An Equilibrium Model of the African HIV/AIDS Epidemic

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Motivation

- HIV is killing 2 million people annually world wide.
  - 2.7 million new infections each year.
- Most affected continent: Africa.
- About 60% of all HIV+ in Africa are female, compared to about 30% in North America and Western Europe.
- Reasons: most transmissions through heterosexual sex + higher transmission risk for women.
- Canning (2006) argues for prevention over treatment.
- What are effective prevention policies?

What We Do

- Build model of sexual behavior.
- Allow for behavioral responses and general equilibrium effects.
- Parameterize model to capture stylized features of sex, marriage, and HIV in Malawi.
- Focus on gender asymmetry in transmission.
- Use model to explore prevention policies.

- Main findings:
  - Behavioral changes to policies are quantitatively important.
  - General equilibrium effects have non-trivial implications.
  - Prevention policies may backfire.

Related Literature

- Few theoretical studies of HIV: Kremer (QJE 1996), Magruder (Demography 2011).
- Large literature using epidemiological simulations: ignore behavioral adjustments.
- Some randomized field experiments: Duflo et al (2006), Thornton et al (AER 2008), Dupas (AEJ applied 2011): no GE effects.
- Some cross-sectional studies: Oster (QJE 2005), Lakdawalla et al (QJE 2006), Auld et al (BE Press 2006).
- Malawi: de Paula et al (2011), Delavande et al (Demographic Research 2009).

Environment

- Rational model of sexual behavior.
- Men and women.
- Risky behavior choices:
  - short term vs. long term relationships
  - condom use
  - search intensity
- People differ in attitude towards risky behavior.
- HIV determined in equilibrium.

Model: Sex

- Search effort to find partner.
- Utility from sex: $u > p$.
- Can have sex in short-term (ST) vs. long-term (LT) relationships.
- Sex in LT relationships:
  - Always unprotected: u.
  - Additional utility benefit/cost: ℓ.
  - Sex every period until exogenous break-up (prob. ξ) or death.

Market Structure

- Three markets: protected, unprotected, long term sex.
- Each characterized by price and fraction of healthy people:

$$(t, \bar{\phi}_m, \bar{\phi}_f)$$

- Sequential market structure:
  - Go to LT market first;
  - If not matched, can search again in ST market.
- ST market:
  - Search in unprotected and protected markets simultaneously.

Model: HIV

- Non-transmission probability: $\gamma_p > \gamma_u$
  - Differs by gender: $\gamma^m > \gamma^f$
- ϕ: prior probability of being healthy.
- Lag from infection to symptoms
  - Probability of showing symptoms conditional on infection: α.
- Lag from symptoms to death: δ_2.
- Assume people with symptoms do not have sex.

Model: Bayesian Updating

- A person does not know whether s/he is sick.
- To update belief, use:
  - prior belief
  - the fact that no symptoms occurred
  - own sex choices

- Updating when abstinent:

$$\phi' = \frac{\Pr(\text{healthy}|\phi)}{\Pr(\text{no symptoms this period}|\phi)}$$
$$= \frac{\phi}{\phi + (1-\phi)(1-\alpha)}$$

Model: Updating after Sex

- Short term market:

$$\phi' = \frac{\phi\bar{\phi} + \phi(1-\bar{\phi})\gamma}{\phi\bar{\phi} + \phi(1-\bar{\phi})\gamma + (1-\phi)(1-\alpha) + \phi(1-\bar{\phi})(1-\gamma)(1-\alpha)},$$

where

$\bar{\phi}$: (endogenous) odds a randomly selected partner (opposite sex) in a given market is healthy.

- Both γ and $\bar{\phi}$ differ by market (u vs. p) and gender.
- Updating in LT market only relevant after break-up:
  - Not allowing affairs makes our life much easier here.

Model: Search Effort

- Searching for a partner is costly.
- More search effort $\rightarrow$ improves odds of finding a partner, π.
- In LT market:

$$V_l = \max_{\pi} \left[\underbrace{\pi \widetilde{V}_l}_{\text{matched}} + \underbrace{(1-\pi) V_s}_{\text{unmatched}} - C_l(\pi) \right],$$

where search cost is

$$C(\pi) = \frac{\omega}{1+\kappa} \left(\frac{\pi}{1-\pi} \right)^{1+\kappa}$$

- Similar in the short term market.

Life-time Value of Unprotected Sex

- Value function (for men):

$$\widetilde{V}_u(\phi) = \frac{(y-t_u)^{1-\sigma}}{1-\sigma} + u$$
$$+ \left\{1 - \alpha\left[(1-\phi) + \phi(1-\bar{\phi}_u^f)(1-\gamma_u^m)\right]\right\}\beta V_I(\phi')$$
$$+ \underbrace{\alpha\left[(1-\phi) + \phi(1-\bar{\phi}_u^f)(1-\gamma_u^m)\right]}_{\Pr[\text{symptoms}]}\beta A,$$

with

$$\phi' = \Phi\left(\phi, \bar{\phi}_u^f, \gamma_u\right).$$

y: period income
A: life-time value of a person with symptoms

- Similar for women and when the person has protected sex.

Stationary Equilibrium

- Prices (t_u, t_p, t_l) adjust to clear all three markets:
  - # of men having sex in given market = # of women having sex.
- Aggregate HIV rates $(\bar{\phi}_u^m, \bar{\phi}_p^m, \bar{\phi}_l^m)$ and $(\bar{\phi}_u^f, \bar{\phi}_p^f, \bar{\phi}_l^f)$ are consistent with individual behavior for both genders.

Application: Malawi

- Data sources:
  - Most data is from DHS 2004 (including micro data).
  - Supplemented with data from MDICP (2001, 2004).
  - HIV specific parameters: from medical literature.
- Survey data shows people in Malawi know:
  - how HIV gets transmitted,
  - what they can do to reduce risk.

Parameterization - a priori

- quarterly model.
- $\xi = 0.03$ (divorce prob.)
  - twice reported divorce risk (no polygyny nor affairs).
- $y = 320$ (quarterly income per working age person).
- $\delta = 0.006$ (non HIV-related death hazard).
- $\gamma_u^m = 0.94$, $\gamma_u^f = 0.895$, $\gamma_p^f = 0.965$
  - corresponds to transmission risk per unprotected sex act of 0.0023 (for men) and 0.0041 (for women).
- $\alpha = 0.025$(10 yrs from infection to symptoms).
- $\delta_2 = 0.125$(2 yrs from symptoms to death).

Parameterization - Calibration

Remaining parameters are chosen to match a set of targets:

Parameter	Meaning
p	joy of protected sex
u	joy of unprotected sex
ℓ	extra benefit/cost of LT relationship
A	continuation value of life with symptoms
β_1, β_2	discount factor, two types
μ	size of impatient group
η	prob. of becoming mature
ω_{ST}	search cost in ST market (level)
ω_{LT}	search cost in LT market (level)
κ	search cost (curvature)

Model Fit (11 Moments)

Observation	*Data*	*Model*
HIV/AIDS rate, %	11.8	11.5
–Males	10	10
–Females	13	13
Fraction of all sex that is casual, %	18	24
Condom use for casual sex, %	39	33
% (of) Singles that had casual sex in past year	37	54
% Singles	33	38
% Married by age 22		
–Males	58	60
–Females	90	67
% Married by age 50		
–Males	100	97
–Females	100	96
% of deaths related to HIV	29	23

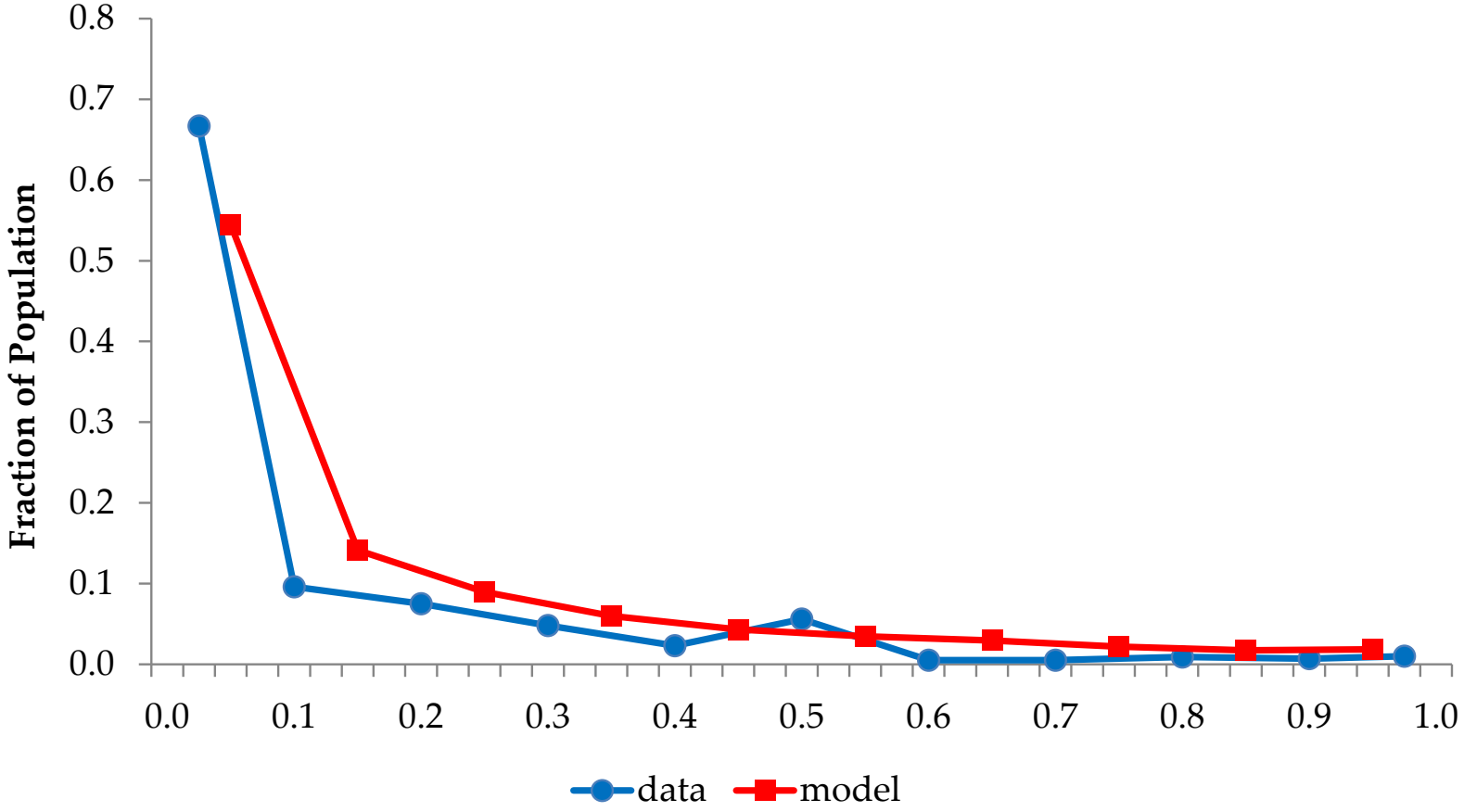
Non-targeted Moments

We also look at some additional model implications.

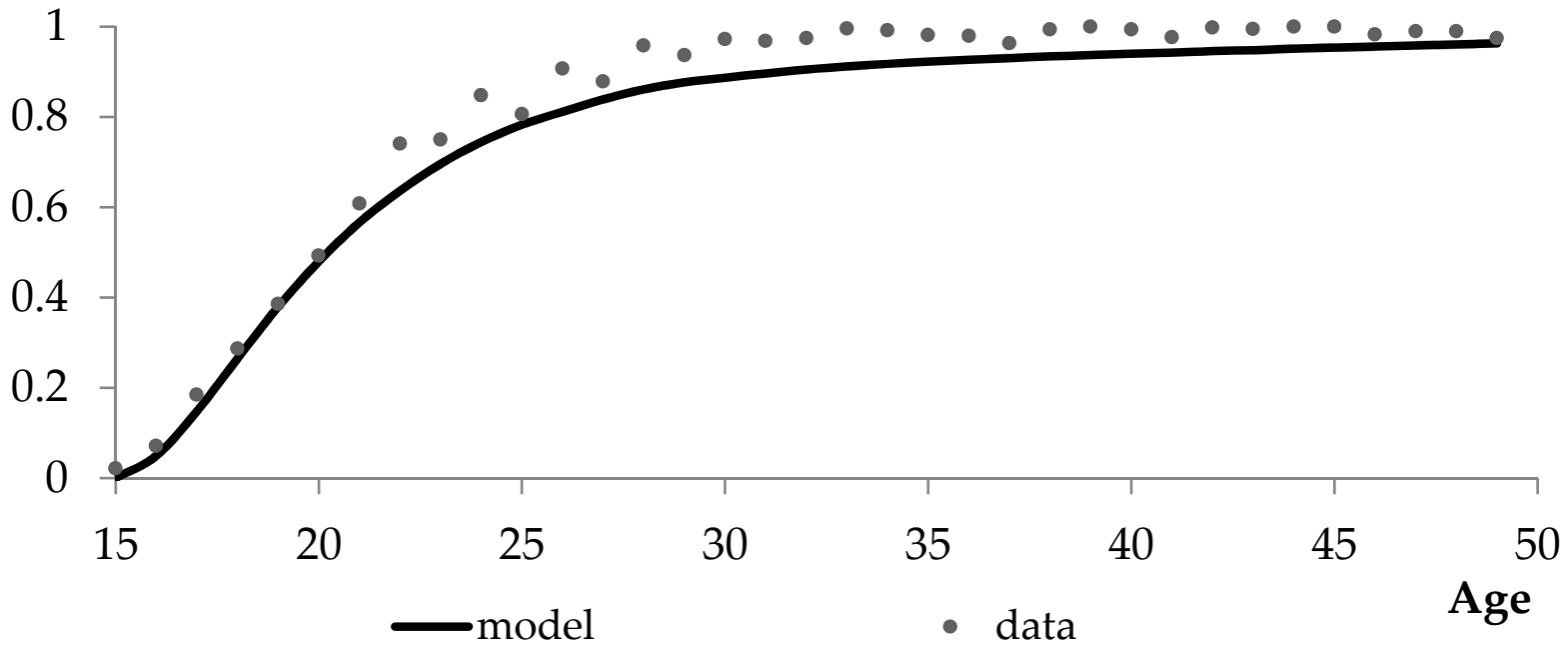
- Data on beliefs from Delavande and Kohler (2009).
- HIV rates by age.
- Timing of marriage.
- Singles by age.
- Casual sex by age.

Model works surprisingly well.

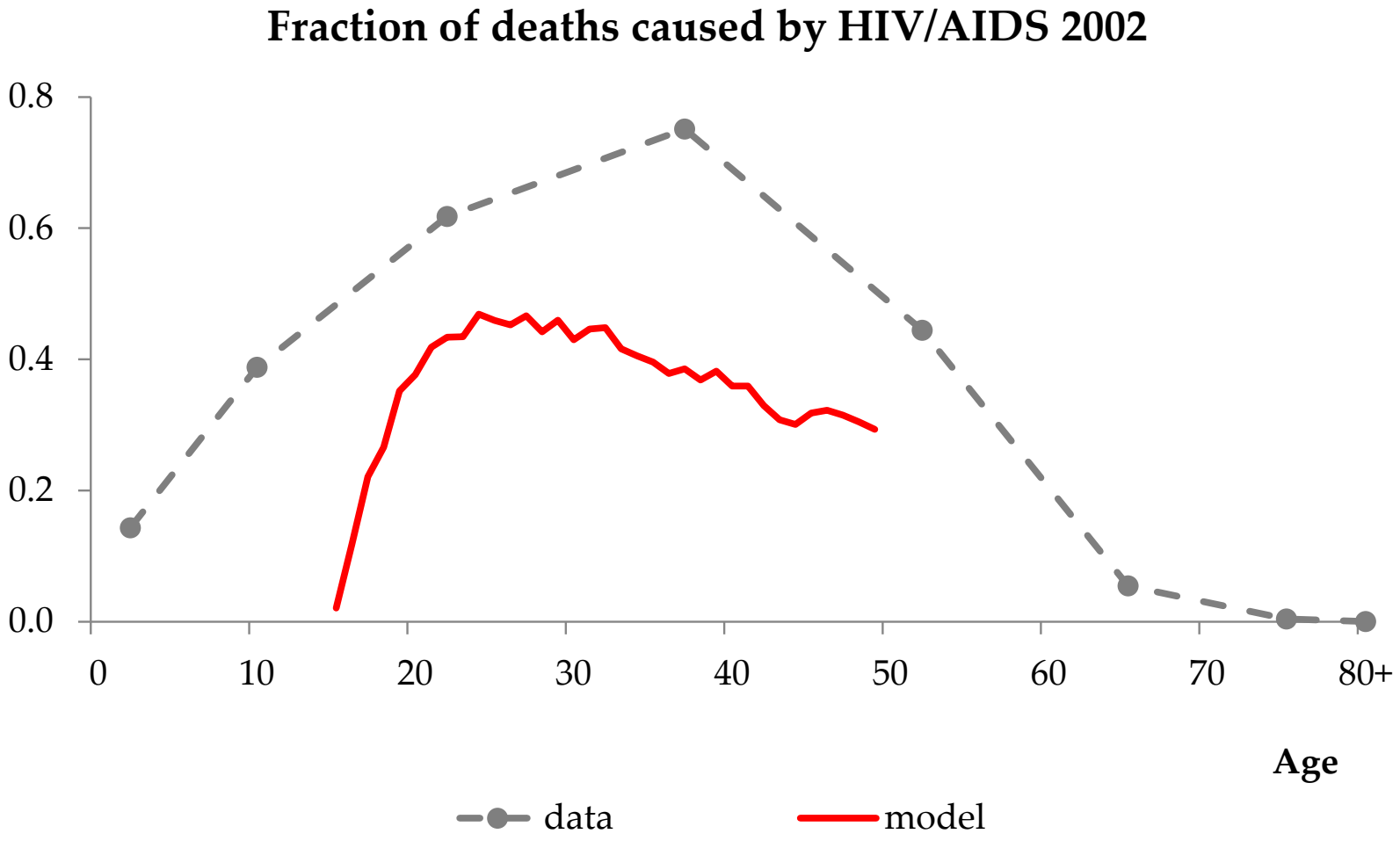
Beliefs about being infected



Fraction Ever Married, by Age



Deaths by HIV/AIDS, by Age



Counterfactual Policy Experiments

- Behavioral changes are important
  - Example 1: making condoms more pleasurable.
  - Example 2a: reducing transmission risk
    – comparison with epidemiological experiment.
- GE effects are important
  - Example 2b: reducing transmission risk
    – comparison with field experiment.
  - Example 3: promoting marriage.

Also conduct "field experiments" and "epidemiological experiments" within our model.

Example 1: more pleasurable condoms

	Benchmark	*Better*
p	2.3	3.8
HIV/AIDS rate, %	**11.5**	**13.3**
Fraction of sex that is casual, %	23.9	39.9
% (of) Casual sex with condom	33.0	66.2
% Singles who have casual sex	54.0	92.2
% Men who are single	42.8	52.5
% Women who are single	38.7	48.2

- Making condoms more pleasurable leads to more singles.
- Singles also have more sex.
- **May increase rather than decrease HIV.**
- Shows that ignoring behavioral changes may give misleading results.

Example 2a: reducing transmission risk (e.g. gels, vaccines, reduction of other STDs, etc.)

	benchmark	full model	epidemiological
female-to-male transmission	6%	5.25%	5.25%
male-to-female transmission	10.5%	9.8%	9.8%
HIV rate (men)	**10.2**	**8.7**	**8.3**
HIV rate (women)	**12.8**	**11.1**	**10.6**
% of men who are single	42.8	42.1	
% of women who are single	38.7	37.9	
% singles have casual sex	54.0	57.6	
Fraction of sex that is casual	23.9	24.2	
% of casual sex with condom	33.0	29.7	

- Reducing transmission risk
  - Singles have more sex
  - More unprotected sex
- **Epidemiological studies may overestimate policy benefits.**

Example 2b: reducing transmission risk

	benchmark	full model	field experiment
female-to-male transmission	6%	5.25%	5.25%
male-to-female transmission	10.5%	9.8%	9.8%
HIV rate (men)	**10.2**	**8.7**	**9.8**
HIV rate (women)	**12.8**	**11.1**	**12.4**
% of men who are single	42.8	42.1	42.6
% of women who are single	38.7	37.9	38.6
% singles have casual sex	54.0	57.6	56
Fraction of sex that is casual	23.9	24.2	24.3
% of casual sex with condom	33.0	29.7	30.9

- Potential partners are not treated in field experiments.
  - reduced infections among treated does not lower population prevalence rate and hence does not feed back into lower infection rates for treated.
  - Leads to an underestimate of policy efficacy.
- **May explain why 8 of 9 studies of STD treatment delivered flat results (Padian et al, 2010).**

Example 3: Promoting Marriage (facilitating search)

	BM	*Search cost* $\downarrow$
Marital search cost, ω_{LT}	30	20
HIV/AIDS rate, %	**11.5**	**12.0**
Fraction of sex that is casual, %	23.9	22.2
% Singles who have casual sex	54.0	60.8
% Men who are single	42.8	37.2
% Women who are single	38.7	34.8

- "Promoting marriage" may increase HIV.
- **Reason: more risky types sort into marriage. Worsens the marriage pool.**

Summary

- Equilibrium model of sexual behavior.
- Captures stylized features of sex, marriage, and HIV in Malawi.
  - In particular, matches HIV and sexual behavior over the life cycle.
- Conduct policy experiments (condoms, reduction of transmission rates, income subsidies, ...). Findings:
  - Randomized field experiments may underestimate benefits of medical policies.
  - Epidemiological studies may overestimate the benefits of medical policies.
  - Some policies may increase HIV.
- Reasons:
  - more risky sexual behavior
  - changes in mixing pattern
  - GE effects