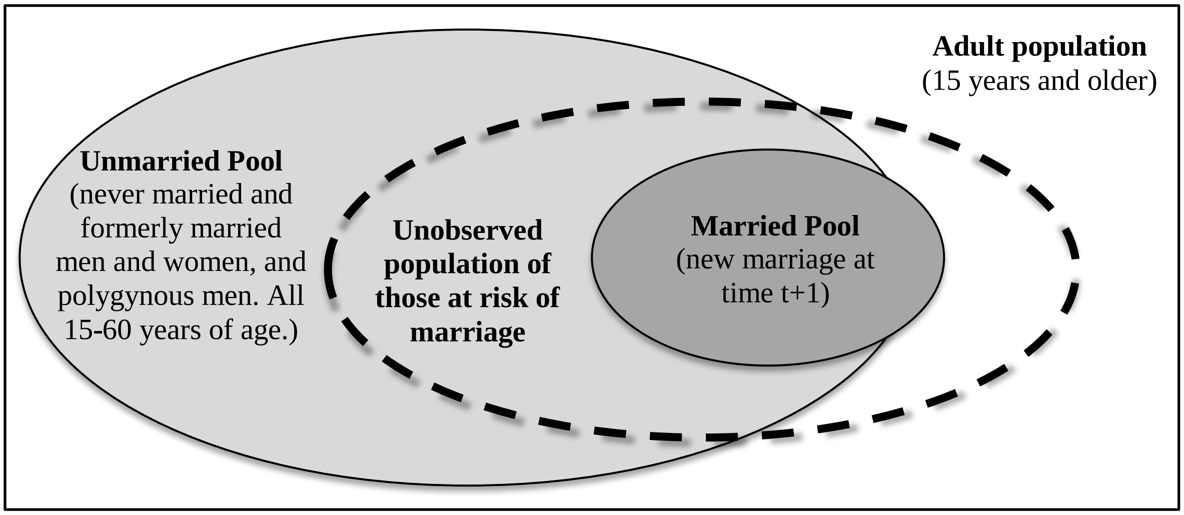


Figure 2: Percent of new marriages by couples HIV status (1999-2011)

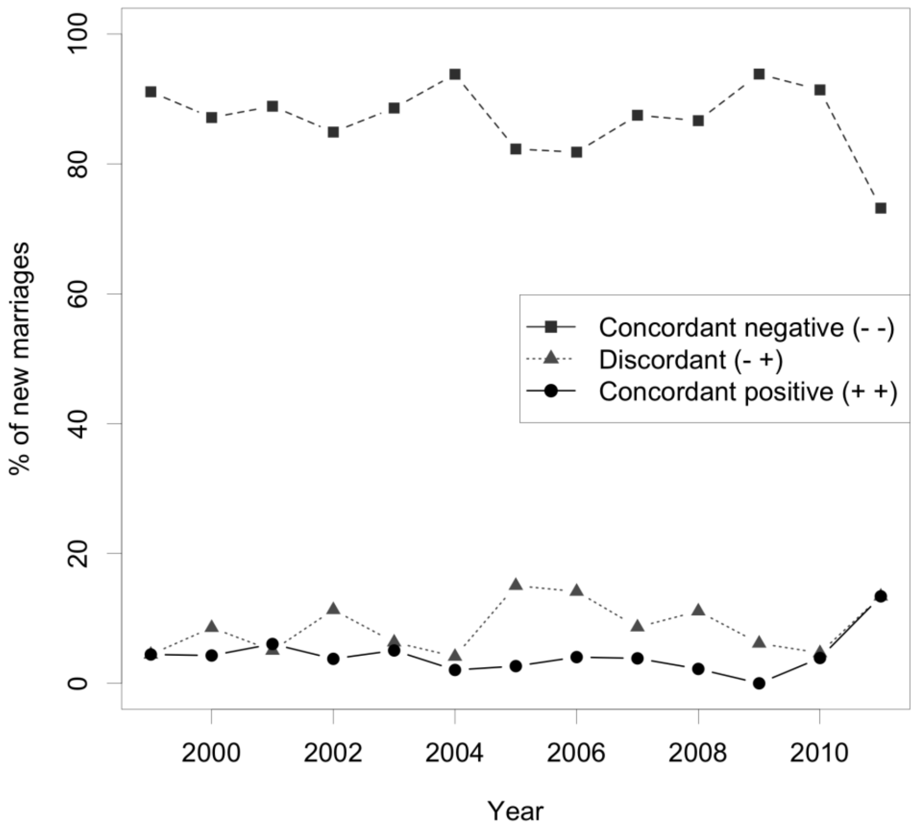


Figure 3: Excess and expected seroconcordant marriages, 1999-2011

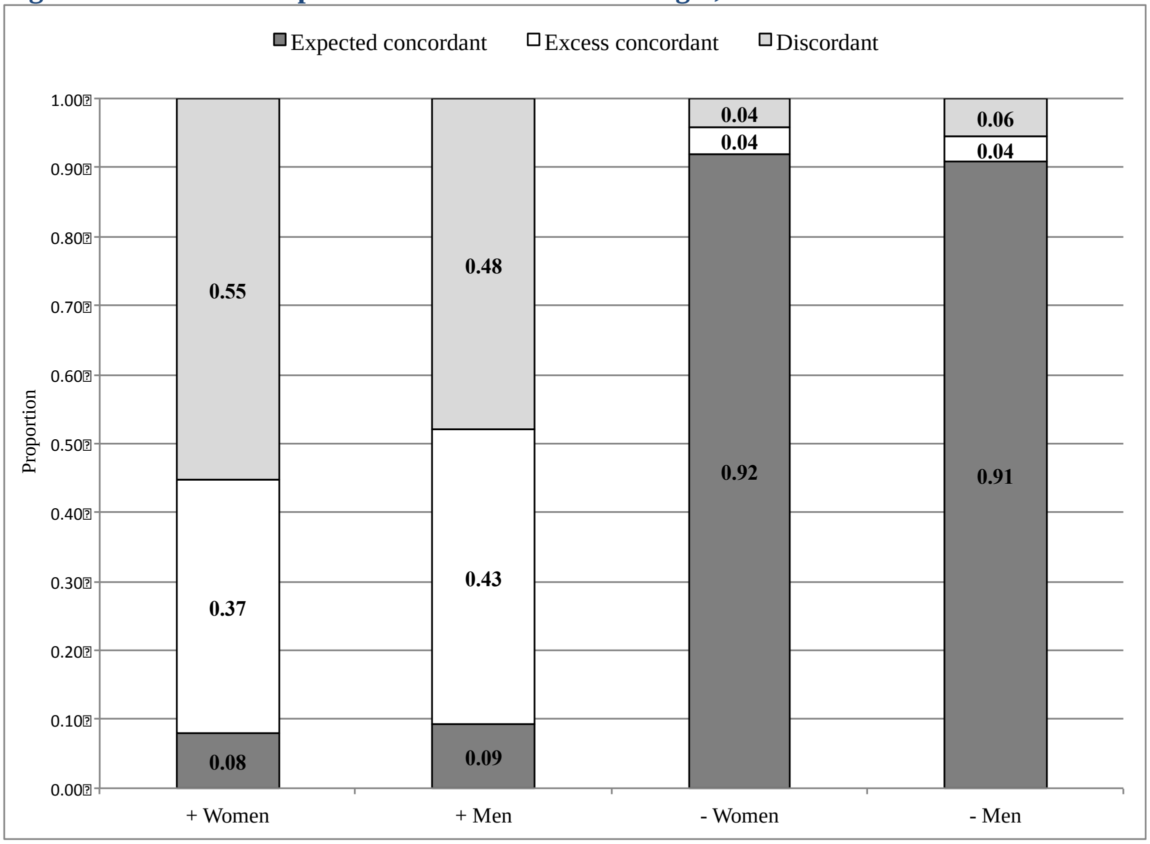


Figure 4: Seroconcordant marriages adjusted for group size (Homogeneity Bias), 1999-2011

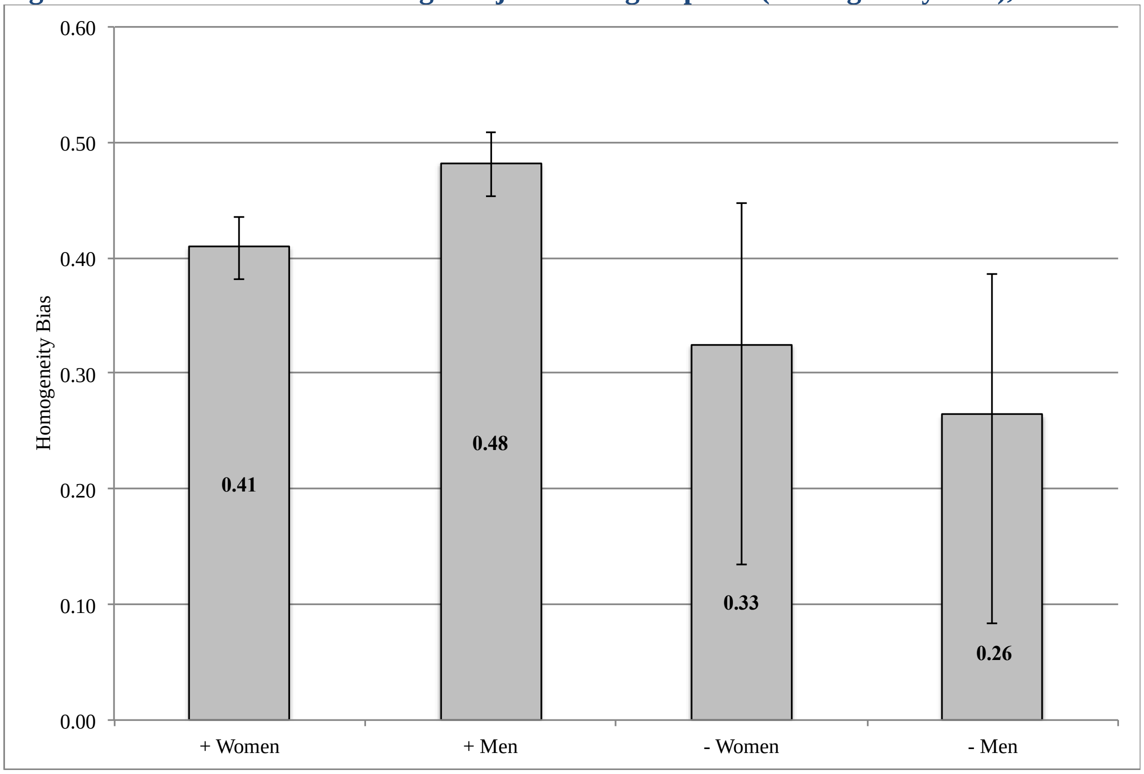
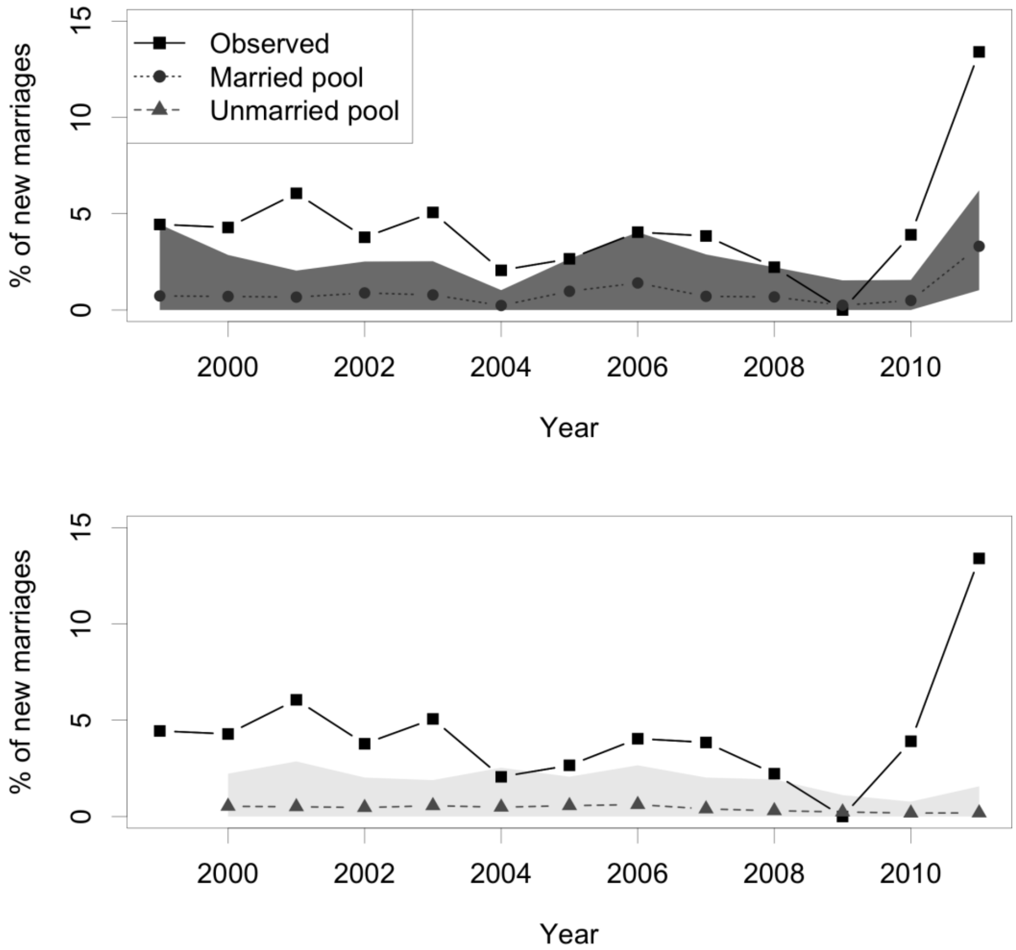


Figure 5: Seroconcordant positive marriages in the observed population, with random mixing in the married pool, and with random mixing in the unmarried pool (1999-2011)



Note: The married pool includes all men and women who marry at time t. The unmarried pool includes those never married, formerly married, and polygynous men at time t-1. The shaded region around each line shows the confidence intervals that were constructed for the two random-mixing models.

Figure 6: Percent of marriages that are seroconcordant positive in the attribute-mixing simulations compared to the observed population