An Equilibrium Model of the African HIV/AIDS Epidemic
(2019 ECTA)

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This Paper

- HIV/AIDS is a major cause of death
  - Killing about 1 million worldwide annually.
- Public policy remedies depends on medical efficacy and behavior of pop.
  - Treatment is less effective if people start engaging more risky sexual practices. (GE effect)
- Choice-theoretic eq. model of sexual behavior to address HIV epidemic in Malawi
  - Capture aspects of choice that are particularly relevant to HIV transimission.
  - Match sexual behavior in the data.
  - Analyze the importance of shifts in sexual behavior for public policy.
- Policy experiments are evaluated
  - Male circumcision, ART, better condoms, treatment of other sexually transmitted disease, better information
- Scientific methodologies
  - Choice-theoretic eq. model (1), Epidemiological studies (2), small-scale field experiments (3)
  - (1) and (2): behavior response
  - (1) and (3): general eq. (GE) effect

Families, Sexual Behavior, and HIV in Malawi

- HIV infection rate 12% in 2004 ($>>$Sub-Saharan 7.2%)
- Heterosexual sex transmission ($> 50\%$ infected are women) $\rightarrow$ gender diff.
- Information and knowledge $\rightarrow$ rational behavior model
  - Heard of HIV (100%)
  - Identified use of condoms to protect against HIV (57% women, 75% men)
  - Knew where to get condoms (74% women, 86% men).
- Public policy and treatment
  - ART 3% (2005) $\rightarrow$ 50% (2014).
  - Circumcision rate is stable 20%. (religion, ethnicity $>$ health)
- Families and sexual behavior
  - Unmarried change partner often.
  - Divorce is relatively common.
  - No condom usage within marriage $\rightarrow$ unprotective sex within marriage
  - Courting practice: money and gift transfer.

Model

- Males m and females f engage sex in relationships: short and long-term l
  - $l > 0$: long-term attachment; $l < 0$: taste for variety
- Sex is risky: protected p and unprotected u, $u > p > 0$.
- Utility from consumption $\ln(w)$, income y minus transfer z_s
- Discount factors $\tilde{\iota} < \tilde{\beta}$ (1-1). Agents start with $\tilde{\iota}$, switch to $\tilde{\beta}$ with prob. η
  - Reduction of dimensionality for computational reasons.
- Death rate $\delta \rightarrow$ effective discount factor $\iota = \tilde{\iota}(1-\delta)$ and $\beta = \tilde{\beta}(1-\delta)$.
- Circumcised $c = 1$. Male $c = 1$ is less likely to be infected by HIV.
- Fixed characteristics $x = (c, \iota, \beta)$ differ across gender.

Model

Searching

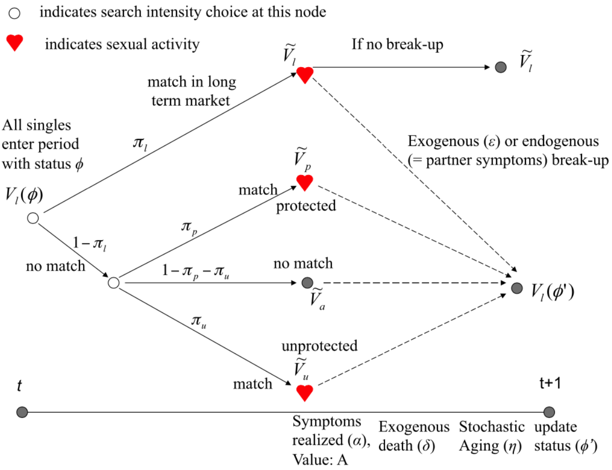

FIGURE 5.—Timing of events.

Model

Searching

- Search partner in different market by picking the odd π of finding a partner with costs $C(\pi)$.
- π_l (long), π_p (protected) and π_u (unprotected)
- Cost function $C(\pi) = \omega[\pi/(1/2 - \pi)]^{\kappa+1}, \kappa \geq 0, \omega \geq 0$
  - Note $C(0) = 0$, $C(1/2) = \infty$.
- Failure of search in market l, then enter in short-term market, and choose π_p and π_u with $C_s(\pi_p) + C_s(\pi_u)$.
- Failure of search in market s, then agent will be abstinent with prob $1 - \pi_p - \pi_u$.
- κ_s, ω_s can be different from κ_l, ω_l.
- Example: one can choose not to enter market l by choosing $\pi_l = 0$, and choose to be abstinent by choosing $\pi_p = \pi_u = 0$.
- Transfer payment z is made between two partners, which is determined in equilibrium (demand and supply).

Model

Health Status and Transition Probability

- Health status ϕ. $\phi = 1$ if healthy, $\phi = 0$ if HIV infection and no ART treatment, $\phi = t$ if infected with treatment.
- Trans. prob is $1 - \gamma(\hat{\phi})$ if agent with $c = 0$ has sex with agent with $\hat{\phi}$.
- Trans. prob is 0 with a healthy partner $= 1$.
- Treated individual is less likely to infect others $1 - \gamma(t) < 1 - \gamma(0)$.
- $c = 1$ male is less likely to contact with virus. $\downarrow$ Trans. prob. $\chi(c)$
  - For male $\chi(1) = \chi < 1$ and $\chi(0) = 1$.
  - For female, $\chi(c) = 1$.
- Info about ϕ: people know their own health, but cannot discern health of other individual, holding correct expectations $R_r(\hat{\phi}), r = l, p, u$.
- Prob of treatment $Q(\phi)$, where $Q : \{0, 1, t\} \to \{q, 0, 1\}$.
- Prob. of symptoms α_ϕ, where $\alpha_1 = 0 < \alpha_t < \alpha_0$.
- Agent in final-stage HIV engages in no further relationships, with remaining utility A, and dies in rate of δ_2.
- Demographics: $\mu(x)$ are born per period.

Model

Short-term Relationships

Abstinence

- Type x old person with discount factor β and health ϕ

$$\widetilde{V}_a^{\beta}(\phi, x) = \underbrace{\ln(y)}_{\text{cons}} + \overbrace{\alpha_\phi \beta A}^{\text{symptom}} + (1 - \alpha_\phi)\, \beta \left\{ \underbrace{Q(\phi) V_l^{\beta}(t, x)}_{\text{treated}} + \underbrace{[1 - Q(\phi)] V_l^{\beta}(\phi, x)}_{\text{untreated}} \right\}$$

- Type x young person with discount factor ι and health ϕ
  - Change all β into ι
  - Change $V_l^{\beta}(\phi, x)$ into $\eta_{V}{}_l^{\beta}(\phi, x) + (1 - \eta) V_l^{\iota}(\phi, x)$.

Model

Short-term Relationships

Sexual relationships: protected p and unprotected u

- Assume the person is already matched
- Infected $\phi \in \{0, t\}$.

$$\widetilde{V}_s^{\beta}(\phi, x) = \underbrace{\ln(y - z_s)}_{\text{cons.}} + \overbrace{\underbrace{pI(s)}_{\text{protected}} + \underbrace{u[1 - I(s)]}_{\text{unprotected}}}^{\text{sex}} + \underbrace{\alpha_\phi \beta A}_{\text{symptom}}$$

$$+ (1 - \alpha_\phi)\,\beta \left\{ \underbrace{Q(\phi) V_l^{\beta}(t, x)}_{\text{treated}} + \underbrace{[1 - Q(\phi)] V_l^{\beta}(0, x)}_{\text{untreated}} \right\}$$

Model

Short-term Relationships

Sexual relationships: protected p and unprotected u

- Assume the person is already matched
- Healthy $\phi = 1$

$$\widetilde{V}_s^{\beta}(1,x) = \underbrace{\ln(y - z_s)}_{\text{cons}} + \overbrace{\underbrace{pI(s)}_{\text{protected}} + \underbrace{u[1 - I(s)]}_{\text{unprotected}}}^{\text{sex}}$$

$$+ \overbrace{\underbrace{\sum_{\widehat{\phi}} R_s(\widehat{\phi}) \left[1 - \gamma_s(\widehat{\phi})\right] \chi(c)}_{\text{prob. of infected}} \beta \left[\underbrace{qV_l^{\beta}(t,x)}_{\text{treated}} + \underbrace{(1-q)V_l^{\beta}(0,x)}_{\text{untreated}}\right]}^{\text{infected}}$$

$$+ \overbrace{\underbrace{\left\{1 - \sum_{\widehat{\phi}} R_s(\widehat{\phi}) \left[1 - \gamma_s(\widehat{\phi})\right] \chi(c)\right\}}_{\text{prob. of uninfected}} \beta V_l^{\beta}(1,x)}^{\text{uninfected}}$$

- Determine the search effort
- Ex ante value of type-x individual

$$V_s^d(\phi,x) = \max_{\substack{0\le \pi_u^d,\pi_p^d,\\ \pi_u^d+\pi_p^d<1}} \left\{ \pi_p^d \widetilde{V}_p^d(\phi,x) + \pi_u^d \widetilde{V}_u^d(\phi,x) + \left(1-\pi_p^d-\pi_u^d\right)\widetilde{V}_a^d(\phi,x) - C\left(\pi_p^d\right) - C\left(\pi_u^d\right) \right\}, \quad \text{for } d = \iota, \beta,$$

Model

Long-term Relationships

- No choices to make: no affairs, all sex is unprotected, some form of exogenous breakup
- Prob of the pair $(\phi, \widehat{\phi})$ enters next period together with status $(\phi', \widehat{\phi}')$ is $Y\left(\phi', \widehat{\phi}' \mid \phi, \widehat{\phi}, c, \widehat{c}\right)$.
- Example 1

$$Y(1, 1 \mid 1, 1, c, \widehat{c}) = 1$$

- Example 2

$$Y(0, t \mid 1, \widehat{\phi}, c, \widehat{c}) = \underbrace{\left[1 - \gamma_u(\widehat{\phi})\right] \chi(c)}_{\text{prob. infected}} \overbrace{(1 - q)}^{\text{untreated}} \underbrace{Q(\widehat{\phi})}_{\text{partner treated}}$$

- Individual with health ϕ with partner's health $\widehat{\phi}$ and circumcision type $\widehat{c}$.

$$\widetilde{V}_l^{\beta}(\phi, \widehat{\phi}, \widehat{c}, x) = \underbrace{\ln(y - z_l)}_{\text{cons.}} + \overbrace{u + l}^{\text{sex}} + \underbrace{\alpha_\phi \beta A}_{\text{symptom}}$$

$$\left.\begin{aligned} &+ (1-\alpha_\phi)(1-\epsilon)(1-\delta)\left(1-\alpha_{\widehat{\phi}}\right) \\ &\times \beta \sum_{\phi', \widehat{\phi}'} Y\left(\phi', \widehat{\phi}' \mid \phi, \widehat{\phi}, c, \widehat{c}\right) \widetilde{V}_l^{\beta}\left(\phi', \widehat{\phi}', \widehat{c}, x\right) \end{aligned}\right\} \text{married}$$

$$\left.\begin{aligned} &+ (1-\alpha_\phi)\left[1-(1-\epsilon)(1-\delta)\left(1-\alpha_{\widehat{\phi}}\right)\right] \\ &\times \beta \sum_{\phi', \widehat{\phi}'} Y\left(\phi', \widehat{\phi}' \mid \phi, \widehat{\phi}, c, \widehat{c}\right) V_l^{\beta}\left(\phi', x\right) \end{aligned}\right\} \text{single}$$

Model

Long-term Relationships

- Value of being matched in the long-term market for individual

$$\widetilde{V}_l^d(\phi, x) = \sum_{\widehat{\phi}, \widehat{c}} R_l(\widehat{\phi}, \widehat{c}) \widetilde{V}_l^d(\phi, \widehat{\phi}, \widehat{c}, x)$$

- The value of searching in the long-term market

$$V_l^d(\phi, x) = \max_{\pi_l^d} \left[\pi_l^d \tilde{V}_l^d(\phi, x) + \left(1 - \pi_l^d\right) V_s^d(\phi, x) - C\left(\pi_l\right) \right]$$

DEFINITION: A stationary equilibrium is described by a set of decision rules for search effort, $\Pi^d_{g,r}(\phi, x)$, a set of transfer payments, $z_{g,r}$, a set of stationary distributions, $\mathcal{S}^d_g(\phi; x)$ and $\mathcal{L}^d_g(\phi, \widehat{\phi}; x, \widehat{x})$, and status/type prevalence in each market, $R_{g,s}(\phi)$ and $R^\delta_{g,l}(\phi, c)$, for all $d = \{\iota, \beta\}, g \in \{f, m\}, r \in \{l, p, u\}, s \in \{p, u\}$, such that:

- The decision rules for search intensities, $\Pi^d_{g,r}(\phi, x)$, satisfy the appropriately gender subscripted versions of the generic problems (4) and (8), taking as given transfer payments and HIV/AIDS prevalence rates.
- The stationary distributions, $\mathcal{S}^d_g(\phi; x)$ and $\mathcal{L}^d_g(\phi, \widehat{\phi}; x, \widehat{x})$, solve the eq.
- The distributions over health status for each market, $R_{g,s}(\phi)$ and $R_{g,l}(\phi, c)$.
- The transfer payments, $z_{r,g}$, are such that the markets for all types of relationships clear.
- The flow of transfers across the genders balances.

Calibration

Parameters Based on Direct Evidence

TABLE I

PARAMETERS CHOSEN OUTSIDE THE MODEL

Parameter	Value	Interpretation
γ_u^m	0.879	12.1% quarterly transmission risk, unprotected sex, uncircumcised men
γ_p^m	0.96	4% quarterly transmission risk, protected sex, uncircumcised men
χ	0.4	Circumcised men are 60% less likely to contract HIV
γ_u^f	0.787	21.3% quarterly transmission risk, unprotected sex, women
γ_p^f	0.929	7.1% quarterly transmission risk, protected sex, women
α	0.025	10 years from infection to symptoms
δ	0.006	6% quarterly death risk
δ_2	0.125	2 years from symptoms to death
ϵ	0.03	3% quarterly divorce hazard
y	320	Quarterly income

Calibration

Parameters Chosen to Match Data Moments

TABLE II

CALIBRATED PARAMETERS

Interpretation	Parameter Value
Flow utility unprotected sex	$u = 7.8$
Flow utility protected sex	$p = 1.4$
Flow utility long-term sex	$l = -4.8$
Discount factor, min and max support	$\widetilde{\beta}_{\text{min}} = 0.969$, $\widetilde{\beta}_{\text{max}} = 0.9999$
Ratio discount factors, young vs. old	$\iota_{\text{change}} = 0.874$
Value of life with AIDS	$A = 5.8$
Prob. of switch to high discount factor	$\eta = 0.116$
Search cost parameters	$\omega_s = 0.44$, $\omega_l = 17.5$, $\kappa = 0.115$

Calibration

Parameters Chosen to Match Data Moments

TABLE III

TARGETED MOMENTS

Observation	Data	Model
HIV/AIDS prevalence rate, %	11.8	10.3
Males	10	8.6
Females	13	12.1
Sex that is casual, % (of all)	18	16
Condom use for casual sex, %	39	33
Singles that had casual sex in past year, %	47	54
Singles, %	33	48
Married by age 22, %		
Males	58	57
Females	90	63
Married by age 50, %		
Males	100	98
Females	100	98
Deaths related to HIV, %	29	25

Policy Experiments

Four policies intended to curb the spread of HIV

- Male circumcision
- ART
- Better condoms
- Treatment of other STDs
- Diffusion of better information.

Two alternative scientific methodology

- Small-scale field experiments: PE version of GE
- Epidemiological experiments: behavior responses.

Policy Experiments

Circumcision

TABLE IV

HIV AND CIRCUMCISION ACROSS COUNTRIES—REGRESSIONS[a]

	Dep. Variable: HIV Prevalence Rate				Dep. Variable: HIV Incidence Rate			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Circumcision	−0.1122	−0.0765	−0.0796	−0.064	−9.840	−4.972	−6.191	−7.339
	(0.001)	(0.028)	(0.027)	(0.126)	(0.015)	(0.238)	(0.150)	(0.125)
Log GDP p.c.	0.0314	0.0293	0.0288	0.0296	3.87	3.73	3.43	2.459
	(0.001)	(0.002)	(0.002)	(0.008)	(0.004)	(0.003)	(0.006)	(0.040)
ART	0.0816	0.104	0.105	0.098	5.63	8.71	9.05	6.266
	(0.126)	(0.049)	(0.051)	(0.134)	(0.396)	(0.175)	(0.155)	(0.398)
Syphilis	0.0025	0.0029	0.003	0.0045	0.359	0.42	0.526	0.711
	(0.380)	(0.316)	(0.286)	(0.334)	(0.322)	(0.234)	(0.146)	(0.187)
Muslim		−0.002	−0.00056	−0.0012		−0.026	−0.128	−0.207
		(0.491)	(0.461)	(0.181)		(0.529)	(0.161)	(0.081)
Christian			−0.00039	−0.00065			−0.121	−0.171
			(0.618)	(0.411)			(0.207)	(0.069)
Condom price				−0.268				−17.5
				(0.056)				(0.249)
R^2	0.72	0.73	0.74	0.79	0.61	0.65	0.67	0.71
N	32	31	31	23	30	29	29	22

[a] *p*-values are in parentheses.

- Cross-country difference in circumcision rates are unrelated to HIV and are due instead to cultural reasons.
- Varying cir. rate in the model (external validation)
- HIV prevalence rate, slope -0.05, HIV incidence rate, slope -6.389.

Policy Experiments

Circumcision

TABLE V

CIRCUMCISION

	Benchmark (20% Circ.)			100% Circ.	
		Males			
	All	Not Circ.	Circ.	G.E.	Epidem.
HIV prevalence, %	10.3			5.6	4.3
Males	8.6	8.75	8.0	3.8	4.1
Females	12.1			7.6	4.6
Sex that is casual (males), %	16	14	22	29	–
Condom use for casual sex (males), %	33	35	27	22	–
Single men, %	50	49	53	59	–
Casual sex in past year, single men, %	21	19	28	31	–
Price—protected	−6.5	–	–	53	–
Price—unprotected	278	–	–	309	–
Price—long term	125	–	–	161	–

- Male would engage in more risky behavior: less marriage, decreased condom use (25% less) and more sex (50% more).
- Female do not directly benefit from circumcision, but benefit through eq. effect.
- Field experiments: only 6 RCTs delivered definitive results on HIV, 3 of them were circumcision RCT.

Policy Experiments
ART

- Introducing ART: $\downarrow \alpha$ and $\uparrow A$

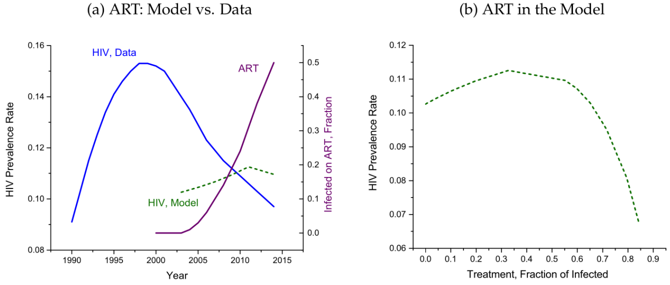

FIGURE 1.—ART in Malawi.

Policy Experiments

Better Condoms

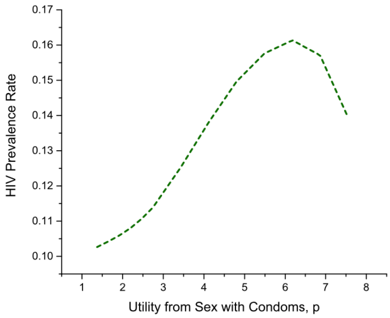

FIGURE 2.—Better condoms.

- Nonmonotomnic pattern.
- Reason: single life is more attractive.
- Insight: some policies may have backfire and increase the overall prevalence rate.

Policy Experiments

Better Condoms

TABLE VII

BETTER CONDOMS

	Benchmark	G. E.	Small Field	G. E.	Small Field
p	1.4	5.5 (Better)		7.5 (Better Still)	
p/u	0.18	0.70		0.97	
HIV prevalence, %	10.3	15.8	15.6	14.0	18.8
Casual sex, % (of all)	15.7	34	31	32	41
Casual sex with condom, %	33.0	59	57	62	61
Singles who have casual sex, %	54.0	66	73	73	78
Single men, %	50	64	60	62	70
Single women, %	46	60	51	58	56
Price—protected	−6.5	246	–	260	–
Price—unprotected	279	264	–	244	–
Price—long term	125	134	–	138	–

Policy Experiments

Treating Other Sexually Transmitted Diseases

- Model: new transmission rate $\lambda(1-\gamma)$

TABLE IX

TREATING OTHER STDS

	Benchmark	G.E.	Epidem.	Small Field
Scaling Factor	1.00	0.85	0.85	0.85
HIV prevalence, %	10.3	9.5	7.0	10.1
Males	8.6	7.9	5.9	8.5
Females	12.1	11.3	8.2	11.9
Casual sex, % (of all)	15.7	18.7	–	16.7
Casual sex with condom, %	33.0	27.6	–	31.2
Singles who have casual sex, %	54.0	60	–	56
Single men, %	50	52	–	51
Single women, %	46	47	–	46
Price—protected	−6.5	10	–	–
Price—unprotected	279	286	–	–
Price—long term	125	127	–	–

Policy Experiments

Treating Other Sexually Transmitted Diseases

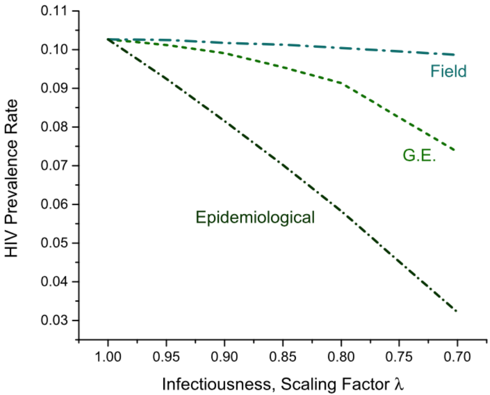

FIGURE 3.—Treating other STDs.

Policy Experiments

Diffusion of Better Information

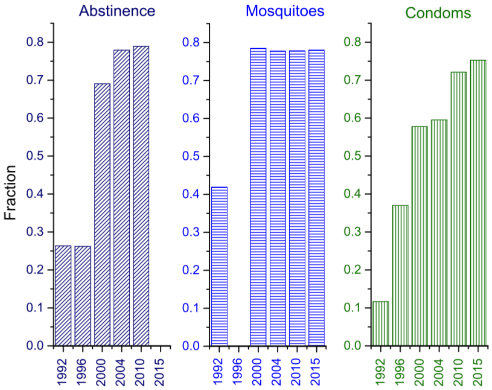

FIGURE 4.—HIV awareness in Malawi, 1992–2015, DHS data.

Modification of Model

- Info: $i = 1$ informed one. $i = 0$, uninformed
- Uninformed ind. believes that the odds of contracting HIV are the same as in the short-term unprotected market, regardless of their sexual behavior.
- Uninformed ind. does not assign protective power to circumcision. (data limitation + justification)
- Assume that 60% of the pop. is uninformed in 1996. Full information in 2004.

Modification of Model

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Policy Experiments

Diffusion of Better Information

TABLE X

IMPROVED INFORMATION—MODEL VERSUS DATA

	Data			Model		
	1996	2004	Δ in p.p.	1996	2004	Δ in p.p.
HIV prevalence, %	14.6	13.5	−1.1	14.4	10.3	−4.1
HIV incidence per 1000 healthy	20.4	11.1	−9.3	17.3	11.7	−5.6
Sex that is casual, %	24	18	−6	20	16	−4
Condom use in casual sex, %	29	39	10	28	33	5
Fraction of singles, %	31	33	2	47	48	1
Singles who had casual sex, %	60	47	−13	67	54	−13

- Decline in HIV rate: Model $>$ Data (steady state eq. vs transitional dynamics)
- The fall in incidence rate is due to safer sexual behavior.
- All policies are quantitatively somewhat more effective in the model with the uninformed people.
  - Circ. all men lower HIV rate: 68% (info) and 46% (baseline)
  - No behavior response for uninformed individual.

Conclusion

- An equilibrium search model to analyze the Malawian HIV epidemic with men and women rationally searching for the type of sexual activities taking into consideration their risks.
- Policy analysis of HIV interventions is complicated and some policies may backfire and actually increase HIV (eg better condoms)
- ART is not driven force of declining HIV. ART can work only if a large fraction of pop is treated.
- Treating other STDs have much smaller effect than suggested by epidemiological research.
- The diffusion of better info appears to be an important driven of the HIV declines over time.
- Future research proposed by this paper: higher HIV prevalence rate in urban than rural; impact of internal migration; extramarital affairs and polygyny.