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Fidelity Networks and Long-Run Trends in HIV/AIDS Gender Gaps

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Abstract

More than half of the HIV/AIDS-infected population today are women. We study a dynamic model of (in)fidelity, which explains the HIV/AIDS gender gap by the configuration of sexual networks. Each individual desires sexual relationships with opposite sex individuals. Two Markov matching processes are defined, each corresponding to a different culture of gender relations. The first process leads to egalitarian pairwise stable networks in the long run, and HIV/AIDS is equally prevalent among men and women. The second process leads to anti-egalitarian pairwise stable networks reflecting male domination, and women bear a greater burden. The results are consistent with empirical observations.

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More than half of the over 34 million individuals who are infected with the AIDS virus today are women (Joint United Nations Programme on HIV/AIDS (UNAIDS) (2010)). In sub-Saharan Africa where the AIDS epidemic is most concentrated, women represent 60% of the infected population (see Figure 1), which leads to 400, 000 more women than men dying from HIV/AIDS each year, a grave public health crisis. Why are women more affected by the HIV/AIDS burden? Early on, it was hypothesized that the male-to-female transmission rate of HIV is greater than the female-to-male transmission rate (World Health Organization (WHO) (2003)). However, this hypothesis was challenged in a ground-breaking study (Gray et al. (2001)) which showed that the female-to-male transmission rate is greater than the male-to-female transmission rate, although the difference is not statistically significant. The question of the origins of gender differences in HIV/AIDS prevalence is therefore still open.

We propose that the HIV/AIDS gender gap can be explained by the configuration of sexual networks. Relying on the dynamic model introduced in Pongou and Serrano (2009), we uncover a simple social mechanism underlying long-run trends in HIV/AIDS gender gaps across heterosexual cultures. A fidelity mating economy where each individual desires to form sexual partnerships with agents of the opposite sex is considered. Networks that result from such interactions are called *(in)fidelity networks*.

I. The Fidelity Model

The formal setting is a mating economy consisting of a finite population of *men* (M) and *women* (W), both of equal size. We denote by m a typical man and by w a typical woman. Agents have preferences over the number of opposite sex partners. Each individual trades off the cost and the benefit of having partners, where the benefit function is strictly concave and the cost function convex, both being increasing in the number of sexual partners. Having no partner has no benefit and no cost. This yields a single-peaked utility function. Assuming peak-homogeneous preferences on each side, s_m^* and s_w^* denote the optimal number of partners for each man and for each woman, respectively. We assume that $s_m^* > s_w^*$, which can be justified by several factors, including a stronger preference over sex for men, or that the cost of having many

partners is greater for women. Finally, we assume that the population is sufficiently large relative to the optimal number of partners, which can be expressed as: $\frac{|M| - (s_w^* - 1)}{|M|} > \frac{s_w^*}{s_m^*}$.

Relationships are links in a network (a set of links between men and women). In a network g , $s_i(g)$ (or simply s_i) denotes the number of partners that an individual i has in g .

II. Static Stability of Fidelity Networks

In a fidelity economy, individuals form new links or sever existing ones based on the reward that the resulting network offers them relative to the current network. A network is *pairwise stable* whenever: (i) no individual has an incentive to sever an existing link he or she is involved in; and (ii) no pair of a man and a woman have a strict incentive to form a new link between them while at the same time possibly severing some of their existing links.²

Pongou and Serrano (2009) prove that a network is pairwise stable if and only if each woman has her optimal number of partners, and each man has at most his optimal number of partners. The intuition for this result is that women supply a smaller number of links than the ones demanded by men, which in turn results in only men competing for female partners while each woman is sure of having the number of male partners she desires.

To understand trends in HIV/AIDS gender gaps, it is necessary to study the dynamics of fidelity networks, to which we now turn.

III. Long-Run Fidelity Networks

We consider a dynamic Markov matching process for the fidelity economy. In each period, a man and a woman, chosen at random with arbitrary positive probability, are given the opportunity to sever their link if they are linked in the current network, or to form a new link if they are not linked. Link severance is a unilateral decision, and link formation is a bilateral decision. While forming a new link, each agent is allowed to sever as many of the links he/she is involved in as possible in the current network. The *long run predictions* –steady or recurrent states– of this process coincide with the set of pairwise stable networks, a very large set.

²See Gale and Shapley (1962) for a first use of pairwise stability in two-sided matching markets.

We therefore perturb the dynamic process above by allowing agents to form or sever links even though such actions may not increase their utility. Two such perturbations are considered, each corresponding to a different culture of gender relations. We study the long-run predictions of these *perturbed processes* –their *stochastically stable networks*–, these are the only networks that form in the very long run.

The perturbed processes, labelled P_1^ε and P_2^ε , are described as follows. In both, if a link formation is mutually beneficial or if a link severance is beneficial to its initiator, it occurs with probability 1. An action that worsens the initiator, which we call a *mistake*, occurs with a small probability $\varepsilon > 0$. Key to our analysis are actions that leave their initiators indifferent. These actions are referred to as (*utility*) *neutral*. In the spirit of assuming that more serious mistakes are less likely, the probability that an agent takes a neutral action always exceeds ε . We explain how.

In the two processes, neutral actions uniquely correspond to situations in which an agent severs an existing link and forms a new link. We shall assume that the probability of such a neutral action is $\varepsilon^{f(.)}$ where the exponent is less than 1. The exponent is the *strength of the existing link* so that stronger links – $f(.)$ closer to 1– are harder to break.

In the first perturbed process, the strength $f(.)$ of a severed link is *decreasing* in the number of partners that the old partner had in the existing network. This link is as strong as the amount of time invested in it by the other partner. In contrast, the second perturbed process assumes that the strength of a severed link $f(.)$ is *increasing* in the number of partners the old partner had. The partner who invests more time in a relationship is perceived as “weak” or dominated by the other partner; it is thus easier for the dominant partner to break the relationship (see, e.g., Caldwell (1976)).

More precisely, assume that an agent i severs a link with k to form a new link with j . Then i takes this action with probability $\varepsilon^{f(1/s_k)}$ in the first process and $\varepsilon^{f(s_k)}$ in the second process, where $f(.)$ is a strictly increasing function mapping into $(0,1)$.

Let $q = (g^0, g^1, \dots, g^k)$ be a dynamic path from network g^0 to network g^k . The resistance of q is the sum of the resistances of its transitions $r(q) = \sum_{t=0}^{k-1} r(g^t, g^{t+1})$, where $r(g^t, g^{t+1})$ is the weighted number of agents directly involved in the transition from g^t to g^{t+1} who do not find

this change profitable; it is the exponent of ε in the corresponding transition probability. The probability of a transition (g^t, g^{t+1}) is the product of the probabilities with which each of the agents involved in this transition takes the corresponding action.

Intuitively, the resistance of a (g^0, g^k) -path q measures how hard it is for network g^0 to transition to g^k . The set of *stochastically stable networks* is the set of networks that are the *easiest* to transition to in the universe of networks (see, e.g., Young (1998)).

Pongou and Serrano (2009) show that in the first process, a network is stochastically stable if and only if it is *egalitarian* and *pairwise stable*: each person is matched to s_w^* partners, the optimum for women. In the second process, a network is stochastically stable if and only if it is *anti-egalitarian* and *pairwise stable*: each matched man has s_m^* partners (except for at most one man, who is matched to the remaining women); the rest of men are unmatched; and each woman is matched to her optimal number of partners s_w^* .

If $s_w^* = 1$, serial monogamy, more common in western countries, is a salient particular case of the first process, whereas polygyny, more common in traditional societies, prevails in the second process. Empirically, each of the two processes is therefore consistent with a different sociological reality.

IV. An Illustrative Example

This section illustrates the two stochastic processes through a mating economy involving six men and six women where $s_m^* = 3$ and $s_w^* = 2$. Network g^0 in Figure 2 is a pairwise stable network that is not stochastically stable under either process. g^0 is described by the following matches:

$$m_1 : w_1 \text{ (} m_1 \text{ is matched with } w_1 \text{)}, m_2 : w_1 w_2, m_3 : w_2 w_3, m_4 : w_3, m_5 : w_4 w_5 w_6, m_6 : w_4 w_5 w_6.$$

Our goal is to determine a network to which g^0 may converge under each of the processes following the path of least resistance.

Under P_1^ε , without loss of generality, let us measure the strength of an existing link with the function $f(s_k) = 1/(s_k + 2)$. First, w_4 severs her link with m_5 and forms a link with m_4 , with resistance $1/5$ (note that if w_4 were to sever this new link with m_4 to link with m_5 , the resistance

would be $1/4$, which is larger). Second, w_4 again severs her link with m_6 to link with m_1 (with resistance $1/5$, and $1/4$ in the opposite direction). The resulting network is the egalitarian pairwise network h_1 . Note that $r(g^0, h_1) = 1/5 + 1/5 = 2/5$, which is smaller than $r(h_1, g^0) = 1/4 + 1/4 = 1/2$, which shows that going from g^0 to h_1 is infinitely more likely than the converse when ε is very small.

Under p_2^ε , without loss of generality, we measure the strength of an existing link with the function $f(s_k) = s_k / |M|$. First, w_1 severs her link with m_1 and forms a link with m_3 (with resistance $1/6$, and $3/6$ in the opposite direction). Second, w_3 severs her link with m_4 to match with m_2 (with resistance of $1/6$, and $3/6$ in the opposite direction). The resulting network is the anti-egalitarian pairwise network h_2 . Note that $r(g^0, h_2) = 1/6 + 1/6 = 1/3$, which is smaller than $r(h_2, g^0) = 3/6 + 3/6 = 1$, showing that going from g^0 to h_2 is infinitely more likely than the opposite when ε is very small.

V. The Long-Run Gender Gap in HIV/AIDS Prevalence

The results from Section III are used to understand the social mechanism underlying the HIV/AIDS gender gap in the long run in heterosexual societies. We recall a simple index of contagion. Let g be an n -person network that has k components, where a component is a maximal set of agents who are directly or indirectly connected in g . Let n_i , $|M_i|$ and $|W_i|$ be the number of individuals, men and women in the i th component ($1 \leq i \leq k$), respectively. Pongou (2010) shows that if a random individual is infected with HIV, and if that individual infects his/her partners who also infect their other partners and so on, the fraction of infected people is given by the contagion potential of g ($P(g)$) in Definition 1. The gender difference in the contagion potential of g is given by $F(g)$.

Definition 1. (1) The *contagion potential* of g is: $P(g) = \frac{1}{n^2} \sum_{i=1}^k n_i^2$.

(2) The *gender difference in the contagion potential* of g is: $F(g) = \frac{2}{n^2} \sum_{i=1}^k |M_i|^2 - |W_i|^2$.

In equilibrium networks, sexual acts are repeated over long time periods, causing the HIV transmission probability to approach 1 as Definition 1 assumes, even if the transmission probability per coital act is smaller than 1.

Pongou and Serrano (2009) show that: (1) for any stochastically stable network g of the perturbed process p_1^ε , $F(g) = 0$; and (2) for any stochastically stable network g of the perturbed process p_2^ε , $F(g) < 0$.

This result implies that if a network is such that the spread of a random HIV infection would affect more men than women, then over time, that network will evolve towards an HIV-gender-neutral network under the first process, and towards a female-infection-biased network under the second process. In the example in Section IV, the gender gap in HIV in the initial network g^0 is

$$F(g^0) = \frac{2}{12^2}(4^2 - 3^2 + 2^2 - 3^2) = \frac{1}{36},$$

which means that the HIV prevalence would be 2.7 percent greater for men than for women if a random infection shock spreads. However, under the process p_1^ε , g^0 would gradually evolve towards h_1 where the gender gap in HIV prevalence is $F(h_1) = 0$, meaning that over time, the share of women among HIV-infected individuals would be close to 50%. Under the process p_2^ε , g^0 would gradually evolve towards network h_2 where the gender gap in HIV prevalence is $F(h_2) = -1/9$, which means that over time, the share of women among HIV-infected individuals will exceed that of men by 11 percentage points.

VI. Concluding Remarks

The analysis reveals that a key factor in the increased vulnerability of women to HIV/AIDS is that the optimal number of partners is greater for men than for women. In societies in which the first perturbed process prevails, women have an easier time breaking relationships with more promiscuous men, which leads to egalitarian pairwise stable networks and gender equality in HIV/AIDS prevalence in the long run. In societies where the second process prevails, the opposite holds, yielding anti-egalitarian pairwise stable networks and higher HIV/AIDS prevalence for women than for men. The second process may therefore be viewed as describing male-dominant societies, whereas the first process describes societies where women have achieved more equality with men. Such a description, however, is a post-fact rationalization, as

all our assumptions, except the one on gender asymmetry in the optimal number of partners, are gender-neutral.

The results are consistent with trends in gender differences in HIV/AIDS in most regions of the world, especially sub-Saharan Africa and the Caribbean where UNAIDS (2010) has established that heterosexual relationships are the main mode of HIV transmission – see Figure 1.³ Our results also admit the possibility of HIV/AIDS being greater for men than for women at certain periods of the transition process. When this is the case, however, one should observe that the share of infected women is growing over time relative to the share of infected men, which is qualitatively consistent with trends in gender differences in HIV/AIDS in all regions of the world, including western societies (Figure 1).

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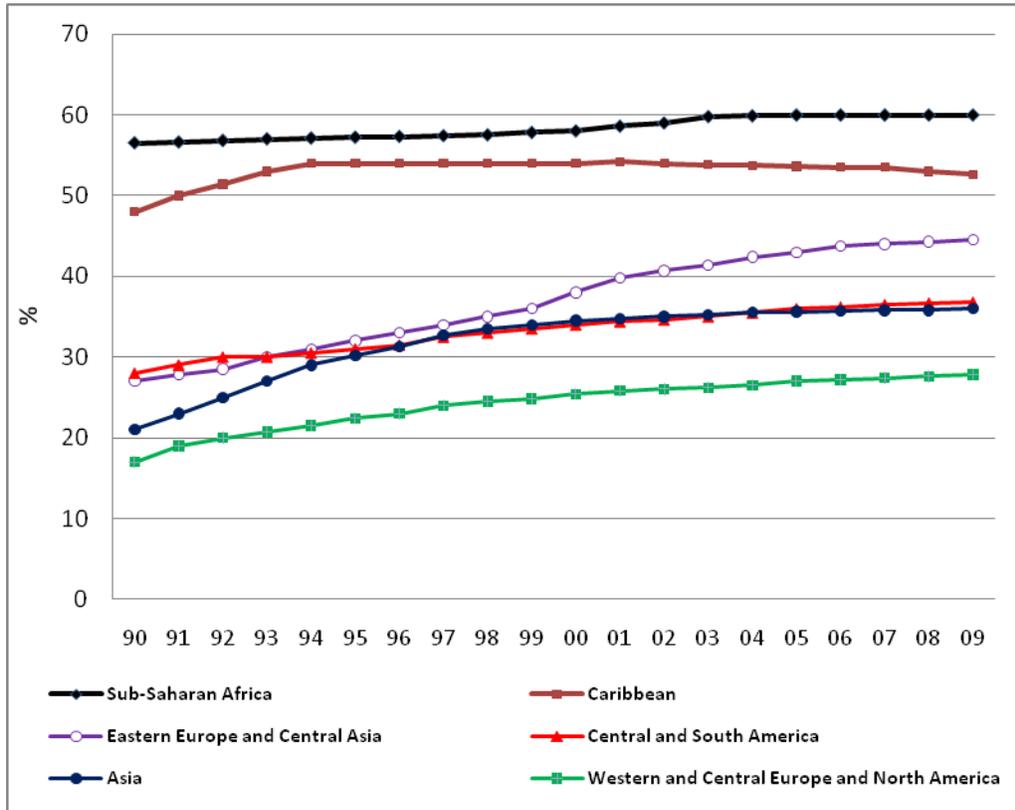
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³Marriage norms differ in the two regions. Polygyny is legal in most sub-Saharan African countries, whereas it is illegal in the Caribbean. The latter therefore is closer to the West in terms of marriage norms. The first process is expected to prevail in that region, whereas the second process prevails in sub-Saharan Africa where the dominant role of men in relationships has been measured by the small amount of time they invest in them (Caldwell (1976)).

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FIGURE 1: SHARE OF WOMEN AMONG HIV-INFECTED ADULTS (15 YEARS AND OLDER), 1990-2009



Based on data from UNAIDS (2010)

FIGURE 2: AN ILLUSTRATION OF THE PERTURBED STOCHASTIC PROCESSES
 p_1^ε AND p_2^ε

