Treatment-as-Prevention: The Household Characteristics of HIV Transmission in a South African Community

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1 Abstract

In this paper we investigate whether exposure to a homestead with at least one resident known to have initiated antiretroviral treatment (ART) reduces the hazard of HIV seroconversion for an at-risk individual of the same homestead, compared to 1) homesteads with at least one resident known to be HIV-positive but not on ART, and 2) homesteads in which no residents are known to be HIV-positive. We use data collected by the Africa Centre for Health and Population Studies, located in the KwaZulu-Natal province of South Africa, to investigate the role of ART in reducing the hazard of secondary HIV seroconversions in the homesteads of a rural community for the years 2002 to 2011. Results show that homestead HIV prevalence is on the increase for the proportion of homestead residents that are HIV-positive and for the number of homesteads that have at least one HIV-positive resident. Results also show an increase in the number of residents who initiated ART for the years 2004 to 2011. Cox proportional hazards results show that exposure to a homestead with at least one resident who initiated ART significantly reduces the hazard of seroconversion for at-risk individual residents. The findings also suggest that the seroconversion hazard is higher for an at-risk individual belonging to a homestead with no HIV-positive residents when compared with a homestead with at least one HIV-positive member not on ART. Future work will need to identify whether the presence of ART in a homestead operates to reduce secondary infections via the treatment-as-prevention channel, or whether the use of ART in the homestead increases social awareness to HIV and thus reduces HIV-risk related behaviors.

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2 Introduction

HIV/AIDS can be described as one of history's worst pandemics, resulting in more than 60 million infections and 30 million deaths (De Cock et al., 2011). Globally, HIV continues to spread unabated and with no foreseeable end in sight. By the end of 2010, the total estimated number of adults and children living with HIV was 34 million (31.6–35.2 million), another 2.7 million (2.4–2.9 million) were estimated to be newly infected with HIV, and 1.8 million (1.6–1.9 million) were estimated to have died of AIDS (UNAIDS, 2011).[1] In recent years the wide-scale provision of antiretroviral treatments (ART) to limit HIV incidence has emerged as the leading strategic initiative. The goal to have more than 5 million people on ART by 2010 constitutes one of the biggest public health interventions thus far attempted (UNAIDS, 2010), by that year coverage had extended to only 20% of sub-Saharan Africa (UNAIDS, 2011).

Treatment-as-Prevention (TasP) has been described as a paradigm shift in the fight against HIV/AIDS (Montaner, 2011; Sidibe, 2011). The elements of TasP—'Seek, Test, Treat, and Retain'—are now being considered by prominent public health officials and scientists as the optimal strategy to prevent secondary HIV infections (Hayden, 2010; Cambiano et al., 2011; Montaner, 2011). The TasP paradigm is grounded on a straightforward proposition: "bringing medication to the maximum number of people infected with HIV will not only bring the promise of greatly enhanced survival and quality of life for people living with HIV, but will also greatly reduce their viral loads and the likelihood of passing the virus onto new people" (Adam, 2011: 3). Clinical researchers have explored the idea of treatment technologies to inhibit HIV transmission since the early development and clinical testing of the antiretroviral agent, azidothymidine (AZT) (see for example, Henry et al., 1988). In one of the earliest and most widely cited studies, Fideli et al. (2001) showed that the viral load of the index case was the strongest predictor of heterosexual HIV transmission. The TasP approach to HIV prevention has regained traction in the last two years with the published findings of the Center for the AIDS Program of Research in South Africa (CAPRISA 004) study (Abdool et al., 2010) and the Pre-Exposure Prophylaxis Initiative (iPREX) study (Grant et al., 2010), which were followed by the results of the HPTN 052 study, which showed that ART reduced the risk of infection in heterosexual HIV-serodiscordant couples by 96% (with a 95% CI of 73% to 99%) (Cohen et al., 2011). This result has been claimed by some commentators to decisively confirm the preventative impact of ART on the heterosexual transmission of HIV (Cohen, 2012; Eaton et al., 2012).[2] Elsewhere, TasP has been forwarded as the most significant HIV/AIDS theme "over and above the human rights issue" (Montaner, 2010).[3] In 2011, the promise of TasP to open up a major new avenue in the global fight against AIDS was recently acknowledged by *Science* magazine as the "breakthrough of the year."

[1] Uncertainty ranges of point estimates reported in parenthesis.

[2] In the United States, two key members of the National Institutes of Health endorsed these findings as "the theoretical basis for a new and potentially important public health policy strategy" (Dieffenbach and Fauci, 2009: 2308), which subsequently prompted the U.S. Federal government to quickly invest in evaluations of the test and treat approach in New York City and Washington D.C. (Holtgrave, 2010; Berkelman, 2012).

[3] Comment made by the outgoing President of the International AIDS Society, Julio Montaner, at the 2010 International AIDS Conference in Vienna, Austria.

In this paper we use observational, longitudinal data to assess the efficacy of TasP outside of the clinical context. In the absence of imminent results from cluster randomized controlled trials (El-Sadr, 2012),[4] observational studies currently provide the empirical backbone for evaluating the outcomes of TasP strategies in terms of real-world implementation (Smith et al., 2011). A number of observational studies have shown that reductions in the viral load of the index case (the first known HIV-positive patient in a population under investigation) through ART is associated with a reduction in the viral loads of subsequent cases (see Smith et al. (2011) for a systematic review of this literature). Most notably, Bunnell et al. (2006) and Donnell et al. (2010) estimated that ART was associated with a 98% and a 92% reduction in the incidence of HIV transmission among heterosexual serodiscordant partners respectively. However, one study found no significant statistical difference in the seroconversion rates of individuals who had a partner on ART and those who did not (Wang et al., 2010). More recently, two papers by Africa Centre researchers showed that high coverage of ART was associated with a decline in risk of HIV acquisition (Tanser et al., 2013), and that dramatic increases in adult life expectancy were attributable to the ongoing scale-up of ART treatment in a rural KwaZulu-Natal community (Bor et al., 2013).

In this paper we investigate the role of ART in reducing the hazard of HIV infection for at-risk members of homesteads in a rural South African community.[5] Specifically, we hypothesize that the hazard of HIV seroconversion will be significantly reduced for at-risk individuals who belong to a homestead in which at least one resident has initiated ART (we define such a homestead as the 'treatment' group). The motivation of this paper is to transition from the emphasis placed on assessing the efficacy of ART in the clinical setting (which typically focuses on serodiscordant individuals in intimate relationships) to an analysis of the role of ART in reducing secondary HIV infections for at-risk individuals at the homestead-level. This research objective is therefore motivated by an understanding of HIV as a social ecology which strongly considers the role of homestead characteristics (such as gender, marriage, family, kinship, and other relevant socio-economic factors) that are likely to influence the well-intended outcomes of health-care interventions (MacQueen, 2011; Kippax et al., 2011). We argue that the implementation of TasP strategies will predominantly take place within the social context of people's living or dwelling spaces, which places a significant weight on the role of homestead characteristics in moderating the efficacy of ART in reducing secondary HIV infections. This work is therefore an analysis of homestead exposure to ART, which we situate between the clinical- and population-level analyses that have thus far evaluated TasP strategies.

The research question of this paper is stated in more precise wording below: *Does exposure to a homestead with at least one resident known to have initiated ART reduce the hazard of HIV seroconversion for an at-risk individual of the same homestead, compared to 1) homesteads with at least one resident known to be HIV-positive but not on ART, or 2) homesteads in which no residents are known to be HIV-positive?*

[4]The Africa Centre for Population and Health Studies (Africa Centre) is currently one of only four research sites in the world that are undertaking a cluster randomized controlled trial to evaluate the efficacy of TasP strategies at the population-level.

[5]A more detailed explanation of the term *homestead*, as differentiated from the more familiar term *household*, is presented in Section 3.3.

3 Background, Data and Methods

3.1 Research Context

In South Africa, HIV is predominantly spread through heterosexual intercourse (Shisana et al., 2008). Of the four official racial groups of South Africa (StatsSA, 2011), Black Africans are disproportionately affected by the epidemic (16.6% are infected) compared to Coloreds (1.7%), Indians (0.3%) and Whites (0.3%) (Shisana et al., 2008). As of 2011, an estimated 16.6% of the male and 19.4% of the female population (aged 15–49 years) in South Africa were reported as HIV-positive (StatsSA, 2011). The national HIV prevalence estimate for women attending antenatal clinics in 2010 was 30.2% (95% CI of 29.39–30.91) (DoH, 2011). Not one of the of the 52 health districts in South Africa recorded an antenatal HIV prevalence below 8%. In 2010, the KwaZulu-Natal province recorded the highest antenatal prevalence at 39.5%, with five districts in that province recording above 40% (DoH, 2011).

In this paper we present the findings of data collected by the Africa Centre, which is located in the KwaZulu-Natal province of South Africa. The Africa Center was established by the University of KwaZulu-Natal and the South African Medical Research Council in 1997, funded by a large core grant from the Wellcome Trust, UK. In 2000 a demographic surveillance system called the Africa Center Demographic Information System (ACDIS) was started, and in 2003 population-based HIV testing was implemented. The ACDIS was set up to "describe the demographic, social and health impact of the HIV epidemic in a population going through the health transition and to monitor the impact of intervention strategies on the epidemic" (Tanser et al., 2008). The ACDIS is a cohort study and a population-based HIV survey, which attempts to mirror the demographic reality of a highly fluid and complex urban township, peri-urban, and rural community. Data has been collected longitudinally at three primary levels: bounded structures, households and individuals (Tanser et al., 2008).

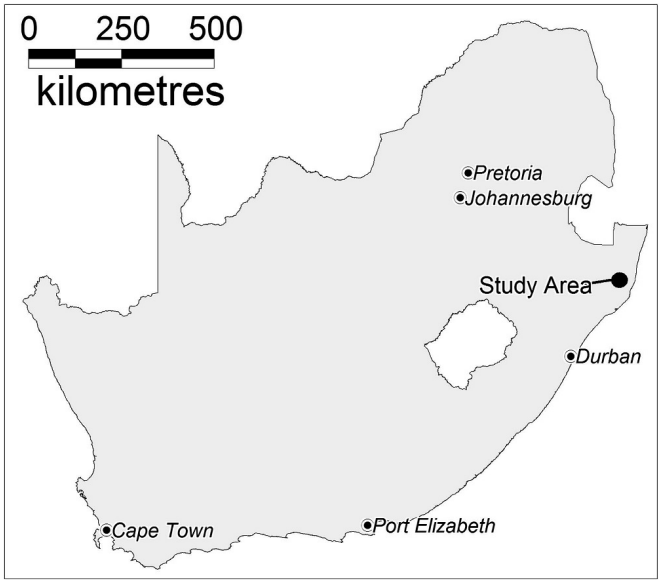

Figure 1: ACDIS study location in South Africa (Tanser et al., 2008)

3.2 Demographic Surveillance Area

The Africa Centre's Demographic Surveillance Area (DSA) is situated in the north-eastern part of KwaZulu-Natal province, and consists of the Mpukunyoni Tribal Area of the Hlabisa Local Municipality and the KwaMsane Township and Indlovu Village of the Mtubatuba Local Municipality. The area is 438 km^2 and is quite typical of a population settlement in South Africa, which is predominantly rural but also containing an urban township and informal peri-urban settlements. The resident population in the surveillance area is numbered at 65,000 although given migration this figure may be closer to 110,000 registered individuals (Africa Center, 2008). The area is mainly Black African and Zulu-speaking; despite rural status, the principle income is waged employment and state pensions rather than agriculture production.

There are three identifiable and distinct living environments in the DSA. 1) The *KwaMsane township*, which is an urban area, 2) *KwaMsane reserve* which is a peri-urban area, and the 3) *Mpukunyoni tribal area*, which is a typical rural area. There is therefore considerable variation in population density (between 20 to 3000 people per km^2). Population based HIV surveys have shown some of "the highest population based infection rates ever documented worldwide" (Tanser et al., 2008: 960). In 2003–2004, prevalence peaked at 51% (95% CI 47-55%) among women aged 25–29 and 44% (95% CI 38–49%) in men aged 30–34.3. Non-resident men were nearly twice as likely (adjusted OR=1.8) to be infected than their resident counterparts; the corresponding ratio for women was 1.5. Geographically, the prevalence of HIV varies from $> 35\,\%$ in informal settlements near the N2 highway to $< 10\,\%$ in the more inaccessible routes in rural areas. Previous studies in the ACDIS show that between 2000 and 2005 orphanhood doubled. However, in terms of the household impact of HIV/AIDS, no evidence was found for the increase in child-headed or skipped-generation households (Tanser et al., 2008).

3.3 Demographic Levels

ACDIS data is collected at three primary levels:

Bounded Structures are defined as "a building, or a group of buildings, on land belonging to a single person or organization, and used for one main purpose" (Africa Center, 2008: 20). Bounded structures are identified as plots of land that have an easily recognizable demarcated boundary or fence. ACDIS differentiates between two types of bounded structures called a homestead and a facility. 1) The homestead consists of houses or huts on one piece of land belonging to a single owner and used by residents for the purposes of living. A homestead may comprise of one or more households. 2) A facility consists of one or more buildings on one piece of land, belonging to a single individual or organization, for which the main purpose is to provide services (e.g. clinics, schools, churches etc), or to sell or make goods (Africa Center, 2008). In this paper we will refer to bounded structure as homesteads since the data relates to those individuals that live in homesteads.

Households are defined as a social group of one or more members. For ACDIS purposes, household are characterized by members who share in the joint resources of the household and who know each other well enough to provide information about each other. Households often have a head of household, and a household member is defined as a person who considers

him or herself as a member of that household, and is considered by household members to be a member (Africa Center, 2008). ACDIS further distinguishes between a *household* member and an *affiliated* member, the latter who is not normally considered to be a full member of the household, but who lives and works there and is supported by the household. The distinction between households and homesteads means that multiple households can be nested within a single homestead (bounded structure). In such a scenario, a homestead can begin as a single household with more households being established on the same plot of land over time. ACDIS would regard tenants who move into an existing homestead with or without their families, and set up an established household, as a separate household for identification and demarcation.

Individuals are recorded as being a resident of a household, and whose movements are recorded from one homestead (bounded structure) to another. Residency is defined as the period of time during which an individual or household lives in a homestead. ACDIS defines a resident as someone who usually lives at the same homestead as the household; a non-resident is a member of a household who does not normally live at the same homestead as the household (Africa Center, 2008). The ACDIS design allows for individuals to be members of more than one household, but is specific about an individual who can only have one place of residency in the homestead (bounded structure) at any one time. Migration is therefore defined as "the event that occurs when an individual or household moves from one bounded structure to another" (Africa Center, 2008: 44). These definitions have important implications for eligibility criteria. Individuals must be a member of a household within the DSA to be eligible for inclusion in the ACDIS cohort, even if they are not residents within it.

3.4 ACDIS Data

This ACDIS cohort includes all women aged 15–49 years and men aged 15–54 years who were resident in the surveillance area and thus eligible for HIV testing. In 2007, eligibility was extended to cover all residents aged > 15 years of age. In addition to the resident sample, a 12.5% stratified sample of non-residents ('migrants') was also included in each round of data collection (Tanser et al., 2008).

There are two separate cycles of ACDIS data collection: household and individual. The Africa Centre administers household questionnaires every six months to a key informant in the household. Information is collected by field workers on the attributes and events of physical structures, households and individuals and their relationship to one another. (Table 1 shows the information collected at the household visit.) The individual survey, which includes an HIV serosurvey, is conducted annually and collects information on HIV status, sexual behavior, and other relevant biomeasures (Table 2 shows the information collected at the individual survey.) Data collected in the HIV sero-survey is undertaken by teams of two trained fieldworkers who visit each eligible individual in his or her household on an annual basis. After obtaining written informed consent, field workers collect blood by finger prick and prepare dried blood spots for HIV testing according to the Joint United Nations Programme on HIV/AIDS (UNAIDS) and World Health Organization (WHO) Guidelines for Using HIV Testing Technologies in Surveillance. Results of the HIV test can be obtained confidentially at a number of counseling centers which have been set up for that purpose

Subject	Types of information
Homestead	Latitude, longitude, Owner, Number of households.
Household	Formation and dissolution, Household head.
Individuals	Individual details: inc. date of birth, sex, parents. Household membership(s).
Household members	Update household list: members who join, leave or die. Residency status: including pattern of return visits, marital and partnership status, relationship to household head.
Births	Pregnancy outcomes: abortions, still and live births. Delivery environment: including assistance, place, birth-weight.
Deaths	Location and care provision at time of death. Open description of circumstances.
Migrations	Details of place of origin or destination. Type of migration, e.g. household or individual migration.
Child health	On first birthday: vaccination history.

Table 1: Data collected at each routine household visit, 2000 and ongoing (Tanser et al., 2008: 958)

in the survey area. A linked, anonymous voluntary HIV testing system with pre- and post-result counseling using confidential personal pin numbers and hand-held computers for result communication has been established (Tanser et al., 2008). HIV status is determined by antibody testing, and status identified in the questionnaire with the question "Date first positive." In 2006, participation rates for household data collection were $> 99\%$ (Tanser et al., 2008).[6]

4 Analysis

4.1 Definitions

We define an at-risk individual as a male or female a) under ACDIS surveillance, b) that has a recorded date for an HIV-negative test, c) has a HIV-negative status, and d) is a resident member of a DSA homestead.

The at-risk individual can be exposed to one of three 'treatment' groups, which is a DSA homestead:

[6]All research initiatives at the Africa Centre are first undertaken in consultation with a Community Advisory Board (CAB) for comment and feedback. The CAB consists of approximately 25 members that are chosen by the community, the Board also provides a forum to discuss the results of specific studies and how best to disseminate these to the community. Names and residential addresses data (as well as any other information that could link individuals to the data) have been delinked; all persons in the dataset are anonymous to the investigators. Ethical approval for research conducted by the Africa Centre has been granted by the University of KwaZulu-Natal, South Africa.

Topic	Types of information	Eligibility criteria
HIV status	HIV status, reason for refusing test	2003–2006: women 15–49 years, men 15–54 years; 2007–: women and men 15 years and older
Sexual behaviour	Pregnancy history (women only), contraceptive use, sexual activity, attitudes to condom use	2000–2003: women 15–49 years only; 2003–2006: women 15–49 years, men 15–54 years; 2007–: women and men 15 years and older
Biomeasures	Blood pressure, height and weight	2003/2004: women 15–49 years, men 15–54 years

Table 2: Data collected at annual individual survey visit, 2000 and ongoing (Tanser et al., 2008: 958)

1. with one or more residents who a) are under ACDIS surveillance and b) have a recorded HIV-positive date that is earlier (measured as time in days) than the at-risk individual's seroconversion event or right consorship status,
2. with one or more residents who a) are under ACDIS surveillance and b) have a recorded ART initiation date that is earlier than the at-risk individual's seroconversion event or right consorship status,
3. with one or more residents who a) are under ACDIS surveillance, b) have a HIV-negative status, and c) who have a recorded HIV-negative test date that is earlier than the at-risk individual's seroconversion event or right censorship status.

For the sake of convenience and brevity we define the exposure to a homestead with one or more residents that initiated ART as the 'treatment' group (item 2 above).

4.2 Statistical Model

We analyze the data using a Cox proportional hazards model, which is a popular method for examining the occurrence of an event—in this case, the HIV seroconversion event of an at-risk individual in one of the three homestead (treatment) groups. Specifically, a Cox model is used to incorporate the time to seroconversion from the earliest observed HIV-negative date in the estimation of the model parameters. We use this model to obtain an estimate for an at-risk individual's seroconversion hazard given his or her residency in one of the three homesteads in comparison to the two remaining homesteads (see Section 4). The hazard function, $h(t)$, gives the instantaneous potential per unit time for the seroconversion event to occur, given that the at-risk individual has survived up to time t. The Cox hazard ratio, which is the exponential of one or more regression coefficients in the proposed model, is much like an odds ratio for the logistic regression model. The HIV seroconversion event, which is the outcome, is measured at the individual-level; the treatment exposure is defined at the homestead-level.

5 Results

A general summary of the ACDIS data is provided in Table 3 in the Appendix for the years 2002 to 2011. ACDIS data was primarily used to construct the resident characteristics of the homestead, as discussed in Section 3.3. Each individual's time under surveillance is split and recorded into numerous 'exposure episodes.' Episodes span at most one calendar year. Two episodes per year are typically created for an individual: the first episode spans from the 1st January up until the day before their recorded birthday, and the second episode from the day of their recorded birthday to the 31st December of that year. A recorded change in an individual's residency will also result in the creation of a separate episode for that calender year. There are 2,386,531 total records and 151,113 unique individuals in the ACDIS demography dataset. There are on average 15.79 episodes per individual.

Table 3 shows the total number of individuals under surveillance at the start of each year, which includes individuals that are not resident in the DSA. Data for the number of individuals who were born and who died by year are shown. In-migration into the DSA is defined as an individual's first recorded episode, thus excluding any subsequent episodes in which the individual out-migrated and returned. Out-migration is defined as an individual's last episode under surveillance, and excludes any previous episodes where the individual migrated out of the DSA and returned. Individuals that out-migrate but retain membership of a resident household continue to accumulate exposure episodes. A household membership start is defined for individuals who record their first episode as members of a household; a membership end is recorded when an individual ceases to be under surveillance because their houseold membership ended.

Table 4 in the Appendix gives descriptive statistics of the homestead (HS) and HIV/ART-related characteristics by year. The number of distinct homesteads in the DSA is approximately 12,000, with on average 9 residents per homestead. Row 3 of Table 4 shows the number of homesteads that have more than one HIV-positive resident by year, and row 4 shows this as a percentage of the total homesteads in the DSA. These figures show evidence of an increase in the prevalence of HIV at the homestead level; more than 40% of the total homesteads in the DSA had at least one HIV-positive resident for the year 2011. The average percentage of HIV positive residents in the homestead is shown by year in row 5; again, these figures show a substantial increase in prevalence over time (0.08% in 2002 to 9.29% in 2011). The remaining three rows show data on residents who initiated ART in the homestead. Data for the years 2002 and 2003 are not available. Overall, the summary statistics show an increase in the number of homesteads in the DSA in which at least one resident initiated ART (row 6) and the percentage of residents per homestead that initiated ART (row 7). Just under 40% of HIV positive residents per homestead initiated ART in 2011 (row 8), a significant increase from 0.17% just 7 years earlier.

Table 5 in the Appendix provides summary statistics for the complete ACDIS dataset. The second dataset is a sub-sample of the ACDIS dataset for all homestead residents who have an earliest HIV negative test and who either subsequently tested HIV-positive (and thus recorded a seroconversion date which is the mid-point between the latest HIV-negative date and the earliest HIV-positive date) or who are right-censored (i.e., who did not seroconvert) at the latest observation date. The ACDIS dataset has 153,409 individuals (including non-residents) and 14,822 distinct homesteads for the years 2002 to 2011. The sub-sample of

homestead members with a earliest HIV test are reduced to 17,979 individuals (including non-residents) and 8,537 distinct homesteads for the years 2002 to 2011. The mean number of episodes per homestead member is 7.55 and the mean time at risk of seroconversion is 1,184.57 days. The total number of failures (seroconversions) is 1,859, which gives mean failure of .103. The remaining demographic characteristics of the individuals and homesteads are displayed in the remaining rows of Table 5.

Table 6 displays the Cox proportional hazards results for time to seroconversion. Three time-dependent variables are included in the analysis, which are 1) The total count of resident members of the homestead for each episode recorded for the at-risk individual, 2) the number of resident members with a recorded HIV-positive result in the homestead, and 3) the number of resident members who have a record for earliest date of ART initiation. All models presented in Table 6 are stratified by Sex and Area. Model 1 of Table 6 shows the exponentiated hazard ratios for the three-category exposure variable, with exposure to a homestead with one or more residents who have initiated ART as the base or reference category. The outcome variable is defined as the time to seroconversion, scaled in days. We see that the hazard of seroconversion is significantly lower for at-risk individuals who were exposed to homesteads with at least one resident member that initiated ART: the effects is consistent across all three models. Model 1, the crude model, shows that the hazard of seroconversion for an at-risk individual in a homestead with at least one HIV-positive resident not on ART is 1.907 times higher than the hazard for an at-risk individual from the 'treatment' group (the standard error is 0.140). Interestingly, the hazard of seroconversion is higher for an at-risk individual who belongs to a homestead in which none of the residents are HIV-positive (the hazard ratio is 2.005, with a standard error of 0.152). For Model 3, the full model, the hazard ratio of seroconversion for an at-risk individual who belongs to a homestead with at least one HIV-positive resident not on ART increases to 2.347 times the hazard ratio of the 'treatment' group when adjusting for number of residents, number of HIV positive residents and number of residents who have initiated ART in the homestead (with a standard error of 0.215). The hazard ratio of seroconversion for an individual exposed to a homestead in which at least one person is HIV positive (and not on ART) is 1.84 times the hazard ratio of the 'treatment' group (with a standard error of 0.147). We see that this hazard ratio is lower than the corresponding hazard ratio relating to an individual within a homestead in which no resident is HIV-positive: 1.841 vs. 2.347 for the full model (Model 3). The hazard ratios for the exposure variable for the three models are all significant at the 0.01 level.

6 Discussion

The results presented in Section 5 show that HIV prevalence is increasing within ACDIS homesteads, both in terms of the proportion of resident members that are HIV-positive and the number of homesteads that have at least one HIV-positive resident. Results also show an increase in the number of residents who initiated ART for the years 2004 to 2011. This increase is expressed both as the proportion of number of HIV-positive residents in the homestead, and as the total number of homesteads with at least one resident member who initiated ART.

The Cox proportional hazards results show that exposure to a homestead with at least one resident who initiated ART significantly reduces the hazard of seroconversion for at-risk individuals, adjusting for number of homestead residents, number of HIV-positive homestead residents, and number of homestead residents on ART. Interestingly, compared with the 'treatment' group, the seroconversion hazard is higher for an at-risk individual belonging to a homestead with no HIV-positive residents than the seroconversion hazard for an at-risk individual belonging to a homestead with at least one HIV-positive member not on ART. This effect is shown in the hazard ratio coefficients for Model 3 in Table 6. This result may suggest that having a HIV-positive member in the homestead may increase the awareness of other residents in the homestead to the health consequences of HIV/AIDS, thereby modifying subsequent HIV risk behaviors. Nevertheless, the results of this analysis shows that exposure to a homestead with at least one resident on ART offers the greatest protective effect against seroconversion for an at-risk individual. Future work will need to identify whether the presence of ART in a homestead operates to reduce secondary infections via the treatment-as-prevention channel, or whether the use of ART in the homestead increases social awareness to HIV and thus reduces HIV-risk related behaviors.

These preliminary findings can be substantially developed by future work that emphasizes the distinct households within the homestead, which the hierarchical structure of the ACDIS data permits. A focus on households as the level of analysis will enable the investigators to assess the role of household socio-economic status, the migratory patterns of household members, the relation of at-risk individuals to the household-head, and the conjugal relationship characteristics of at-risk individuals in the household, amongst other relevant household characteristics. Analyses of these household characteristics as predictors of time to seroconversion can be undertaken with ACDIS data.

7 Appendix

	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
At surveillance start	90,403	90,424	90,600	90,752	91,239	93,283	92,891	93,049	93,179	93,100
Born	2,019	1,936	2,007	2,081	2,000	2,034	2,008	1,902	1,842	1,722
Household membership start	431	307	291	370	471	410	552	641	918	742
Immigrated during the year	4,346	3,227	2,585	2,455	2,370	2,318	2,038	2,283	1,927	1,358
Died during year	1,520	1,591	1,484	1,404	1,273	1,332	1,208	1,131	1,015	934
Household membership end	2,206	1,510	1,233	1,275	1,344	1,398	1,374	1,445	1,059	399
Outmigrated during year	2,041	1,293	1,053	751	582	922	661	739	788	606
Lost to follow-up	1,008	900	961	989	1,003	1,502	1,197	1,381	1,904	1,941

Table 3: All Individuals (incl. non-residents) at the Start of Year

	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
DSA HS Count	11,117	11,169	11,249	11,319	12,273	12,344	12,392	12,477	12,470	12,275
Inidvidual Residents per HS	10.12	9.82	9.53	9.43	9.2	9.18	9.17	9.2	9.17	9.16
HS Count with an HIV+ Resident	56	892	2,414	2,986	3,411	3,828	4,175	4,542	5,035	5,193
Percent of these HS in the DSA	.5	7.99	21.46	26.38	27.79	31.01	33.69	36.4	40.38	42.31
Percent HIV+ in the HS	.08	1.36	3.89	5.08	5.75	6.49	7.23	7.86	8.79	9.29
HS Count with a Resident on ART	0	0	4	107	304	567	928	1,245	1,606	1,964
Percent of these HS in the DSA	0	0	.04	.95	2.48	4.59	7.49	9.98	12.88	16
Percent of HIV+ Residents on ART	0	0	.17	3.58	8.91	14.81	22.23	27.41	31.9	37.82

Table 4: Homesteads (HS) with HIV+ residents and residents on ART in the DSA

	For years 2002-2011
ACDIS data	.
Total Individuals	153,409
Total Homesteads	14,822
Total Episodes	2,570,263
ACDIS subsample data	.
Total Individuals	17,979
Total Homesteads	8,537
Episodes	.
Mean	7.55
Min	1
Max	23
Time at risk	.
Mean	1,184.57
Min	1
Max	3,328
Failures (Seroconversions)	1,859
Sex	.
Female	10,996
%	61.16
Age	.
12-19	4,110
20-24	4,347
25-29	1,731
30+	7,791
Exposure	.
No Exposure to HIV	6,204
Exposure to ART	3,775
Exposure to HIV only	8,000
Area	.
Rural	10,819
Peri-urban	4,763
Urban	528
Outside DSA	1,634
Residency type in BS	.
Resident	16,354
Non-Resident	1,445
No prior residency	180

Table 5: Summary Statistics of the ACDIS Dataset

Table 6: Cox proportional hazards results

	(1)	(2)	(3)
Base: Resident Exposure to ART			
No Resident Exposure to HIV	2.005***	2.292***	2.347***
	[1.728,2.326]	[1.925,2.728]	[1.962,2.808]
Resident Exposure to HIV only	1.907***	1.842***	1.841***
	[1.652,2.202]	[1.579,2.149]	[1.573,2.154]
Base: Zero Positive Residents			
One Positive Resident		1.332***	1.307***
		[1.172,1.514]	[1.147,1.490]
More than one Positive Resident		1.519***	1.395***
		[1.278,1.805]	[1.164,1.673]
Base: Zero Residents on ART			
One Resident on ART		0.653*	0.659*
		[0.454,0.938]	[0.456,0.953]
More than one Resident on ART		0.375	0.396
		[0.0925,1.517]	[0.0977,1.604]
Base: 0–7 Homestead Residents			
8–14 Homestead Residents			1.193***
			[1.074,1.324]
15+ Homestead Residents			1.250*
			[1.038,1.505]

Exponentiated coefficients; 95% confidence intervals in brackets

N=17979; stratified by Sex and Residential Area

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

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