The end of AIDS? Insights from economic epidemiology

Pierre-Yves Geoffard

Paris School of Economics & CEPR

July 10, 2012
HIV epidemic

- Not over! 2.7M people newly infected (2010).
HIV epidemic

- Not over! 2.7M people newly infected (2010).
- A Southern disease...
HIV epidemic

- Not over! 2.7M people newly infected (2010).
- A Southern disease...
- ... which has also hit the North.
HIV epidemic

- Not over! 2.7M people newly infected (2010).
- A Southern disease...
- ... which has also hit the North.
- Transmission modes:
HIV epidemic

- Not over! 2.7M people newly infected (2010).
- A Southern disease...
- ... which has also hit the North.
- Transmission modes:
  - injection drug use (needle sharing)
HIV epidemic

- Not over! 2.7M people newly infected (2010).
- A Southern disease...
- ... which has also hit the North.
- Transmission modes:
  - injection drug use (needle sharing)
  - Sexual behavior (heterosexual, homosexual)
HIV epidemic

- Not over! 2.7M people newly infected (2010).
- A Southern disease...
- ... which has also hit the North.
- Transmission modes:
  - injection drug use (needle sharing)
  - Sexual behavior (heterosexual, homosexual)
  - Mother to child
HIV epidemic

- Not over! 2.7M people newly infected (2010).
- A Southern disease...
- ... which has also hit the North.
- Transmission modes:
  - injection drug use (needle sharing)
  - Sexual behavior (heterosexual, homosexual)
  - Mother to child
- Individual behavior: key to understand the dynamics
HIV epidemic

- Not over! 2.7M people newly infected (2010).
- A Southern disease...
- ... which has also hit the North.
- Transmission modes:
  - injection drug use (needle sharing)
  - Sexual behavior (heterosexual, homosexual)
  - Mother to child
- Individual behavior: key to understand the dynamics
- Policy responses must be based upon such understanding.
The benchmark: S(E)IR models

- Simplest version:
The benchmark: S(E)IR models

- Simplest version:
  - two compartments: $S_t$ and $I_t$. 
The benchmark: S(E)IR models

- Simplest version:
  - two compartments: $S_t$ and $I_t$.
  - homogeneous population
The benchmark: S(E)IR models

- Simplest version:
  - two compartments: $S_t$ and $I_t$.
  - homogeneous population
  - random matching between susceptibles and infected
The benchmark: S(E)IR models

- Simplest version:
  - two compartments: $S_t$ and $I_t$.
  - homogeneous population
  - random matching between susceptibles and infected
  - Force of infection: $\lambda = \beta I_t$. 
The benchmark: S(E)IR models

- Simplest version:
  - two compartments: $S_t$ and $I_t$.
  - homogeneous population
  - random matching between susceptibles and infected
  - Force of infection: $\lambda = \beta I_t$.
  - New cases: $\lambda S_t = \beta I_t S_t$. 
The benchmark: S(E)IR models

- Simplest version:
  - two compartments: \( S_t \) and \( I_t \).
  - homogeneous population
  - random matching between susceptibles and infected
  - Force of infection: \( \lambda = \beta I_t \).
  - New cases: \( \lambda S_t = \beta I_t S_t \).
  - Exit from infection: recovery (rate \( v \)) and death (rate \( \delta \))
The benchmark: S(E)IR models

- Simplest version:
  - two compartments: $S_t$ and $I_t$.
  - homogeneous population
  - random matching between susceptibles and infected
  - Force of infection: $\lambda = \beta I_t$.
  - New cases: $\lambda S_t = \beta I_t S_t$.
  - Exit from infection: recovery (rate $v$) and death (rate $\delta$)
  - Change in prevalence: $\frac{dl_t}{dt} = \beta S_t I_t - (v + \delta)I_t$
The benchmark: $S(E)IR$ models

- Key ingredient: $\beta$
The benchmark: S(E)IR models

- Key ingredient: $\beta$
- Depends on (for STD):
The benchmark: S(E)IR models

- Key ingredient: $\beta$
- Depends on (for STD):
  - the number of sexual partners $n_i$
The benchmark: S(E)IR models

- Key ingredient: $\beta$
- Depends on (for STD):
  - the number of sexual partners $n_i$
  - the probability of infection given a sexual act
The benchmark: S(E)IR models

- Key ingredient: $\beta$
- Depends on (for STD):
  - the number of sexual partners $n_i$
  - the probability of infection given a sexual act
- Benchmark model (homogenous matching): the average number of partners matters: $E(n_i)$
First variation: heterogeneity

- Individual behavior is heterogeneous
First variation: heterogeneity

- Individual behavior is heterogeneous
- Still random matching, but more compartments
First variation: heterogeneity

- Individual behavior is heterogeneous
- Still random matching, but more compartments
- Force of infection proportional to $E(n) + V(n)/E(n)$:
First variation: heterogeneity

- Individual behavior is heterogeneous
- Still random matching, but more compartments
- Force of infection proportional to $E(n) + V(n)/E(n)$:
- Heterogeneity matters: “super spreaders”,...
Second variation: endogeneity / economics

- Risk behavior of an individual: affected by the environment
Second variation: endogeneity / economics

- Risk behavior of an individual: affected by the environment
- Bentham view: costs and benefits (i.e., “rational” behavior)
Second variation: endogeneity / economics

- Risk behavior of an individual: affected by the environment
- Bentham view: costs and benefits (i.e., “rational” behavior)
- Economics: a theory of choice (*Incentives matter*)
Second variation: endogeneity / economics

- Risk behavior of an individual: affected by the environment
- Bentham view: costs and benefits (i.e., "rational" behavior)
- Economics: a theory of choice (Incentives matter)
- Benefits of risk taking (pleasure...)

Key concept: prevalence elasticity

How behavior responds to changes in prevalence
Second variation: endogeneity / economics

- Risk behavior of an individual: affected by the environment
- Bentham view: costs and benefits (i.e., “rational” behavior)
- Economics: a theory of choice (*Incentives matter*)
- Benefits of risk taking (pleasure...)
- Costs: risk of infection
Second variation: endogeneity / economics

- Risk behavior of an individual: affected by the environment
- Bentham view: costs and benefits (i.e., “rational” behavior)
- Economics: a theory of choice (*Incentives matter*)
- Benefits of risk taking (pleasure...)
- Costs: risk of infection
- Perception of risk may be biased
Second variation: endogeneity / economics

- Risk behavior of an individual: affected by the environment
- Bentham view: costs and benefits (i.e., “rational” behavior)
- Economics: a theory of choice (*Incentives matter*)
- Benefits of risk taking (pleasure...)
- Costs: risk of infection
- Perception of risk may be biased
- Cost/benefits depend on risk of infection (i.e., prevalence)
Second variation: endogeneity / economics

- Risk behavior of an individual: affected by the environment
- Bentham view: costs and benefits (i.e., “rational” behavior)
- Economics: a theory of choice (*Incentives matter*)
- Benefits of risk taking (pleasure...)
- Costs: risk of infection
- Perception of risk may be biased
- Cost/benefits depend on risk of infection (i.e., prevalence)
- Behavior related to prevalence: \( n(l_t) \).
Second variation: endogeneity / economics

- Risk behavior of an individual: affected by the environment
- Bentham view: costs and benefits (i.e., “rational” behavior)
- Economics: a theory of choice (Incentives matter)
- Benefits of risk taking (pleasure...)
- Costs: risk of infection
- Perception of risk may be biased
- Cost/benefits depend on risk of infection (i.e., prevalence)
- Behavior related to prevalence: $n(l_t)$.
- Key concept: prevalence elasticity
Second variation: endogeneity / economics

- Risk behavior of an individual: affected by the environment
- Bentham view: costs and benefits (i.e., “rational” behavior)
- Economics: a theory of choice (Incentives matter)
- Benefits of risk taking (pleasure...)
- Costs: risk of infection
- Perception of risk may be biased
- Cost/benefits depend on risk of infection (i.e., prevalence)
- Behavior related to prevalence: $n(l_t)$.
- Key concept: prevalence elasticity
  - How behavior responds to changes in prevalence
Prevalence elasticity

- Pandemic context: infectious risk increases
Prevalence elasticity

- Pandemic context: infectious risk increases
- → individual risk taking behavior decreases
Prevalence elasticity

- Pandemic context: infectious risk increases
- → individual risk taking behavior decreases
- Negative feedback effect
Prevalence elasticity

- Pandemic context: infectious risk increases
- → individual risk taking behavior decreases
- Negative feedback effect
- Self-limiting dynamics.
Prevalence elasticity

- Pandemic context: infectious risk increases
- → individual risk taking behavior decreases
- Negative feedback effect
- Self-limiting dynamics.
- Individual responses contribute to limit the spread of the disease
Prevalence elasticity

- Pandemic context: infectious risk increases
- $\rightarrow$ individual risk taking behavior decreases
- Negative feedback effect
- Self-limiting dynamics.
- Individual responses contribute to limit the spread of the disease
- Economic epidemiology: large and growing literature
Less optimistic view

- During the asymptomatic phase, some individuals may leave high prevalence areas to lower prevalence areas...
Less optimistic view

- During the asymptomatic phase, some individuals may leave high prevalence areas to lower prevalence areas...
- And carry the disease with them, contributing to the (spatial) diffusion of the disease (positive feedback).
Less optimistic view

- During the asymptomatic phase, some individuals may leave high prevalence areas to lower prevalence areas...
- And carry the disease with them, contributing to the (spatial) diffusion of the disease (positive feedback).
- (e.g. plague in the XIV th century)
Vaccination

- Endogenous behavior limits disease growth, but also makes eradication more difficult.
Vaccination

- Endogenous behavior limits disease growth, but also makes eradication more difficult.
- Incentives to vaccinate diminish as prevalence decreases.
Vaccination

- Endogenous behavior limits disease growth, but also makes eradication more difficult.
- Incentives to vaccinate diminish as prevalence decreases.
- Free-riding problem: best situation is when everybody is vaccinated...
Vaccination

- Endogenous behavior limits disease growth, but also makes eradication more difficult.
- Incentives to vaccinate diminish as prevalence decreases.
- Free-riding problem: best situation is when everybody is vaccinated...
- ... everybody but me.
Vaccination

- Endogenous behavior limits disease growth, but also makes eradication more difficult.
- Incentives to vaccinate diminish as prevalence decreases.
- Free-riding problem: best situation is when everybody is vaccinated...
- ... everybody but me.
- Empirical evidence that vaccination decisions respond to local prevalence (measles,...)
Vaccination and eradication

- More than 40 vaccines available, and only one disease (smallpox) eradicated...
Vaccination and eradication

- More than 40 vaccines available, and only one disease (smallpox) eradicated...
- Polio: close to eradication, but not yet.
Vaccination and eradication

- More than 40 vaccines available, and only one disease (smallpox) eradicated...
- Polio: close to eradication, but not yet.
- Free riding issue more and more severe as eradication gets closer
Vaccination and eradication

- More than 40 vaccines available, and only one disease (smallpox) eradicated...
- Polio: close to eradication, but not yet.
- Free riding issue more and more severe as eradication gets closer
- More and more distortions between individual and social C/B analysis:
Vaccination and eradication

- More than 40 vaccines available, and only one disease (smallpox) eradicated...
- Polio: close to eradication, but not yet.
- Free riding issue more and more severe as eradication gets closer
- More and more distortions between individual and social C/B analysis:
  - “externality” (i.e., missing market)
Vaccination and eradication

- More than 40 vaccines available, and only one disease (smallpox) eradicated...
- Polio: close to eradication, but not yet.
- Free riding issue more and more severe as eradication gets closer
- More and more distortions between individual and social C/B analysis:
  - “externality” (i.e., missing market)
  - social gain from vaccination not internalized by each individual
Vaccination and eradication

- More than 40 vaccines available, and only one disease (smallpox) eradicated...
- Polio: close to eradication, but not yet.
- Free riding issue more and more severe as eradication gets closer
- More and more distortions between individual and social C/B analysis:
  - “externality” (i.e., missing market)
  - social gain from vaccination not internalized by each individual
  - subsidies should increase as eradication gets closer.
Vaccination and eradication

- More than 40 vaccines available, and only one disease (smallpox) eradicated...
- Polio: close to eradication, but not yet.
- Free riding issue more and more severe as eradication gets closer
- More and more distortions between individual and social C/B analysis:
  - “externality” (i.e., missing market)
  - social gain from vaccination not internalized by each individual
  - subsidies should increase as eradication gets closer.
- Eradication: costs now, benefits later (for future generations)
Vaccination and eradication

- More than 40 vaccines available, and only one disease (smallpox) eradicated...
- Polio: close to eradication, but not yet.
- Free riding issue more and more severe as eradication gets closer
- More and more distortions between individual and social C/B analysis:
  - “externality” (i.e., missing market)
  - social gain from vaccination not internalized by each individual
  - subsidies should increase as eradication gets closer.
- Eradication: costs now, benefits later (for future generations)
- Under mandatory vaccination, main issue: compliance.
Preventing HIV

- No vaccine (yet...)
Preventing HIV

- No vaccine (yet...)
- Prevention:
  - Abstinence, reduction of number of partners, condom use,...
  - Needle exchange programs,...
  - Antiretroviral therapy (ART): stops mother to child transmission
  - More recent evidence:
    - Male circumcision
    - PrEP (pre-exposure prophylaxis): treating susceptible individuals (those at high risk)...
    - TASP (treatment as prevention): ART lowers the concentration of HIV in the bloodstream. Infected individuals under treatment (almost) do not transmit the disease.
Preventing HIV

- No vaccine (yet...)
- Prevention:
  - Abstinence, reduction of number of partners, condom use,...
Preventing HIV

- No vaccine (yet...)
- Prevention:
  - Abstinence, reduction of number of partners, condom use,...
  - Needle exchange programs,...
Preventing HIV

- No vaccine (yet...)
- Prevention:
  - Abstinence, reduction of number of partners, condom use,...
  - Needle exchange programs,...
  - Antiretroviral therapy (ART): stops mother to child transmission
Preventing HIV

- No vaccine (yet...)
- Prevention:
  - Abstinence, reduction of number of partners, condom use,...
  - Needle exchange programs,...
  - Antiretroviral therapy (ART): stops mother to child transmission
- More recent evidence:
Preventing HIV

▶ No vaccine (yet...)
▶ Prevention:
  ▶ Abstinence, reduction of number of partners, condom use,...
  ▶ Needle exchange programs,...
  ▶ Antiretroviral therapy (ART): stops mother to child transmission
▶ More recent evidence:
  ▶ Male circumcision
Preventing HIV

- No vaccine (yet...)
- Prevention:
  - Abstinence, reduction of number of partners, condom use,...
  - Needle exchange programs,...
  - Antiretroviral therapy (ART): stops mother to child transmission
- More recent evidence:
  - Male circumcision
  - PrEP (pre-exposure prophylaxis): treating susceptible individuals (those at high risk)...
Preventing HIV

- No vaccine (yet...)
- Prevention:
  - Abstinence, reduction of number of partners, condom use, ...
  - Needle exchange programs, ...
  - Antiretroviral therapy (ART): stops mother to child transmission
- More recent evidence:
  - Male circumcision
  - PrEP (pre-exposure prophylaxis): treating susceptible individuals (those at high risk) ...
  - TASP (treatment as prevention): ART lowers the concentration of HIV in the bloodstream. Infected individuals under treatment (almost) do not transmit the disease.
Can TASP lead to the eradication of AIDS?

- Mathematical model of HIV/AIDS (Granich et al., Lancet, 2009)
Can TASP lead to the eradication of AIDS?

- Mathematical model of HIV/AIDS (Granich et al., Lancet, 2009)
- Simulation of active policy:
Can TASP lead to the eradication of AIDS?

- Mathematical model of HIV/AIDS (Granich et al., Lancet, 2009)
- Simulation of active policy:
  - Treat “all” infected individuals
Can TASP lead to the eradication of AIDS?

- Mathematical model of HIV/AIDS (Granich et al., Lancet, 2009)
- Simulation of active policy:
  - Treat “all” infected individuals
  - Requires to test the entire population, and to do it frequently
Can TASP lead to the eradication of AIDS?

- Mathematical model of HIV/AIDS (Granich et al., Lancet, 2009)
- Simulation of active policy:
  - Treat “all” infected individuals
  - Requires to test the entire population, and to do it frequently
  - Also relies on compliance (during the asymptomatic phase)
Can TASP lead to the eradication of AIDS?

- Mathematical model of HIV/AIDS (Granich et al., Lancet, 2009)
- Simulation of active policy:
  - Treat “all” infected individuals
  - Requires to test the entire population, and to do it frequently
  - Also relies on compliance (during the asymptomatic phase)
  - Assumes no induced changes in sexual behavior.
With endogenous behavior

▶ Testing: “voluntary universal” testing
With endogenous behavior

- Testing: “voluntary universal” testing
  - Need to better understand the determinants of individual decisions to test...
With endogenous behavior

- Testing: “voluntary universal” testing
  - Need to better understand the determinants of individual decisions to test...
  - … and how these decisions may evolve during an eradication dynamics.
With endogenous behavior

- Testing: “voluntary universal” testing
  - Need to better understand the determinants of individual decisions to test...
  - ... and how these decisions may evolve during an eradication dynamics.
  - smaller incentives to test as disease prevalence decreases!
With endogenous behavior

- Testing: “voluntary universal” testing
  - Need to better understand the determinants of individual decisions to test...
  - ... and how these decisions may evolve during an eradication dynamics.
  - smaller incentives to test as disease prevalence decreases!
- Early treatment (as early as possible)
With endogenous behavior

- Testing: “voluntary universal” testing
  - Need to better understand the determinants of individual decisions to test...
  - ... and how these decisions may evolve during an eradication dynamics.
  - smaller incentives to test as disease prevalence decreases!

- Early treatment (as early as possible)
  - Individual benefit of early treatment (wrt being treated once CD4 cell count gets below 350) unclear.
With endogenous behavior

- Testing: “voluntary universal” testing
  - Need to better understand the determinants of individual decisions to test...
  - ... and how these decisions may evolve during an eradication dynamics.
  - smaller incentives to test as disease prevalence decreases!

- Early treatment (as early as possible)
  - Individual benefit of early treatment (wrt being treated once CD4 cell count gets below 350) unclear.
  - Compliance? (asymptomatic yet under daily treatment, and for ever...)
With endogenous behavior

▶ Testing: “voluntary universal” testing
  ▶ Need to better understand the determinants of individual decisions to test...
  ▶ ... and how these decisions may evolve during an eradication dynamics.
  ▶ smaller incentives to test as disease prevalence decreases!

▶ Early treatment (as early as possible)
  ▶ Individual benefit of early treatment (wrt being treated once CD4 cell count gets below 350) unclear.
  ▶ Compliance? (asymptomatic yet under daily treatment, and for ever...)

▶ Evolution of sexual behavior
With endogenous behavior

- Testing: “voluntary universal” testing
  - Need to better understand the determinants of individual decisions to test...
  - ... and how these decisions may evolve during an eradication dynamics.
  - smaller incentives to test as disease prevalence decreases!

- Early treatment (as early as possible)
  - Individual benefit of early treatment (wrt being treated once CD4 cell count gets below 350) unclear.
  - Compliance? (asymptomatic yet under daily treatment, and for ever...)

- Evolution of sexual behavior
  - Evidence that C/B affect risky sexual behavior (smaller prevalence, new treatments,...)
Modeling behavioral response

- Force of infection $\lambda$

Under exogenous behavior, $\lambda = \beta I$

Simple variation: $\lambda = \beta I \phi(I, \alpha)$

Function $\phi$ increases with prevalence level: prevalence elasticity of prevention.

Simulations, or analytical solutions.
Modeling behavioral response

- Force of infection $\lambda$
- Under exogenous behavior, $\lambda = \beta I$
Economic epidemiology

MODELING BEHAVIORAL RESPONSE

- Force of infection $\lambda$
- Under exogenous behavior, $\lambda = \beta I$
- Simple variation:

$$\lambda = \frac{\beta I}{\phi(I, \alpha)}$$

Function $\phi$ increases with prevalence level: prevalence elasticity of prevention.

Simulations, or analytical solutions.
Modeling behavioral response

- Force of infection $\lambda$
- Under exogenous behavior, $\lambda = \beta I$
- Simple variation:
  $\lambda = \frac{\beta I}{\phi(I, \alpha)}$
- Function $\phi$ increases with prevalence level: prevalence elasticity of prevention.
Modeling behavioral response

- Force of infection $\lambda$
- Under exogenous behavior, $\lambda = \beta I$
- Simple variation:
  $$\lambda = \frac{\beta I}{\phi(I, \alpha)}$$
- Function $\phi$ increases with prevalence level: prevalence elasticity of prevention.
- Simulations, or analytical solutions.
Analytical solution

- Examples of reaction function:
Analytical solution

▶ Examples of reaction function:
  ▶ $\phi(I, \alpha) = 1 + \alpha I^2$
Analytical solution

- Examples of reaction function:
  - $\phi(I, \alpha) = 1 + \alpha I^2$
  - $\phi(I, \alpha) = \exp(\alpha I^n)$
Analytical solution

- Examples of reaction function:
  - $\phi(I, \alpha) = 1 + \alpha I^2$
  - $\phi(I, \alpha) = \exp(\alpha I^n)$
- $\partial\phi/\partial I > 0$ represents prevalence elasticity
Analytical solution

- Examples of reaction function:
  - $\phi(I, \alpha) = 1 + \alpha I^2$
  - $\phi(I, \alpha) = \exp(\alpha I^n)$
- $\partial \phi / \partial I > 0$ represents prevalence elasticity
- Endemic prevalence level $I^*$:

$$\delta l^* = \frac{\beta l^* S}{\phi(l^*, \alpha)} = \frac{\beta l^*(1 - l^*)}{\phi(l^*, \alpha)}$$

$$R_0(1 - l^*) = \phi(l^*, \alpha).$$
Conclusion

- Empirical evidence of individual behavior adaptation to pandemic contexts
Conclusion

- Empirical evidence of individual behavior adaptation to pandemic contexts
- "Prevalence elasticity": key notion in "economic epidemiology".
Conclusion

- Empirical evidence of individual behavior adaptation to pandemic contexts
- “Prevalence elasticity”: key notion in “economic epidemiology”.
- Incorporating behavioral response in pandemic models:
  - Affects costs and benefits analysis
  - Enables to study discrepancies between individual and social welfare
  - Helps to design efficient public policy
  - Eradication of AIDS: costs will be larger than estimated, and increasing with closeness to eradication.
Conclusion

- Empirical evidence of individual behavior adaptation to pandemic contexts
- “Prevalence elasticity”: key notion in “economic epidemiology”.
- Incorporating behavioral response in pandemic models:
  - Affects costs and benefits analysis
Conclusion

- Empirical evidence of individual behavior adaptation to pandemic contexts
- "Prevalence elasticity": key notion in "economic epidemiology".
- Incorporating behavioral response in pandemic models:
  - Affects costs and benefits analysis
  - Enables to study discrepancies between individual and social welfare

Eradication of AIDS? Costs will be larger than estimated, and increasing with closeness to eradication.
Conclusion

- Empirical evidence of individual behavior adaptation to pandemic contexts
- "Prevalence elasticity": key notion in "economic epidemiology".
- Incorporating behavioral response in pandemic models:
  - Affects costs and benefits analysis
  - Enables to study discrepancies between individual and social welfare
  - Helps to design efficient public policy

Pierre-Yves Geoffard
Paris School of Economics & CEPR
Conclusion

- Empirical evidence of individual behavior adaptation to pandemic contexts
- “Prevalence elasticity”: key notion in “economic epidemiology”.
- Incorporating behavioral response in pandemic models:
  - Affects costs and benefits analysis
  - Enables to study discrepancies between individual and social welfare
  - Helps to design efficient public policy
- Eradication of AIDS: costs will be larger than estimated, and increasing with closeness to eradication.