An Equilibrium Model of the African HIV/AIDS Epidemic

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ESSIM, Izmir, May 2013
Motivation

- HIV is killing 2 million people annually worldwide.
  - 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.
- 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.
Few theoretical studies of HIV: Kremer (QJE 1996), Magruder (Demography 2011).

Large literature using epidemiological simulations: ignore behavioral adjustments.


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.
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: $\ell$.
- Sex every period until exogenous break-up (prob. $\xi$) 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: $\gamma^m > \gamma^f$
- $\phi$: prior probability of being healthy.
- Lag from infection to symptoms
  - Probability of showing symptoms conditional on infection: $\alpha$.
- Lag from symptoms to death: $\delta_2$.
- Assume people with symptoms do not have sex.
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 \( \gamma \) 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, $\pi$.
- In LT market:

$$V_I = \max_\pi \left[ \pi \tilde{V}_I + (1 - \pi) V_S - C_I(\pi) \right],$$

where search cost is

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

- Similar in the short term market.

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Life-time Value of Unprotected Sex

- Value function (for men):

\[
\tilde{V}_u(\phi) = \frac{(y - t_u)^{1-\sigma}}{1-\sigma} + u \\
+ \left\{ 1 - \alpha \left[ (1 - \phi) + \phi (1 - \bar{\phi}_u)^m (1 - \gamma_u^m) \right] \right\} \beta V_l(\phi') \\
+ \alpha \left[ (1 - \phi) + \phi (1 - \bar{\phi}_u)^f (1 - \gamma_u^m) \right] \beta A,
\]

Pr[symptoms]

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).
  - 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).
Remaining parameters are chosen to match a set of targets:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>$p$</td>
<td>joy of protected sex</td>
</tr>
<tr>
<td>$u$</td>
<td>joy of unprotected sex</td>
</tr>
<tr>
<td>$\ell$</td>
<td>extra benefit/cost of LT relationship</td>
</tr>
<tr>
<td>$A$</td>
<td>continuation value of life with symptoms</td>
</tr>
<tr>
<td>$\beta_1, \beta_2$</td>
<td>discount factor, two types</td>
</tr>
<tr>
<td>$\mu$</td>
<td>size of impatient group</td>
</tr>
<tr>
<td>$\eta$</td>
<td>prob. of becoming mature</td>
</tr>
<tr>
<td>$\omega_{ST}$</td>
<td>search cost in ST market (level)</td>
</tr>
<tr>
<td>$\omega_{LT}$</td>
<td>search cost in LT market (level)</td>
</tr>
<tr>
<td>$\kappa$</td>
<td>search cost (curvature)</td>
</tr>
</tbody>
</table>
## Model Fit (11 Moments)

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

![Graph showing fraction ever married by age with model and data points.]

- X-axis: Age (15 to 50)
- Y-axis: Fraction
- Data points and model line indicating the percentage of individuals who have ever married by age.

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Deaths by HIV/AIDS, by Age

Fraction of deaths caused by HIV/AIDS 2002

Age

Fraction of deaths caused by HIV/AIDS 2002

Age

data

model
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

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

- 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.)

<table>
<thead>
<tr>
<th></th>
<th>benchmark</th>
<th>full model</th>
<th>epidemiological</th>
</tr>
</thead>
<tbody>
<tr>
<td>female-to-male transmission</td>
<td>6%</td>
<td>5.25%</td>
<td>5.25%</td>
</tr>
<tr>
<td>male-to-female transmission</td>
<td>10.5%</td>
<td>9.8%</td>
<td>9.8%</td>
</tr>
<tr>
<td>HIV rate (men)</td>
<td>10.2</td>
<td>8.7</td>
<td>8.3</td>
</tr>
<tr>
<td>HIV rate (women)</td>
<td>12.8</td>
<td>11.1</td>
<td>10.6</td>
</tr>
<tr>
<td>% of men who are single</td>
<td>42.8</td>
<td>42.1</td>
<td></td>
</tr>
<tr>
<td>% of women who are single</td>
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<td>37.9</td>
<td></td>
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<td>57.6</td>
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<td></td>
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- Reducing transmission risk
  - Singles have more sex
  - More unprotected sex

- Epidemiological studies may overestimate policy benefits.
Example 2b: reducing transmission risk

<table>
<thead>
<tr>
<th></th>
<th>benchmark</th>
<th>full model</th>
<th>field experiment</th>
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</thead>
<tbody>
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<td>female-to-male transmission</td>
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<td>56</td>
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<tr>
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<td>24.2</td>
<td>24.3</td>
</tr>
<tr>
<td>% of casual sex with condom</td>
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<td>29.7</td>
<td>30.9</td>
</tr>
</tbody>
</table>

- 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)**

<table>
<thead>
<tr>
<th>BM</th>
<th>Search cost ↓</th>
</tr>
</thead>
<tbody>
<tr>
<td>Marital search cost, $\omega_{LT}$</td>
<td>30</td>
</tr>
<tr>
<td>HIV/AIDS rate, %</td>
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- “Promoting marriage” may increase HIV.
- **Reason:** more risky types sort into marriage. Worsens the marriage pool.
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