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An Intimate Epidemic: HIV and Marriage in Rural Uganda

Sully, Elizabeth Anne

Princeton, NJ : Princeton University

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AN INTIMATE EPIDEMIC:
HIV AND MARRIAGE IN RURAL UGANDA

Elizabeth Anne Sully

A DISSERTATION

PRESENTED TO THE FACULTY

OF PRINCETON UNIVERSITY

IN CANDIDACY FOR THE DEGREE

OF DOCTOR OF PHILOSOPHY

RECOMMENDED FOR ACCEPTANCE

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Advisers: Georges Reniers & Noreen Goldman

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ABSTRACT

This dissertation examines the relationship between HIV and marriage before and after the introduction of antiretroviral treatment (ART) in rural Uganda.

Chapter one employs 13 years of sero-surveillance data from Masaka and Rakai districts to measure HIV incidence by marital status. I find that, despite having lower incidence rates, the majority of new HIV infections occur among married men and women. To understand how married couples become infected with HIV, I measure the HIV incidence in serodiscordant marriages and marriages with extra-marital partnerships (EMPs). I find that the majority of new HIV cases among married people are attributable to EMPs, despite incidence rates being higher in serodiscordant marriages. The greatest risk in marriage does not come from spouses who are already HIV-positive, but rather from external partners or newly infected spouses.

Chapter two uses mixed methods to investigate the HIV status of couples at marriage formation. Controlling for population composition effects, I find evidence of serosorting, that is, where both HIV-positive and HIV-negative men and women are more likely to marry someone of the same HIV status. Using simulation models, I find little evidence that indirect selection of partners on attributes other than HIV could lead to the observed HIV mixing patterns. I do, however, find qualitative evidence that people directly select partners of the same HIV status.

Chapter three concludes by examining the impact of HIV on marital dissolution and remarriage. Historically, marriages with an HIV-positive partner had higher dissolution rates via both widowhood and divorce, and the remarriage rates of HIV-positive people tended to be lower than those of HIV-negative people. Since the introduction of ART, seroconcordant positive marriages have stabilized and the remarriage rates of HIV-positive men have increased.

This suggests that the availability of treatment is having a stabilizing effect on only some types of marriages, and is only improving the remarriage prospects of men, but not women.

These chapters explore three unique aspects of HIV and marriage dynamics: marital formation, intra- and extra-marital HIV transmission, and marital dissolution. They document important changes in the transmission and social repercussions of HIV with the roll-out of ART.

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leaving your door open for me. It was a pleasure getting to precept for you. Thank you Thomas Espenshade for introducing me to demography, and for your unwavering encouragement and support. Thank you Robert Keohane for teaching me how to design better research, to search for great puzzles and find creative new ways to solve them, for believing in me early on, and helping me believe in myself, too. I owe a special thank you to Professor Shelley Clark, at McGill University. I would not be where I am without your mentorship and support. You took a misguided undergraduate who thought she wanted to do an MPH, and directed me to a PhD demography program. It was the perfect choice, and you knew it. I cherish our lunches at PAA every year, and value the advice you continue to provide. You have become a mentor, inspiration, and friend.

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Earlier versions of these chapters have benefited from the feedback of discussants and conference attendees. I presented an early version of Chapter 2 at PAA in 2013 and in a poster at IUSSP in 2013, and a full version of the chapter at PAA in 2015. I presented Appendix 1B (the reincarnation of an earlier Chapter 1) in a poster at PAA in 2012, and in oral presentations at PAA in 2014 and IUSSP in 2013, and Chapter 3 at PAA in 2015. Thank you to all the demographers that provided feedback on this work throughout the dissertation process.

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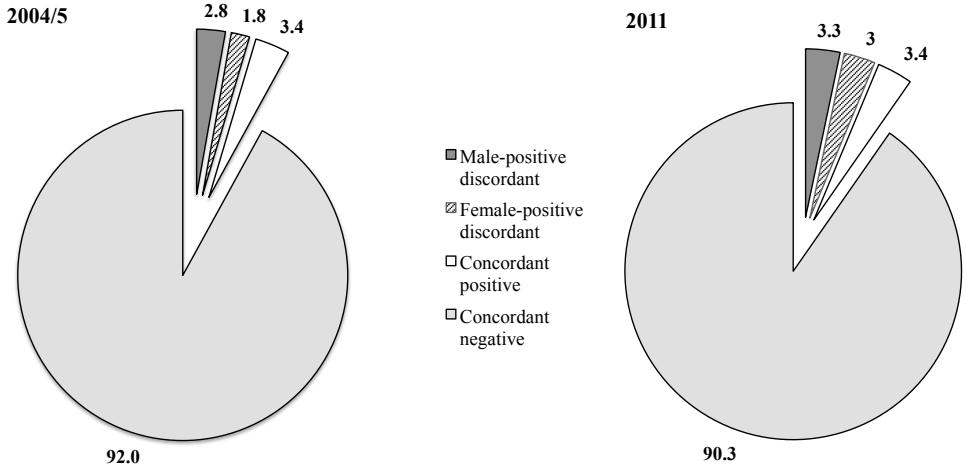
Introduction

In generalized epidemic settings [1], HIV transmission occurs primarily through heterosexual transmission in intimate sexual relationships. Short-term casual partnerships, considered to be higher risk, were the primary focus of early HIV research and prevention programming. However, as the HIV epidemic has matured, people have modified their sexual behaviors and number of short-term partners (Green et al. 2006). With a decreasing share of HIV transmissions occurring in short-term relationships, it has been suggested that more and more infections will occur in long-term, or marital, partnerships (Gregson and Garnett 2000). HIV risk is therefore not just about casual sex and risky behaviors, but also about the most intimate of relationships - marriage.

[1] Generalized epidemics refer to epidemics where the HIV prevalence in the general population is greater than 1%.

In a 2004-2005 nationally representative survey in Uganda, HIV was prevalent in 8% of marriages (Figure I.1). This rose to 10% by 2011. These marriages can be decomposed into three types of HIV-infected partnerships: seroconcordant positive, in which both partners are HIV-positive; female-positive serodiscordant, in which only the wife is HIV-positive; and male-positive serodiscordant, in which only the husband is HIV-positive. While we know that HIV is present in 10% of marriages in Uganda, we actually know very little about how married men and women become infected, and how access to antiretroviral therapy (ART) may be affecting these pathways of transmission.

Figure I.1: HIV status of married or cohabiting couples in Uganda



Data source: Uganda HIV/AIDS Sero-Behavioural Survey (2004-2005), and Uganda AIDS Indicator Survey (2011)

In addition to understanding how married people become infected with HIV, it is also important to understand how HIV is affecting marriage. Without treatment, HIV-infected marriages are at a higher risk of widowhood through AIDS-related mortality (Porter et al. 2004). Moreover, an HIV-negative spouse may be worried about HIV transmission from their marital

partner, and divorce their partner to mitigate this risk (Grant and Soler-Hampejsek 2014; Reniers 2008). HIV may additionally create marital discord through interfering with couples' reproductive ambitions, or through HIV-related household economic stress (Nabaitu, Bachengana, and Seeley 1994). As a result, HIV may have profound effects on the social institution of marriage, and this relationship may be undergoing important transformations with the roll-out of ART.

***

This dissertation makes three main contributions to the study of HIV and marriage. First, I measure the risk of HIV infection among married men and women, and examine how married couples become infected with HIV. There are two pathways through which HIV can enter into marriage: at marriage formation and through extra-marital partnerships (EMPs). Considerable research has focused on EMPs (e.g., Clark 2010; Cordero Coma 2013; Kwena et al. 2014; Parikh 2007; Benefo 2007), but the HIV status of partners at the start of relationships has received much less attention. To prevent HIV infections among married men and women, we first need to know how they acquire HIV.

Second, I draw critical attention to sexual behaviors that are pertinent to HIV infection, but that are not classically discussed in the HIV prevention literature in Sub-Saharan Africa (SSA). Specifically, I focus on the occurrence of partnership selection and dissolution processes that may be used mitigate HIV risk. For example, serosorting, where people form partnerships with someone of the same HIV status as themselves, may be used to limit the onwards transmission of HIV. HIV research frequently discusses the sexual behaviors people engage in with their partners, but not how partners are chosen in the first place. This dissertation examines

the occurrences and mechanisms behind serosorting, highlighting an underexplored behavioral response to HIV risk in SSA.

Third, this dissertation examines how ART may be changing the biomedical, and therefore social implications of HIV. I look at how marital dissolution and remarriage patterns have changed before and after the availability of ART, and find that men and women experience the social impacts of ART differently. As ART access expands across SSA, there is a growing need to better understand and document its social effects. My dissertation's examination of marital change before and after ART is a first step in this direction.

My work takes place in a larger policy context in which there is a growing emphasis on treatment as prevention (TasP), and a reliance on biomedical solutions to reduce HIV transmission. My dissertation, however, shows that ART is mainly impacting serodiscordant marriages, but not seroconcordant negative couples risk of HIV transmission through EMPs. My dissertation suggests there are limitations to relying only on treatment as a prevention strategy, and emphasizes the need to continue to pursue behavioral prevention strategies in combination with biomedical approaches.

***

This dissertation is concerned with investigating the relationship between HIV and marriage, and how this relationship has been changing over time. My work focuses on rural Uganda, where the majority of men and women marry, and where HIV prevalence rates are high. I ask three questions to better understand how HIV affects marriage. First, how important is HIV transmissions among married men and women are to the overall epidemic. Second, how does

HIV enter marriage. I am interested in the HIV status of couples when they marry, and how each spouse's HIV status changes over the course of marriage. Finally, I ask how HIV is changing marriage, and in particular, whether HIV and ART affect marital dissolution and remarriage.

I answer these questions in three chapters that are each intended to serve as stand-alone papers. I discuss in detail in each chapter the literature, data, and methods relevant to each paper. Here, I set up the three chapters that follow by asking two main questions: Why Uganda? And, why marriage?

Why Uganda?

Siliimu, or slim, the local term for AIDS in Uganda (Serwadda et al. 1985), has been around since the early 1980s when the first cases of HIV were identified in the southwest of the country. Uganda was the first of many countries to be hit by the HIV/AIDS epidemic, but only one of a few subsequent success stories: Prevalence in Uganda dropped from 18.5% in 1992 to 6.4% by 2005 (Ugandan AIDS Commission 2013). The source of this decline has generated considerable debate (Green et al. 2006; Gray et al. 2006; Stoneburner and Low-Beer 2004; Parkhurst 2002), but it generally appears to be a confluence of factors, including sexual behavior change widely attributed to the "zero-grazing" campaign, political stabilization with the end of war, a government that initiated early and strong leadership to address HIV/AIDS, a strong response from civil society and religious-based organizations, and AIDS-related mortality.

Unfortunately, Uganda's success was short-lived. Reliable HIV prevalence estimates from a sero-surveillance site in southwestern Uganda found that HIV prevalence actually increased from 6.2% in 1999/2000 to 7.7% in 2004/2005 (Shafer et al. 2008). Researchers argue

that this change stemmed from an increase in sexual risk behaviors (Shafer et al. 2008). Since then, prevalence estimates for Uganda have also continued to rise, from 6.4% to 7.3% by 2011. As of 2013, there were 1.6 million adults living with HIV in a population of 37.6 million people.

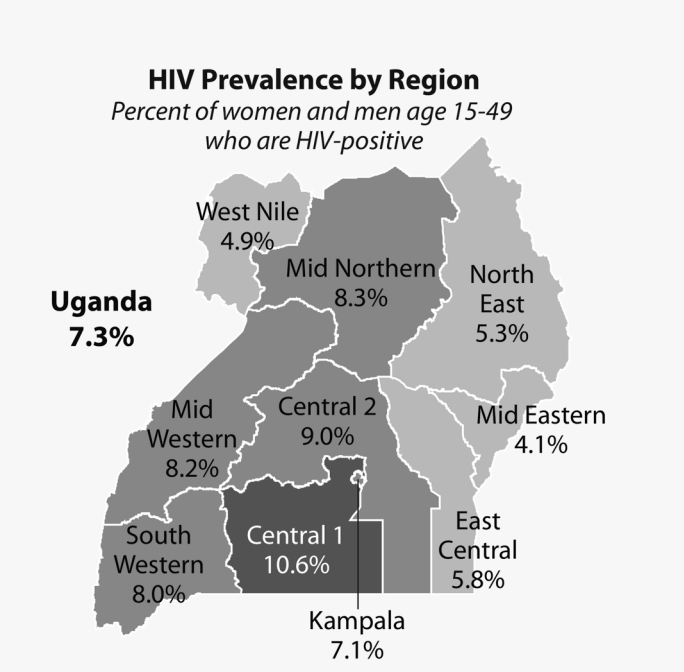
The most important factor that changed over time is the rollout of ART, resulting in more HIV-positive people living longer. By 2012, 64% of those eligible for ART (based on the WHO 2010 guidelines) were receiving treatment. ART not only reduces mortality and morbidity, it also reduces the HIV viral load, and as a result, the risk of onward transmission (Cohen et al. 2011). These shifts in health outcomes and transmission risks may be fundamentally changing the meaning of HIV.

In many respects, Uganda is an ideal country in which to study the relationship between HIV and marriage. Having been hit early on with HIV, it has the oldest epidemic on the continent. Uganda experienced widespread behavior change in the 1990s (Gray et al. 2006), making it an excellent location to examine the potential shift in the epidemic from casual to marital partnerships. At the same time, Uganda has a distinct epidemic due to its diverse and fragmented ethnic groups. Thornton (2008) argues that these social divisions, compounded with class differences, create a more clustered epidemic than in countries like South Africa, resulting in a slower spread of HIV. Uganda also has much higher rates of marriage than Southern Africa, which makes it a more useful case for studying HIV's effects on marriage. The findings in this dissertation, therefore, may not apply in contexts with vastly different epidemics or marriage regimes.

My dissertation draws on data from two sero-surveillance sites in the southwest of the country in Masaka and Rakai districts. Hit first and hit hardest, southwestern Uganda continues to have the highest prevalence rates in the country (Figure I.2, Central 1 region). To my

knowledge, these two sites have the longest available time series sero-surveillance data in SSA. This provides an ideal setting to study the changing dynamics of HIV and marriage in the time periods before and after the availability of ART.

Figure I.2: HIV prevalence by region



Source: (MEASURE DHS 2012a)

Why marriage?

> *"...marriage is a fundamental economic, social and cultural institution in almost every known society – an institution that most people anticipate, engage in, and evaluate both individually and collectively, no matter their cultural context, social class, country of origin, ethnic group or religious background. Further, the institution of marriage sits at the nexus of large-scale social processes and intimate life, between the concrete tasks of economic subsistence and the biological and social imperatives of reproduction, and in the unfolding of an individual's life course. As such, marriage is the focus of pragmatic strategies and behavior, and the locus of intense moral scrutiny and social preoccupation"*
>
> (Hirsch et al. 2009, 2)

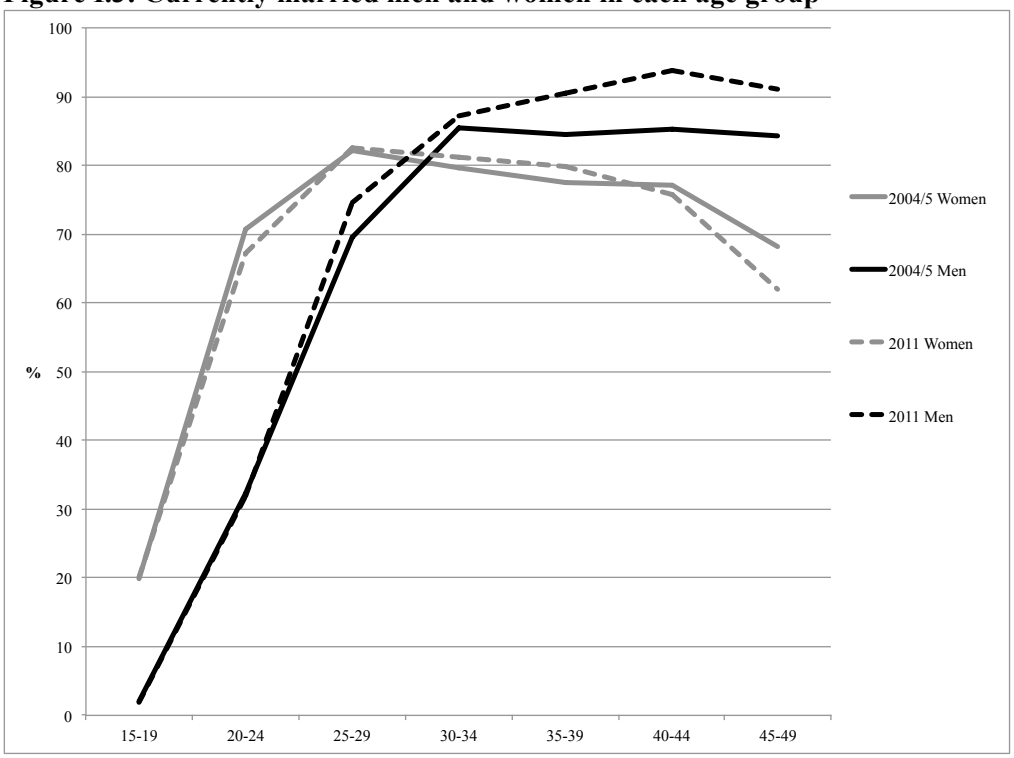
Marriage is a social institution that shapes the cultural, social, economic and sexual realities of men and women. There are two main reasons why it is important to study marriage, and in particular, to study marriage in the context of the HIV epidemic. First, whom people marry, how they form marital partnerships, the rate of partnership turnover, as well as the types of marriages people create (monogamous, polygynous, and marriages with extra-marital partnerships) are some of the key building blocks of sexual networks. To understand how HIV spreads, we need to take into account marital partnership dynamics.

The second reason it is important to study marriage is that we know marriage is beneficial to individuals and families. Scholars have found that marital instability in SSA is associated with an earlier age of sexual debut and marriage among adolescents (Beegle & Krutikova 2008; Birdthistle et al. 2008; Palermo & Peterman 2009), a higher risk of child mortality among younger children (Clark & Hamplová 2013; Thiombiano, LeGrand, & Kobiané 2013), and a higher risk of adolescent childbearing, early school drop-out or grade repetition, and underemployment (Goldberg 2013). The effect of HIV on marital partnership dynamics will therefore have important implications for family and child wellbeing.

Marriage in Uganda

Marriage is a fundamental experience of adulthood in Uganda, where the majority of men and women marry: As of 2011, over 97% of women and 99% of men 35 years and older were ever married (MEASURE DHS 2012b). Figure I.3 shows the percentage of men and women in each age group who were married in 2004/2005 and 2011.

Figure I.3: Currently married men and women in each age group



Data source: Uganda HIV/AIDS Sero-Behavioural Survey (2004-2005), and Uganda AIDS Indicator Survey (2011)

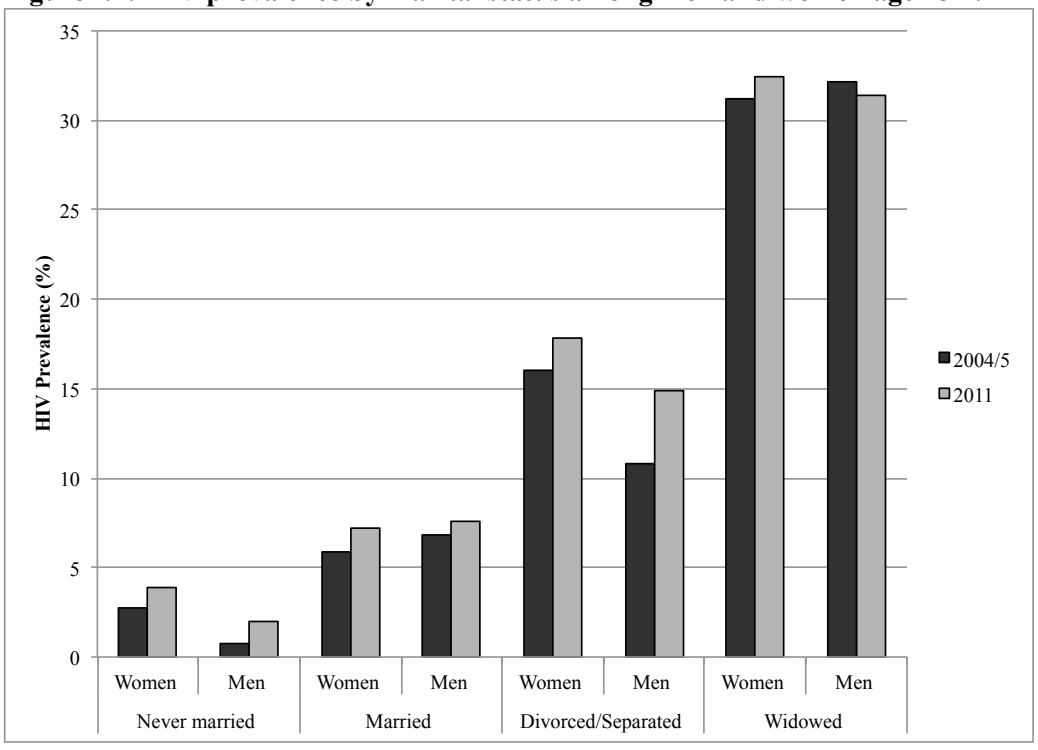
There are four types of marriage in Uganda: customary, religious, civil, and informal. Informal, or cohabiting, unions are considered synonymous to marriage. In these unions, men and women live together and often refer to themselves as husbands and wives, even in the absence of a formal ceremony (Mukiza-Gapere and Ntozi 1995). Polygyny is also a key feature

of marriage in Uganda among Muslims and non-Muslims (Seeley 2012). In 2011, 25.0% of married women and 16.9% of married men age 15-49 reported being in polygynous relationships (MEASURE DHS 2012b). While marriage is socially portrayed as permanent (Agol et al. 2014), there is in fact a high level of marital instability (Nabaitu, Bachengana, and Seeley 1994).

HIV and Marriage

Figure I.4 shows HIV prevalence by marital status group in Uganda in 2004/2005 and 2011. For every group other than widowed men, HIV prevalence increased over time. Married men's and women's HIV prevalence is greater than that of never-married people, but much lower than that of formerly married people.

Figure I.4: HIV prevalence by marital status among men and women age 15-49



Data source: Uganda HIV/AIDS Sero-Behavioural Survey (2004-2005), and Uganda AIDS Indicator Survey (2011)

This dissertation is premised on the idea that married men and women are at risk of HIV infection. There are three reasons why this is the case. First and foremost, in a society where the vast majority of men and women marry and remarry, people have the longest exposure from their marital partner.

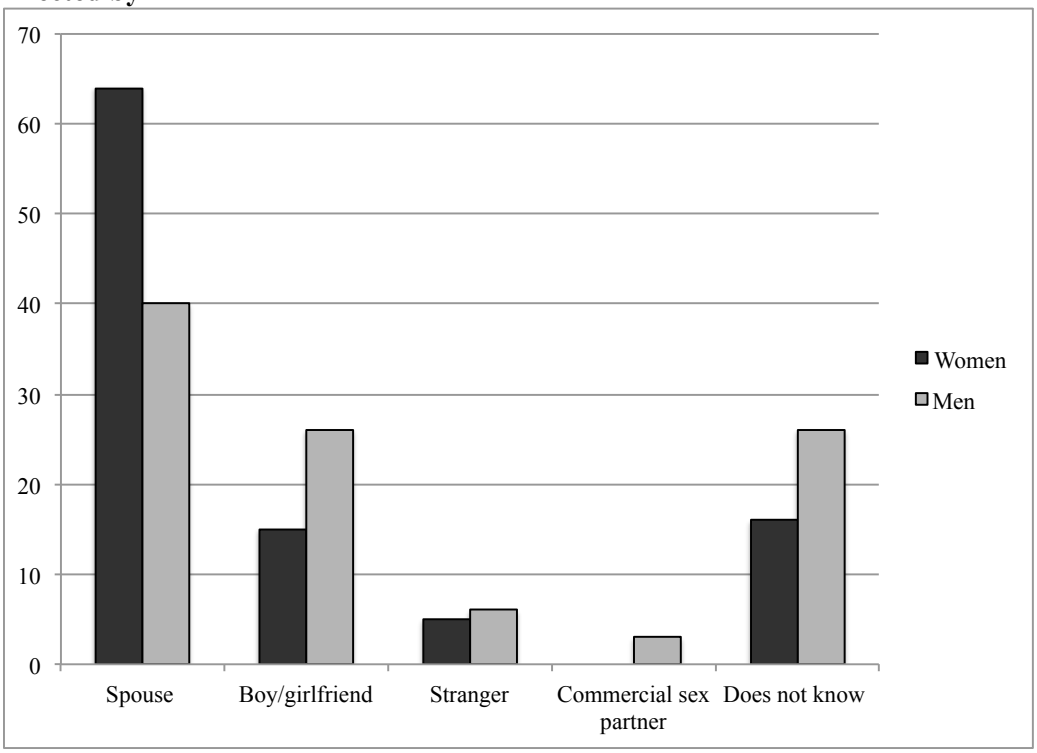
The second reason marriage can be risky is that married individuals are much less likely to use condoms than their unmarried counterparts. Married couples will inevitably have sex without condoms to conceive. Uganda is a high-fertility society, with a total fertility rate of 6.2 in 2011 (MEASURE DHS 2012b), the fourth highest in the world. Aside from interfering with reproductive ambitions, condoms are also less acceptable in marriage, as asking for a condom can signal a lack of trust: "Rather than using a condom as an element of safe sex, men and women commonly strive to avoid using condoms to demonstrate that the sex they are having is already safe sex" (Hirsch et al. 2009, 19). Scholars have even gone so far as to call condoms "intruders" in marriage (Chimbiri 2007). In countries that have seen an increase in condom use, this has mainly been driven by single women's behavior change (Cleland, Ali, and Shah 2006). One study in Jinja district in Uganda did find an increase in consistent use of condoms among married couples between 1998 and 2008, but the levels remain staggering low: consistent condom use increased from 1.1 to 8.3% among married men, and from 4.0 to 8.6% among married women (Maharaj et al. 2012). It is clear that condoms are not a viable HIV prevention option for married couples, nor is abstaining from sex. For these reasons, married men and women may be at risk of acquiring HIV from their spouse.

The third factor driving HIV risk in marriage is the prominence of EMPs. In 2011, 2.7% of married women and 25.9% of married men reported more than one sexual partner in the

previous 12 months (MEASURE DHS 2012b).[2] Each new EMP represents a new opportunity for HIV to enter into marriage. A husband or wife may not even know they are at risk of HIV if they are unaware of their partner's EMPs. However, there is some evidence that men and women are very aware of the HIV risk within marriage; Figure I.5 shows that the largest percentage of HIV-negative married men and women in Uganda thought their spouse was the most likely person to infect them.

These three factors combine to make marriage an important context for HIV transmission. It is for these reasons that this dissertation focuses on marital partnerships as the subject of investigation.

Figure I.5: Who HIV-negative married men and women think they are likely to be infected by



Data source: Uganda AIDS Indicator Survey (2011)

[2] Some of men's additional partners may be other wives in a polygynous union.

Chapter Summaries

I have organized my dissertation into three chapters. Chapter one focuses on the importance of married men and women to the HIV epidemic. First, I examine whether married men and women are more or less likely to acquire HIV than unmarried men and women. Second, I measure the different ways in which married men and women become infected with HIV. I find that the majority of new HIV infections occur among married men and women, even though the incidence rates are lower in marriage. Among married people, the majority of incident cases are attributable to EMPs, even though the incidence rates are highest among serodiscordant couples. Since ART became available, the relative importance of HIV transmission due to EMPs has increased.

Chapter two then looks at the HIV status of couples at marriage formation. In the first part of the chapter, I present the first evidence of serosorting in a generalized epidemic setting, showing that men and women are more likely to marry someone of the same HIV status as themselves. The second part of this chapter uses a mixed-methods approach to investigate the direct and indirect selection mechanisms that drive serosorting. I find no evidence that other factors associated with partnership choices (e.g., age, education, ethnicity, and marital histories) result in serosorting. Ruling out indirect selection, this paper presents qualitative evidence of a direct preference for partners of the same HIV status.

Chapter three describes the relationship between HIV status and marriage transitions both before and after the availability of ART. I find that patterns of marriage formation and dissolution are highly dependent on HIV status, but also display changes following the introduction of ART. Historically, unions with an HIV-positive partner had higher dissolution rates via both widowhood and divorce, and the remarriage rate of HIV-positive men and women

tended to be lower than those of HIV-negatives. Since the introduction of ART, seroconcordant positive unions have stabilized and the remarriage rate of HIV-positive men has increased. The availability of treatment does not seem to have affected the divorce rate in serodiscordant couples, or the remarriage rate of HIV-positive women. In the conclusion, I lay out some of the implications these findings have for HIV research and policy.

Together, these chapters reveal the growing importance of marriage in the HIV epidemic in Uganda, and how HIV is changing marriage. They also document important changes occurring over time with the rollout of ART, and the ways in which the pathways to infection and the social repercussions of HIV are beginning to shift.

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Chapter 1

Marriage matters: HIV incidence in a generalized epidemic

CHAPTER SUMMARY: This paper examines how important HIV transmission among married men and women is to the overall HIV epidemic before and after the availability of antiretroviral therapy (ART) in rural Uganda. The first aim of this paper is to determine if married men and women are more or less likely to acquire HIV than unmarried men and women. The second aim of this paper is to understand how married men and women become infected with HIV. Using data from two demographic surveillance sites in southwestern Uganda, I measure changes in incidence rates and the share of new infections by marital status from 1999-2011. I find that HIV incidence rates are often much higher in never or formerly married women, and formerly married men, compared to married men and women. However, these marital status categories contribute a minority of the new infections. The expansion of HIV treatment programs is associated with a decline in the incidence rates of married men and women, but they continue to account for the largest share of new infections.

Developing a conceptual framework for understanding HIV transmission within marriage, I then isolate the different transmission pathways through which one or both spouses become infected. Within marriage, the majority of incident cases are attributable to extra-marital partnerships, even though the incidence rates are highest among serodiscordant couples. Since ART became available, the incidence rates among serodiscordant couples have declined, and the relative importance of HIV transmission through extra-marital partnerships has increased. The large and growing role of seroconcordant negative married couples in new HIV infections reflects not only a changing epidemic, but also the limits of our current prevention strategies.

1.1 INTRODUCTION

Casual partnerships are important in the spread of HIV in the early stages of an epidemic, but as the epidemic matures, and as men and women modify their behavior with casual partners, more HIV transmissions are thought to occur in long-term partnerships (Gregson and Garnett 2000). Such a change may now be occurring in Uganda: a modeling study conducted by the Ugandan AIDS Commission suggests that the majority of new HIV infections occur in long-term partnerships (Wabwire-Mangen et al. 2009). However, this modeling work has not been subjected to peer-review nor verified by empirical estimates. It is unknown how important HIV incidence among married people is to the overall epidemic in Uganda. This paper therefore addresses two main questions to understand HIV risk among married men and women: First, are married men and women more or less likely to acquire HIV than unmarried men and women? Second, what are the different pathways through which married men and women become infected?

Using data from two rural Ugandan study sites, I analyze HIV incidence by marital status from 1999-2004, and from 2005-2011. Analyzing differences in HIV incidence over time is necessary to identify changes resulting from HIV interventions: antiretroviral therapy (ART) became available in the study sites in 2004, and male circumcision has been widely promoted following evidence of its success in three randomized-control trials between 2005 and 2007 (Auvert et al. 2005; Bailey et al. 2007; Gray et al. 2007)[3]. HIV awareness and testing may also have increased over time in Uganda, changing HIV risk behaviors.

If marriage is playing an important role in the transmission of HIV, it is important that we understand how husbands and wives are acquiring HIV, and whether this is also changing over time. There are two potential ways that HIV might enter marriage: the first is through serodiscordance at partnership formation, and the second through extra-marital partnerships (EMPs). I develop a conceptual framework that identifies all of the possible transmission pathways associated with both serodiscordant transmission and extra-marital related transmission. I then measure HIV incidence related to serodiscordant partnerships, and HIV incidence that can be attributed to EMPs, based on the observable sequence of HIV seroconversions.

Understanding the role of marriage in a maturing HIV epidemic is necessary to ensure that HIV programs are being accurately targeted. However, current HIV prevention approaches do not adequately address the needs of married men and women. Conventional behavioral prevention strategies, such as abstinence and condom use, are unlikely to be viable options in marriage. Likewise, popular new biomedical prevention strategies, such as pre-exposure prophylaxis (PrEP), are also not scalable for all married couples, particularly where married

[3] The three RCTs found that circumcision reduced the risk of acquiring HIV among men by approximately 60%. Circumcision is now considered one of the most effective, and proven, HIV prevention methods.

couples make up the majority of the adult population. We need to develop new prevention tools that meet the needs of married couples, and the first step toward doing this is understanding HIV risk within marriage.

1.2 *BACKGROUND*

1.2.1 HIV risk and marriage

Most of what we know about HIV and marriage comes from research on how HIV prevalence varies across marital status groups. For example, De Walque and Kline (2012) analyzed Demographic and Health Survey data from 13 countries in Sub-Saharan Africa and found that formerly married men and women have higher HIV prevalence than both never married and married people. HIV prevalence captures the cumulative exposure of a population, while marital status is normally measured at the time of data collection. HIV-positive men and women may transition in and out of marital status groups at a different rate than HIV-negative men and women, overstating the relative risk of certain marital statuses. HIV incidence data is therefore necessary in order compare HIV risk across marital status groups.

One recent study that measured HIV incidence found that married women had lower incidence rates than both formerly married and never married women, while married men's incidence rates were lower than formerly married men's rates, but similar to those of never married men (Nalugoda et al. 2014). Despite married men and women having lower incidence rates, the Ugandan AIDS Commission modeling study on the modes of transmission suggested that 43% of new HIV infections in adults in 2008 occurred in monogamous long-term serodiscordant relationships (Wabwire-Mangen et al. 2009). One potential reason for the large

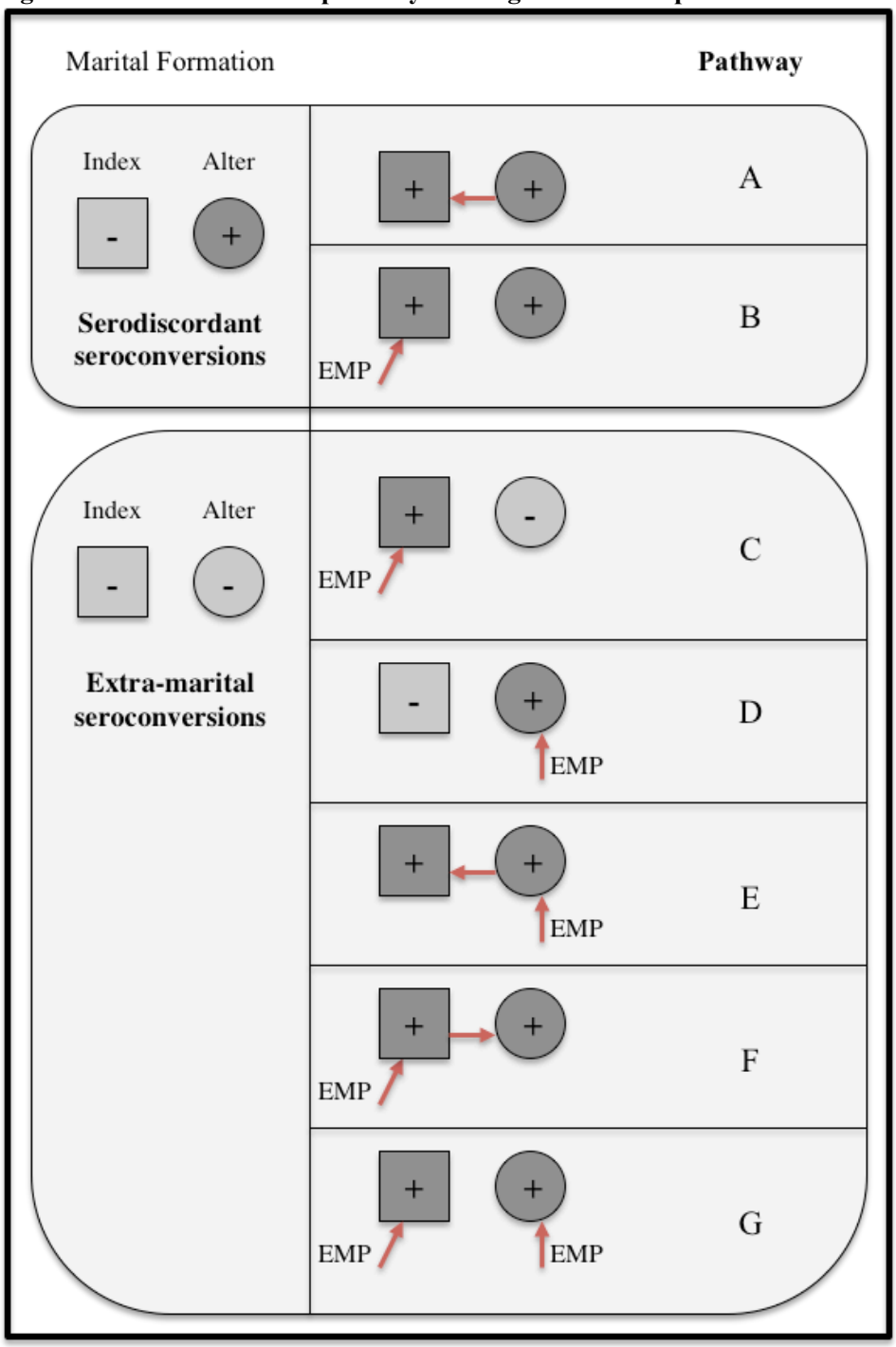
share of infections occurring in long-term relationships is that the overwhelming majority of men and women in Uganda marry: In 2011, 97% of women and 99% of men 35 years and older in Uganda have ever been married (MEASURE DHS 2012). Even with lower incidence rates in marriage, the larger number of married men and women can lead to more HIV cases compared to other marital status groups.

1.2.2 Pathways to infection in marriage: a conceptual framework

New HIV infections within marriage can be further broken down into different seroconversion pathways. Figure 1.1 presents a framework for understanding HIV transmission within marriage, outlining seven possible pathways through which HIV can enter marriage. The spouse whose seroconversion is being analyzed is considered the index, and his or her marital partner is the alter. For example, in measuring married women's seroconversions, the index refers to the wife and the alter refers to the husband.

HIV infections that occur among originally serodiscordant marriages are classified as serodiscordant seroconversions (Pathways A and B). HIV infections that occur among originally seroconcordant negative couples are classified as extra-marital seroconversions (Pathways C-G) as one, or both partners must have had an extra-marital partnership for HIV to enter marriage. There are extra-marital transmissions that occur among couples that were initially serodiscordant and intra-marital transmissions that occur among couples that were initially seroconcordant negative but one spouse subsequently seroconverted. I classify seroconversions using HIV status at first observation, as without tracing viral strains I cannot differentiate between some of the potential pathways (e.g. Pathway A and B).

Figure 1.1: Seroconversion pathways among married couples



Note: These pathways are exhaustive and mutually exclusive. EMP's refer to extra-marital partnerships. Arrows refer to the direction in which HIV is transmitted. This schematic breakdown of seroconversion pathways holds for polygynous marriages if every non-dyadic HIV transmission pathway is further broken down into a transmission from an EMP or a transmission from an OMP (Other Marital Partner).

1.2.3 Pathways to infection in marriage: evidence

Serodiscordant seroconversions

Initial modeling studies of urban populations in Zambia and Rwanda found that 55 to 93% of new HIV infections in adults were due to serodiscordant marriages or cohabiting partnerships (Pathway A or B), with the estimate varying by sex and location (Dunkle et al. 2008). More recent modeling studies have produced much lower estimates (Chemaitelly et al. 2013; Bellan et al. 2013). For example, Chemaitelly et al. (2013) found that across 20 countries 10-52% (mean 29.3%) of new infections occurred within serodiscordant partnerships. The share of HIV infections within serodiscordant partnerships was lower in higher prevalence settings. Kenya, (the country in their sample most comparable to Uganda, with an HIV prevalence of 6.36%), had 25.8% of new infections occur in serodiscordant partnerships.

Some studies have differentiated Pathways A and B (Figure 1.1) by identifying the share of external transmissions. For example, one virology study found that 18.4% of seroconversions in serodiscordant partnerships came from outside of the marital partnership (Eshleman et al. 2011), while another study of viral linkages found 26.5% of seroconversions among serodiscordant couples were not from respondents' marital partners (Campbell et al. 2011). Accounting for epidemic size, Chemaitelly and Abu-Raddad (2013) estimated that in intermediate prevalence countries (the category in which Uganda would fall), 4.9-11.7% of seroconversions among serodiscordant couples were the result of external transmissions. Together, this research reveals that we cannot assume all seroconversions in serodiscordant couples are the result of intra-marital transmission.

The relative importance of seroconversions among serodiscordant couples may also be changing over time. With the rollout of ART, HIV-positive partners may be more likely to know

their status and be on treatment, reducing the likelihood that they will transmit the virus to their HIV-negative spouse. Empirical estimates of the share of HIV incidence cases that occur in serodiscordant couples dropped from 18.3% before ART became available to 13.7% after ART (Gray et al. 2011). However, Gray et al. only analyzed incident cases in two short survey intervals, and did not explore differences by the sex of the seroconverting spouse. Despite these limitations, the findings suggest that serodiscordant couples' share of HIV incidence is lower than modeling studies have suggested, and decreased since the rollout of ART.

Extra-marital-related seroconversions

While it is hard to untangle pathway A from pathway B, it becomes even more complicated to differentiate the pathways through which seroconcordant negative couples become infected. Modeling work estimating the share of new HIV cases that are directly the result of extra-couple transmission (the index's seroconversion in pathways C, F, and G, and the alter's seroconversion in D, E and G) found that these infections accounted for 27-61% of men's and 21-51% of women's incidence across 18 countries in sub-Saharan Africa (SSA) (Bellan et al. 2013).

The primary challenge to measuring extra-marital-related seroconversions is the reliability and validity of EMP reports. Reporting EMPs is common among men in Uganda, but less so among women; in 2011, 25.7% of married or cohabiting men but only 1.3% of married or cohabiting women reported two or more sexual partners in the previous 12 months (MEASURE DHS 2012). Estimates for the prevalence of EMPs are likely biased, with 'swaggering' men overreporting their number of sexual partnerships and 'secretive' females underreporting their sexual partners (Nnko et al. 2004). Measurement of EMPs is also sensitive to the method of data

collection (Caraël and Kretzschmar 2012; Morris and O'Gorman 2000; Eaton, McGrath, and Newell 2012; Nelson et al. 2007; Glynn et al. 2012). Due to misreported EMPs and changing data collection methods, we know very little about changes in EMP-related seroconversions over time.

One way to get around the limitations imposed by self-reported EMPs is to group pathways C to G based on observed seroconversion sequencing, ignoring self-reported sexual behavior. Table 1.1 re-categorizes the pathways in Figure 1.1 into *observable* pathways based on the timing in which the index and the alter spouse seroconvert. Pathway #1 includes all seroconversions among couples that were serodiscordant. Pathways #2 to #4 are among couples that began seroconcordant negative, but had different timings of seroconversions. Pathway #2 occurs when the index spouse seroconverts while the alter is still HIV-negative. In the absence of data errors, this pathway can be defined as an extra-marital transmission. Pathway #3 occurs when the alter seroconverts first and the index spouse seroconverts in a later period. This pathway temporarily becomes serodiscordant, but it is labeled as extra-marital because the index spouse would not have been exposed to HIV in the absence of an EMP. Pathway #4 occurs when both the alter and the index spouse seroconvert in the same period. It is not possible to tell which partner brought HIV into the marriage, or if both partners became infected from an EMP. These observed pathways are the framework through which this paper analyzes how HIV enters marriage in rural Uganda.

Table 1.1: Observed pathways of seroconversion among married men and women (based on all potential pathways in Figure 1.1)

Observed pathways	Actual pathway	Definition
#1	A + B	Serodiscordant (can not differentiate A and B without linked viral data)
#2	C + F(time gap)	Index-first (includes F if the index seroconverts in a time period before the alter)
#3	E (time gap)	Alter-first (includes E if the alter seroconverts in a time period before the index)
#4	E + F + G	Both seroconvert (includes E, F and G if both the alter and the index seroconvert in the same time period)

Note: Pathway D is excluded as these observed pathways are constructed to calculate the different ways the index spouse becomes infected. In Pathway D, only the alter becomes HIV-positive.

1.3 DATA

The data come from two rural community sero-surveillance surveys in southwestern Uganda: the General Population Cohort (GPC) study conducted by the Medical Research Council and the Uganda Virus Research Institute (MRC/UVRI) in Masaka district, and the Rakai Community Cohort Study (RCCS) conducted by the Rakai Health Sciences Program (RHSP) in Rakai district. They are both open-cohort studies with longitudinal data on marital histories, linked partnerships, sexual behavior and HIV incidence. The Masaka study was established in 1989 and now covers all adults 15 years and older in 25 villages. Details of the Masaka cohort profile and study methodology have been described elsewhere (Nunn et al. 1997; Nakibinge et al. 2009; Asiki et al. 2013). I use all linked marital partnerships in the GPC, providing a sample of 5,300 marriages from 1999-2011. The Rakai study was established in 1994 and covers 50 villages with approximately 16,000 adults between 15 and 49 years of age. Details of the cohort have also been described in previous work (Sewankambo et al. 1994). There are 12,403 linked marital partnerships in the RCCS sample from 1999-2011.

Couples are included in the analysis if both partners were residing in the study site and had non-missing HIV status data at first observation. Blood specimens were collected in both study sites and tested for HIV antibodies using two independent enzyme-linked immunosorbent assays, and positive results were confirmed with a Western blot test (Asiki et al. 2013; Mbulaiteye et al. 2002). The irreversible nature of HIV infection allows for backwards imputation of negative HIV status, and forward imputation of positive HIV status. When HIV status was missing in rounds between a negative and a positive HIV test, I assume that HIV seroconversion occurred at the mid-point of the interval for missing data gaps of three years or less. When the gap between a negative and a positive HIV test was greater than three years, I impute a negative HIV test forward by a maximum of two person-years, and a positive HIV backwards a maximum of two person-years. Appendix 1C presents evidence that the findings in this chapter are not sensitive to this method of imputation.

Table 1.2: HIV status of couples at first observation in the study site

Rakai (N=12,403)		Husband's HIV status		
		Negative	Positive	Unknown
Wife's HIV status	Negative	**8,938**	**567**	656
	Positive	**569**	691	113
	Unknown	552	115	202

Masaka (N=5,300)		Husband's HIV status		
		Negative	Positive	Unknown
Wife's HIV status	Negative	**3,284**	**154**	909
	Positive	**137**	143	81
	Unknown	474	45	73

Note: First observation refers to couples being present in the study site in 1999, forming a marriage together after 1999, or migrating into the study site together. Bolded numbers represent couples whose seroconversion pathways are followed, as either one or both partners can seroconvert.

Table 1.2 shows the HIV status of all couples at first observation, including unknown HIV status. I exclude couples with incomplete HIV status information at first observation from the analysis, which accounts for 13.2% of married couples in Rakai (N=1,638), and 29.8% of married couples in Masaka (N=291). Table 1.3 shows the study sample characteristics, compared to the characteristics of couples with incomplete HIV information. There are some statistically significant differences between the study sample and those excluded, but these differences are not consistent across the two study sites. For example, men in marriages with incomplete HIV information were more likely to report an EMP in Rakai, but less likely in Masaka. Only the RCCS measured the perceived likelihood that one's spouse is HIV-positive. Respondents in Rakai with incomplete HIV information were less likely to think their spouse was HIV-positive, suggesting that those with incomplete HIV status information may have had lower risk of HIV infection than the study sample if their perceptions were accurate.

Table 1.3: Characteristics of couples with known HIV status at first observation compared to couples where one or both partners had unknown HIV status at first observation

	Rakai		Masaka	
	Study sample	**Unknown HIV status at first observation**	**Study sample**	**Unknown HIV status at first observation**
Observations	10,765	1,638	3,718	1,582
Joined study 2005-2001	29.4%	23.2% ***	62.6%	74.0%***
Polygynous marriage	25.3%	39.8%***	19.2%	28.1%***
Wife's Characteristics				
Age				
15-24	54.1%	50.8% ***	40.1%	37.3%
25-34	31.7%	30.1%	28.6%	31.6%
35-44	11.4%	13.4%	15.6%	15.2%
45-54	2.7%	4.8%	9.6%	9.5%
55+	0.2%	0.8%	6.1%	6.4%
Ethnic group				
Muganda	68.5%	61.2% ***	61.1%	65.1%*
Munyankole	6.4%	5.9%		
Munyanrwanda	13.2%	19.4%	14.1%	11.3%
Other	11.9%	13.6%	10.7%	9.1%
Unknown			14.1%	14.4%
Religion				
Christian	82.8%	83.6% ***	67.3%	65.5%
Muslim	16.3%	15.7%	22.7%	23.7%
None/Other	0.9%	0.6%	10.0%	10.8%
Education				
No education	9.3%	15.0% ***	14.6%	10.2%***
Primary	66.4%	66.1%	66.7%	67.2%
Secondary or more	24.3%	18.8%	18.7%	22.7%
Extra-spousal partnership	3.6%	3.5%	2.2%	1.2%*
Sexual partners in last 12 mnths				
1	93.9%	94.5%	95.4%	97.7%
2	5.4%	5.3%	3.9%	2.0%
3+	0.7%	0.3%	0.7%	0.3%
Condom use				
Never	49.9%	52.4%		
Sometimes	46.4%	43.5%		
Always	3.7%	4.1%		
Ever			12.2%	11.6%
Perceived likelihood spouse is HIV-positive				
Very likely	15.1%	13.3% ***		
Somewhat likely	36.5%	31.1%		
Unlikely	40.7%	45.5%		
Not at all	7.7%	10.1%		

Table 1.3 cont'd:

	Rakai		Masaka	
	Study sample	**Unknown HIV status at first observation**	**Study sample**	**Unknown HIV status at first observation**
Husband's Characteristics				
Age				
15-24	24.2%	17.8% ***	17.3%	14.2%
25-34	44.7%	40.9%	34.6%	34.6%
35-44	21.1%	22.6%	20.2%	23.5%
45-54	7.0%	10.6%	11.7%	11.5%
55+	3.1%	8.2%	16.2%	16.2%
Ethnic group				
Muganda	78.0%	75.0% ***	62.1%	63.0%
Munyankole	3.3%	2.2%		
Munyanrwanda	8.8%	12.5%	11.5%	86.1%
Other	9.9%	10.4%	11.3%	11.7%
Unknown			15.1%	16.4%
Religion				
Christian	80.8%	78.1%	68.1%	63.0%**
Muslim	18.1%	21.0%	23.2%	24.0%
None/Other	1.0%	0.9%	87.2%	12.1%
Education				
No education	5.1%	8.2% ***	7.7%	5.9%
Primary	64.3%	66.9%	66.8%	71.1%
Secondary or more	30.5%	24.9%	25.6%	23.0%
Extra-spousal partnership	48.1%	53.5% ***	15.4%	11.9%**
Sexual partners in last 12 mnths				
1	48.0%	43.9%*	63.4%	67.2%
2	34.4%	37.4%	24.1%	23.3%
3+	17.7%	18.7%	12.5%	9.6%
Condom use				
Never	49.9%	52.4%		
Sometimes	46.4%	43.5%		
Always	3.7%	4.1%		
Ever			16.6%	9.4%***
Perceived likelihood spouse is HIV-positive				
Very likely	2.3%	1.1% *		
Somewhat likely	22.7%	18.6%		
Unlikely	68.1%	70.8%		
Not at all	7.0%	9.6%		
Circumcised	7.3%	6.0%		

*** p<0.001, ** p<0.01, * p<0.05

Note: Asterisks denote statistically significant differences between the study sample and respondents with an unknown HIV status at first observation.

1.4 METHODS

The first part of this analysis measures changes in HIV incidence by marital status in the Masaka and Rakai study sites from 1999-2011. I calculate HIV incidence rates, as well as the share of total incidence, among never married, married and formerly married men and women. I examine changes over time, comparing HIV incidence in the pre-ART time period (1999-2004), to the post-ART time period (2005-2011).

Marital status transitions are assumed to occur at the mid-point of the interval, such that a woman entering into a first marriage is assumed to have contributed half the person-time between survey intervals to never married exposure and half to married exposure. When a new HIV infection occurred during a survey round with a marital transition, I attribute it to the newly reported marital status in that survey round.

To test for differences between the pre- and post-ART time periods, I use a Poisson regression model to calculate incidence rate ratios (IRR) for men and women, with marital status as the primary predictor of interest. The estimated IRR is used to compare the relative difference between two incidence rates. For example, the IRR for married women = (incidence rate for married women) / (incidence rate for never married women), where never married women are the reference group. I include a time-period interaction to test for changes in the IRR between 1999-2004 and 2005-2011. The model includes person-years as an offset, and demographic variables (age, ethnicity and religion) as controls. I do not include sexual behavior controls as there is much more missing data on sexual behavior questions for unmarried respondents. However, circumcision information is available for Rakai and included as an additional control in a nested model.

After comparing the HIV incidence among married men and women to unmarried men and women, the second part of this paper analyzes the different pathways through which HIV enters marriage. I follow all married men and women, and identify the seroconversions that occur in each of the four pathways outlined in Table 1.1. I follow all couples from the time they are first observed in the study site, rather than from the point of marital formation. First observation is defined as the first time the couple is reported married in the study site, either in 1999, at marriage formation, or through in-migration.

Tracing the seroconversion pathways in marriage becomes more complicated when taking into account non-dyadic unions, such as polygyny. Polygyny was reported by 25% of men in Rakai, and 19% of men in Masaka. Polygynous men can become infected through external transmission from either an EMP or other marital partner. To take this into account, I measure men's incidence pathway based on whether any of their wives seroconverted. For example, if an HIV-negative man had one HIV-positive wife and one HIV-negative wife at first observation, he is classified as being in a serodiscordant union. If all of a polygynous man's wives were HIV-negative at first observation, I determine his seroconversion pathway by the marital partnership in which a seroconversion first occurred. For example, if a husband and one of his wives both became positive in the same year, and another wife the following year, the husband's seroconversion trajectory is characterized as pathway #4, as the first wife to seroconvert did so at the same time as her husband.

1.5 RESULTS

1.5.1 HIV incidence by marital status

HIV incidence rates over the 13 years were higher in Rakai compared to Masaka: women's incidence in Rakai was 1.07 per 100 PY (95% CI: 0.99-1.15) and men's 0.90 (95% CI: 0.82-0.98), while the incidence rates in Masaka for women and men were 0.64 (95% CI: 0.55-0.73) and 0.54 (95% CI: 0.46-0.64), respectively (Table 1.4). As expected, HIV incidences rates declined in the two study sites between 1999-2004 and 2005-2011. ART was not the only substantial change between these two times periods: male circumcision and HIV testing also increased between these two time periods, potentially reducing HIV incidence rates. While I refer to this as the pre- and post-ART time periods, I do not claim that changes over time are due to only ART.

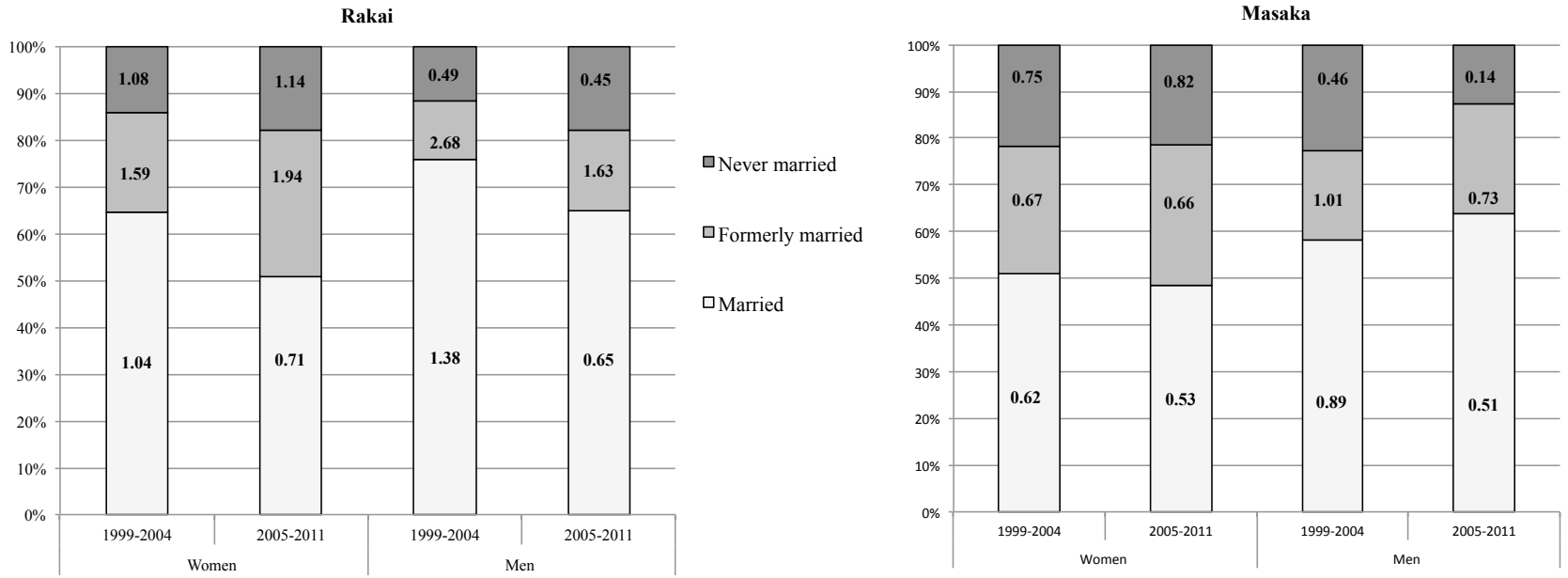
The majority of new HIV infections in both sites occurred among married men and women. Figure 1.2 shows the share of new HIV cases that can be attributed to each marital status group in the pre- and post-ART periods, with HIV incidence rates presented inside the bars. Before ART, 64.7% of women's new infections in Rakai, and 51.1% in Masaka, occurred among married women. Despite married women having a lower HIV incidence rate than both never married and formerly married women in the pre-ART period, they still accounted for the majority of women's new HIV infections. Even after ART, when married women's incidence rates declined, married women still accounted for the half of women's new HIV infections in Rakai and Masaka. Married men accounted for an even higher share of men's new infections than women before ART; married men accounted for 76.0% of new HIV infections in Rakai, and for 58.3% in Masaka. After ART became available, married men still accounted for 64-65% of new HIV infections.

Table 1.4: New HIV infections by sex and study site

	Rakai					
	Women			Men		
	1999-2004	2005-2011	All	1999-2004	2005-2011	All
HIV-negative at first observation	13,666	6,517	20,183	11,777	4,718	16,495
HIV-negative at start of period❖		10,672			7,720	
Seroconverions						
N	305	388	693	251	225	476
%	2.2%	3.6%	3.4%	2.1%	2.9%	2.9%
Person Years	24847.79	40146.75	64994.54	19462.58	33700.58	53163.17
Incidence rate (per 100 PY)	1.23	0.97	1.07	1.29	0.67	0.90
	(1.09-1.37)	(0.87-1.07)	(0.99-1.15)	(1.14-1.46)	(0.58-0.76)	(0.82-0.98)
	Masaka					
	Women			Men		
	1999-2004	2005-2011	All	1999-2004	2005-2011	All
HIV-negative at first observation	6,635	2,404	9,039	5,825	2,706	7,901
HIV-negative at start of period❖	6,635	7,310		5,825	6,932	
Seroconverions						
N	93	127	220	84	74	158
%	1.4%	1.7%	2.4%	1.4%	1.1%	2.0%
Person Years	14011.21	20584.96	34596.17	11259.67	17739.83	28999.5
Incidence rate (per 100 PY)	0.66	0.62	0.64	0.75	0.42	0.54
	(0.54-0.81)	(0.51-0.73)	(0.55-0.73)	(0.60-0.92)	(0.33-0.52)	(0.46-0.64)

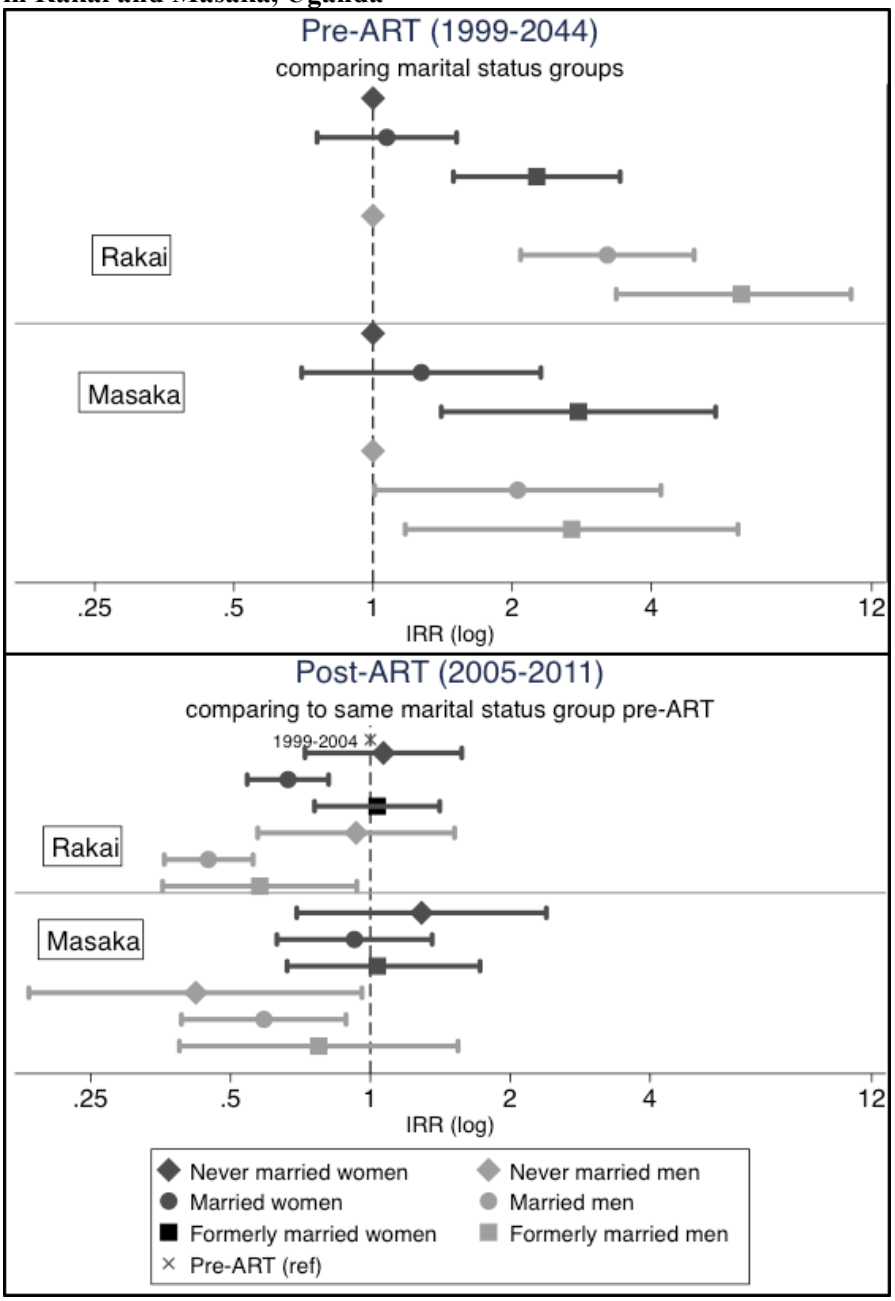
❖ HIV-negative at start of period includes those who were HIV-negative at first observation in 2005, as well as those from the 1999-2004 period who were observed HIV-negative at the start of 2005. HIV-negative individuals can contribute to both time periods.

Figure 1.2: The share of new HIV infections and incidence rates (per 100 PY) by marital status, sex, and study site



Note: The numbers in bars are the incidence rates by marital status. Detailed incidence rates and the share of new HIV infections are provided in Appendix 1A (Table 1A.1)

Figure 1.3: Incidence rate ratios (IRR) of HIV seroconversion among men and women in Rakai and Masaka, Uganda



Note: The pre-ART panel on the top presents IRRs that compare the incidence of each marital status group to the reference, never married men or women. The post-ART bottom panel presents coefficients that estimate the IRR between the 1999-2004 period to the 2005-2011 period for people of the same sex and marital status group. The site and sex specific models all included controls for age group, religion, and ethnic group.

Figure 1.3 presents plotted coefficients from the Poisson regression (Appendix 1A, Table 1A.2, Model 2) to test for changes in marital status incidence rates between the pre- and post-ART periods. The graph in the top panel for 1999-2004 shows IRRs that compare the incidence rate of each marital status group to the reference group of never married men or women in the same time period. The graph on the bottom for 2005-2011 compares the incidence rates for men and women of the same marital status between the two time periods.

In the 1999-2004 period, only formerly married women had a significantly higher incidence rate then never-married women, though both married and formerly married men had a higher incidence rate compared to never married men. Before ART, married men in Masaka were twice as likely, and in Rakai over three times as likely, to contract HIV than never married men (Rakai IRR = 3.253, 95% CI: 2.111-5.012; Masaka IRR = 2.057, 95% CI: 1.008-4.198). After ART became available, the incidence rate of married men in Masaka and Rakai, and of married women in Rakai, declined. (Rakai men IRR = 0.448, 95% CI: 0.360-0.559; Masaka men IRR: 0.590, 95% CI: 0.392-0.886; Rakai women IRR = 0.665, 95% CI: 0.543-0.813).

Before 2005, approximately 19-21% of men in Rakai reported being circumcised, but this increased to 32% by 2011. To control for circumcision among men in Rakai, I estimated a third model (Appendix 1A, Table 1A.2, Model 3). As expected, circumcised men had a 50% lower HIV incidence rate compared to uncircumcised men. Adding circumcision to the model did not change the marital status coefficients in either the pre or post-ART period. These results suggest that in Rakai marital status differences in HIV incidence were not being driven by differences in circumcision.

1.5.2 HIV incidence within marriage

Despite marital incidence rates declining after ART, the majority of new HIV cases still occurred among married men and women. To determine how these married men and women become infected, I measure the seroconversion pathways among all seroconcordant negative couples (N=8,938 in Rakai and N=3,284 in Masaka) and all serodiscordant couples (N=1,136 in Rakai and N=291 in Masaka). Figure 1.4 presents the share of all new HIV cases among married men and women by the observed pathways outlined in Table 1.1. Figure 1.5 presents the incidence rates for serodiscordant seroconversions (pathway #1), and extra-marital related seroconversions (pathways #2-#4). (See Appendix 1A for confidence intervals of incidence rates.)

While serodiscordant couples made up 9-12% of all couples that could have seroconverted, they made up between a 28-49% of all new HIV infections among married men and women from 1999-2004. For everyone but men in Rakai, there was a reduction in the share of new HIV cases that occurred in serodiscordant marriages after ART. Pathway #1 dropped from 48% to 30% of Rakai women's new HIV cases, from 40% to 25% among women in Masaka, and from 49% to 31% among men in Masaka. For men and women in both study sites, however, there was a substantial reduction in the incidence rate for serodiscordant seroconversions (Figure 1.5).

The largest share of marital HIV incidence among seroconcordant negative couples was through pathway #2, where the index spouse seroconverted first through an EMP. The percentage of new HIV cases that occurred through pathway #2 increased for Rakai women between the two time periods (24% to 36%), decreased for Rakai men (51% to 42%), and remained relatively stable in Masaka (38% to 41% among women and 49% to 47% among men).

However, with very few women reporting an EMP it is surprising that such a large share of married women's new HIV infections resulted from women engaging in EMPs (3.6% of Rakai and 2.2% of Masaka women compared to 48.1% of Rakai and 15.4% of Masaka men). One explanation for this difference could be misreporting of EMPs, which is discussed in Appendix 1B in detail.

Pathway #3, where the alter spouse seroconverted first, accounted for a larger share of married women's incident cases than married men's incident cases. In the post-ART period, more men and women were becoming infected in marriages in which their spouse had already seroconverted.

Pathway #4 applies when both spouses seroconverted at the same time, so it is not possible to identify which spouse had the EMP or if both spouses had an EMP. These cases accounted for 19-20% of women and men's new HIV cases in Rakai before ART, and 15-17% after ART became available. The share of new HIV cases occurring when both the index and the alter seroconverted in the same year was much lower in Masaka.

Together, pathways #2 to #4 accounted for a growing share of new HIV cases that occur among married men and women (aside from men in Rakai). EMP-related HIV incidence rates actually decreased between the pre- and post-ART periods (by 4% among women in Rakai, 58% among men in Rakai, 11% among women in Masaka, and 33% among men in Masaka).

Figure 1.4: The share of new HIV infections among married men and women in Rakai and Masaka

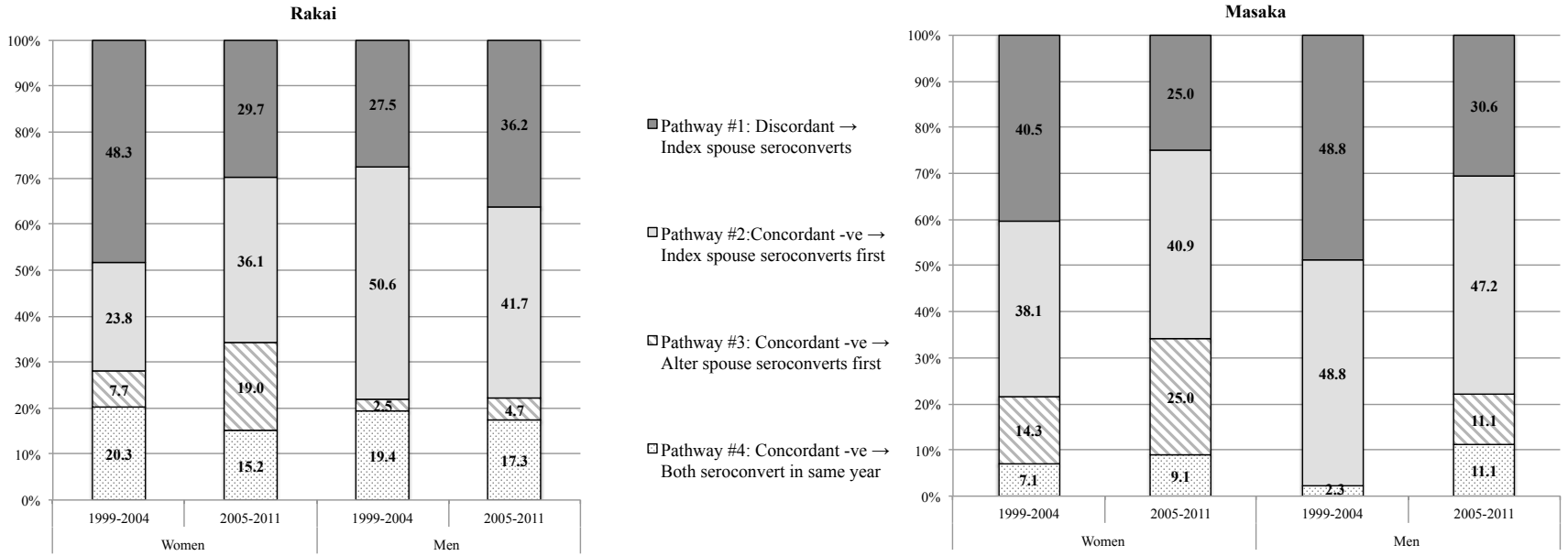
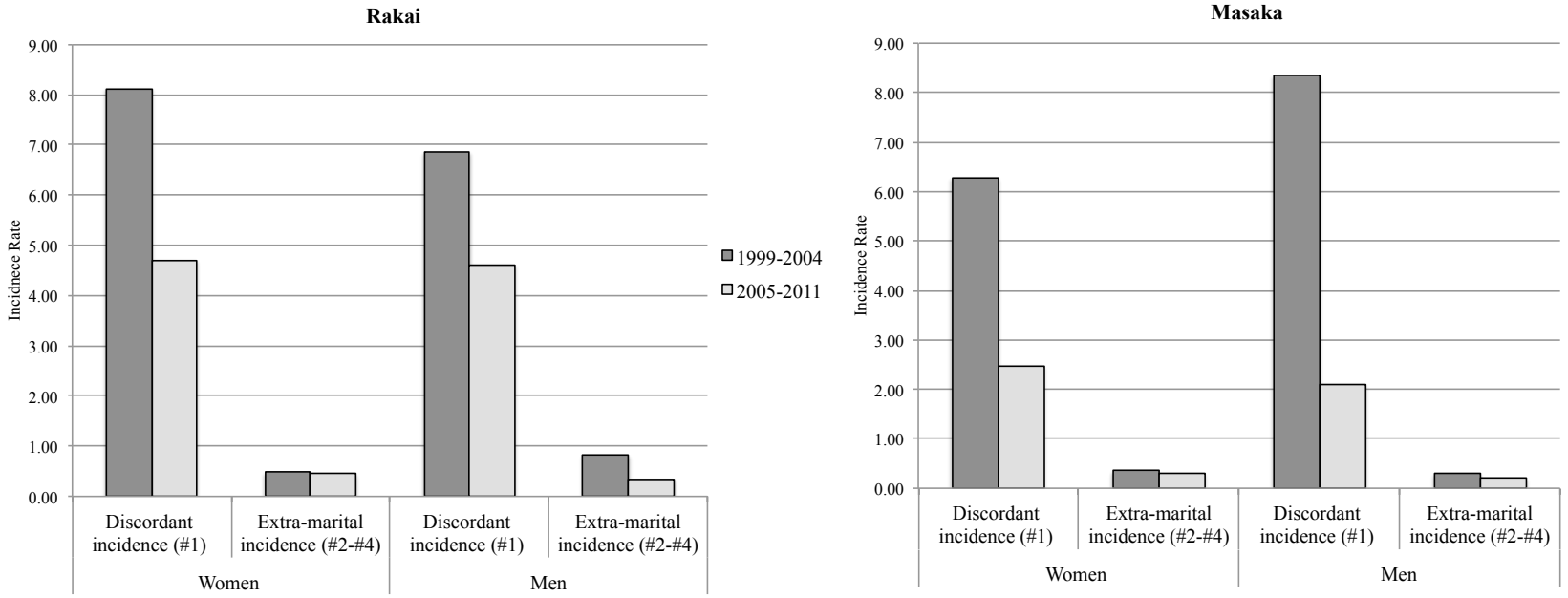


Figure 1.5: Incidence rates (per 100PY) by pathway of infection among married men and women in Rakai and Masaka



1.6 DISCUSSION

The majority of new HIV infections among men and women in Masaka and Rakai occur among married men and women, and that is primarily because men and women spend the most of their sexually active lives in a union. HIV incidence rates are often much higher in never or formerly married women, but these marital status categories contribute a minority of the new infections. The expansion of HIV treatment programs is associated with a decline in the incidence rates of married men and women, but they continue to account for the largest share of new infections.

Within marriage, the majority of incident cases are attributable to EMPs. While HIV incidence rates declined in the post-ART period for both serodiscordant and seroconcordant negative couples, the declines among serodiscordant couples were greater. This has resulted in fewer new HIV cases among serodiscordant couples, and the growing prominence of EMP-related transmissions among married men and women in the post-ART period.

The large and growing role of seroconcordant negative married couples in new HIV infections reflects not only a changing epidemic, but also the limits of our current prevention strategies. Couples that are serodiscordant at first observation are more likely to know they are serodiscordant, and the HIV-positive spouse may be more likely to seek treatment. As a result, the risk of HIV transmission in these marriages becomes minimal (Cohen, Shaw, et al. 2011). Seroconcordant negative couples, on the other hand, may not know that one or both partners have subsequently become HIV-positive unless they are testing frequently, or suspect they are at risk because they or their spouse had an EMP. The decreasing incidence rate and number of new infections among serodiscordant married couples suggests the HIV epidemic may be shifting from those infected for longer durations, to newly infected people transmitting the virus.

ART is unlikely to immediately impact marriages where infections occur as the result of EMPs. The first spouse to seroconvert is unlikely to know he or she is HIV-positive right away, and will not be eligible for treatment for a number of years. This poses a policy challenge as a greater number of new HIV cases occur among seroconcordant negative couples, where new infections may be harder to identify. Other prevention options, such as condoms or pre-exposure prophylaxis (PrEP), can reduce the number of new infections, but again, these interventions are more likely to be used in marriages where an HIV-positive partner is aware that he or she is infected and is therefore more likely to have been infected for a longer time. We do not currently have prevention tools to address the needs of newly infected people in what are considered the safest types of partnerships: marriages that start off seroconcordant negative.

When seroconcordant negative couples seroconvert, it is often assumed that men are the ones who brought HIV in from outside of the partnership. This assumption reinforces the paradigm of women's vulnerability to HIV, where men's sexual behaviors are seen to control and shape women's HIV risk (Higgins, Hoffman, and Dworkin 2010). However, in this analysis, men were not the only ones to bring HIV into the marriage. Women seroconverted while their husbands were still HIV-negative in 24% of women's new HIV infections in Rakai in the pre-ART period, and they seroconverted first in 36% of cases after ART. Likewise, women in Masaka seroconverted first in 38% of their new HIV infections pre-ART and 41% post-ART. These findings corroborate previous research from South Africa, where only the wife was HIV-positive in 1/3 of serodiscordant marriages with a migrant husband (Lurie et al. 2003). The results in this paper challenge the female vulnerability paradigm, showing that married men are not the only ones bringing HIV into marriage, and are not solely responsible for HIV-negative women's seroconversions. Characterizing HIV risk within marriage as exclusively the result of

men's infidelity ignores the real and sizeable risk posed by women's largely unreported EMPs (see Appendix 1.B).

Focusing on whether a spouse seroconverts as the result of his or her own or a partner's EMP misses the larger, and perhaps more important, point: without one or both partner's engaging in EMPs, there would not be any EMP-related incidence. The precise share of these incidence cases that is due to intra- versus extra-marital transmission is debatable, and worth exploring further in modeling studies. However, we can unequivocally state that men and women with EMPs are responsible for the majority of new HIV infections among married people in Rakai and Masaka, which translates into one-third to one-half of all new HIV cases among all adults. By getting caught up in the details of who infected whom, we lose sight of what we do know: in Uganda EMPs are the main source of new HIV infections among married men and women.

One of the primary limitations of this paper is that I rely on married couples' HIV status at first observation, not at marital formation. As a result, some couples are misclassified: some couples classified as serodiscordant may actually have been seroconcordant negative at marriage formation, while some couples first observed as seroconcordant positive may have been serodiscordant or even seroconcordant negative at the start of their marriage. Since one type of misclassification would lead to an overestimate of the share of infections due to serodiscordance, and the other an underestimate, it is unclear how this data limitation biases the results.

A second limitation of this paper is that it does not address the dynamics of how HIV enters and spreads within polygynous marriages. I tested and found no differences in the HIV incidence rates between monogamous and polygynous men, including EMP and serodiscordance-related incidence. However, it is worth exploring further whether there are

differences in HIV risk between men who started off and remained monogamous, and men who started off monogamous but became polygynous. For a monogamous man to marry a second wife, he has to go through the process of a new partnership search, and by definition will take on an EMP. Further research should examine not only the seroconversion pathways in non-dyadic unions, but also HIV risk in the time periods leading up to transitions to polygyny.

1.7 CONCLUSION

As the share of new infections due to serodiscordance decreases with the roll-out of HIV treatment, new infections as a result of EMPs will play a more important role in shaping the future of the HIV epidemic. These are also the infections that are harder to address, as people may not know they are HIV-positive. Prevention activities are needed to meet the unique needs of married couples, and especially to reduce the HIV risk associated with EMPs. While programs emphasizing fidelity, such as the zero-grazing campaign in Uganda in the 1990s, were initially successful (Green et al. 2006), their impacts were not sustained (Shafer et al. 2008). If men and women are reluctant to relinquish their EMPs, we will need to develop a new harm reduction approach, such as promoting risk-mitigating behaviors, such as condoms, with EMPs as a way of protecting oneself and one's spouse. Innovation is necessary to address the new face of the HIV epidemic in generalized epidemic settings, including the unique prevention requirements of married couples and the real and large risk EMPs pose.

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Chapter 2

Marital partnership selection and HIV seroconcordance in a generalized epidemic setting

CHAPTER SUMMARY: 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 sero-surveillance site in Southwestern Uganda to describe serosorting. Taking into account changes in population composition, I 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, I 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. I 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.

2.1 INTRODUCTION

Serosorting, where individuals select partners of the same HIV status as themselves, is a potentially important avenue for HIV prevention. Who people chose as their sexual partners, and the HIV status of those partners, determines whether or not a sexual partnership could result in 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.

Overlooking serosorting as an HIV prevention strategy may underestimate the impact of HIV programs. HIV testing and counseling (HTC), for example, is evaluated based on changes to individual risk behaviors such as condom use. However, HTC programs may also be impacting partnership decision-making. 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.

Serosorting can impact HIV transmission via individual and network level effects (Table 2.1). 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 (Reniers and Helleringer 2011). At the network level, 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.

Table 2.1: 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

Seroconcordant partnerships are the observed outcome of serosorting. These partnerships can emerge with or without a direct preference for a partner of the same HIV status. To emphasize this difference, I frame this paper around an important conceptual distinction 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 determines actual HIV risk. I use the terms serosorting and homogeneity on HIV status interchangeably. However, serosorting is not the same as homophily. 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, examining whether homophily on HIV status is a potential explanation of homogeneity.

The first part of this paper examines whether there is evidence of serosorting, or homogeneity on HIV status, 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. I use 13 years of longitudinal data on marital partnership formation and HIV status from a demographic surveillance site in rural southwestern Uganda. 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 homophily, where men and women have a direct 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.

2.2 BACKGROUND

2.2.1 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 a more achievable HIV prevention strategy.

Research on the HIV status of married couples in Sub-Saharan Africa has 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, the two studies by De Walque 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 surveillance site in rural Uganda.

2.2.2 Evidence of Homophily on HIV Status and Indirect Selection

Homophily on HIV status is one potential explanation for homogeneity on HIV status if people are directly selecting their partners because of their HIV status. However, homogeneity can also arise in the absence of homophily if indirect selection is occurring, where people choose their partners based on characteristics that are associated with HIV. Prior research suggests that both of these pathways may be important.

There is some evidence that people have a preference for the HIV status of a prospective partner. 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 identify antiretroviral therapy (ART) clinics and support groups as places where prospective partners meet.

Even with a preference for serosorting, HIV-positive and HIV-negative men and women may 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 all 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 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.

Homophily on HIV status may also be changing over time. ART became available from 2004 onwards in Uganda, altering the risk of having an HIV-positive partner. 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). With a decreased risk of HIV transmission in serodiscordant unions, homophily on HIV status may decline. However, HIV

clinics distributing ART may provide more opportunities for HIV-positive men and women to meet one another. Being on ART may also provide a shared experience that HIV-positive men and women can bond over. It is therefore possible that with the roll-out of ART, serosorting preferences among HIV-negative men and women may have gone down, while HIV-positive men and women may have greater preferences for serosorting.

2.3 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).

2.4 DATA

2.4.1 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 1,182 first marriages and 1,394 remarriages. Of those respondents reporting new marriages, approximately 74% marry partners within the study site, leading to 879 linked first marriages and 1,032 linked remarriages, providing a total sample of 1,911 marriages over 13 years.

2.4.2 HIV Status Imputation

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 conducted without imputation, with logical imputation and with limited-logical imputation. The findings are not substantially different (see Appendix 2A), so this paper only includes the limited-logical imputation results.

2.4.3 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. The spouses of sampled responses were not interviewed in an attempt to encourage more open and honest responses. 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 his or her interviews into English, providing detailed notes on context, gestures, and interpretations of local terms. A 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 these data is the insight the data provide 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 his or her name, a thumbprint was given and witnessed by an independent observer.

2.5 PART 1: EVIDENCE OF SEROSORTING

2.5.1 Analytic Methods

Collapsing all newly formed marriages together over 13 years, including both first marriages and remarriages, I 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, I 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 2.1). 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

(where Cm denotes seroconcordant marriages), 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 2.2.1 and 2.2.2. 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^M = 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.

$$p_e^{GH} = \frac{N_e^{Cm(H)}}{N_o^{GH}} \tag{2.1}$$

$$N_e^{Cm(+)} = (Pr(F^+) * Pr(M^+) * N_o^M) \tag{2.2.1}$$

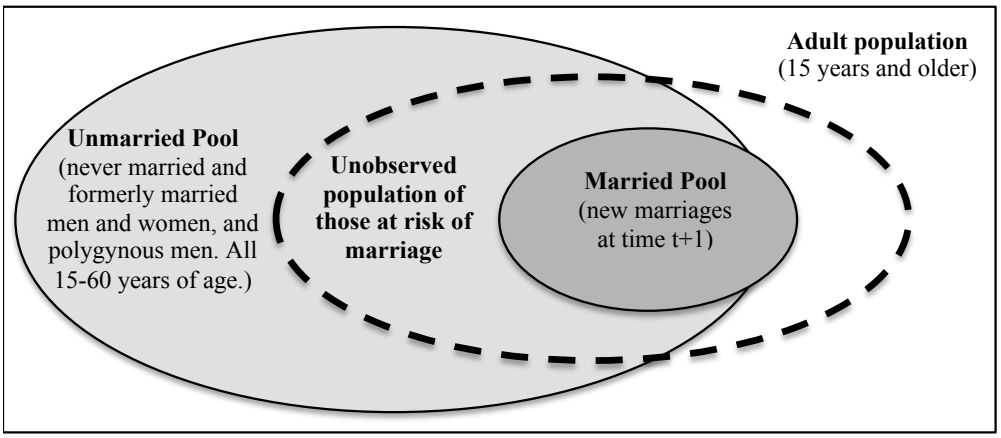
$$N_e^{Cm(-)} = (Pr(F^-) * Pr(M^-) * N_o^M) \tag{2.2.2}$$

To calculate the expected proportions of marriages types I make the assumption of random mixing. I assume that the risk of selecting an HIV-positive spouse is determined by the HIV prevalence among men and women that married in a given year. In reality, however, people choose their partners from a much larger pool of individuals, including those never married, formerly married, and polygynous men. 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. I 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 2.1 illustrates the relationship between the married pool, the unmarried pool and the real, but unobserved, population of those at risk of marrying. The majority of men and

women in the married pool come from the unmarried pool the previous year. However, the married pool is not completely nested in the unmarried pool: monogamous men are not included in the unmarried pool, but may transition to a polygynous marriage and enter the married pool. The real population of those at risk of marriage does not include everyone in the unmarried pool as not everyone who is unmarried may want to marry. In addition, some people not in the unmarried pool are likely to still be at risk of marriage, such as monogamous men who may become polygynous. Since we are unable to know everyone who might marry in a given year – and many people themselves may not know if they will marry – I rely on the observed married pool and unmarried pool.

Figure 2.1: Profile of adults exposed to the risk of marriage at time t=1 in the Unmarried Pool, Married Pool, and unobserved true population



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 2.2 presents descriptive characteristics of both samples.

Table 2.2: 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

It is necessary to adjust for group size in order to compare the level of homogeneity among HIV-positive and HIV-negative men and women. The population of HIV-negative people is much larger than HIV-positive people, resulting in a greater proportion of seroconcordant negative marriages. 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 2.3 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 here to reflect that it measures homogeneity, not homophily.

$$H_B^{GH} = \frac{(p_o^{GH} - p_e^{GH})}{(1 - p_e^{GH})} \tag{2.3}$$

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. 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 maximum 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 that both HIV-

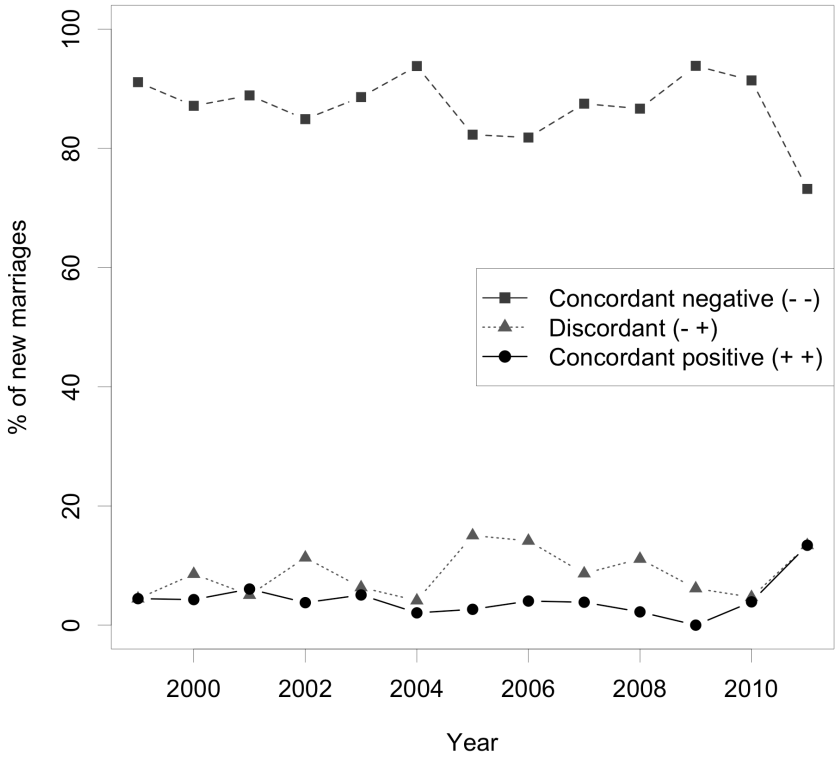
negative and HIV-positive men and women are more likely to form seroconcordant marriages, homogeneity bias in this study does not take on negative values, and is therefore not affected by this limitation. Given the large population size differences between HIV-positive and HIV-negative men and women, 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}, calculating H_B, and then constructing confidence intervals from the distribution H_B.

2.5.2 Results

The majority of marriages that occur each year are seroconcordant negative, accounting for 80-90% of new marriages across years (Figure 2.2). 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, and are statistically different from the percent of marriages before 2010 ($p<0.01$).

Figure 2.2: Percent of new marriages by couples HIV status (1999-2011)



I collapse all newly formed marriages over 13 years and present the proportion of new marriages to someone of the same HIV status, by respondents' HIV status and gender (Figure 2.3). Seroconcordant positive marriages are decomposed into those that one would expect if people were mixing randomly and the excess seroconcordant positive marriages. The excess is 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 2.3: Excess and expected seroconcordant marriages, 1999-2011

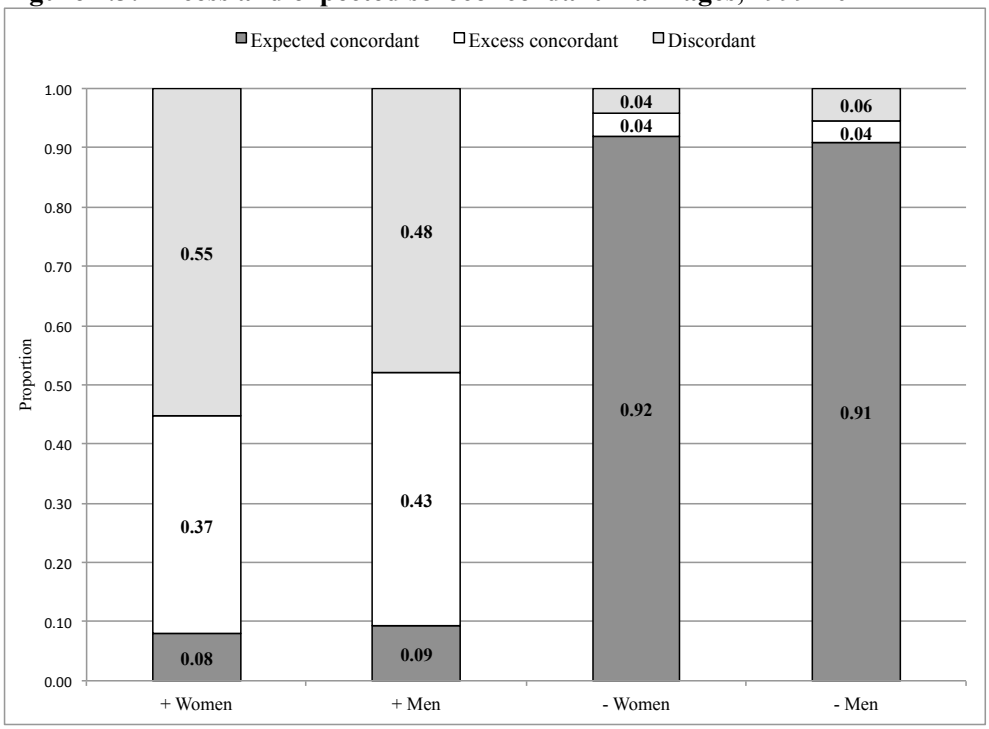
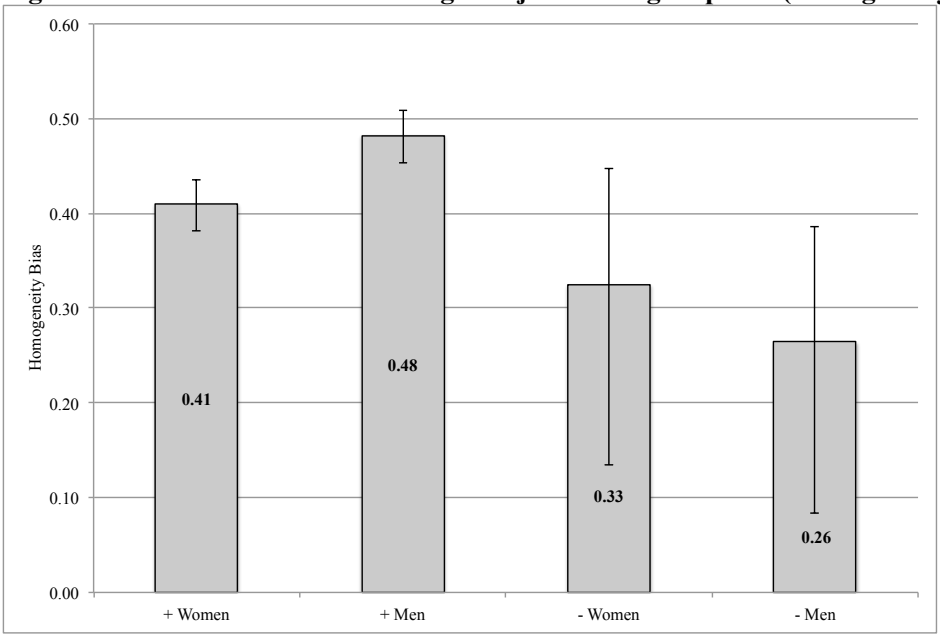


Figure 2.4 presents homogeneity bias for each group, or the normalized excess proportion of seroconcordant marriages. Men and women of both HIV statuses have a homogeneity bias far above zero, suggesting that there is a strong selection for seroconcordant marriages. Serosorting is greater among HIV-positive men and women compared to HIV-negative men and women. However, 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. As such, it is not possible to interpret homogeneity bias across groups in terms of statistically significant differences.

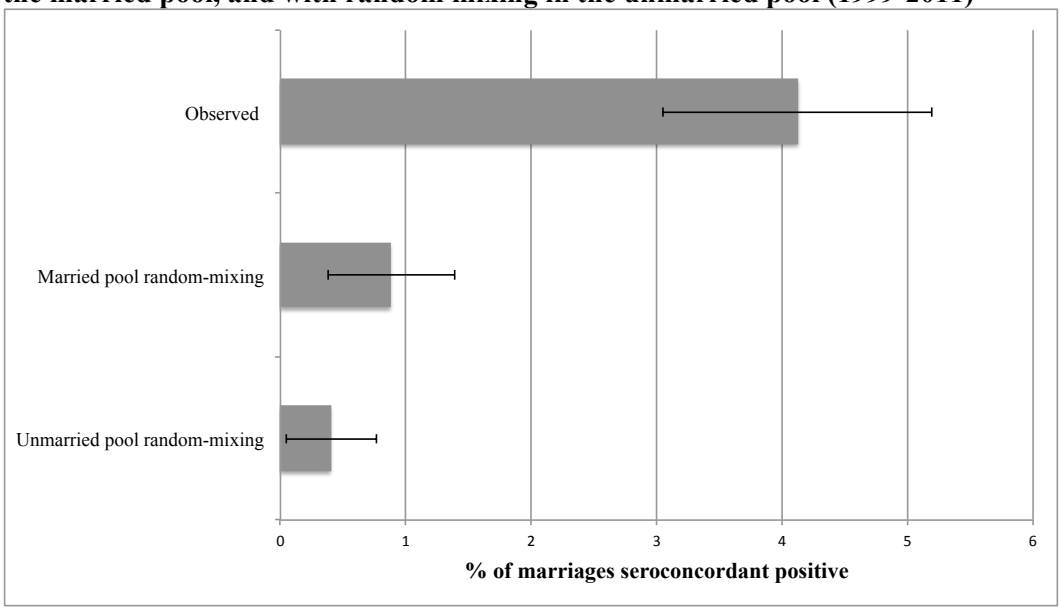
Figure 2.4: Seroconcordant marriages adjusted for group size (homogeneity bias), 1999-2011



Note: Homogeneity bias calculated using the expected proportion of seroconcordant partnerships in the unmarried pool. 95% confidence intervals are indicated by the lines in each bar.

Homogeneity bias was calculated using the expected proportion of seroconcordant marriages under the assumption of random mixing in the unmarried pool. Figure 2.5 displays the results of testing the sensitivity of this assumption by comparing the observed percentage of seroconcordant positive marriages with random mixing among those in the married and unmarried pools. Regardless of whether I use the married pool or unmarried pool, there are more seroconcordant positive marriages occurring than we would observe if people were forming their partnership at random.

Figure 2.5: 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 lines in each bar show the 95% confidence intervals that were constructed for the two random-mixing models.

This paper uses homogeneity bias to measure the degree 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 2.3 presents the results in this paper along with homogeneity bias on education and ethnicity in the GPC study site. There are two main ethnic groups in the area, the Baganda and Ugandans of Rwandese origin (individuals of these ethnicities are referred to as a Mugandans and Munyarwandans, respectively). Smaller ethnic groups in the area are categorized as Other Ethnicity.

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 reader. 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 2.3 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.

Table 2.3: 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.

2.6 PART 2: SEROSORTING MECHANISMS

2.6.1 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 there is homophily on HIV status, and 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, I 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 homophily on HIV status, but rather provides evidence of whether it is even possible that indirect selection could result in serosorting.

I evaluate four attributes that are considered important in marriage formation in the study site: age, education, ethnicity, and marital history. Couples' HIV statuses are simulated based on their observed values across each of these attributes. Table 2.2 describes HIV prevalence across these attributes in both the married and the unmarried pool. For both ethnicity and education, Table 2.3 presents evidence that people in the GPC mix assortatively, being more likely to marry someone of the same ethnicity or education level. The ethnic-mixing model categorizes both

spouses by their ethnicity (Mugandans, Munyarwandans, and Other). 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. I therefore test whether mixing based on being formerly married is influencing serosorting, categorizing each spouse as formerly married, or in a first marriage. 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, I 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, I 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, I determine the probability that the wife in that partnership would be HIV-positive if I 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, I 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.

I 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. However, there are other pathways through which serosorting may occur that the simulation models cannot test for. The simulation analyses are therefore coupled with a qualitative investigation of homophily, or direct sorting on HIV status.

To explore direct selection of HIV status, I analyze qualitative data from the 50 in-depth interviews from the Intimacy and Risk Study. In addition to interview transcripts, I 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.

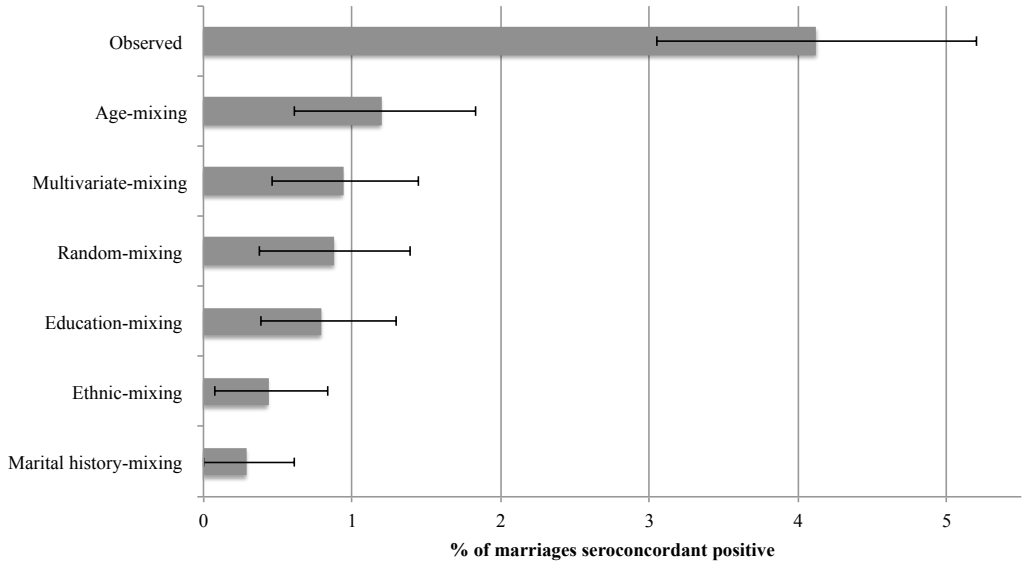
To understand serosorting's mechanisms, the third stage of analysis involves axial coding (Strauss 1987; LaRossa 2005), taking into account preferences for serosorting, the actions taken to achieve serosorting, as well as the context, strategies and consequences of these actions. To understand personal,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

To minimize the risk of misinterpretation, I conducted a stakeholder check with the MRC/UVRI study team that designed and implemented the Intimacy and Risk Study. The study team is not only familiar with the setting, data collection and transcripts, but is 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.

2.6.2 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 2.6 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. The likely reason that marital history-mixing does not result in serosorting is that men and women marrying in the study site are mixing disassortatively on marital history, counter to the hypothesized relationship of assortative mixing. While approximately 29% of men and women who had a new marriage had been formerly married, only 3% of the 1310 new marriages that occurred were among men and women who had both been formerly married. Together, these results suggest that indirect selection, at least on these most apparent attributes, is unlikely to be the driving mechanism behind serosorting in rural Uganda.

Figure 2.6: Percent of marriages that are seroconcordant positive in the attribute-mixing simulations compared to the observed population



Note: 95% confidence intervals are indicated by the lines in each bar.

2.6.3 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, but there has been a growing shift towards free choice for both men and

women in initiating relationships. Even among more recent relationships, however, there are gendered differences in agency. 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 over time.

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.

2.7 DISCUSSION

This paper provides a longitudinal quantitative analysis of couples' HIV status at marriage formation in rural Uganda. Even after adjusting for population composition, I find evidence to suggest that marital serosorting is occurring among both HIV-positive and HIV-negative men and women (Figure 2.4). Exploring what mechanisms could account for serosorting, I find that disassortative age-mixing may be one mechanism leading to serosorting, but it cannot account for most of the observed serosorting (Figure 2.6). I 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. 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, I am 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, I 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. I find only small differences (Appendix 2B), suggesting that even after adjusting for premarital seroconversions, HIV-positive and HIV-negative men and women are still 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. I do

not have data on HIV-positive men's 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, I 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 only presents 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 transmission; in the absence of serosorting the modeled HIV prevalence increases from 16% to 24.5% (Cassels et al. 2009). Knowledge is essential for translating homophily on HIV status into homogeneity on HIV status: to serosort, people need to know their own status and the status of their partner. As a result, the effectiveness of preferences for 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). Attempts at 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 higher than the national average.

There has been an increase in seroconcordant positive marriages since 2010 (Figure 2.2). 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 marriage 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, we do not observe changes in the proportion of seroconcordant positive marriages until 2010, despite ART become freely accessible to study participants as early as 2004. We might also expect ART to be associated with a decrease in serosorting: ART-related viral suppression reduces the risk of forming a serodiscordant marriage (Cohen, Shaw, 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 facilitate 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. HIV testing programs for couples 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 youth, 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, they 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 (Burns 2009). 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 facilitate serosorting is by creating platforms and opportunities to help 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 term of sexual partners than their sexual behavior per se. 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 (Helleringer and Reniers 2011). 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.

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Chapter 3

Marriage in the era of antiretroviral therapy: HIV status and marital change in rural Uganda[4]

CHAPTER SUMMARY: Growing awareness about HIV and increasing access to antiretroviral therapy (ART) may be profoundly changing the social implications of HIV in generalized epidemic settings. In particular, ART may impact the association between HIV and marital change, including the formation and dissolution of marriages. This paper describes the relationship between HIV status and marriage transitions both before and after the availability of ART. Our data contain linked marital partnerships and marital histories over 13 years (1999-2011) from a general population cohort with sero-surveillance in southwestern Uganda. We find that patterns of marriage formation and dissolution are highly dependent on HIV status, but also

[4] Joint work with Georges Reniers, Ivan Kasamba, Gershim Asiki, Noreen Goldman and Janet Seeley

document changes following the introduction of ART. Historically, unions with an HIV-positive partner had higher dissolution rates via both widowhood and divorce, and the remarriage rate of HIV-positive men and women tended to be lower than those of HIV-negatives. Since the introduction of ART, seroconcordant positive unions have stabilized and the remarriage rates of HIV-positive men have increased. The availability of treatment does not seem to have affected the divorce rates in serodiscordant couples, or the remarriage rates of HIV-positive women.

3.1 INTRODUCTION

With the expansion of antiretroviral therapy programs, HIV is no longer a death sentence, and no longer debilitates adults in their economic prime. The potential impact of ART is also large: Under the 2013 WHO guidelines an estimated 21.2 million people are eligible for ART in Sub-Saharan Africa, 7.6 million of whom were already receiving treatment as of 2012 (UNAIDS 2013). There are still important gains to be made in improving access to ART, but as the number of people on treatment increases, it is important that we begin to document the social impacts of ART.

Marriage is one domain where ART is likely to have profound effects. ART may not only increase the longevity of HIV-positive individuals – and therefore reduce the incidence of widowhood – but it may also reduce the risks of HIV transmission within unions. Lower transmission risk may alter some of the concerns that men and women have about staying in a union with an HIV-positive partner or about forming new partnerships with someone who is HIV-positive. In other words, we expect that marriage patterns involving HIV-positive individuals will change over time, as awareness increases and treatment is rolled out.

Our current knowledge of the association between marital change and HIV is based on data preceding the availability of ART (Carpenter et al. 1999; Grinstead 2001; Porter et al. 2004; Reniers 2008), or on analyses that control for changes over time but do not make time trends the object of inquiry (Anglewicz and Reniers 2014). As a result, the downstream effects of ART scale-up on marriage dynamics have not yet been described in a generalized epidemic setting. This paper fills this gap, using individual longitudinal data with linked marital partnerships from the pre- and post-ART periods to examine how ART is impacting the association between HIV status and marital change.

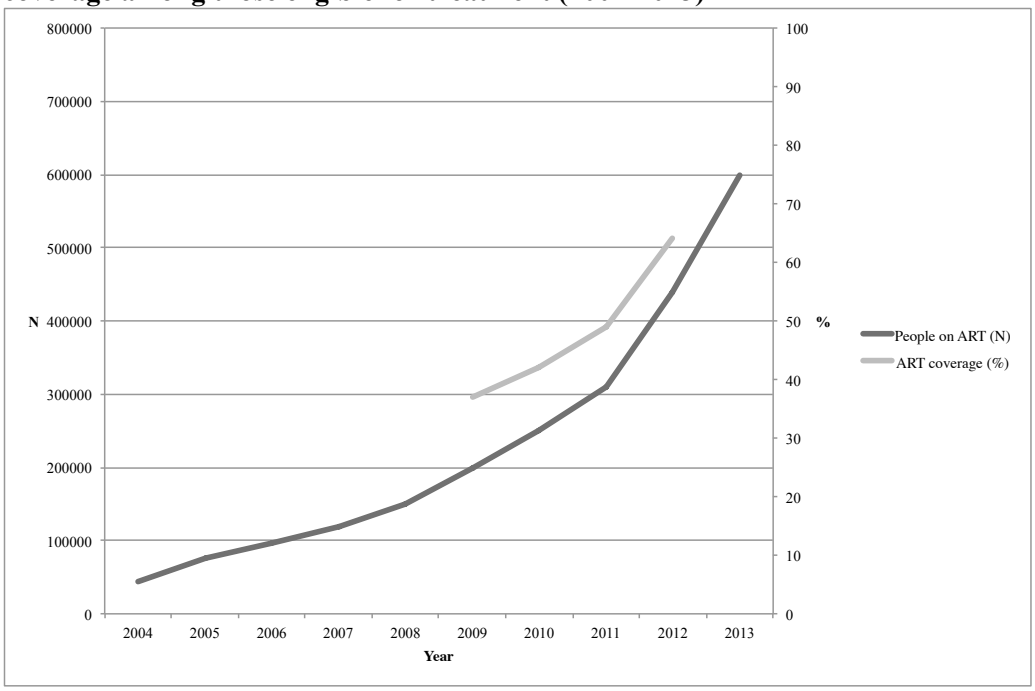
We use data between 1999 and 2011 from a demographic and HIV surveillance site in rural Uganda. This period covers the pre-ART era as well as seven years during which ART was locally available at no cost to the patients in the study site. The immediate roll-out of ART to all respondents in the study site who met WHO eligibility guidelines, compared to the slow resource-constrained scale-up of most other settings, makes this study-site the ideal location to examine the impact of ART. We examine three aspects of HIV status-based partnership mixing before and after ART: (i) the association between couples' HIV status and marriage dissolution, (ii) the association between HIV status and remarriage, and (iii) the HIV status configuration of new partnerships among those remarrying. This association between HIV status and marital change is likely to have important implications for the onward transmission of HIV, as well as the social and economic wellbeing of families.

3.2 HIV AND MARRIAGE IN THE PRE- AND POST-ART PERIODS

Marriage – including customary, religious, civil, or informal union – is a central institution for social organization. Among married couples in Uganda, either one or both partners

were HIV-positive in 9.7% of marriages in 2011 (Uganda Ministry of Health and ICF International 2012). The number of HIV-positive men and women on treatment in Uganda has also been increasing exponentially over time. Figure 1 shows the number of men and women on ART in Uganda from 2004 to 2013 and ART coverage among those needing treatment based on WHO 2010 eligibility guidelines. By 2013, an estimated 600,000 men and women – or 1.6% of the total population – were on ART. As of 2012, approximately 64% of those needing treatment were receiving treatment. As more men and women access treatment, the potential impact of ART on the association between marital change and HIV is becoming increasingly important. In the next section, we summarize the evidence for the association between HIV infection and marital dissolution and formation, and discuss how ART may alter these relationships.

Figure 3.1 Antiretroviral therapy access in Uganda: Number of people on treatment and ART coverage among those eligible for treatment (2004-2013)



Source: Data for the number of people on ART come from from AIDSinfo by UNAIDS (http://www.unaids.org/en/dataanalysis/datatools/aidsinfo) and ART coverage estimates come from the World Development Indicators (http://data.worldbank.org/data-catalog/world-development-indicators)
Note: ART coverage estimates are based on the WHO 2010 guidelines for treatment eligibility, and not the WHO 2013 guidelines that increased the CD4 count eligibility from 350 to 550.

3.2.1 Selection out of Marriage: Separation, Divorce and Widowhood

Previous longitudinal analyses have documented a clear association between HIV infection and marital dissolution, including both divorce and widowhood. Examining women's marital histories in Rakai (Uganda), Porter et al. (2004) found that HIV-positive women experienced a very high risk of widowhood (OR 7.56, $p<0.001$) and an elevated risk of divorce or separation (OR 1.94, $p<0.001$), compared to the risk of the marriage staying intact. The association between HIV infection and marital instability holds for individuals who are HIV-positive (Anglewicz & Reniers 2014; Porter et al. 2004) as well as for couples where one or both partners are HIV-positive (Porter et al. 2004). Marriages in which only the wife is HIV-positive (F+M-) are at an elevated risk of divorce compared to seroconcordant negative unions (F-M-), but there is no difference in the risk of divorce for marriages in which only the husband was HIV-positive (F-M+). Widowhood is more common in seroconcordant positive (F+M+) unions and male-positive serodiscordant unions than in seroconcordant negative unions.

The elevated rates of widowhood are not surprising given AIDS-related mortality, but the mechanisms through which HIV can affect separation and divorce are more complex. HIV infection and the fear of HIV transmission can destabilize unions in both direct and indirect ways. Perceptions of HIV risk have been found to be associated with a higher likelihood of divorce among young women who recently married (Grant and Soler-Hampejsek 2014). HIV may also precipitate marital discord through morbidity-induced economic stress, interference with reproductive ambitions, alcohol use, and sexual dissatisfaction (Nabaitu, Bachengana, & Seeley 1994). In addition, the association between divorce and HIV may be endogenous since some behaviors, such as extra-marital sex, are associated with both HIV infection and union dissolution (Reniers 2008).

We expect that the association between HIV-positive status and divorce is stronger for women than for men because HIV-positive women face greater stigma than HIV-positive men, in part due to women's extra-marital partnerships being less socially acceptable than men's (Amuyunzu-Nyamongo, Okeng'O, Wagura, & Mwenzwa 2007; Hutchinson & Mahlaela 2006; Simbayi et al. 2007), making men more likely to leave HIV-positive wives. Women, in contrast, may have a harder time leaving an HIV-positive husband due to their economic dependence on their partners and the power differential between husbands and wives.

While there is a clearly documented association between marital dissolution and HIV, almost all research to date has used data from the early and mid-2000's, before the wide-scale introduction of ART. The roll-out and scale-up of ART has fundamentally changed the outlook for people living with HIV (PLHIV) and their partners. Once on and adhering to ART, the risk that an individual will transmit HIV is nominal; incidence rates in serodiscordant couples have started to decline (Biraro et al. 2013; Cohen et al. 2011) and ART has drastically increased the expected number of years one can live with HIV (Mills et al. 2011). We therefore expect to see reductions in marriage dissolution rates through both declines in widowhood from lower ART-associated mortality and declines in divorce from reduced HIV transmission risk. Moreover, as more people live, and live healthily, on ART, social perceptions of the consequences of HIV may begin to shift. For example, ART may change childbearing prospects for HIV-infected couples and make HIV-positive partners a more promising choice. However, if ART makes HIV infections easier to hide (Mbonye et al. 2013), it is also possible that partnerships may become more stable because spouses might be unaware of their partners' HIV status.

This paper hypothesizes that while HIV has been historically associated with higher levels of marital dissolution, ART will be associated with a stabilization of HIV-positive

marriages. We expect to see the greatest declines in widowhood as ART has a direct effect on mortality. Because the uptake of ART services and treatment outcomes are better for women than for men (Cornell et al. 2012; Druyts et al. 2013; Hawkins et al. 2011; May et al. 2010; Mills et al. 2011; Muula et al. 2007), we expect the changes in widowhood following ART scale-up to be larger for men than for women. We also hypothesize that divorce will have decreased following ART, but more so for seroconcordant positive than serodiscordant couples.

3.2.2 Selection into Marriage: Remarriage

HIV prevalence in Uganda is highest among formerly married men and women. Divorced or separated women have a prevalence of 17.8%, and widowed women a prevalence of 32.4%. Both are substantially higher than the 7.2% prevalence among currently married women (Uganda Ministry of Health and ICF International 2012). Similarly, divorced and separated men have a prevalence of 14.9%, widowed men a prevalence of 31.4%, while currently married men's prevalence is 7.6% (Uganda Ministry of Health and ICF International 2012). One potential explanation for these high rates is that HIV-positive men and women are being selected out of marriages and are less likely to remarry.

Due to the high rates of HIV infection among formerly married men and women, remarriage poses a significant avenue for future HIV transmission if HIV-infected partners in serodiscordant partnerships are not on ART. These riskier unions are also the most common; most marriages where at least one partner was formerly married were found to be serodiscordant, rather than seroconcordant positive (De Walque & Kline 2012), posing a potential risk to the HIV-negative spouse. While remarriage may play an important role in onward HIV transmission, we do not know the frequency of remarriage. Cross-sectional data across 13 Sub-Saharan

African countries indicate that remarried individuals made up 10% of the adult population of reproductive age (De Walque & Kline 2012), and, in Uganda, 18.8% of all marriages were remarriages (MEASURE DHS 2012). These percentages are influenced not only by the likelihood of remarriage, but also by the rates of marital dissolution that determine the proportion of the population exposed to remarriage. Despite the uncertainty of remarriage rates, remarriages comprise an important share of all marriages.

There is evidence to suggest that HIV-positive individuals are less likely to remarry. Widows in Malawi were found to have much lower rates of remarriage, which could be due to their status as widows, or due to the strong association between widowhood and HIV infection (Reniers 2008). More recent research in Malawi has found that HIV-positive women - but not men - were less likely to remarry compared to HIV-negative men and women (Anglewicz & Reniers 2014). Lower remarriage rates may be driven by fears of HIV transmission, but this may change with ART as the risk of transmission among those on treatment is minimal (Cohen et al. 2011). Moreover, those accessing treatment are more likely to interact with HIV clinics and service providers, creating opportunities to meet other HIV-positive people. Previous qualitative research in Uganda (Seeley et al. 2009), Malawi (Gombachika 2012), and Nigeria (Rhine 2009) found that HIV-positive men and women expressed a preference for finding a partner who was also HIV-positive. Treatment may not only decrease the risk of partnering with someone who is HIV-positive, but also facilitate finding partners who would want to marry someone who is HIV-positive.

This paper hypothesizes that remarriage rates are lower for HIV-positive men and women compared to HIV-negative individuals, but that this difference will have attenuated since ART became available. The lower rates of remarriage among HIV-positive individuals may be based

on direct selection due to fears of partnering with someone who is HIV-positive. Alternatively, indirect selection could be occurring if HIV is correlated with other attributes that are less desirable for remarriage, such as widowhood or a high number of previous sexual partners. ART could affect the association between HIV and remarriage by decreasing the risk associated with marrying an HIV-positive partner.

3.3 METHODS AND MEASUREMENT

Data for this analysis come from the General Population Cohort (GPC) in the Masaka district in rural southwest Uganda. The GPC study consists of an annual population census, a medical survey, and sero-survey that has been conducted in the area since 1989. It comprises a rural open population cohort with approximately 20,000 adult and child respondents from 25 villages. Details of the population and methodology have been described elsewhere (Nunn et al. 1997; Nakibinge et al. 2009; Asiki et al. 2013). This paper draws on data from 1999-2011 (census rounds 9-22), when data were collected on linked marital partnerships. The dataset includes information on individual demographic variables, sexual behavior and marriage histories, and HIV status. The census had a participation rate of 95-99%, while the adult medical survey had a 63-75% participation rate, varying over the 13 rounds in this sample (Asiki et al. 2013).

Among those participating in the adult medical survey, HIV status is missing for 18-35% of respondents in each round. The irreversible nature of HIV infection allows for backwards imputation of negative HIV status and forward imputation of positive HIV status. When HIV status is missing in rounds between a negative and a positive HIV test, the assumption is made

that HIV seroconversion occurred at the mid-point of the interval for missing data gaps of three years or less. When the gap between a negative and a positive HIV test is greater than three years, a negative HIV test is imputed forward a maximum of two person-years, and a positive HIV test is imputed backwards a maximum of two person-years. All other missing HIV data are not imputed. The results presented in this paper are not sensitive to this method of imputation. Similar methods of imputation have been employed by other studies using the GPC and other similar sero-surveillance sites (e.g. Reniers et al. 2014). After imputation of HIV status, 23% of men's person-years and 14% of women's person-years still have missing HIV status among ever-married adults. They are hence excluded from the analysis.

Union status information is collected during the adult survey and is self-reported by respondents. Marriage is defined in the GPC as both formal (religious, customary and civil) and informal unions. Respondents are asked if they are married, and if there is someone whom they consider to be their husband or wife. Respondents report the names of their marital partners during the adult survey. If their marital partner was ever included in the GPC census, they have a unique identification number that is recorded in the original survey questionnaire. For this analysis, marital identification numbers are derived from individual identification numbers in order to construct an analytic sample based on couples.

There are 1,154 cases of discrepant reports of marital status between husbands and wives out of the 20,591 couple observation-years. To address these discrepant reports we use residential status and past and future marital status reports to determine the most likely status of the marital union. Unions are considered to have ended if at least one of the spouses reported dissolution and they were no longer co-residing in a household in the current or following census round. When there is disagreement in the timing of dissolution, it is assumed that dissolution

occurred at the mid-point between the two reports. Census data from the study site are used to confirm reported cases of widowhood. In 15.3% of discrepant cases we find no evidence to indicate the union had dissolved. We resolve all discrepant reports of marital status through place of residence, reported deaths and migrations, and differential timing in reports on union dissolution. All analyses are run excluding discrepant marital status reports and this does not change any of the findings (See Appendix 3A). As such, the results presented in this paper include resolved discrepant reports.

The GPC survey does not consistently record the date of union formation or the previous number of marriages across survey rounds, resulting in a large amount of missing data on marital duration. This study therefore makes use of observed, rather than actual, marital duration as the measure of exposure. Duration is counted from the first year in which a couple is observed in the study, though it is possible the union formed prior to the couple's inclusion in the study, potentially biasing interpretation of duration estimates. Analyses restricted to marriages that started between 1999-2011 yield similar results, but come with a loss in statistical power (See Appendix 3B).

3.3.1 Marital Dissolution

To examine trends in marital dissolution, we construct a dataset based on couples to include all currently married respondents aged 15 years and older with a matched spouse in the study site. We exclude from the dataset those couples where either one or both partners have missing HIV status (12% of couples' person-years among linked partnerships). Over the 13 years of observation, there were 3,647 couples. Men and women could contribute multiple marriages

to the analysis through either polygyny or remarriage. 3,440 women and 2,772 men contributed to the couples' analysis, for a total of 20,591 marital person-years.

Table 3.1 presents background characteristics for the couples' sample along with percentages experiencing divorce or widowhood. Of the 3,647 marriages, 645 ended in divorce/separation and 247 in widowhood. For simplicity, we use the term divorce to encompass both divorce and separation. Not surprisingly, widowhood was more common in partnerships with at least one HIV-positive spouse. Divorce was more common in serodiscordant marriages; divorce was equally prevalent in seroconcordant negative marriages as seroconcordant positive marriages. Both divorce and widowhood were more common when there were large age differences between spouses, with divorce being more likely when the wife was older, and widowhood when the husband was older.

Table 3.1: Background characteristics of marital partnerships in Masaka, Uganda (1999-2011)

	Couples Sample		
	All	Percent experiencing event	
		Divorce	Widowhood
Couple's Characteristics			
Number of Couples	3,647		
Number of Women	3,440		
Number of Men	2,772		
Marriage-years of observation	20,591		
Marital dissolution			
Divorce/Separation	645		
Widowhood	247		
Observed marital duration			
<=1 year	137	11.7%	0.7%
2-5 years	1,812	25.1%	7.0%
6-10 years	817	14.4%	10.2%
11-14 years	881	6.5%	4.1%
HIV status (at last observation)			
(F- M-)	3,083	16.9%	5.4%
(F- M+)	166	21.1%	12.0%
(F+ M-)	166	30.1%	9.6%
(F+ M+)	232	16.8%	19.4%
Age difference between spouses			
Wife >= 10 years younger	1,257	16.9%	9.1%
Wife 5-9 years younger	1,118	16.2%	4.9%
Wife < 5 years younger or older	1,132	17.8%	6.0%
Wife >= 5 years older	140	35.0%	6.4%
Wives' Characteristics			
Age (at last observation)			
15-24	821	20.8%	1.1%
25-34	1,175	18.4%	3.4%
35-44	777	16.6%	8.9%
45-54	470	16.8%	8.7%
55+	404	12.4%	21.8%
Observed number of marriages			
First marriage	3,467	17.5%	6.8%
2-3 previous marriages	170	20.0%	6.5%
4+ previous marriages	10	30.0%	10.0%
Ethnicity			
Muganda	2,239	16.2%	5.4%
Munyanrwanda	516	20.7%	5.4%
Other/Unknown	892	19.7%	10.9%
Education			
No Education	312	21.5%	19.9%
Some Primary	2,399	18.3%	6.7%
Some Secondary	748	13.2%	2.5%
Unknown	188	20.7%	2.7%
Husbands' Characteristics			
Age (at last observation)			
15-24	182	19.8%	1.1%
25-34	1,051	20.8%	1.9%
35-44	968	18.5%	5.2%
45-54	582	16.7%	6.4%
55+	864	13.5%	16.0%
Observed number of marriages			
First marriage	2,042	29.6%	11.3%
2-3 previous marriages	630	6.3%	2.4%
4+ previous marriages	50	0.0%	2.0%
Ethnicity			
Muganda	2,283	17.0%	3.8%
Munyanrwanda	421	19.0%	4.3%
Other	943	18.7%	15.2%
Education			
No Education	168	23.2%	18.5%
Some Primary	2,368	19.3%	6.4%
Some Secondary	978	13.8%	5.0%
Unknown	133	9.8%	12.0%

To establish whether marriages where one or both partners are HIV-positive are more likely to dissolve, we use a multinomial logistic regression model (Eq. 3.1). This model estimates the log odds of the hazard of divorce ($h_{ct}^{(r=1)}$) and hazard of widowhood ($h_{ct}^{(r=2)}$)), relative to the hazard of the couple staying married ($h_{ct}^{(r=0)}$). The subscript *c* denotes couples and the superscript *r* denotes marital outcome, where *r* = 0, 1, and 2 represents no dissolution, divorce, and widowhood, respectively, and *t* refers to the observed duration married. Marriages that are intact at the time of the last contact with a fieldworker, or that have one or both spouses migrate outside of the study site, are censored.

Couples' lagged HIV status (at time *t-1)* is the primary predictor of interest, with seroconcordant negative couples (F-M-) as the reference category. Three models compare how the association between couples' HIV status and union dissolution changes over time. Model 1 includes the controls for couples' lagged HIV status (F-M+, F+M-, and F+M+), with seroconcordant negative couples as the reference category (F-M-). Model 2 adds a dummy variable control for whether the observation falls into the time period after ART became available. ART was first introduced in the study site in 2004, after which point all participants in the GPC had access to free ART. In the analyses, we use a simple dichotomy (pre/post ART). Other specifications of time are tested, including a variable with an additional category identifying the rollout phase, and a continuous time variable with 2004 as the reference year. These do not change the results and are not included.

Model 3 (shown in Eq. 3.1) includes interaction terms between the post-ART dummy and the couples' lagged HIV status. The first three parameters ($\beta_1^{(r)}$ to $\beta_3^{(r)}$) estimate the relative risk of each outcome among seroconcordant positive and serodiscordant couples in the pre-ART period, compared to the relative risk of each outcome among seroconcordant negative couples in

the pre-ART period. The following four parameters ($\beta_4^{(r)}$ to $\beta_7^{(r)}$) predict how the relative risk of divorce and widowhood differs in the post-ART period, compared to the pre-ART risk for couples of the same HIV status.

In Eq. 3.1 the time-invariant control variables are estimated with the vector $\gamma^{(r)}$, including husbands' and wives' education and ethnicity, and the age difference between spouses. $\delta_t^{(r)}$ is a vector of time-varying covariates, including a linear and quadratic term for the observed duration married. Age, age-squared, husbands' and wives' marital order, age at first marriage and age at first sex are removed from the models presented here as they did not improve model fit. The model also includes a constant, $\alpha^{(r)}$.

(3.1)

$$log\left[\frac{h_{ct}^{(r)}}{h_{ct}^{(0)}}\right] = \alpha^{(r)} + \beta_1^{(r)}\left(F+M+\right)_{c(t-1)} + \beta_2^{(r)}(F+M-)_{c(t-1)} + \beta_3^{(r)}(F-M+)_{c(t-1)} + \beta_4^{(r)}PostART_t \times (F-M-)_{c(t-1)} + \beta_5^{(r)}PostART_t \times (F+M+)_{c(t-1)} + \beta_6^{(r)}PostART_t \times (F+M-)_{c(t-1)} + \beta_7^{(r)}PostART_t \times (F-M+)_{c(t-1)}\Big) + \boldsymbol{\gamma^{(r)}} + \boldsymbol{\delta_t^{(r)}}$$

The multinomial regression model is based on the assumption of independent observations, but, since both men and women contribute multiple marriages to the analysis, the observations are correlated. This is typically addressed through the inclusion of random effects in the model. However, since both men and women contribute multiple marriages, marriages are

not nested hierarchically under individuals, but rather are crossed (Rabe-Hesketh & Skrondal 2012). A multinomial model with crossed-effects cannot be run using conventional statistical software (e.g., Stata 13). Instead, we choose to randomly sample from men and women's marriages so as to include only one marriage per respondent in the sample in the following manner: First, one marriage is randomly selected from men who contribute multiple marriages to the analysis. This procedure is then repeated among women using only the marriages that are selected in the men's random sample. The resulting sample consists of 2,627 marriages contributing 15,556 marriage-years of observations (reduced from 3,647 marriages contributing 20,591 marriage-years of observations in the full sample). We estimate robust standard errors clustered at the couple level. The results using this sample are compared with (1) randomly selecting women's marriages first, and then men's, and (2) separate logit models to analyze divorce and widowhood with sex-specific random effects on the full set of marriages. The results from these alternative model specifications and those presented in this paper are not substantively different.

3.3.2 Remarriage

To study the association between HIV status and remarriage among formerly married individuals, we limit our dataset to individuals between 15 and 60 years of age, as remarriage is rare in older ages. We also look only at selection into higher order marriages, excluding first marriages. Given the near universal experience of first marriage in rural Uganda, we expect HIV to matter more for more selective higher-order marriages. Table 3.2 provides background characteristics of formerly married men and women, including the percentage that remarries.

An unmarried episode is defined as the time between the end of a previous marriage (or someone is first observed as unmarried in the study and reported being formerly married) and remarriage. There are 2,226 women who were formerly married, contributing a total of 2,674 unmarried episodes, and 1,198 men contributing 1,509 unmarried episodes. Men's unmarried episodes are more likely to result in remarriage: 47.1% of men's unmarried episodes resulted in marriage, but only 34.9% of women's. Remarriage is more common among those who were divorced, rather than widowed, and among those with higher education levels.

Table 3.2: Characteristics of formerly married respondents in Masaka, Uganda (1999-2011)

	Individual Sample			
	Female		Male	
	N	Percent experiencing remarriage	N	Percent experiencing remarriage
Formerly married episodes	2,674		1,509	
Formerly married respondents	2,226		1,198	
Person-years formerly married	9,341		4,459	
Remarriages	934		711	
Observed number of times formerly married				
1	1,855	20.1%	955	30.2%
2	309	36.5%	191	54.5%
3	50	36.0%	39	61.5%
4	9	33.3%	10	20.0%
5	3	33.3%	3	100.0%
Characteristics of formerly married episodes				
Observed duration formerly married				
<=1 year	371	59.0%	382	74.4%
2-5 years	1,732	34.9%	903	42.0%
6-10 years	414	23.7%	180	24.4%
11-14 years	157	8.3%	44	9.1%
HIV status (at last observation)				
Negative	2,095	37.4%	1,222	49.2%
Positive	579	26.1%	287	38.3%
Sex in last 12 months (at last observation)				
Yes	971	70.7%	810	74.4%
No	1,703	14.6%	699	15.5%
Age (at last observation)				
15-24	325	47.4%	88	40.9%
25-34	719	46.9%	503	59.6%
35-44	678	38.8%	454	49.1%
45-59	952	18.2%	464	32.8%
Observed prior marriages				
1	2,070	20.1%	922	19.9%
2-3	574	86.1%	555	90.1%
4+	30	83.3%	32	87.5%
Marital status				
Ever divorced/ separated	1,551	35.7%	1,060	40.8%
Ever widowed	453	16.3%	91	44.0%
Both divorced and widowed	503	27.8%	176	32.4%
Dissolution cause unknown	167	100.0%	182	100.0%
Ethnicity				
Muganda	1,765	36.6%	844	52.5%
Munyanrwanda	419	34.6%	258	41.1%
Other	490	29.2%	407	39.8%
Education				
No education	243	28.0%	77	31.2%
Some primary	1,792	37.1%	1,082	47.3%
Some secondary	460	39.6%	296	55.1%
Unknown	179	11.2%	54	22.2%

Note: The percent remarrying is influenced by the duration a man or woman has remained single. However, since duration single is only observed from the 1999 onwards, we do not know the exact length people have been exposed to the risk of remarriage. Percentages of those experiencing remarriage presented in this table do not take into account exposure.

A discrete-time logistic regression model is used to estimate the odds of remarriage among the formerly married, with separate models for men and women. Time (t) is the observed duration unmarried, not reported duration. We compare the full sample in this paper with the sample of only those with known duration unmarried, and find similar substantive conclusions (See Appendix 3B). Similar to the models for marital dissolution, a series of three models examine how remarriage changes with ART. Model 1 includes a dummy variable for lagged HIV-positive status, and model 2 a dummy variable for the post-ART period (2005-2011). Model 3 (shown in Eq. 3.2) includes the dummy variable for lagged HIV-positive status, and two interaction terms between lagged HIV-status and the post-ART dummy variable. We estimate three parameters of interest: β_1 estimates the odds of remarriage for HIV-positive individuals in the pre-ART period, compared to HIV-negative individuals in the pre-ART period. β_2 estimates the odds of remarriage among HIV-negative men and women in the post-ART period, compared to HIV-negative men and women in the pre-ART periods. Likewise, β_3 estimates the odds of remarriage among HIV-positive men and women after ART, compared to HIV-positive men and women before ART.

All three models include a series of time-invariant controls, including education, ethnicity, and number of previous marriages, represented by the vector γ in Eq. 3.2. Time-varying covariates, including a linear and quadratic term for age, are included in vector $\eta(t)$. $\delta(t)$ is a vector of discrete-time variables controlling for the duration unmarried. Since men and women can contribute multiple unmarried episodes, we include the individual-level random effect u_j, which is assumed to be normally distributed with a mean of 0 and variance σ_u^2. In Eq. 3.2, t denotes the duration unmarried, j the individual, and i the unmarried-episode for that individual.

$$logit[h_{ij}(t)] = \alpha + \beta_1 HIV(+)_{ij}(t-1) + \beta_2 PostART \times HIV(-)_{ij}(t-1) + \beta_3 PostART \times HIV(+)_{ij}(t-1) + \gamma + \eta(t) + \delta(t) + u_j \quad (3.2)$$

$$u_j \sim N(0, \sigma_u^2)$$

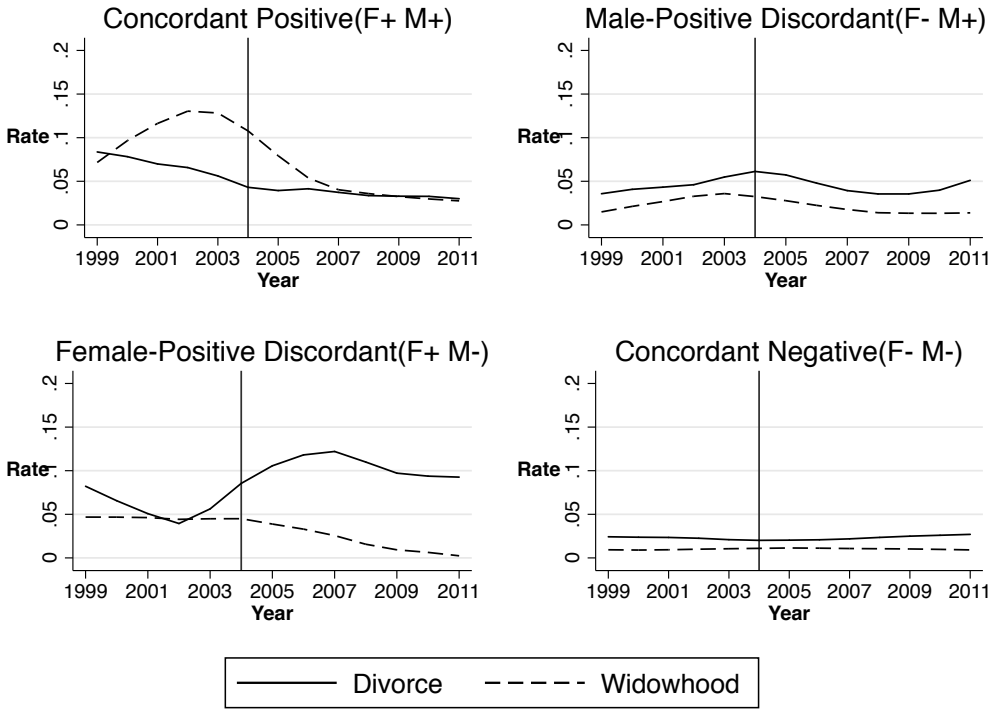
We also use the model in Eq. 3.2 to analyze the HIV status of new spouses among those who remarry. The sample is restricted to formerly married men and women who have remarried and can be linked to a partner with a known HIV status at the time of marriage (N=918, 56% of remarriages). The outcome variable is the HIV status of their spouse at remarriage, represented by a binary variable equal to one when their spouse is HIV-positive. The primary predictor continues to be the individual's own HIV status at remarriage, and an interaction between HIV status and the post-ART period. We again control for age (a linear and quadratic term), education, ethnicity and the number of previous marriages, and a series of discrete-time variables to control for duration unmarried. Men and women are included in the same model. We test for differences between men and women, but find that the odds of marrying an HIV-positive partner by the individual's own HIV status do not vary by gender. For this reason the gender controls are excluded from the models shown here.

3.4 RESULTS: MARITAL DISSOLUTION

The rates of divorce and widowhood in Figure 3.2 support our hypothesis that marital dissolution is higher in HIV-infected marriages, and that since the introduction of ART there have been important changes in the rates of divorce and widowhood. Figure 3.2 shows the Lowess smoothed (Cleveland 1981) rates of divorce and widowhood for each combination of

husbands' and wives' HIV status. The vertical line at 2004 denotes the introduction of ART. The upper left quadrant shows that seroconcordant positive couples experience a reduction in both widowhood and divorce over time. While seroconcordant positive couples experience a convergence in their rates of divorce and widowhood, female-positive serodiscordant marriages experience an increasing persistently high rate of divorce after ART but a declining rate of widowhood. Male-positive serodiscordant couples do not see a large reduction in divorce, though they experience a decline in widowhood since the introduction of ART.

Figure 3.2 Lowess smoothed rates of divorce and widowhood by couples' HIV status from 1999-2011 in rural Uganda



Note: Lowess graph constructed in Stata. The smoothed value is calculated using the weighted surrounding observations with a bandwidth of 0.8 (StataCorp 2013). The vertical line indicates the time at which ART became freely accessible in the study site.

Examining how couples' HIV status predicts marital dissolution in the subsequent year, we find that couples in which at least one partner is HIV-positive are more likely to experience dissolution than have their marriage remain intact (Table 3.3, Model 1). Overall, the relative risk for widowhood is higher than the relative risk of divorce. The relative risk of widowhood is highest in marriages where both partners are HIV-positive, while the relative risk of divorce is highest in marriages in which only the female is HIV-positive, compared to the risk of widowhood and divorce, respectively, for seroconcordant negative marriages. Marriages in which the woman is older than the man by five or more years have over three times the relative risk of divorce rather than the marriage not dissolving, compared to women and men who are

within five years of each other's age. Marriages in which the wife is younger than the husband by more than 10 years have the highest relative risk of widowhood rather than the marriage not dissolving, compared to the risk of widowhood for couples within five years of age of each other.

Model 2, which adds an indicator variable for the post-ART period, shows that the relative risk of widowhood compared to staying married decreases by 35.2% after the introduction of ART, and that the relative risk of divorce compared to staying married increases by 54.4% after ART. Once the interaction terms are added (Model 3), we see that the relative risk of divorce and widowhood in the post-ART varies greatly by the HIV status of the couple. Seroconcordant negative couples have no change in their relative risk of widowhood between the pre- and post ART periods. The relative risk of divorce, on the other hand, increases in the post-ART period for seroconcordant negative marriages compared to the pre-ART period (RRR = 1.680). Seroconcordant positive marriages seem to benefit from the availability of treatment, as the relative risk of widowhood compared to no dissolution decreases by 70.3% compared to seroconcordant positive couples before ART.

Table 3.3: Multinomial logistic regression of lagged couples sero-status on the risk of divorce and widowhood compared to no dissolution (relative risk ratios)

	Model 1		Model 2		Model 3	
	Divorce	Widowhood	Divorce	Widowhood	Divorce	Widowhood
Couples HIV Status (lagged)						
Concordant Negative (F- M-)	1	1	1	1	1	1
Concordant Positive (F+ M+)	1.950**	6.843***	1.854**	7.142***	2.908***	11.20***
	(1.277 - 2.979)	(4.396 - 10.65)	(1.202 - 2.860)	(4.552 - 11.21)	(1.672 - 5.058)	(6.586 - 19.06)
Female-Positive Discordant (F+ M-)	3.020***	3.437***	2.854***	3.548***	2.906***	5.532***
	(2.059 - 4.430)	(1.738 - 6.797)	(1.939 - 4.200)	(1.793 - 7.024)	(1.564 - 5.402)	(2.487 - 12.31)
Male-Positive Discordant (F- M+)	1.877**	2.646**	1.862**	2.684**	2.228**	3.905***
	(1.212 - 2.905)	(1.437 - 4.871)	(1.200 - 2.888)	(1.458 - 4.938)	(1.244 - 3.992)	(1.875 - 8.134)
Post-ART			1.544***	0.648*		
			(1.226 - 1.945)	(0.434 - 0.967)		
Post-ART X HIV						
(F-M-) x ART					1.680***	0.902
					(1.304 - 2.165)	(0.584 - 1.393)
(F+ M+) x ART					0.681	0.297**
					(0.288 - 1.613)	(0.131 - 0.673)
(F+ M-) x ART					1.608	0.233+
					(0.734 - 3.521)	(0.0430 - 1.259)
(F- M+) x ART					1.155	0.319
					(0.480 - 2.779)	(0.0793 - 1.280)
Wife's Education						
No Education (ref)	1	1	1	1	1	1
Some Primary	1.257	0.438***	1.136	0.472***	1.127	0.467***
	(0.883 - 1.790)	(0.297 - 0.646)	(0.792 - 1.630)	(0.320 - 0.697)	(0.786 - 1.615)	(0.316 - 0.691)
Some Secondary	1.240	0.195***	1.051	0.221***	1.033	0.212***
	(0.805 - 1.909)	(0.0979 - 0.387)	(0.673 - 1.641)	(0.111 - 0.442)	(0.662 - 1.612)	(0.106 - 0.424)
Unknown	2.973***	0.201*	2.553***	0.223*	2.529***	0.215*
	(1.752 - 5.043)	(0.0451 - 0.899)	(1.481 - 4.399)	(0.0496 - 0.999)	(1.466 - 4.362)	(0.0479 - 0.966)
Husband's Education						
No Education (ref)	1	1	1	1	1	1
Some Primary	0.878	0.454***	0.805	0.476**	0.798	0.459***
	(0.585 - 1.317)	(0.289 - 0.712)	(0.534 - 1.215)	(0.304 - 0.744)	(0.530 - 1.203)	(0.292 - 0.724)
Some Secondary	0.608*	0.418**	0.560*	0.437**	0.556*	0.435**
	(0.385 - 0.960)	(0.239 - 0.732)	(0.353 - 0.888)	(0.250 - 0.764)	(0.351 - 0.881)	(0.248 - 0.763)
Unknown	0.828	1.650	0.805	1.725	0.781	1.653
	(0.393 - 1.744)	(0.724 - 3.757)	(0.388 - 1.673)	(0.760 - 3.916)	(0.375 - 1.630)	(0.720 - 3.798)
Wife's Ethnicity						
Muganda (ref)	1	1	1	1	1	1
Munyanrwanda	1.011	0.900	0.995	0.919	0.987	0.911
	(0.724 - 1.411)	(0.542 - 1.496)	(0.716 - 1.385)	(0.551 - 1.534)	(0.710 - 1.371)	(0.547 - 1.517)
Other	0.723	1.150	0.717	1.152	0.716	1.173
	(0.483 - 1.084)	(0.704 - 1.878)	(0.481 - 1.070)	(0.701 - 1.893)	(0.480 - 1.068)	(0.714 - 1.927)
Husbands's Ethnicity						
Muganda (ref)	1	1	1	1	1	1
Munyanrwanda	1.016	0.361**	0.990	0.368**	0.987	0.368**
	(0.711 - 1.452)	(0.186 - 0.699)	(0.696 - 1.409)	(0.189 - 0.717)	(0.694 - 1.404)	(0.189 - 0.717)
Other	1.106	0.528*	1.071	0.539*	1.075	0.540*
	(0.773 - 1.584)	(0.298 - 0.935)	(0.750 - 1.529)	(0.303 - 0.960)	(0.753 - 1.536)	(0.303 - 0.960)
Age Difference with Spouse						
Wife >= 10 years younger	1.131	1.725**	1.120	1.731**	1.122	1.722**
	(0.880 - 1.453)	(1.205 - 2.470)	(0.871 - 1.440)	(1.210 - 2.476)	(0.873 - 1.443)	(1.205 - 2.461)
Wife 5-9 years younger	0.934	0.971	0.927	0.982	0.935	0.996
	(0.720 - 1.211)	(0.649 - 1.453)	(0.714 - 1.202)	(0.657 - 1.466)	(0.721 - 1.214)	(0.669 - 1.483)
Wife < 5 years younger or older	1	1	1	1	1	1
Wife >= 5 years older	3.368***	1.025	3.214***	1.057	3.184***	1.032
	(2.201 - 5.155)	(0.340 - 3.094)	(2.098 - 4.924)	(0.351 - 3.183)	(2.085 - 4.862)	(0.345 - 3.083)
Observed Marital Duration						
Duration	0.821***	1.146	0.824**	1.156+	0.827**	1.167+
	(0.731 - 0.922)	(0.964 - 1.362)	(0.732 - 0.928)	(0.973 - 1.374)	(0.734 - 0.931)	(0.979 - 1.390)
Duration Squared	1.009*	0.994	1.006	0.996	1.006	0.995
	(1.000 - 1.018)	(0.983 - 1.006)	(0.997 - 1.016)	(0.985 - 1.008)	(0.997 - 1.016)	(0.984 - 1.007)
Model Fit						
AIC	5559.649		5545.289		5542.032	
BIC	5850.432		5851.377		5894.033	
Number of couples	2,627	2,627	2,627	2,627	2,627	2,627
Number of events	400	197	400	197	400	197
Marriage-years of observation	15,556	15,556	15,556	15,556	15,556	15,556

*** p<0.001, ** p<0.01, * p<0.05, + p<0.1

Note: The reference category for all relative risk ratios is no dissolution. Age, marital order, age at first marriage and age at first sex were also tested as controls, but were not included as they were insignificant and did not improve the model fit. Further information on the AIC and BIC measures of model fit can be found in Akaike (1981) and Gelfand and Dey (1994).

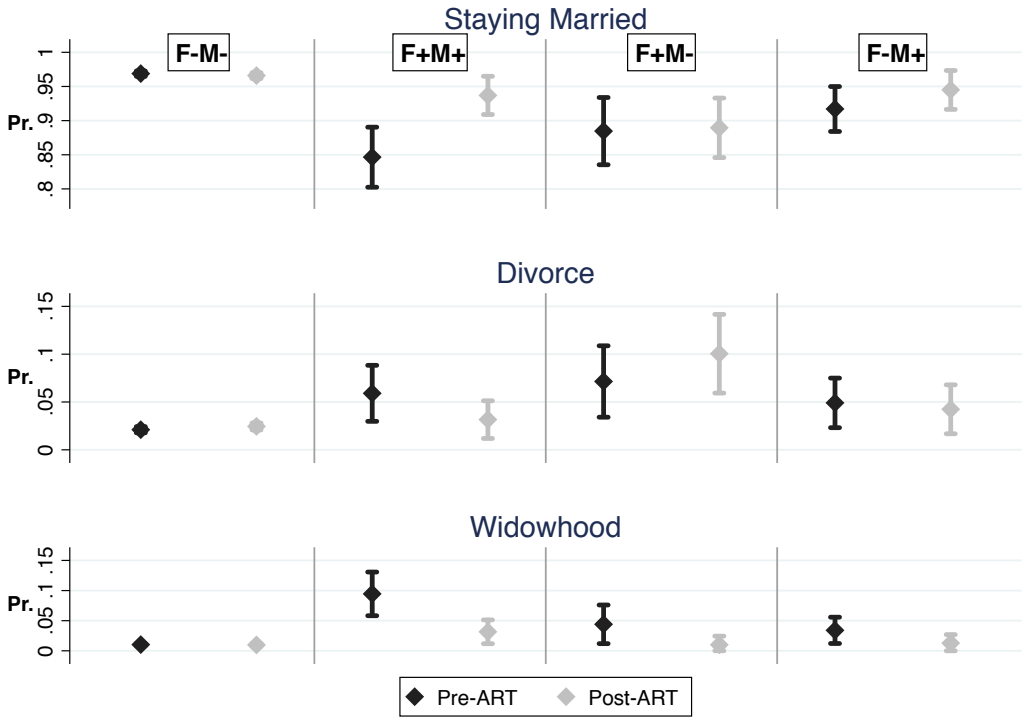
These relative risks are difficult to interpret because the risk of divorce or widowhood is in relation to the base outcome of the couple staying married. The risks of each outcome – becoming divorced, becoming widowed, or remaining remarried – change over time. To obtain insight into the absolute risks, rather then just relative risks, we estimate the average predicted probability of divorce and widowhood among seroconcordant and serodiscordant marriages in the pre- and post-ART period using the margins command in Stata (StataCorp 2013). This calculation uses the average of the predicted probabilities for each marriage, rather than the predicted probability for the average marriage.

Serodiscordant couples experience a decline in their probability of widowhood, from .044 in the pre-ART period to .010 in the post-ART period for female-positive serodiscordant couples, and from .034 to .013 for male-positive serodiscordant couples (Fig. 3.3). However, the decline in widowhood between the pre- and post-ART period is not significant for either type of marriage. We see no statistically significant changes in the average predicted probability of divorce in the post-ART period for serodiscordant marriages. Although the average predicted probability of divorce among female-positive serodiscordant marriages increases from .071 to .100 between the pre- and post-ART periods, this change is not statistically significant. We observe no change in the predicted probability of divorce for male-positive serodiscordant couples.

The average predicted probability of both widowhood and divorce decrease between the pre- and post-ART periods for seroconcordant positive couples. Together, these reductions in widowhood and divorce lead to a stabilization of seroconcordant positive marriages; seroconcordant positive couples are the only group to have a significantly higher predicted

probability of staying married in the post-ART period than in the pre-ART period, an increase from .846 to .937.

Figure 3.3 Average predicted probability of staying married, divorce and widowhood by couples' HIV status in the pre- and post-ART periods (calculated from Table 3.3, Model 3)



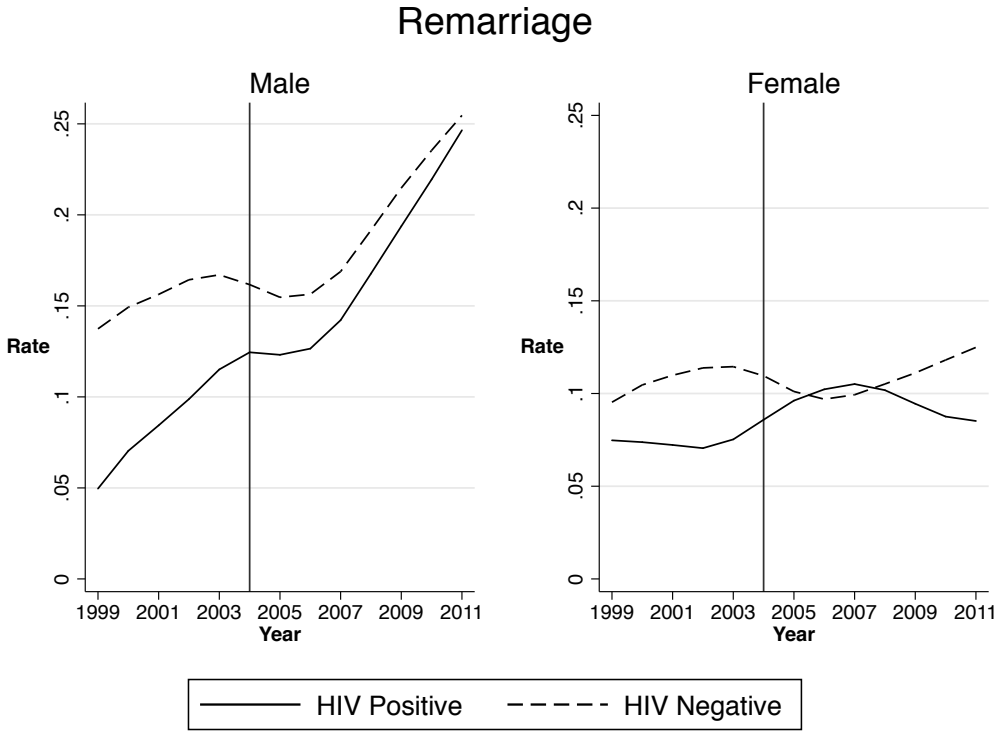
Note: Average predicted probabilities calculated using the Margins command in Stata (StataCorp 2013). The predicted probability of staying married is plotted in a different scale from the predicted probability of divorce and widowhood. The sum of all three predicted probabilities for each HIV-status group equals one.

3.5 RESULTS: REMARRIAGE

The hypothesis that PLHIV are being excluded from marriage would suggest that both HIV-positive men and HIV-positive women are less likely to remarry. We find, however, that Lowess smoothed remarriage rates (unadjusted for covariates) increase for HIV-positive and HIV-negative men over time, whilst remaining relatively stable for women (Fig. 3.4). In the pre-ART period, HIV-positive men have much lower remarriage rates than HIV-negative men, but

after the introduction of ART there is a convergence of remarriage rates by HIV status. Remarriage rates for HIV-positive and HIV-negative women remain below those of men, except in the earliest years. For the majority of years, HIV-negative women have higher rates of remarriage than HIV-positive women.

Figure 3.4 Lowess smoothed remarriage rates by individual HIV status from 1999-2011 in rural Uganda



Note: Lowess graph constructed in Stata. The smoothed value is calculated using the weighted surrounding observations with a bandwidth of 0.8 (StataCorp 2013). The vertical line indicates the time at which ART became freely accessible in the study site.

The lower likelihood of remarriage among HIV-positive men and women holds even after controlling for factors that may affect remarriage prospects, and are correlated with HIV status (e.g., age, education, ethnicity, the previous number of marriages, and the duration of non-married life) (Table 3.4). Without any controls for pre- and post-ART differences (Model 1), we find that women have a 42.7% lower odds of remarrying when they are HIV-positive, and HIV-

positive men have a 31.5% lower odds of remarriage, compared to HIV-negative women and men, respectively. In the post-ART period, remarriage rates increase for men (OR 1.332), but are unchanged for women (post-ART indicator, Model 2). We see no significant interaction between HIV status and the post-ART period for women (Model 3). Men, however, experience a change in their odds of remarriage between the pre- and post-ART period: HIV-negative men have a 24.2% higher odds of remarriage in the post-ART period than in the pre-ART period, while HIV-positive men have over two times the odds of remarriage in the post-ART period than HIV-positive men in the pre-ART period. In the post-ART period, HIV-positive and HIV-negative men have a similar average predicted probability of remarriage (.167 for HIV-positive men and .190 for HIV-negative men, results not shown).

Conditional on remarriage, HIV-positive men and women have, on average, over 24 times the odds of remarrying someone who is also HIV-positive, compared to the odds of someone who is HIV-negative marrying someone who is HIV-positive (Table 3.5, Model 1). In Model 3 we see no change in the odds of remarrying an HIV-positive spouse among both HIV-positive or HIV-negative men and women.

Table 3.4: Logistic regression of lagged HIV status on remarriage among formerly married respondents (odds ratios)

	Females			Males		
	Remarriage Model 1	Remarriage Model 2	Remarriage Model 3	Remarriage Model 1	Remarriage Model 2	Remarriage Model 3
HIV Status (lagged)						
HIV Negative (ref)	1	1	1	1	1	1
HIV Positive	0.573***	0.565***	0.490***	0.685**	0.671**	0.498**
	(0.449 - 0.733)	(0.441 - 0.726)	(0.345 - 0.696)	(0.526 - 0.894)	(0.511 - 0.882)	(0.325 - 0.764)
Post-ART		1.134			1.332**	
		(0.953 - 1.349)			(1.095 - 1.621)	
Post-ART X HIV						
HIV Negative X ART			1.086			1.242*
			(0.902 - 1.309)			(1.010 - 1.527)
HIV Positive X ART			1.405+			2.048**
			(0.943 - 2.092)			(1.251 - 3.352)
Age (Centered)						
Age	0.927***	0.925***	0.926***	0.973***	0.972***	0.972***
	(0.913 - 0.940)	(0.912 - 0.939)	(0.912 - 0.939)	(0.963 - 0.983)	(0.962 - 0.983)	(0.962 - 0.983)
Age Squared	0.998***	0.998***	0.998***	0.999*	0.999*	0.999*
	(0.997 - 0.999)	(0.997 - 0.999)	(0.997 - 0.999)	(0.998 - 1.000)	(0.998 - 1.000)	(0.998 - 1.000)
Education						
No Education (ref)	1	1	1	1	1	1
Some Primary	1.248	1.200	1.206	2.088**	1.954**	1.960**
	(0.907 - 1.717)	(0.865 - 1.664)	(0.870 - 1.671)	(1.301 - 3.350)	(1.204 - 3.169)	(1.209 - 3.177)
Some Secondary	1.468*	1.401+	1.407+	2.947***	2.715***	2.710***
	(1.014 - 2.125)	(0.959 - 2.047)	(0.964 - 2.052)	(1.775 - 4.893)	(1.614 - 4.565)	(1.613 - 4.551)
Unknown	0.469*	0.451**	0.455**	1.386	1.255	1.262
	(0.260 - 0.847)	(0.248 - 0.822)	(0.251 - 0.828)	(0.635 - 3.027)	(0.564 - 2.792)	(0.568 - 2.803)
Ethnicity						
Muganda (ref)	1	1	1	1	1	1
Munyanrwanda	1.116	1.112	1.110	0.922	0.931	0.936
	(0.873 - 1.426)	(0.867 - 1.425)	(0.867 - 1.421)	(0.713 - 1.192)	(0.715 - 1.213)	(0.719 - 1.218)
Other	1.015	1.007	1.007	0.993	0.999	0.999
	(0.734 - 1.405)	(0.724 - 1.400)	(0.725 - 1.397)	(0.758 - 1.300)	(0.757 - 1.319)	(0.757 - 1.317)
Number of previous marriages	2.012***	1.929***	1.940***	2.186***	2.000***	1.981***
	(1.593 - 2.542)	(1.507 - 2.468)	(1.518 - 2.479)	(1.784 - 2.680)	(1.603 - 2.497)	(1.589 - 2.469)
Observed duration controls	Yes	Yes	Yes	Yes	Yes	Yes
ϱ	0.189	0.203	0.197	0.0646	0.0870	0.0839
σ	0.875	0.914	0.899	0.477	0.560	0.549
AIC	5597.857	5597.803	5598.409	3649.343	3642.647	3640.993
BIC	5769.269	5776.357	5784.105	3789.984	3789.681	3794.419
Number of respondents	2,226	2,226	2,226	1,198	1,198	1,198
Person-years formerly married	9,341	9,341	9,341	4,459	4,459	4,459
Number of remarriages	934	934	934	711	711	711

*** p<0.001, ** p<0.01, * p<0.05, + p<0.1

Note: All respondents aged 15-59 who were unmarried but formerly married were included in the model. Sigma is the square root of the variance of the individual-level random effect, and Rho is intra-class correlation, or the fraction of the variance that is explained by the individual-level random effect.

Table 3.5: Logistic regression of lagged HIV status on remarrying an HIV-positive spouse among formerly married respondents who experienced a remarriage (odds ratios)

	All men and women who remarried (with a linked spouse)		
	HIV-Positive Spouse Model 1	HIV-Positive Spouse Model 2	HIV-Positive Spouse Model 3
HIV Status (lagged)			
HIV Negative (ref)	1	1	1
HIV Positive	24.81***	23.40***	27.85***
	(8.708 - 70.66)	(8.454 - 64.78)	(7.067 - 109.7)
Post-ART		1.699+	
		(0.932 - 3.099)	
Post-ART X HIV			
HIV Negative X ART			1.827+
			(0.900 - 3.713)
HIV Positive X ART			1.418
			(0.478 - 4.208)
Age (Centered)			
Age	1.014	1.009	1.009
	(0.980 - 1.049)	(0.975 - 1.045)	(0.975 - 1.045)
Age Squared	0.998	0.998	0.998
	(0.995 - 1.001)	(0.995 - 1.001)	(0.995 - 1.001)
Education			
No Education (ref)	1	1	1
Some Primary	0.617	0.511	0.497
	(0.198 - 1.925)	(0.160 - 1.632)	(0.153 - 1.614)
Some Secondary	0.642	0.524	0.509
	(0.178 - 2.316)	(0.142 - 1.937)	(0.136 - 1.913)
Unknown	10.21*	7.208+	7.064+
	(1.027 - 101.5)	(0.726 - 71.54)	(0.704 - 70.91)
Ethnicity			
Muganda (ref)	1	1	
Munyanrwanda	0.843	0.851	0.846
	(0.356 - 1.995)	(0.360 - 2.013)	(0.356 - 2.013)
Other	1.418	1.421	1.436
	(0.594 - 3.382)	(0.598 - 3.377)	(0.600 - 3.433)
Number of previous marriages	1.292	1.166	1.172
	(0.765 - 2.182)	(0.687 - 1.979)	(0.690 - 1.992)
Observed duration controls	Yes	Yes	Yes
ϱ	0.485	0.481	0.488
σ	1.759	1.747	1.769
AIC	693.2951	692.2765	693.942
BIC	746.3392	750.1428	756.631
Number of respondents	740	740	740
Person-years formerly married	918	918	918
Number of remarriages	918	918	918

*** p<0.001, ** p<0.01, * p<0.05, + p<0.1

Note: All respondents aged 15-59 who were unmarried but formerly married were included in the model. We tested for gender differences, including an interaction between HIV status and gender, but the results were insignificant. Gender controls were no included in the final model. Sigma is the square root of the variance of the individual-level random effect, and Rho is intra-class correlation, or the fraction of the variance that is explained by the individual-level random effect.

Our analysis focuses on the changes in marital partnership mixing, but it is also possible that ART changes non-marital partnership dissolution and formation. Unfortunately, we are unable to conduct the same analysis on non-marital partnerships as we only have linked partnership data for marital partners. However, we explore whether there are any broad changes in non-marital sexual behavior among HIV-positive men and women before and after the introduction of ART. Table 3.6 presents the odds of any reported sexual partnership in the previous 12 months among formerly married men and women. This analysis uses the same model and set of controls presented in Eq. 3.2. We find that, similar to remarriage, HIV-positive women and men have lower odds of having any sexual partner in the previous 12 months, compared to HIV-negative women and men (Table 3.6, Model 1). In the post-ART period (Model 3), HIV-negative women have a 39.4% lower odds of having any sexual partner, compared to HIV-negative women before ART. Despite finding that remarriage among HIV-positive men increases in the post-ART period, we find no corresponding changes for any reported sexual partner for HIV-positive men or women. ART does not seem to change non-marital partnership mixing patterns in the same way as marital partnership mixing.

Table 3.6: Logistic regression of lagged HIV status on any sexual partner in the previous 12 months among formerly married respondents (odds ratios)

	Females			Males		
	Sexual Partner Model 1	Sexual Partner Model 2	Sexual Partner Model 3	Sexual Partner Model 1	Sexual Partner Model 2	Sexual Partner Model 3
HIV Status (lagged)						
HIV Negative (ref)	1	1	1	1	1	1
HIV Positive	0.624***	0.643***	0.571***	0.669**	0.668**	0.715+
	(0.506 - 0.770)	(0.521 - 0.792)	(0.436 - 0.748)	(0.516 - 0.868)	(0.515 - 0.866)	(0.508 - 1.005)
Post-ART		0.633***			1.205*	
		(0.548 - 0.732)			(1.010 - 1.438)	
Post-ART X HIV						
HIV Negative X ART			0.606***			1.092
			(0.517 - 0.710)			(0.898 - 1.329)
HIV Positive X ART			0.760+			0.959
			(0.564 - 1.023)			(0.647 - 1.421)
Age (Centered)						
Age	0.910***	0.911***	0.911***	0.958***	0.958***	0.958***
	(0.901 - 0.919)	(0.902 - 0.920)	(0.902 - 0.920)	(0.948 - 0.968)	(0.948 - 0.968)	(0.948 - 0.968)
Age Squared	0.997***	0.997***	0.997***	0.999*	0.999*	0.999*
	(0.996 - 0.998)	(0.996 - 0.998)	(0.996 - 0.998)	(0.998 - 1.000)	(0.998 - 1.000)	(0.998 - 1.000)
Education						
No Education (ref)	1	1	1	1	1	1
Some Primary	1.238	1.443*	1.450**	2.169***	2.131***	2.130***
	(0.938 - 1.632)	(1.092 - 1.909)	(1.097 - 1.918)	(1.463 - 3.216)	(1.433 - 3.170)	(1.431 - 3.168)
Some Secondary	1.031	1.240	1.246	3.270***	3.196***	3.200***
	(0.738 - 1.438)	(0.886 - 1.737)	(0.890 - 1.745)	(2.089 - 5.116)	(2.033 - 5.024)	(2.035 - 5.031)
Unknown	0.352***	0.398***	0.400***	1.045	1.023	1.021
	(0.218 - 0.568)	(0.247 - 0.641)	(0.248 - 0.645)	(0.525 - 2.081)	(0.512 - 2.044)	(0.511 - 2.040)
Ethnicity						
Muganda (ref)	1	1	1	1	1	1
Munyanrwanda	1.394**	1.437**	1.437**	0.953	0.955	0.955
	(1.099 - 1.769)	(1.134 - 1.821)	(1.134 - 1.821)	(0.721 - 1.258)	(0.723 - 1.262)	(0.722 - 1.262)
Other	0.710*	0.739+	0.739+	1.106	1.107	1.108
	(0.515 - 0.980)	(0.537 - 1.018)	(0.537 - 1.018)	(0.816 - 1.498)	(0.817 - 1.500)	(0.818 - 1.502)
Number of previous marriages	1.338**	1.551***	1.552***	1.925***	1.881***	1.888***
	(1.076 - 1.664)	(1.241 - 1.939)	(1.242 - 1.940)	(1.503 - 2.466)	(1.458 - 2.428)	(1.462 - 2.438)
Observed duration controls	Yes	Yes	Yes	Yes	Yes	Yes
ϱ	0.350	0.345	0.345	0.281	0.281	0.282
σ	1.331	1.317	1.315	1.133	1.135	1.136
AIC	9253.240	9222.796	9222.427	5366.496	5367.303	5369.000
BIC	9346.088	9322.786	9329.560	5449.731	5456.941	5465.040
Number of respondents	2,226	2,226	2,226	1,198	1,198	1,198
Person-years formerly married	9,341	9,341	9,341	4,459	4,459	4,459
Number of remarriages	934	934	934	711	711	711

*** p<0.001, ** p<0.01, * p<0.05, + p<0.1

Note: All respondents aged 15-59 who were previously married but currently not married were included in the model. Sigma is the square root of the variance of the individual-level random effect, and Rho is intra-class correlation, or the fraction of the variance that is explained by the individual-level random effect.

3.6 DISCUSSION

This paper finds strong evidence that ART may be having an impact on marriage. While HIV-positive men and women have historically faced a higher likelihood of marital dissolution, and lower rates of a subsequent remarriage, we find three important changes occurring after the introduction of ART: a lower risk of widowhood in unions with HIV-positive women, an overall stabilization of seroconcordant positive couples, and a higher likelihood of HIV-positive men remarrying.

While marriage has never been particularly stable among the Baganda (Nahemow 1979), the predominant ethnic group in the study site, we do find clear differences in the level of marital instability by HIV status. We see three possible reasons for the higher stability of seroconcordant positive compared to serodiscordant marriages following the roll out of ART. First, ART may reconfigure couples' fertility intentions as viral suppression brings childbearing within reach of seroconcordant positive couples. Infertility has historically been a primary reason for marital discord and divorce in rural Uganda (Nabaitu, Bachengana, and Seeley 1994b), so we would anticipate that changes in childbearing feasibility in marriage may have a stabilizing effect on marriage. Childbearing behaviors may be less likely to change among serodiscordant couples if they are not on ART, or if they are unaware of the lower transmission risk associated with ART. Second, couples may bond over the shared experience of being on ART, thus strengthening relationships. Third, it could be that seroconcordant positive unions are now being purposefully formed, as HIV-positive partners seek out partners of the same HIV status as themselves (Gombachika 2012; Rhine 2009; Seeley et al. 2009). The observed change over time in the stability of seroconcordant positive marriages may not only be about how ART is changing the

dynamics within marriage, but also about how ART is changing the types of marriages that are being formed.

The continued higher risk of divorce in serodiscordant marriages suggests that ART may not be impacting marriage dynamics as much as predicted. If one's partner is not on ART, there remains a very real risk of HIV transmission, which could make an HIV-negative partner more likely to leave. Moreover, even if one's spouse is on ART, the knowledge that ART can prevent the transmission of HIV may not be widely held, or believed. The perception of HIV risk may therefore be high, even if the real risk of transmission is low, and we know that risk perception is an important determinant of divorce (Grant & Soler-Hampejsek 2014). ART could also be impacting marriage dynamics, but not in the way we hypothesized. ART drugs create physical evidence of HIV infection, making it harder for PLHIV to hide their HIV status from their partner. Forced disclosure among serodiscordant couples could increase the risk of divorce, offsetting any reductions in the risk of divorce resulting form the lower transmission risk following ART. Future research should explore the risk of marital dissolution by HIV status, taking into account perceived risk of HIV and knowledge of the preventative effects of ART on HIV transmission, as well as changes in disclosure between the pre- and post-ART periods.

The persisting instability of serodiscordant marriages also suggests that HIV infection may not be the primary driver of divorce, but rather that divorce may be driven by the extra-marital partnerships that HIV infection signifies. Previous research found that infidelity or suspected infidelity were associated with divorce (Nabaitu et al. 1994; Reniers 2008). We would not necessarily expect to see a change between the pre- and post-ART period if extra-marital partnerships were the primary driver of divorce.

We find that widowhood rates are lower in the post-ART period for couples in which the wife is HIV-positive, including seroconcordant positive couples and female-positive serodiscordant couples (though the latter was only significant at $p<.10$). This is consistent with the literature on services uptake: Compared to men, HIV positive women are more likely to enroll in treatment and have better treatment outcomes (Cornell et al. 2012; Druyts et al. 2013; Hawkins et al. 2011; May et al. 2010; Mills et al. 2011; Muula et al. 2007). Male-positive serodiscordant marriages do not see a similar reduction in widowhood, highlighting the disproportionate gains in health for women as a result of their different treatment-seeking behaviors.

The dynamics of marital change in the pre- and post-ART period in rural Uganda also reveal important gender differences. While female-positive serodiscordant couples see a reduction in widowhood over time, they continue to experience a relatively high risk of divorce. Women are also less likely to remarry in both the pre- and post-ART periods than men. Together, these dynamics lead to an exclusion of HIV-positive women from the marriage market. More research is needed to explore whether the exclusion from marriage is coupled with other forms of social and economic disadvantage.

This paper presents an analysis of the HIV status among spouses who remarry, finding that PLHIV who remarry are much more likely to have a partner who is also HIV-positive. The formation of seroconcordant positive marriages among those formerly married may limit the onward transmission of HIV, as long as formerly married HIV-positive men and women who remarry have not infected their partners prior to marriage and do not engage in extra-marital sex. That said, the greater inclusion of PLHIV in marriage might create new opportunities for HIV transmission: HIV-negative men and women remarrying in the post-ART period see a marginally

significant increase in their likelihood of marrying someone who is HIV-positive. The increased survivorship of PLHIV in the post-ART period may be one explanation for the increased odds of HIV-negative men and women marrying an HIV-positive spouse after the introduction of ART: Reductions in AIDS-related mortality imply that HIV-positive men and women live longer, increasing the number of HIV infected men and women in the marriage market.

Beyond HIV transmission, HIV-related marital change also has important implications for the social and economic wellbeing of families and children. A growing body of literature documents the effects of marital instability on children in sub-Saharan Africa, including earlier age of sexual debut and marriage (Beegle & Krutikova 2008; Birdthistle et al. 2008; Palermo & Peterman 2009), a higher risk of child mortality among younger children (Clark & Hamplová 2013; Thiombiano, LeGrand, & Kobiané 2013), and a higher risk of adolescent childbearing, early school drop out or grade repetition, and underemployment (Goldberg 2013). As a result, children of HIV-infected parents may experience greater social disadvantage through HIV-related marital instability. However, the growing stabilization of marriage in the post-ART period may also improve conditions for children and families. The effect of ART on family wellbeing is an important area for further study.

The pre- and post-ART differences in marital change may have important public health implications for the future transmission of the virus. The exclusion of HIV-positive men and women from marriage offers fewer opportunities for the transmission of HIV within marriage. While this is changing with the introduction of ART, the suppressed viral loads resulting from ART are reducing the risk of HIV transmission. The stabilization of seroconcordant positive marriages is promising, as more HIV-positive individuals form sustaining and strong partnerships without the risk of HIV transmission (assuming that ART is not also impacting

extra-marital partnership formation). More research is needed to determine whether the increasing rate of remarriage since ART is increasing HIV transmission, or whether ART is offsetting the risk associated with new partnerships being formed.

While the immediate implications for HIV transmission are unclear, the historic exclusion of HIV-positive individuals from marriage, and the ways in which ART is altering this association, have important implications for the wellbeing of families and children. We need to move beyond seeing ART as only a medical intervention, and begin to document its social impacts.

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Conclusion

I ask three questions in this dissertation: (1) what role do married couples play in the transmission of HIV? (2) how are married couples becoming infected? and (3) is HIV changing marriage? I also address how the widespread roll-out of HIV treatment may be changing HIV risk among married couples, and the impact of HIV on marriage. Here, I summarize the answers to each of these questions, and discuss the implications of my dissertation's findings for HIV policy and research.

Does marriage matter for HIV transmission?

Chapter one finds that marriage matters a great deal for HIV transmission. Married women's HIV incidence rates are lower compared to women of other marital status groups, but the large number of married women results in married women accounting for half of all women's HIV incident cases. Married men comprise an even larger share of men's new HIV infections,

accounting for 58-76% of incident cases. These infections include married people who are infected by their spouse, as well as married people who are infected by an EMP.

After ART became available, incidence rates among married men and women have significantly declined (with the exception of married women in Masaka). Even with a decreasing risk over time, married men and women still account for over half of new HIV infections. If we want to prevent new HIV infections, we therefore need to seriously address HIV risk among married men and women.

How are married couples becoming infected?

Chapter one measures the share of new HIV infections among married men and women in serodiscordant marriages and in seroconcordant negative marriages. I find that the largest share of new HIV cases among married men and women occur as the result of EMPs in marriages that were first observed as seroconcordant negative. While the incidence rate is in fact higher among serodiscordant couples, this risk has declined substantially over time with ART availability. As the risk of HIV transmission among serodiscordant couples has declined, EMP-related marital incidence has taken on greater prominence in the HIV epidemic. In the post-ART period, EMP-related incident cases account for 36-44% of all new HIV infections among married, never married and formerly married men and women.

Serodiscordant marriages, while smaller in number, have the highest incidence rate of any married or unmarried group. One of the primary ways to prevent serodiscordant transmission is for people to serosort, or in other words, marry people of the same HIV status as themselves. In the absence of EMPs, these are the most protective type of partnership people can form. Chapter 2 shows evidence that HIV-positive and HIV-negative men and women in rural Uganda

are more likely to marry someone of the same HIV status as themselves, even after adjusting for population composition effects. I find that serosorting is unlikely to be arising indirectly through other partnership selection processes, but rather, that men and women have a preference for serosorting and act on these preferences. This process of serosorting can reduce the number of serodiscordant marriages, and prevent intra-marital HIV transmissions.

Is HIV changing marriage?

Chapter three finds that HIV is associated with higher levels of marital dissolution and lower levels of remarriage. However, with the roll out of ART, I find that seroconcordant positive marriages have begun to stabilize, and HIV-positive men are more likely to remarry. In the post-ART period, seroconcordant positive couples have stabilized to such an extent that their predicted probability of staying married is nearly identical to that of seroconcordant negative couples. However, I do not observe any significant changes for serodiscordant marriages or for HIV-positive women. These HIV- and gender-based differences in marital change have important implications not only for the onward transmission of the virus, but also for the social and economic wellbeing of people living with HIV or living in HIV-affected households.

Implications for policy

This dissertation is based off data from two study sites in southwestern Uganda, limiting the generalizability of the findings. Any implications drawn from this research need to take into account what is unique about this site, as well as what is applicable in other settings. Given that these results are based on a rural study site with high marriages rates, the findings from this dissertation are less applicable in urban settings, or in contexts with very different marriage

regimes. The study site infrastructure and ongoing presence of HIV research in these communities may also result in study respondents having a higher level of HIV knowledge, and access to treatment and testing services, compared to the general population. However, as countries across SSA increase HIV awareness and access to HIV services, they may begin to more closely resemble these study sites. Some of the most important findings of this dissertation, such as the risk associated with EMPs, the occurrence of serosorting, and the stabilizing effects of ART on some marriages, are not necessarily unique to southwest Uganda. In fact, my research is based on prior work that comes from across Eastern and Southern Africa.

The policy recommendations that stem from this dissertation are therefore best geared for this study population, but are also applicable in other contexts. I highlight three main policy implications below, though each chapter also discusses policy implications specific to each research paper.

(1) Different interventions for different married couples

We need to have different HIV prevention options for different types of married couples. Seroconcordant negative couples have very different HIV prevention needs than serodiscordant couples. As Champredron and colleagues (2013, 1) argue, "If most transmission occurs within stable, serodiscordant couples, then couple-based intervention is a promising route for cost-effective interventions. However, if a lot of transmission is occurring outside of couples, population-based interventions will be necessary." I would argue, however, that we can pursue both of these options simultaneously. Couples that want to serosort can be assisted through voluntary premarital testing. ART can be used to prevent transmission among already serodiscordant couples. And for seroconcordant negative couples, we can employ population-

level interventions to reach a much larger, and lower risk, audience that comprises an important share of all new infections. While seroconcordant negative couples are a low HIV risk group, since ART became available they account for the largest share of new infections among married men and women. Mitigating future HIV transmission requires widespread interventions across a large, and lower risk, population.

(2) Address the risk of EMPs

We need to develop better population-level interventions to address EMP-related HIV transmission. Simple fidelity-promoting campaigns are unlikely to be successful for a variety of reasons. First, such programs may increase the secrecy around EMPs, rather than lead to a reduction in EMPs (Parikh 2007). Second, infidelity is not always viewed as bad: "certain acts of infidelity are not considered socially harmful, and structural factors including mobility, masculine sexual privilege, and social and economic inequalities support extramarital liaisons" (Parikh 2007, 1206). If structural factors drive EMPs, then poverty reduction or women's empowerment programs may also be an effective way to address their associated HIV risk. Third, fidelity may mean different things to different people. Prior research from the Intimacy and Risk Study in Masaka found that faithfulness was often associated with financial or emotion support, but not necessarily sexual fidelity: "Infidelity may be ignored or discounted in this context because of the other benefits of marriage or simply of cultural norms that men need to satisfy their sexual urges" (Agol et al. 2014, 92). Given the complexity of what fidelity means socially and personally to men and women in Uganda, we need more research to figure out how to either reduce the occurrence of EMPs, or to ensure that people who do have EMPs, have safe EMPs.

Most of the research on EMPs also assumes that women's low reported EMPs imply that only men are bringing HIV into marriage. My dissertation finds evidence to the contrary. By the post-ART period, women seroconverted first in 36-41% women's new HIV infections. Addressing EMP-related risk reduction also means acknowledging and accurately measuring women's EMPs.

(3) Start identifying HIV infections earlier

As more and more people who infected with HIV are put on ART, the share of HIV transmission among those with acute, or early, infections will increase (Powers and Cohen 2014). Chapter one finds that most married men and women become infected through EMP-related seroconversions, particularly after ART became available and the incidence rate among serodiscordant couples declined. Some of theses EMP-related seroconversions are likely to be acute, or early, HIV infections. However, these early infections are impossible to catch with standard HIV tests which measure the antibodies that develop only a few moths after infection. One proposed solution is to improve early detection efforts. For example, Powers and Cohen (2014) suggest the use of detection algorithms to identify people with acute HIV infection who present at clinics. These cases are often mistaken as malaria (Bebell et al. 2010), and represent a missed opportunity to prevent onward transmission among those newly infected.

* * *

This dissertation furthers our understanding of HIV risk among married men and women, and how HIV is impacting marriage. This work makes important contributions to the field of public health, providing empirical estimates of the HIV risk among married men and woman.

This dissertation also presents the first evidence of serosorting in a generalized epidemic setting. In addition, this work contributes to the literature on family demography and marriage in Africa, highlighting how HIV and access to ART may be changing processes of union formation and dissolution. Methodologically, this dissertation advances the work on sexual behavior measurement, using linked partnership information and HIV biomarker data to test the sensitivity of women's reported EMPs. Together this research informs our understanding of HIV risk within marriage, and identifies gaps in our ability to adequately meet the prevention needs of married men and women.

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Appendices

APPENDIX 1A: HIV INCIDENCE AND MARITAL STATUS: DETAILED RESULTS

Table 1A.1: Share of new HIV infections and incidence rates by marital status and marital pathway

	Rakai					
	Women			Men		
	1999-2004	2005-2011	All	1999-2004	2005-2011	All
Incidence by marital status (% of incidence)						
Never married	40 (14.1%)	70 (18.0%)	110 (16.4%)	27 (11.6%)	40 (17.8%)	67 (14.6%)
Married	183 (64.7%)	197 (50.8%)	380 (56.6%)	177 (76.0%)	146 (64.9%)	323 (70.5%)
Discordant incidence (#1)	69 (31.2%)	47 (15.1%)	116 (21.8%)	44 (20.9%)	46 (23.5%)	90 (22.1%)
Extra-marital incidence (#2-#4)	74 (33.5%)	111 (35.7%)	185 (34.8%)	116 (55.1%)	81 (41.4%)	197 (48.4%)
Spouse misssing HIV status	40	39	79	17	19	36
Formerly married	60 (21.2%)	121 (31.2%)	181 (27.0%)	29 (12.4%)	39 (17.3%)	68 (14.8%)
Unknown marital status	22	0	22	18	0	18
Incidence rate per 100 PY						
Never married	1.08	1.14	1.12	0.49	0.45	0.46
	(0.77-1.47)	(0.89-1.44)	(0.92-1.35)	(0.32-0.71)	(0.32-0.61)	(0.36-0.59)
Married	1.04	0.71	0.84	1.38	0.65	0.92
	(0.90-1.20)	(0.61-0.82)	(0.76-0.93)	(1.18-1.59)	(0.55-0.77)	(0.82-1.02)
Discordant incidence (#1)	8.12	4.70	6.27	6.85	4.61	5.49
	(6.32-10.27)	(3.46-6.25)	(5.18-7.52)	(4.98-9.19)	(3.38-6.15)	(4.41-6.75)
Extra-marital incidence (#2-#4)	0.48	0.46	0.47	0.83	0.35	0.53
	(0.38-0.61)	(0.38-0.55)	(0.40-0.54)	(0.69-1.00)	(0.28-0.43)	(0.46-0.61)
Formerly married	1.69	1.94	1.85	2.68	1.63	1.96
	(1.29-2.17)	(1.61-2.31)	(1.59-2.13)	(1.80-3.86)	(1.16-2.23)	(1.52-2.48)

	Masaka					
	Women			Men		
	1999-2004	2005-2011	All	1999-2004	2005-2011	All
Incidence by marital status (% of incidence)						
Never married	20 (21.7%)	27 (21.4%)	47 (21.6%)	19 (22.6%)	9 (12.5%)	28 (17.9%)
Married	47 (51.1%)	61 (48.4%)	108 (49.5%)	49 (58.3%)	46 (63.9%)	95 (60.9%)
Discordant incidence (#1)	17 (20.7%)	11 (12.1%)	28 (16.1%)	21 (28.5%)	11 (19.5%)	32 (24.7%)
Extra-marital incidence (#2-#4)	25 (30.4%)	33 (36.3%)	58 (33.4%)	22 (29.8%)	25 (44.4%)	47 (36.2%)
Spouse misssing HIV status	5	17	22	6	10	16
Formerly married	25 (27.2%)	38 (30.2%)	63 (28.9%)	16 (19.0%)	17 (23.6%)	33 (21.2%)
Unknown married status	1	1	2	0	2	2
Incidence rate per 100 PY						
Never married	0.75	0.82	0.79	0.46	0.14	0.27
	(0.45-1.15)	(0.54-1.19)	(0.58-1.04)	(0.28-0.72)	(0.06-0.28)	(0.18-0.39)
Married	0.62	0.53	0.57	0.89	0.51	0.65
	(0.46-0.83)	(0.41-0.69)	(0.47-0.69)	(0.66-1.17)	(0.37-0.68)	(0.53-0.80)
Discordant incidence (#1)	6.29	2.47	3.92	8.34	2.10	4.12
	(3.66-10.07)	(1.23-4.24)	(2.60-5.66)	(5.17-12.76)	(1.05-3.75)	(2.82-5.82)
Extra-marital incidence (#2-#4)	0.35	0.31	0.33	0.30	0.20	0.24
	(0.23-0.52)	(0.22-0.44)	(0.25-0.43)	(0.19-0.49)	(0.13-0.30)	(0.18-0.32)
Formerly married	0.67	0.66	0.67	1.01	0.73	0.84
	(0.43-0.98)	(0.47-0.91)	(0.51-0.85)	(0.58-1.63)	(0.42-1.16)	(0.58-1.18)

Table 1A.2: HIV incidence rate ratios (IRR) by sex and study site

	Rakai					Masaka			
	Women		Men			Women		Men	
	Model 1	Model 2	Model 1	Model 2	Model 3	Model 1	Model 2	Model 1	Model 2
Marital Status									
Never married	1	1	1	1	1	1	1	1	1
Married	0.821	1.071	2.110***	3.215***	3.253***	1.053	1.272	2.404**	2.057*
	(0.657 - 1.026)	(0.757 - 1.517)	(1.559 - 2.857)	(2.086 - 4.954)	(2.111 - 5.012)	(0.686 - 1.616)	(0.701 - 2.308)	(1.287 - 4.491)	(1.008 - 4.198)
Formerly married	2.236***	2.261***	4.508***	6.269***	6.313***	2.465***	2.783**	3.602***	2.690*
	(1.729 - 2.892)	(1.493 - 3.426)	(3.118 - 6.518)	(3.630 - 10.83)	(3.656 - 10.90)	(1.494 - 4.068)	(1.405 - 5.514)	(1.795 - 7.225)	(1.174 - 6.164)
Never married X (2005-2011)		1.067		0.932	0.879		1.289		0.421*
		(0.723 - 1.573)		(0.572 - 1.518)	(0.538 - 1.434)		(0.694 - 2.392)		(0.184 - 0.959)
Married X (2005-2011)		0.665***		0.448***	0.417***		0.924		0.590*
		(0.543 - 0.813)		(0.360 - 0.559)	(0.332 - 0.522)		(0.629 - 1.358)		(0.392 - 0.886)
Formerly married X (2005-2011)		1.034		0.578*	0.542*		1.035		0.774
		(0.758 - 1.410)		(0.357 - 0.935)	(0.334 - 0.879)		(0.622 - 1.722)		(0.388 - 1.544)
Age									
15-24	1	1	1	1	1	1	1	1	1
25-34	0.960	0.977	1.160	1.113	1.116	0.920	0.929	2.160*	2.215*
	(0.806 - 1.143)	(0.821 - 1.164)	(0.908 - 1.483)	(0.870 - 1.424)	(0.873 - 1.428)	(0.628 - 1.349)	(0.633 - 1.363)	(1.142 - 4.086)	(1.173 - 4.182)
35-44	0.537***	0.541***	0.778	0.770	0.776	0.428***	0.433***	1.374	1.414
	(0.420 - 0.686)	(0.423 - 0.692)	(0.576 - 1.051)	(0.570 - 1.041)	(0.574 - 1.049)	(0.263 - 0.699)	(0.265 - 0.706)	(0.672 - 2.810)	(0.693 - 2.887)
45-54	0.237***	0.237***	0.326***	0.282***	0.283***	0.442**	0.446**	1.296	1.314
	(0.141 - 0.396)	(0.141 - 0.397)	(0.169 - 0.630)	(0.146 - 0.544)	(0.147 - 0.547)	(0.264 - 0.739)	(0.266 - 0.747)	(0.606 - 2.772)	(0.616 - 2.806)
55+ ❖						0.102***	0.103***	0.522	0.533
						(0.0517 - 0.202)	(0.0521 - 0.204)	(0.239 - 1.139)	(0.244 - 1.164)
Ethnic group									
Muganda	1	1	1	1	1	1	1	1	1
Munyankole	1.268	1.277	0.957	0.958	0.954				
	(0.921 - 1.745)	(0.928 - 1.758)	(0.561 - 1.633)	(0.562 - 1.635)	(0.559 - 1.627)				
Munyanrwanda	1.060	1.063	0.892	0.873	0.878	1.635**	1.632**	1.071	1.061
	(0.818 - 1.374)	(0.820 - 1.378)	(0.611 - 1.302)	(0.598 - 1.274)	(0.602 - 1.282)	(1.134 - 2.356)	(1.132 - 2.353)	(0.673 - 1.705)	(0.667 - 1.689)
Other	1.417**	1.423**	1.021	0.998	1.007	1.139	1.137	0.896	0.887
	(1.109 - 1.811)	(1.113 - 1.818)	(0.725 - 1.438)	(0.708 - 1.405)	(0.715 - 1.419)	(0.702 - 1.848)	(0.700 - 1.844)	(0.538 - 1.493)	(0.532 - 1.478)
Unknown						0.816	0.806	1.009	0.972
						(0.423 - 1.572)	(0.418 - 1.554)	(0.509 - 1.999)	(0.489 - 1.929)
Religion									
Christian	1	1	1	1	1	1	1	1	1
Muslim	0.753*	0.750*	0.530***	0.531***	0.663*	0.912	0.910	0.381***	0.384***
	(0.599 - 0.947)	(0.596 - 0.943)	(0.385 - 0.731)	(0.385 - 0.732)	(0.467 - 0.944)	(0.652 - 1.276)	(0.651 - 1.274)	(0.218 - 0.665)	(0.220 - 0.671)
None/Other	0.767	0.767	0.339	0.330	0.334				
	(0.318 - 1.851)	(0.317 - 1.851)	(0.0845 - 1.362)	(0.0823 - 1.326)	(0.0832 - 1.341)				
Circumcised					0.500*				
					(0.291 - 0.859)				
Observations	41,216	41,216	31,125	31,125	31,125	25,707	25,707	21,827	21,827

*** p<0.001, ** p<0.01, * p<0.05

❖ There were no incident cases among men and women in Rakai 55 years of age and older. The Rakai study has an age cut off for HIV testing at 59 years, while Masaka tests all adults 15 years and older for HIV

Note: Circumcision data was only available in Rakai. While the Masaka study asked about circumcision in some survye rounds, it did not collect this data consistently over time. Other sexual behavior controls were not included in the model as they greatly reduced the sample size due to higher levels of missing data among never married and formerly married men and women.

APPENDIX 1B: UNDERREPORTING OF CONCURRENT[5] (OR EXTRA-MARITAL) PARNTERSHIPS

1B.1 Background

There is an intense debate about whether concurrent partnerships are a primary driver of the high rates of HIV in Southern and Eastern Africa (Morris and Kretzschmar 1997; Halperin and Epstein 2004; Mah and Halperin 2009; Mah and Halperin 2010; Maas and Zijdeman 2010; Morris 2009; Lurie and Rosenthal 2009a; Lurie and Rosenthal 2009b; Lagarde et al. 2001; Sawers and Stillwaggon 2010; Reniers and Watkins 2010). Partnership concurrency is defined as two overlapping sexual partnerships, where sex with one partner falls in between two acts of intercourse with another partner (UNAIDS 2010). It is hypothesized that concurrent partnerships drive higher HIV rates due to (1) an individual effect, due to the increased risk of HIV transmission immediately following seroconversion, and (2) a network effect, where concurrency creates a more connected sexual network structure through which HIV can spread. At the individual level, the viral load, which determines infectiousness, peaks in the first few months following seroconversion (Boily et al. 2009; Wawer et al. 2005). In concurrent partnerships, recently infected individuals are likely to have sex with an HIV-negative individual during the highly infectious early (or acute) period, and to transmit the virus to a HIV-negative partner. Models suggest that the risk of transmission is reduced in serial monogamy, as the likelihood of coitus with new partners during acute infection stage is lower (Goodreau et al. 2012). Even though the hypothesis that concurrency results in higher HIV transmission has intuitive appeal, a considerable debate has evolved around the empirical evidence –or lack thereof.

[5] Extra-marital partnerships are one type of concurrent partnership. While Chapter one focuses only on extra-marital partnerships, this appendix reflects more broadly on concurrency, and how the misreporting of extra-marital partnerships can inform what we know, and do not know, about the effect of concurrent partnerships more broadly on HIV transmission.

One of the primary limitations to testing whether concurrency affects HIV transmission is the misreporting of concurrent partnerships. There are two main ways to measure concurrency: asking respondents directly if they had sex with anyone else during another sexual partnership, or indirectly asking about the dates of first and last sex with all reported sexual partners. UNAIDS recommends measuring concurrency using the indirect approach, calculating the point-prevalence of concurrency at six months prior to the survey (Huang, Cassels, and Winer 2015; Eaton, McGrath, and Newell 2012).

Both the direct and indirect approaches have measurement error. While reported dates of first and last sex are thought to be moderately to very reliably reported (Huang, Cassels, and Winer 2015), and partner's generally agree on reported dates of first and last sex (Brewer et al. 2006), the indirect approach suffers from reporting errors, including missing data, date heaping, and recall error (Caraël and Kretzschmar 2012; Eaton, McGrath, and Newell 2012; Glynn et al. 2012; Nelson et al. 2007; Morris and O'Gorman 2000). There is also evidence that some partners reported using the direct approach were left out when respondents answered questions using the indirect approach (Maughan-Brown and Venkataramani 2011), and underreporting using the indirect approach is particularly high for non-marital partners (Glynn et al. 2012). However, social desirability bias is thought to be greater with the direct approach (Caraël and Kretzschmar 2012; Morris and O'Gorman 2000). Aside from one notable attempt to develop a new measure of concurrency that takes into account uncertainty in reported concurrency (Helleringer, Mkandawire, and Kohler 2014), all concurrency research is subject to substantial measurement error from one or both of these approaches.

The primary problem with evaluating measures concurrency is that we do not have a gold standard with which to compare the direct, indirect, or any new approach. While there are a

growing number of studies addressing reliability across measures, we lack research on the validity of concurrency measures. Below, I outline a novel approach to testing the sensitivity of concurrency measurement, using data from married men and women who seroconvert while their spouses remain HIV-negative. In a context where sexual transmission is the predominant, if not exclusive, route of infection, the seroconverting spouse must have brought HIV in from outside the partnership, and therefore must have had a concurrent partner. HIV biomarker data from men and women who seroconvert with an HIV-negative spouse can therefore be considered a gold standard measure of concurrency in this specific case.

1B.2 Sensitivity of Concurrency Measures

The data come from two rural open-cohort HIV surveillance surveys in southwestern Uganda: the General Population Cohort (GPC) in Masaka district, and the Rakai Community Cohort Study (RCCS) in Rakai district.

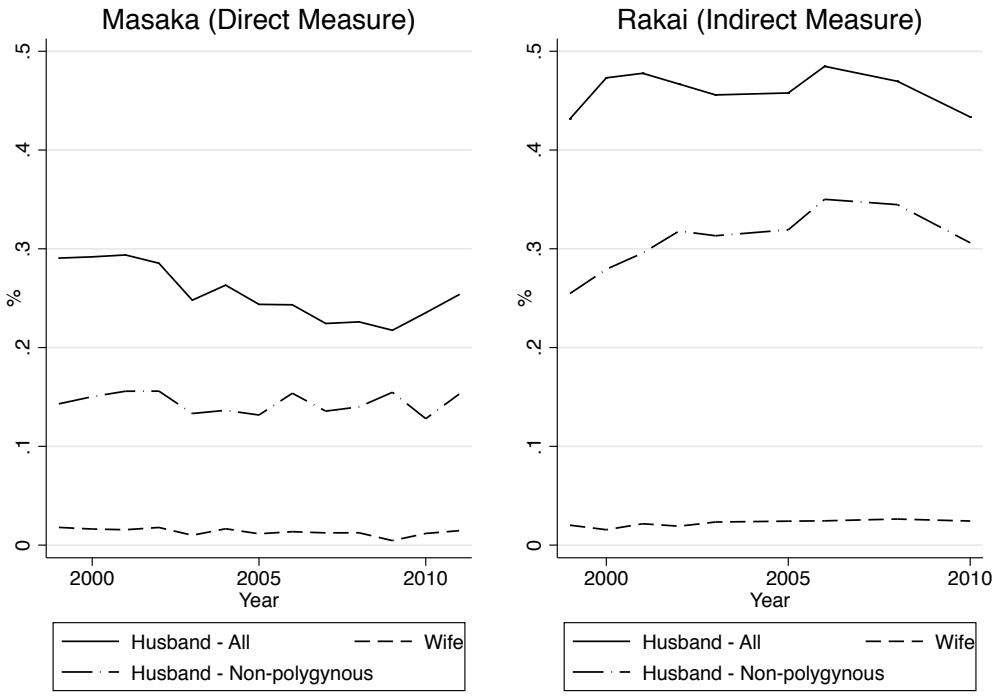
Concurrency is measured in Masaka using a version of the direct approach, where married men and women were asked how many sexual partners they had in preceding 12 months. The main assumption of this measure is that all individuals who are married are engaging in coitus with their spousal partner, and any reported number of partners greater than one indicates concurrency. In Rakai, concurrency is measured with the indirect approach, using dates of first and last sex for up to four sexual partners in the last 12 months. After determining the overlap in partnership duration, I calculate the cumulative prevalence of concurrency in the previous 12 months.

I measure cumulative concurrency in Masaka and Rakai, rather than the recommended point-prevalence, as I want a measure of concurrency that covers the full period in which

seroconversion may occur. A seroconverting individual may have started, and reported, a concurrent partnership only 3 months prior to the survey. Using point-prevalence, they would be coded as someone who seroconverted with an HIV-negative spouse and did not report concurrency. However, a cumulative prevalence measure of concurrency would correctly classify the concurrent partnership as accurately reported.

Figure 1B.1 shows the cumulative 12-month prevalence of concurrency among men and women in both study sites. Men's concurrency prevalence is shown for all men, and then only for non-polygynous men.

Figure 1B.1: Cumulative prevalence of concurrency in the last 12 months among married men and women by study site approach



To assess the sensitivity of concurrency reports, I follow 3,284 seroconcordant negative married couples in Masaka, and 8,938 seroconcordant negative married couples in Rakai, and identify when one spouse seroconverts while the other remains HIV-negative. In Masaka, 46 women and 46 men seroconverted with an HIV-negative spouse, and in Rakai 74 women and 100 men seroconverted while their spouse was still HIV-negative.

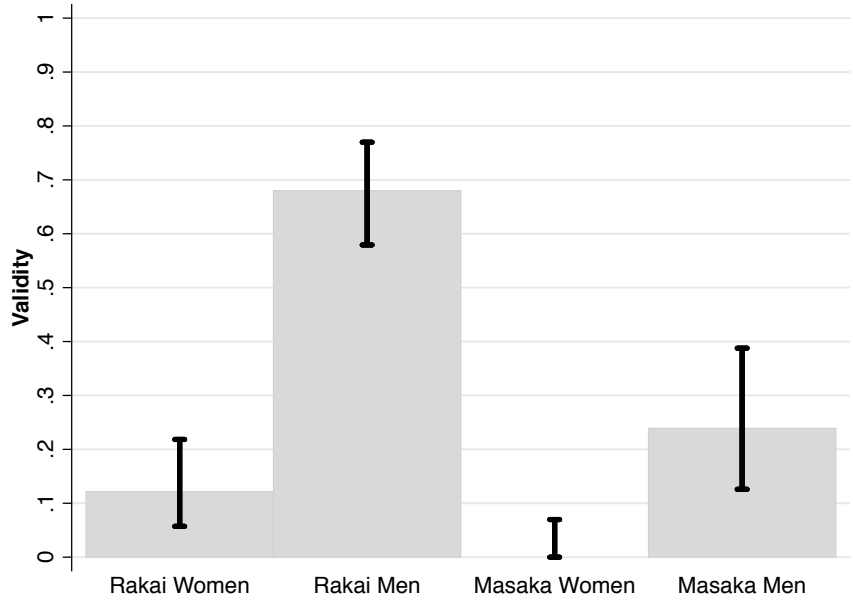
Sensitivity of concurrency reports among those seroconverting first is measured by taking the number of individuals seroconverting first who report concurrency but still have a HIV-negative partner, and dividing by the total number of individuals seroconverting first with a HIV-negative partner (Equation 1B.1). Values close to 1 indicate a high level of sensitivity, i.e., that the measure of concurrency is capturing most of the known cases of concurrency. The closer the value is to zero, the higher the level of misreporting among men and women who seroconverted first.

Unfortunately, I do not have a comparable gold-standard measure with which to test the specificity of concurrency reports. As such, I am only able to identify the problem of false negative, but not false positive, concurrency reports.

(1B.1)

$$Sensitivity\ of\ concurrency\ reports\ (among\ those\ seroconverting\ first) = \frac{\#\ first\ seroconverters\ reporting\ concurrency}{\#\ first\ seroconverters}$$

Figure 1B.2: Sensitivity of concurrency reports among men and women seroconverting first



In this sub-population of men and women who are known to have had a concurrent partnership, the sensitivity of reported concurrency is very low (Figure 1B.2). The extreme case of this is among women in Masaka, where none of the women that seroconverted first reported concurrency. The sensitivity is higher in Rakai compared to Masaka for both men and women. This could be due to differences in the sensitivity of indirect and direct measures, but there are also other critical differences in the survey methodology and study site population. For example, the Rakai study respondents come to an interview center set up within a village, while in Masaka interviewers go household to household, where there may be a greater likelihood of someone overhearing responses.

Women were less likely to report their concurrency than men, supporting previous work that has found that women are more likely to underreport sexual behaviors (Nnko et al. 2004). However, I do not find evidence that married men overreport their sexual behaviors; even in Rakai, with the highest sensitivity, only 68% of men who were known to have had a concurrent partner actually reported concurrency.

It is only possible to assess the sensitivity of concurrency measurement among men and women who seroconverted while their spouse was HIV-negative. Men and women who seroconvert may be different in important ways from the broader population. It is very possible that men and women who seroconverted report their concurrency behaviors differently than men and women who engaged in concurrency but did not become HIV-positive. In addition, I am only looking at concurrency reports among married men and women. Previous research has suggested married couples are more reliable in reporting concurrency than unmarried men and women (Glynn et al. 2012; Eaton, McGrath, and Newell 2012). It is therefore possible that sensitivity of concurrency reports is the same, or even lower, among unmarried men and women.

1B.3 Implications

I find evidence that there is a large level of underreporting of concurrency among married men and women who were known to have a concurrent partnership. This problem persists even using the UNAIDS recommended indirect measure. I also find that the vast majority of women who were known to have concurrent partnerships did not report their concurrent partners. The extraordinarily high level of underreporting among women reveals important challenges to testing the concurrency hypothesis. Women's seroconversions may be falsely attributed to their spouse if they misreport their own concurrency. As a result, any empirical test of concurrency is likely to overstate the onward transmission attributed to men's concurrent partnerships.

Without addressing the large measurement error in reported concurrency it will be difficult, if not impossible, to test the effect of concurrency on HIV transmission. These findings reveal the important limitations of using self-reported sexual behaviors in understanding the role of concurrent partnerships.

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APPENDIX 1C: HIV INCIDENCE AND MARITAL STATUS: HIV IMPUTATION SENSITIVITY ANALYSIS

Table 1C.1 replicates the findings in Table 1A.1 using non-imputed HIV status. The results in Chapter 1 are not sensitive to the method of imputation used.

Table 1C.1: Sensitivity test for HIV imputation: share of new HIV infections and incidence rates by marital status and marital pathway using non-imputed HIV status

	Rakai					
	Women			Men		
	1999-2004	2005-2011	All	1999-2004	2005-2011	All
Incidence by marital status (% of incidence)						
Never married	40 (16.1%)	82 (18.4%)	122 (17.6%)	28 (14.4%)	45 (16.0%)	73 (15.3%)
Married	155 (62.5%)	225 (50.6%)	380 (54.8%)	144 (74.2%)	187 (66.3%)	331 (69.5%)
Discordant incidence (#1)	57 (34.3%)	43 (15.8%)	100 (22.6%)	38 (24.7%)	47 (22.3%)	85 (23.3%)
Extra-marital incidence (#2-#4)	47 (28.2%)	95 (34.8%)	142 (32.2%)	76 (49.5%)	92 (44.0%)	168 (46.2%)
Formerly married	53 (21.4%)	138 (31.0%)	191 (27.6%)	22 (11.3%)	50 (17.7%)	72 (27.6%)
Incidence rate per 100 PY						
Never married	1.08	1.33	1.24	0.51	0.50	0.51
	(0.77-1.47)	(1.06-1.66)	(1.03-1.48)	(0.34-0.74)	(0.37-0.67)	(0.40-0.64)
Married	0.88	0.81	0.84	1.12	0.83	0.94
	(0.75-1.03)	(0.71-0.92)	(0.76-0.93)	(0.94-1.32)	(0.71-0.96)	(0.84-1.04)
Discordant incidence (#1)	6.66	4.35	5.42	5.88	4.49	5.02
	(5.04-8.63)	(3.15-5.85)	(4.41-6.60)	(4.16-8.07)	(3.30-5.97)	(4.01-6.21)
Extra-marital incidence (#2-#4)	0.31	0.39	0.36	0.55	0.40	0.46
	(0.23-0.41)	(0.32-0.48)	(0.30-0.43)	(0.43-0.69)	(0.32-0.49)	(0.39-0.53)
Formerly married	1.49	2.20	1.94	2.04	2.07	2.06
	(1.12-1.95)	(1.85-2.60)	(1.68-2.24)	(1.28-3.09)	(1.53-2.73)	(1.61-2.60)
	Masaka					
	Women			Men		
	1999-2004	2005-2011	All	1999-2004	2005-2011	All
Incidence by marital status (% of incidence)						
Never married	14 (16.7%)	23 (17.2%)	37 (17.0%)	14 (18.4%)	9 (11.3%)	23 (14.7%)
Married	46 (54.8%)	63 (47.0%)	109 (50.0%)	45 (59.2%)	51 (63.8%)	96 (61.5%)
Discordant incidence (#1)	16 (25.8%)	9 (10.8%)	25 (17.1%)	19 (30.4%)	11 (20.6%)	30 (26.0%)
Extra-marital incidence (#2-#4)	18 (29.0%)	30 (36.2%)	48 (32.9%)	18 (28.8%)	23 (43.2%)	41 (35.5%)
Formerly married	24 (28.6%)	48 (35.8%)	72 (33.0%)	17 (22.4%)	20 (25.0%)	37 (23.7%)
Incidence rate per 100 PY						
Never married	0.52	0.69	0.62	0.34	0.14	0.22
	(0.29-0.88)	(0.44-1.04)	(0.43-0.85)	(0.19-0.57)	(0.06-0.27)	(0.14-0.33)
Married	0.61	0.55	0.57	0.81	0.56	0.66
	(0.44-0.81)	(0.42-0.71)	(0.47-0.69)	(0.59-1.10)	(0.42-0.74)	(0.53-0.80)
Discordant incidence (#1)	6.80	2.53	4.23	8.30	2.52	4.51
	(3.88-11.04)	(1.16-4.81)	(2.74-6.24)	(5.00-12.96)	(1.26-4.52)	(3.05-6.44)
Extra-marital incidence (#2-#4)	0.25	0.29	0.28	0.28	0.22	0.24
	(0.15-0.40)	(0.20-0.41)	(0.20-0.37)	(0.17-0.44)	(0.14-0.33)	(0.17-0.33)
Formerly married	0.64	0.83	0.76	1.07	0.85	0.94
	(0.41-0.95)	(0.61-1.10)	(0.59-0.95)	(0.62-1.71)	(0.52-1.31)	(0.66-1.29)

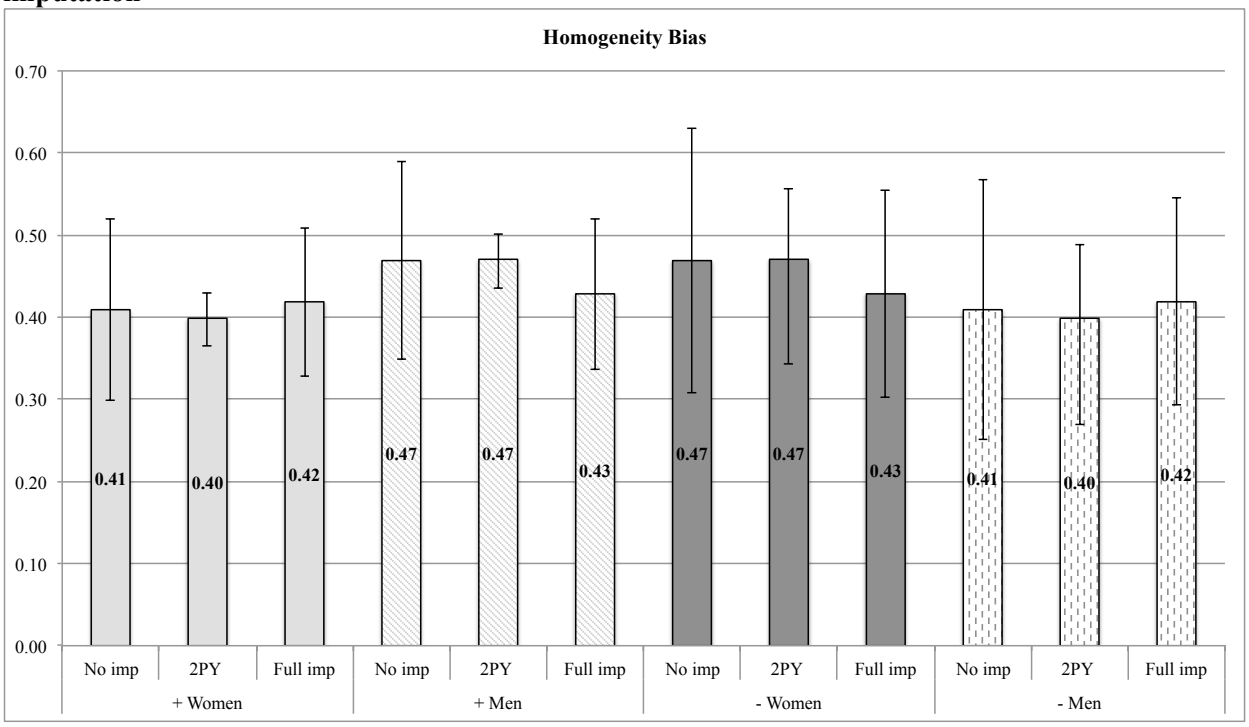
APPENDIX 2A: HOMOGENEITY BIAS BY HIV STATUS IMPUTATION METHOD

Measurement of serosorting is highly influenced by population composition, and in particular the number of HIV-positive and HIV-negative men and women in the population. As such, any method of imputing HIV status will affect the number of HIV-positive men and women in previous and subsequent years.

Chapter 2 discusses three different ways missing HIV status was dealt with: (1) no imputation, (2) imputing HIV-positive statuses forward two person-years and HIV-negative statuses back two person-years, and (2) imputing HIV-positive statuses forward to the last observation, and HIV-negative statuses backwards to the first observation. The results presented in Chapter 2 use the two person-year method of imputation. Results in Figure 2A.1 compare the measure of homogeneity bias across the three different methods of handling (or not handling) missing HIV data.

The differences in homogeneity bias by the method of handling missing HIV data are small and insignificant. The results presented in Chapter 2 are robust to different methods of handling missing HIV data.

Figure 2A.1: Homogeneity bias for HIV-positive and HIV-negative men and women under three models of HIV imputations: (1) no imputation, (2) two person-year imputation, and (3) full imputation



Note: Homogeneity bias calculated using the expected proportion of seroconcordant partnerships in the married pool. 95% confidence intervals are indicated by the lines in each bar.

APPENDIX 2B: HOMOGENEITY BIAS BY LAGGED HIV STATUS

Men and women are likely to have sex with their prospective marital partners prior to marriage. If seroconversions occur prior to marital formation, the measure of homogeneity bias presented in Chapter two may actually overstate serosorting in the study site. This appendix tests how sensitive the measure of homogeneity presented in Chapter two is to using HIV status at the time of marital formation, versus HIV status in previous study round. If seroconversions are occurring prior to marital formation, I would expect the measure of homogeneity bias calculated using lagged HIV status from year *t-1* to be lower for HIV-positive men and women than homogeneity biased calculated using actual HIV status at the survey year in which marital formation occurred.

There some important limitations to this sensitivity test. First, people may relocate into the study site at the time of marital formation, such that their HIV status in prior years will be missing. This sensitivity test is therefore only conducted on a sub-group of the population where both partners were in the study site the year before they were married. Previous research in the study site has found that in-migrants are more likely to be HIV-positive, such that couples excluded from this sensitivity test may be more likely to have one or both partners who are HIV-positive. Of the 1,310 new marriages, HIV status was unknown the year prior to marriage for one or both spouses in 295 cases.

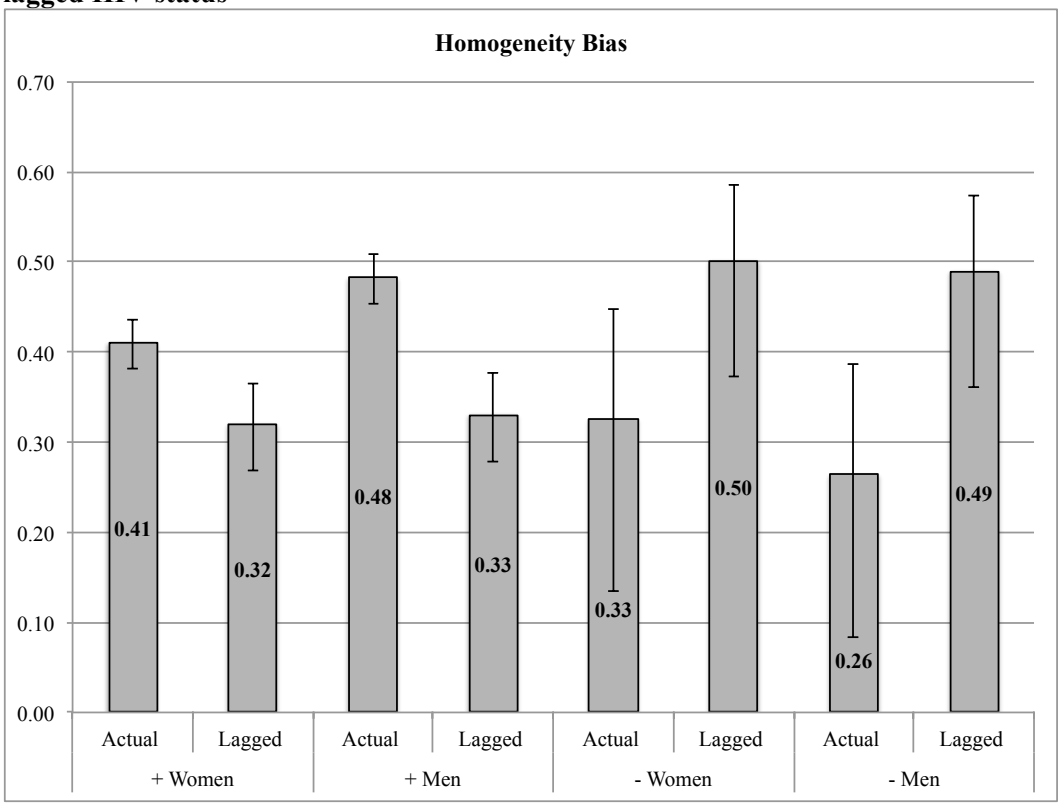
The second limitation to this sensitivity test is that not all seroconversions that occur in the year prior to marriage are the result of HIV transmission between prospective marital partners. A person could become HIV infected from another partner, and then later find a new partner who is also HIV-positive. However, it is unlikely that someone who has newly acquired HIV would learn their status in such a short period of time, particularly given that a test of HIV

antibodies is only effective three months after seroconversion. Of newly married couples who's HIV status was known the year prior to marriage, there were four men and three women who seroconverted the year that they formed a serodiscordant marriage. These seroconversions must have occurred from someone other than their prospective spouse, who was HIV-negative.

Of 1,015 new marriages with lagged HIV status, only three women and ten men seroconverted the year before they formed a seroconcordant positive marriage. These relationships may have started off serodiscordant, or one or both partners could have brought HIV in from outside the partnerships and infected their prospective spouse.

Figure 2B.1 presents the homogeneity bias measure of HIV-positive and HIV-negative men and women using their actual HIV status at marital formation, and lagged HIV status. The expected proportion of seroconcordant marriages was calculated assuming random mixing in the unmarried pool. As predicted, homogeneity bias is lower among HIV-positive men and women when calculated with lagged HIV status. It is possible that Chapter two is biased upwards in its measurement of homogeneity bias. However, there is still more serosorting than we would expected under random mixing. The lagged results are also run on a sub-group of the sample of all new marriages. The differences between lagged and non-lagged homogeneity bias may therefore be due to (1) seroconversion occurring prior to marriage or (2) difference in serosorting between relationships with and without in-migrants.

Figure 2B.1: Homogeneity bias for HIV-positive and HIV-negative men and women with actual and lagged HIV status



Note: Homogeneity bias calculated using the expected proportion of seroconcordant partnerships in the unmarried pool. 95% confidence intervals are indicated by the lines in each bar.

APPENDIX 3A: DISCREPANT REPORTS OF MARITAL DISSOLUTION

Marital dissolution is measured through men and women's self-reported marital status. There were 1,154 marriages where the husband and wife had discrepant reports on the status of their marriage. Table 3A.1 outlines how each of these cases were resolved using reports from subsequent years, households of residency data, and the census from the study site. The left column presents the number of discrepant reports still remaining to be resolved after each coding step. Each row in the middle column describes a different method used to assess discrepant marital status reports, and how cases identified in each step were coded. The right column presents the number of cases resolved with each coding step, where cases in parentheses were considered to be false reports of dissolution and cases without parentheses were coded as dissolved. Of the 1,154 discrepant reports, 177 marriages were considered to still be intact despite one spouse reporting dissolution.

Table 3A.1: Data coding for discrepant reports of marital status

Discrepant reports (N)	Issue and coding scheme	Cases resolved
1,154	**Co-residence:** Coded dissolution as true if no longer residing together, and are not polygynous (polygynous couples are often coded in different households since each wife's home has a different household identification number)	679
475	**Co-residence at time *t+1*:** Couple no longer residing together in the following survey round were coded as having a dissolution occur at time *t* when one of the spouses first reported a dissolution	88
387	**False widowhood:** Coded dissolution as false when there was reported widowhood but the spouse was still alive and participating in the study that year	(107)
280	**Confirmed widowhood:** Report widowhood and spouse confirmed dead, code dissolution as true	13
267	**One-off misreport:** Report married to same person at time *t-1* and time *t+1*, code dissolution at time *t* as false	(68)
199	**Difference in timing:** One spouse reports dissolution at time *t*, and the other spouse at time *t +1*, dissolution assumed to occur at the mid-point between the two surveys and coded as true at time *t+1*	10
189	**Consistently reported:** Dissolution reported at time *t*, and at *t +1*, dissolution coded as true	67
122	**Already dissolved:** A discrepancy in marital status reports existed in an early survey round and was resolved. The dissolution was coded as false as the dissolution had already occurred in a prior year	(2)
120	**Out-migrated censoring:** One or both partners left the study site, but dissolution was reported by the remaining spouse or by a family member in the census. Dissolution coded as true	77
43	**Partnership not reported in future years:** Both spouse no longer reported their spouses partner identification number in a subsequent survey round, dissolution coded as true	43

Table 3A.2 presents results for the sensitivity of the findings in Chapter three to the coding of marital dissolution. Model 1 considers dissolution to have occurred if either of the spouses reported dissolution. Model 2 uses the coding from Chapter three (and outlined above in Table 3A.1). Model 3 codes all discrepant reports as not dissolved. The different methods of addressing discrepant marital status reports do not alter the findings presented in Chapter three.

Table 3A.2: Sensitivity of results to the coding of marital dissolution

	Model 1		**Model 2**		**Model 3**	
	All reported dissolutions		Dissolution with resolved discrepancies		Dissolution excluding discrepant reports	
	Divorce	Widowhood	Divorce	Widowhood	Divorce	Widowhood
Couples HIV Status (lagged)						
Concordant Negative (F- M-)	1	1	1	1	1	1
Concordant Positive (F+ M+)	2.725***	9.646***	2.909***	11.19***	2.671**	11.11***
	(1.569 - 4.735)	(5.970 - 15.59)	(1.672 - 5.059)	(6.579 - 19.05)	(1.484 - 4.807)	(6.524 - 18.92)
Female-Positive Discordant (F+ M-)	2.905***	3.810***	2.907***	5.525***	2.847**	5.503***
	(1.609 - 5.246)	(1.746 - 8.316)	(1.564 - 5.402)	(2.484 - 12.29)	(1.494 - 5.425)	(2.475 - 12.24)
Male-Positive Discordant (F- M+)	2.187**	3.231***	2.219**	3.446**	2.157*	3.436**
	(1.255 - 3.811)	(1.657 - 6.300)	(1.238 - 3.977)	(1.589 - 7.472)	(1.188 - 3.916)	(1.585 - 7.448)
Post-ART						
Post-ART X HIV						
(F-M-) x ART	1.716***	0.904	1.680***	0.911	1.591***	0.909
	(1.354 - 2.174)	(0.632 - 1.294)	(1.304 - 2.165)	(0.590 - 1.406)	(1.226 - 2.065)	(0.589 - 1.403)
(F+ M+) x ART	0.649	0.361**	0.681	0.299**	0.775	0.302**
	(0.275 - 1.531)	(0.182 - 0.717)	(0.288 - 1.613)	(0.132 - 0.678)	(0.321 - 1.873)	(0.133 - 0.684)
(F+ M-) x ART	1.452	0.233+	1.607	0.234+	1.533	0.233+
	(0.696 - 3.032)	(0.0435 - 1.244)	(0.734 - 3.521)	(0.0433 - 1.266)	(0.685 - 3.431)	(0.0432 - 1.260)
(F- M+) x ART	1.141	0.407	1.160	0.364	1.112	0.364
	(0.507 - 2.567)	(0.136 - 1.217)	(0.482 - 2.791)	(0.0888 - 1.494)	(0.452 - 2.736)	(0.0888 - 1.492)
Number of couples						
Number of events						
Marriage-years of observation	15,556	15,556	15,556	15,556	15,556	15,556

APPENDIX 3B: SENSITIVITY OF MARITAL DISSOLUTION AND REMARRIAGE RESULTS TO LEFT-CENSORING

Table 3.3 in chapter three presents the relative risk ratios of marital dissolution, controlling for marital duration using the observed duration married. Table 3B.1 compares these results to a sub-sample of the population whose marital duration is known (marriages that started during the period of observation, 1999-2011). This sensitivity analysis comes with a substantial reduction in sample size, from 15,556 married person-years to 3,930 married person-years. The reduced sample size and the relatively rare event of widowhood, result in a quasi-separation problem. As can be observed in the column for widowhood among couples with known marital duration, the coefficients for widowhood are unreliable. This sensitivity test is still included in this appendix, but needs to be interpreted in light of these substantial limitations.

Table 3B.2 presents a similar sensitivity analysis for the results on remarriage, comparing the sample of all single individuals to single individuals who became single between 1999-2011 and therefore have a known duration single. In the table, these groups are referred to as observed duration and actual duration, respectively.

Table 3B.1: Sensitivity analysis of multinomial logistic regression results (lagged couples HIV status on the risk of divorce and widowhood compared to no dissolution (relative risk ratios))

	Marital Dissolution			
	Couples			
	Observed Duration		Acutal Duration	
	Divorce	Widowhood	Divorce	Widowhood
Couples HIV Status (lagged)				
Concordant Negative (F- M-)	1	1	1	1
Concordant Positive (F+ M+)	2.909***	11.19***	4.062**	8.919**
	(1.672 - 5.059)	(6.579 - 19.05)	(1.526 - 10.81)	(2.320 - 34.29)
Female-Positive Discordant (F+ M-)	2.907***	5.525***	4.078**	16.98***
	(1.564 - 5.402)	(2.484 - 12.29)	(1.537 - 10.82)	(5.090 - 56.63)
Male-Positive Discordant (F- M+)	2.219**	3.446**	2.156+	3.16e-06***
	(1.238 - 3.977)	(1.589 - 7.472)	(0.919 - 5.057)	(9.82e-07 - 1.02e-05)
Post-ART				
Post-ART X HIV				
(F-M-) x ART	1.680***	0.911	1.314	0.913
	(1.304 - 2.165)	(0.590 - 1.406)	(0.874 - 1.976)	(0.370 - 2.255)
(F+ M+) x ART	0.681	0.299**	0.376	0.344
	(0.288 - 1.613)	(0.132 - 0.678)	(0.0989 - 1.426)	(0.0522 - 2.272)
(F+ M-) x ART	1.607	0.234+	1.266	0.149
	(0.734 - 3.521)	(0.0433 - 1.266)	(0.403 - 3.975)	(0.0152 - 1.463)
(F- M+) x ART	1.160	0.364	1.068	356,857***
	(0.482 - 2.791)	(0.0888 - 1.494)	(0.343 - 3.326)	(46,505 - 2.738e+06)
Observations	15,556	15,556	3,930	3,930

*** p<0.001, ** p<0.01, * p<0.05

Note: Table. 3.3 controls were included in all models presented here, but coefficients are not presented.

Table 3B.2: Sensitivity analysis of logistic regression of lagged HIV status on remarriage among formerly married respondents (odds ratios)

	Remarriage			
	Females		Males	
	Observed Duration	Acutal Duration	Observed Duration	Acutal Duration
HIV Status (lagged)				
HIV Negative (ref)	1	1	1	1
HIV Positive	0.490***	0.288***	0.498**	0.406**
	(0.345 - 0.696)	(0.139 - 0.595)	(0.325 - 0.764)	(0.220 - 0.750)
Post-ART X HIV				
HIV Negative X ART	1.086	0.733+	1.242*	1.121
	(0.902 - 1.309)	(0.535 - 1.005)	(1.010 - 1.527)	(0.861 - 1.461)
HIV Positive X ART	1.405+	1.079	2.048**	2.270*
	(0.943 - 2.092)	(0.526 - 2.214)	(1.251 - 3.352)	(1.181 - 4.360)
Number of respondents	2,226	1,198	1,198	830
Person-years formerly married	9,341	4,602	4,415	2,874
Number of remarriages				

*** p<0.001, ** p<0.01, * p<0.05

Note: Table 3.4 controls were included in all models presented here, but coefficients are not presented.