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C. Robert Clark, Désiré Vencatachellum

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Economic Development and HIV/AIDS Prevalence*

C. Robert Clark[†], *Désiré Vencatachellum*[‡]

Résumé / *Abstract*

Nous documentons une forte relation négative entre le taux de prévalence du VIH/SIDA et le niveau de développement économique au niveau mondial. Cependant, cette relation ne tient pas en Afrique Sub-Saharienne qui est paradoxalement la région la plus touchée par le VIH/SIDA. Plusieurs pays parmi les plus riches de cette région ont des taux de prévalence très élevés. Afin d'expliquer ce phénomène, nous construisons un modèle où chaque individu vit pendant deux périodes et où son utilité est fonction de sa consommation et de son activité sexuelle. Ceux qui s'attendent à obtenir un revenu relativement faible pendant le reste de leur vie peuvent décider d'avoir des rapports sexuels non protégés en dépit du risque de contracter le VIH. Ce choix est motivé par l'utilité instantanée plus élevée qu'ils obtiennent en ayant un rapport sexuel sans préservatif. Nous démontrons que le taux de prévalence du VIH/SIDA devrait être plus élevé dans les pays pauvres car une plus grande part de la population choisirait d'avoir des rapports sexuels non protégés. Cependant, il peut exister des équilibres multiples dans les économies où les externalités associées au capital humain sont élevées. Dans ce cas, même ceux qui sont relativement riches peuvent choisir d'avoir des relations sexuelles non protégées s'ils anticipent qu'une part importante de la population ferait de même. Si telles sont les anticipations, alors le niveau de capital humain anticipé est faible en raison de la mortalité due au SIDA. Ceci a un effet négatif sur le revenu et la consommation futurs. Ceci explique pourquoi même ceux qui sont relativement riches peuvent choisir d'avoir des relations sexuelles sans préservatif. Si les conditions sont requises pour qu'il y ait des équilibres multiples dans une économie, alors l'équilibre où la prévalence du VIH/SIDA est le plus élevé pourrait être choisi en raison des croyances sur les modes de transmission du VIH/SIDA.

Mots clés : VIH/SIDA, capital humain, Afrique Sub-Saharienne.

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† Institut d'économie appliquée, HEC Montréal, 3000 Côte-Sainte-Catherine, Montréal, Québec, and CIRANO. Email: robert.clark@hec.ca.

‡ Corresponding author: Institut d'économie appliquée, HEC Montréal, 3000 Côte-Sainte-Catherine, Montréal, Québec, and CIRANO. Email: dv@hec.ca.

There is a strong negative relationship between economic development and HIV/AIDS prevalence throughout the world. However in Sub-Saharan Africa where the epidemic is worst, this relationship does not hold. Some of the wealthier countries in this region have some of the highest rates of HIV/AIDS prevalence in the world. In order to explain these observations, we set up a two-period model where individuals derive utility from consumption and sexual encounters. Those who expect their second-period consumption to be sufficiently low may engage in unsafe sex, despite the possibility of contracting HIV, if it provides higher instantaneous utility. We show that poorer countries will feature a higher share of the population engaging in unsafe sex, and therefore a higher prevalence of HIV. In economies where the external effect of human capital is high, additional equilibria exist in which even wealthier individuals choose unsafe sex if they expect a large share of the population to do so. This is because if many people engage in unsafe sex, there will be a lower level of aggregate human capital (due to AIDS deaths) and hence lower second-period income, and consumption. Economies featuring multiple equilibria may select one in which a large fraction of the population is engaged in unsafe sex because of beliefs about the transmission of HIV/AIDS.

Keywords: *HIV/AIDS, human-capital externalities, Sub Saharan Africa.*

Codes JEL : I10, I18, O10

1 Introduction

The HIV/AIDS epidemic has reached staggering proportions. At the end of 2002, 42 million adults and children were living with HIV/AIDS in the world (UNAIDS 2002). Using data from a worldwide sample of countries we find that there exists a strong relationship between HIV/AIDS prevalence and poverty. Table 1 shows for the full sample of countries a negative and significant relationship between per capita GDP and HIV prevalence. An amazing 29.4 million of those infected live in Sub-Saharan Africa. However, for these countries the negative relationship between per capita GDP and HIV prevalence does not hold. Some of the wealthier countries in this region (South Africa, Botswana) have among of the highest rates of HIV/AIDS prevalence in the world.[1] Understanding the relationship between poverty and HIV/AIDS prevalence is of critical importance for determining proper HIV prevention policy.

In this paper we develop a two-period model to explain the observed relationships between economic development and HIV prevalence throughout the world and in Sub-Saharan Africa. Our goal is to explain how poverty and the nature of the production technology combine to differentiate countries in terms of HIV/AIDS prevalence. In our model individuals derive utility from consumption and sexual encounters. Taking into account the fraction of the population they expect to engage in unsafe sex, individuals must decide whether their first-period sexual encounter should involve the use of a condom or not. Those who do not use a condom may contract HIV and not survive into the second period. We start from the premise that there is a disutility from using a condom (Agha, Kusanthan, Longfield, Klein and Berman 2002, Rao, Gupta, Lokshin and Jana 2003). As a result, some individuals willingly trade-off future utility for the current utility gain from unsafe sex. In our model, the willingness of individuals to engage in this trade-off is decreasing

[1]The sad reality is well summarized by The Economist in its February 19th 2002 issue: "Although little Botswana and Zimbabwe probably have a higher rate of [HIV] infection, South Africa, with more than 40m people, has the biggest problem anywhere. A quarter of pregnant women are found to be infected. In some provinces, such as Kwa-Zulu-Natal, over a third of them have HIV. A report by the Medical Research Council last year found that between 4m and 7m people will die of the disease within a decade. [...] Because of it [AIDS] life expectancy is plummeting towards 40 years, and an estimated 2m children will be orphaned by AIDS within a decade."

in their income. In other words, living conditions for the poor are at times sufficiently unrewarding that individuals might choose current enjoyment over future utility.[2]

The expected share of the population choosing unsafe sex generates conflicting effects. On the one hand, the more people having unsafe sex, the more likely an individual is to contract HIV and so individuals are more likely to engage in safe sex–we refer to this as the *survival* effect. Individuals will be more likely to protect themselves for fear of contracting HIV/AIDS. And, since willingness to engage in unsafe behaviour is inversely related to income, if this were the lone effect, only very poor individuals would opt for unsafe sex. On the other hand, an individual may be more likely to engage in unsafe sex if the production technology exhibits human-capital externalities. If an individual's income depends not just on his own human capital but on the aggregate level of human capital in the economy, an individual may be more likely to engage in unsafe sex if he expects a large fraction of the population to engage in unsafe sex. This will be referred to as the *income* effect. A large share of the population engaged in unsafe sex leads to a lower level of aggregate human capital (due to AIDS deaths) and hence lower second-period income, and consumption.

These effects provide an explanation for the observed relationships between poverty and HIV/AIDS. Depending on the importance of aggregate human capital for individual income, multiple equilibria may exist. If human-capital externalities are low (or non-existent), the *survival* effect dominates and there exists a unique equilibrium where only the poorest in a country engage in unsafe sex. In this case, the richer the economy, the smaller the share engaged in unsafe sex. If, however, human-capital externalities are high, there may be additional equilibria generated by the *income* effect in which even wealthy individuals opt for unsafe sex when they expect a low level of aggregate human capital in the economy But, this is only true up to a certain threshold level of national wealth, after which economies exhibit just one equilibrium–in which only the poorest in the population engage

[2] For example, a survey conducted by the World Bank in Ethiopia revealed the ten most common local terminologies of 'well-being' at a number of interview sites. These terminologies include: "we live only for today", "our livelihood is as useless as a piece of straw", and "life is like a terminal disease" (World-Bank 1999).

in unsafe sex. These economies are rich enough that the tension between the two effects disappears. The individuals at the upper end of the wealth distribution are sufficiently rich that even if a large share of the population chooses unsafe sex, the former will not since their initial wealth ensures them a high income regardless of the aggregate level of human capital in the economy– in other words, the *survival* effect dominates.

Essentially what we claim is that some of the countries in Sub-Saharan Africa are caught in a vicious cycle in which a large number of deaths due to AIDS leads to economic decline, and economic decline leads to greater willingness to engage HIV propagating behaviour. Husain and Badcock-Walters (2002) note that over the next 15 years 10% to 30% of the labour force will be lost in Southern Africa. They suggest that HIV/AIDS will "generate a new class of poor and push those who are already living at the margin closer to the edge". This is supported by Arndt and Lewis (2000, 2001) who use a computable general equilibrium approach to compare "AIDS" and "no-AIDS" scenarios and find that GDP per capita in South Africa falls by around 8% over the 1997-2010 simulation period. This effect combined with a fall in output and a decline in investment into certain sectors means that labour demand will fall.

Our results have policy implications for the fight against HIV/AIDS. Aid organizations have suggested that the relationship between poverty and HIV/AIDS prevalence can be explained by the fact that individuals in poorer countries have more limited access to condoms and are less-well informed about the disease, the manner in which it can be contracted and methods to prevent its spread (contraceptive use). Increased use of condoms and other contraceptive devices and lower HIV/AIDS prevalence could be achieved by improving the availability of condoms and by educating individuals in poorer countries.

We suggest that availability of condoms and knowledge of HIV/AIDS and the means by which it is transmitted are not sufficient conditions for safer sexual behavior in poorer countries. Survey evidence from a number of African nations suggests that many individuals in these countries are in fact aware of HIV/AIDS, the means by which it is transmitted and possible methods to prevent contraction. In a survey of a number of Sub-Sahara African nations by Population Services International, lack of availability was found not to be a barrier to condom use (Agha et al. (2002)). Surveys conducted in Ethiopia (USAID 2000) and South Africa (Booysen and Summerton 1990) revealed that, in each case, over ninety percent of those surveyed were aware of HIV/AIDS. Of these, over ninety percent knew of the sexual transmission routes of HIV/AIDS. Nonetheless, knowledge of HIV/AIDS and the benefits of safe sex is not being translated into behavioral changes: only 17% if those surveyed in Ethiopia claimed to have started to use condoms to help prevent the spread of HIV/AIDS and 76.3% of the individuals surveyed in South Africa admitted to having unsafe sex.[3]

Education about the existence and transmission routes of HIV/AIDS is a necessary tool for increased condom use and decreased HIV/AIDS prevalence. This paper shows that it may not, however, be a sufficient policy instrument. Reducing poverty, and income inequality, may be necessary to fight the spread of HIV/AIDS. As long as individuals are sufficiently poor that they are willing to take risks with their lives, condom use will not be widespread. This has implications for the nature of foreign aid policies and for wealth redistribution policies in poor countries. Some foreign-aid dollars in the fight against HIV might be more effective if targeted at reducing poverty. Income redistribution can help to raise the living standards of the poorest individuals to the point where they opt for safe rather than unsafe sex. In the absence of human-capital externalities redistribution would be difficult to implement since the wealthy have no incentive to transfer resources to the poor.[4] However, if the *income* effect dominates, it may be in the best interest of richer individuals to share their wealth.

[3]See also Renne (1993, Tables 1 and 2), who, in a study of a Nigerian village, reports that slightly less than half of married men with girlfriends ever use a condom although 95 percent of them knew of condoms and they are freely available in the village. In a study among youth in Kwa-Zulu Natal, South Africa, Varga (1997) finds that all subjects had heard of aids, knew that it is a deadly disease, and more that three quarters knew that using a condom provides good protection. However, no male used a condom regularly and only one female ever had sex with a condom!

[4]Unless, for instance, they can be convinced that a large number of AIDS orphans will generate a negative externality (Skordis and Nattrass 2002).

We also discuss the merits of a free antiretroviral drug plan. If human-capital externalities are low, such that the *survival* effect dominates, then providing the drug encourages more individuals to engage in unsafe sex since the probability that they will die is lower. If human-capital externalities are important, then the *income* effect counter-balances the survival effect. Since the probability of dying after contracting HIV is lower, the expected second period aggregate human capital increases. This increases second period expected income and therefore lifetime utility from safe sex. Hence, fewer individuals engage in unsafe sex. If the *income* effect dominates the *survival* effect, HIV prevalence is lower in an economy with a free antiretroviral drug plan than in one without such a plan.

The remainder of the paper is organized as follows. In the next section we examine HIV prevalence throughout the world and in Sub-Saharan Africa. We outline the model economy in section 3. We then define the equilibrium concept, prove existence and characterize equilibria in section 4. This section also compares the equilibrium share(s) of the population engaged in unsafe sex in economies that differ in terms of their level of economic development. Section 5 examines policy issues stemming from our model. We first look at how economies might select different equilibria in situations where more than one exists. We also examine how increased life expectancy can effect the rate of HIV prevalence. Finally, we discuss the benefits of providing the antiretroviral drug for free. Lastly, Section 6 concludes. All proofs, tables and figures are in the Appendix.

2 HIV/AIDS prevalence throughout the world

We are interested in the relationship between HIV prevalence and economic development throughout the world. We begin by distinguishing between three groups of countries: developed, intermediate and poor. Not only do these countries vary in terms of their wealth levels, but also in terms of the importance of human-capital externalities. As noted by Lucas (1990), the external effects of human capital must be higher in richer more developed countries than in poorer and less developed ones (since otherwise there should be huge inflows of capital into the latter). So poor countries such as Ethiopia and Haiti have relatively unimportant human-capital externalities, and these countries are also characterized by relatively high HIV prevalence (for Ethiopia and Haiti, around 6%). Developed economies are wealthy industrialized nations, for example OECD members. Despite the fact that human-capital externalities are very important, these countries have very low HIV prevalence (usually less than 1%). Intermediate countries are less wealthy than developed countries, however human-capital externalities are important since a large segment of their economies are industrialized. For instance in South Africa, where agriculture represents only 3% of gross domestic product, human-capital externalities are found to be very important (Michaud and Vencatachellum 2003). HIV prevalence in these countries ranges from the quite low (for example 0.28% in Mexico) to the very high (the rate in South Africa is 20.1%).

Examining Sub-Saharan Africa more closely, we see that countries in this region fall either into the poor or intermediate category. For instance, Ethiopia and the Democratic Republic of the Congo, where agriculture represents 52% and 56% of overall output and where GDP per capita is \$668 and \$765 respectively (purchasing power parity in 2000 \$US), must be considered poor. In these two countries the rates of HIV prevalence are 6.4% and 4.9% respectively. Contrast these with intermediate countries, such as South Africa and Botswana where industry and services represent at least 97% of output, GDP per capita is \$9,401 and \$7,480, and where the prevalence of HIV is 20.1% and 39% respectively. Table 1 shows that countries in Sub-Saharan Africa where agriculture represents a larger share of gross domestic product have a lower prevalence of HIV infection. So wealthier industrial and/or service based economies in this region may be characterized by very high rates of HIV infection.

3 The Model

We consider a two-period economy populated by a measure one of individuals. Each individual is endowed with w units of wealth drawn from the bounded support $[\underline{w}, \overline{w}]$ with cumulative density function Ψ. We assume that Ψ is strictly increasing and differentiable. Wealth cannot be consumed and must be used in the first period to generate human capital according to the function $h(w)$. Individuals have no access to capital markets, so human capital is increasing in the person's wealth (Bowles 1972).

In each period $t \in \{1, 2\}$, individuals earn an income, y_t, that is a function of their human capital and, in the spirit of Lucas (1988) , of the aggregate level of human capital in the economy in that period, φ_t.[5]

A. 1 (Income) *An agent's income is as follows:*

$$\begin{aligned} y_t &= y(h(w), \varphi_t) \\ &\equiv y(w, \varphi_t) \end{aligned} \tag{1}$$

for $t = 1, 2$, *and* y *is monotone increasing and differentiable in each of its arguments.*

Each individual has access to a technology which transforms one unit of income into one unit of a non-storable homogenous consumption good in each period.

Individuals engage in sexual encounters, denoted ξ, which can either be safe, $\xi = s$, or unsafe, $\xi = n$.[6] Unsafe sex reduces one's likelihood of surviving into the next period because of the likeli-

[5] Alternatively, one could assume an aggregate production function with human-capital externalities where agents are paid their marginal product. In this case y would simply denote an agent's wages.

[6] It is well documented that abstinence or condom use are the two means to avoid contracting HIV. We could allow sexual abstinence in the first period, but we assume that both protected and unprotected sex provide greater utility than abstinence. Moreover, the predominantly heterosexual mode of transmission in Sub Saharan Africa (e.g. Ramjee et al (2001)), means that people are becoming HIV positive because they do not use a condom. This is confirmed by Philipson and Posner (1995, Table 2 and Figure 1) who provide evidence of the "clear negative correlation between

hood of contracting HIV/AIDS. Since agents only live for two periods, the likelihood of surviving beyond the second period is zero. We let $f(\xi, x)$ denote the likelihood of surviving into the second period for an agent who chooses a sexual encounter ξ in the first when the fraction of the population having unsafe sex is x. Clearly a fully dynamic matching model is desirable for the study of the transmission of HIV throughout a population. In a dynamic model individuals would choose for each sexual match whether to protect themselves or not. For the sake of tractability, we capture these decisions with a single decision to engage in safe or unsafe sex. In a dynamic model, each unprotected encounter would come at some risk depending on the number of infected individuals in the population. We capture this by allowing the survival function to depend on the share of the population engaged in unsafe sex.[7] We make the following assumptions about the survival function:

A. 2 (Survival Function) *The second-period survival function is such that:*

a) $f(s, x) = \alpha < 1$ *for all* $x \in [0, 1]$.

b) $f(n, x) = g(x) < \alpha$ *for* $x \in]0, 1]$, *and* $g(0) = \alpha$.

c) g *is continuous and differentiable in* x, *with* $g' < 0$ *for all* x.

Assumption 2a means that even if an individual engages in safe sex, he has a probability of dying of $(1 - \alpha)$ which is independent of the population share engaging in unsafe sex. This assumption makes sense since there is more than one way to die, and HIV is not transmitted trough casual contact. However, one could argue that a large HIV-positive population share may have a negative impact on the life expectancy of the rest of the population through lower provision of services. We

condom access and HIV prevalence". Recent evidence from Uganda indicates that increased condom used is one important factor in explaining the decline in HIV incidence.

[7]The probability of contracting HIV from unsafe sex should also depend on the initial HIV prevalence. Since our model is static, we lack any heterogeneity across countries in the initial HIV prevalence. A fully dynamic *matching* model in which the probability of HIV contraction from unsafe sex evolves over time is the subject of ongoing research. However, such a dynamic model is unlikely to yield tractable analytical solutions because it falls in the class of dynamic games as in Breton, St-Amour and Vencatachellum (2003). For examples of economic models of the dynamic spread of infectious diseases see Auld (2003) and Geoffard and Philipson (1996).

abstract from such considerations here. Changes in α allow us to capture how variations in lifetime expectancy impact on the likelihood of having unsafe sex.

Assumption 2b means that someone who engages in unsafe sex has a lower probability of survival into the second period than someone who has safe sex. By engaging in unsafe sex, HIV can be contracted which shortens lifetime. Moreover, assumption 2c states that the probability that an individual who engages in unsafe sex survives into the second period is decreasing in the share of the population that engages in unsafe sex. This assumption is meant to capture the fact that the likelihood that one may be contaminated is increasing in the share of individuals who have unsafe sex. Note that this paper does not distinguish between HIV incidence (new infections) and prevalence (the stock) because agents live only for two periods, may be infected in the first and not survive in the second, and all die afterwards.

Given that unsafe sex is risky, a necessary condition for some individuals to engage in it in the first period, is that they derive greater utility from sex without a condom than sex with one. Otherwise, as remarked by Philipson and Posner (1993, p.31), if the price of condoms is sufficiently low, the "AIDS epidemic would be inexplicable in economic terms". Hence, in what follows we assume that the instantaneous utility from unsafe sex is greater than from safe sex. This occurs because of the increased pleasure that sex without a condom provides, or because of the opportunity cost of purchasing a condom, or for both reasons. As pointed out by Philipson and Posner (1993, Tables 1 and 2) the price of condoms relative to other goods may be negligible in developed countries, but this is not necessarily the case in poor countries. Moreover survey evidence from Agha et al. (2002), who interviewed individuals in eight Sub-Saharan Africa countries shows that the dislike of condoms is the number one reason cited for not wearing one during casual sexual encounters.[8]

[8]This same assumption is made in Levy (2002), and is informally discussed in Philipson and Posner (1995). Further evidence can be found in Bonda and Dover (1997) and in Rao et al. (2003) who use survey data from Calcutta to find that sex workers who always use condoms face income losses of at least 66 %. They attribute this lower income in part to the "inherent preference against condoms".

In the first period individuals derive utility from income (consumption) and a sexual encounter. For simplicity we assume that utility is separable:

A. 3 (Instantaneous utility) *An agent derives instantaneous utility* u *from a sexual encounter* $\xi \in \{s, n\}$ *and consumption* c*. The utility function* $u(\xi, c)$*, is monotone increasing and strictly concave in consumption, and separable:*

$$u(n, c) - u(s, c) \equiv \Delta \tag{2}$$

for all c*, and where* Δ *is a positive constant.*

We also make the following assumption:

A. 4 (Sex Technology) *An individual's sex technology completely depreciates at the end of the first period, so that, if they survive into the second period, they cannot derive any utility from a sexual encounter. In this case* ξ *is set equal to 0.*

While assumption 4 may be consistent with the fact that an individual sexual drive diminishes as he or she gets older, it is made purely for simplicity. Since there is some instantaneous utility benefit from unsafe sex and since everyone dies at the end of the second period regardless of the type of sex in which they have engaged, dropping assumption 4 would mean that everyone in the population would choose unsafe sex in the second period. This would increase everyone's second period utility but would not change the qualitative results of our model.

Finally, we make the following assumption:

A. 5 (Second-period Human Capital) *Individual human capital does not depreciate.*

It follows from A.5 that the second-period aggregate human capital is a function of first-period aggregate human capital. However, some fraction of first-period aggregate human capital does not 'survive' into the second period. So second-period aggregate human capital is also a function of the share of the population that survives into the second period, which is decreasing in the share of the population engaged in unsafe sex. Consequently, we can write φ_2 as:

$$\varphi_2 = \varphi(\varphi_1, x) \tag{3}$$

with $\varphi_{21} = \frac{\partial \varphi_2}{\partial \varphi_1} > 0$, and $\varphi_{2x} = \frac{\partial \varphi_2}{\partial x} < 0$. Therefore, making use of A.4, an individual endowed with w who survives into the second period enjoys utility $u(0, y_2(w, \varphi_2)) \equiv v(y_2)$, where v is the present value utility from consuming y_2 in the second period.

We can now calculate the benefits that an agent of wealth w derives from safe sex as the difference between the lifetime utility from safe and unsafe sex. The net benefits from safe sex depend on the fraction of the population engaged in unsafe sex, which means that there exists an interdependence of individuals' decisions of what type of sex to engage in. Each individual has to form expectations about others' behavior when deciding between safe and unsafe sex. To be precise, the benefits from safe sex depend on expectations about the fraction of the population engaged in unsafe sex, x^e. Using (2) the benefits from safe sex of an individual endowed with wealth w, when his expectations are that a share x^e of the population has unsafe sex, equals:

$$B(w, x^e) = -\Delta + [\alpha - g(x^e)]v(y_2(w, \varphi_2)) \tag{4}$$

where φ_2 is as in (3). An individual w who predicts that the realized share of the population engaging in unsafe sex will be x^e, will choose safe sex if and only if $B(w, x^e) > 0$.

4 Equilibrium Analysis

In this section we determine the equilibrium share of individuals who engage in unsafe sex. We first show that if everyone expects everyone else to engage in safe sex, then the benefits function is negative for everyone regardless of their wealth level. In other words, there is no equilibrium in which everyone in the population engages in unsafe sex. We then define the equilibrium concept and establish that there always exists an equilibrium.

4.1 Indifferent individual

Lemma 1 (Safe Sex Expectations) *If individuals derive greater instantaneous utility from unsafe sex than from safe sex, the benefits function (4) is negative for everyone when the expectations are that everyone has safe sex.*

Lemma 1 is a direct consequence of (i) positive instantaneous utility benefits from unsafe sex, and (ii) the absence of any costs if the expectations are that no one has unsafe sex.

Next we consider expectations $x^e \in (0, 1]$ and note that for a given x^e, the benefits function from safe sex (4) is increasing in the wealth level (w). Since the functions u and v are monotone increasing, it follows that B is a monotone increasing function in w. The benefits function (4) is negative for a wealth level which equals 0, and there exists a sufficiently high wealth level, not necessarily in the economy's wealth support, for which the function is positive. Therefore, there exists some wealth level w^* such that $B(w^*, x^e) = 0$. Nothing guarantees that w^* is in the wealth support $[\underline{w}, \overline{w}]$ which characterizes the economy. If and only if this is the case does there exist a cut-off individual with wealth level w^* such that those with wealth levels below w^* opt for unsafe sex and those above w^* choose to have safe sex.

We first investigate how the cut-off agent varies with the expected share of individuals who engage in unsafe sex. This allows us to calculate the population-share which chooses unsafe sex. Equating (4) to 0 and differentiate with respect to x^e and w we obtain B_{x^e} and B_w.[9] The implicit function theorem holds as (i) B_{x^e} and B_w are continuous because and u and g are continuous functions by assumption, and (ii) $B_w \neq 0$ as $g(x^e) < \alpha$ for all $x \in (0, 1]$. Therefore, there exists a unique continuous differentiable function $w^*(x^e)$ that solves $B(w^*(x^e), x^e) = 0$ for all $x^e \in (0, 1]$. Note that there is no need to investigate the existence of a cut-off agent when $x^e = 0$ as a result of Lemma 1.

4.2 Existence of equilibrium

In line with the literature on strategic complementarities (Katz and Shapiro 1985), we assume that agents have identical expectations on the share of individuals having unsafe sex. In equilibrium these expectations are fulfilled. In other words, in equilibrium the share of the population engaged in unsafe sex must be equal to the measure of agents with wealth levels below the agent who is indifferent between safe and unsafe sex:

Definition 1 (Equilibrium) *An unsafe-sex equilibrium is a realized share x of the population engaged in unsafe sex such that individuals' expectations are fulfilled* ($x = x^e$), *their decisions are optimal, and the realized unsafe sex rate solves*

$$x = \Psi(w^*(x)) \tag{5}$$

Hence, the equilibrium share(s) of individuals who have unsafe sex is (are) the fixed point solution(s) to (5).

[9] See (9) and (10) in the appendix for the explicit expressions for B_{x^e} and B_w respectively.

Proposition 1 (Existence) *There always exists an equilibrium.*

Depending on the fundamentals of the economy, the fixed point problem (5) can have multiple solutions. In particular, in order to characterize equilibria we must consider the 'shape' of $\Psi(w(x))$. Since Ψ is monotone increasing in w, we determine the properties of $w^*(x)$.

Lemma 2 (Properties of $w^*(x)$) *If human-capital externalities are sufficiently high (low), $w^*(x)$ is convex (non-increasing) in x, and so is $\Psi(w^*(x))$.*

The formal conditions for 'sufficiently' high and 'sufficiently' low human-capital externalities are given in the appendix. If human-capital externalities are low, then the *survival* effect dominates. The cost of having unsafe sex is increasing in x and so as x increases, the wealth level of the indifferent agent falls. If human-capital externalities are sufficiently high, then if enough people are having unsafe sex, the *income* effect is stronger. So the cost of having unsafe sex is decreasing in x and even wealthier individuals may now choose unsafe sex.

Now we characterize the equilibria. We make use of Lemma 2 to establish when the equilibrium is unique and interior.

Proposition 2 (Unique Interior Equilibrium) *There exists a unique unsafe-sex equilibrium if the economy is sufficiently rich relative to the level of human-capital externalities.*

There exists a unique and interior unsafe sex equilibrium if there is some measure of individuals that benefit from safe sex even if they expect everyone else to engage in unsafe sex. Two related factors are at play: (i) the richest individuals' wealth and (ii) how their wealth is affected by aggregate human capital. If there are very high human-capital externalities, even wealthier individuals are likely to suffer from an important *income* effect when many people are HIV positive. Hence, their wealth must be sufficiently high for them to choose safe sex even though they expect a low second-period income.[10] This condition is likely to be met by industrialized countries but not by all middle-income ones. If there are low, or no, human-capital externalities, the *income* effect is weaker than in the previous case. Those at the upper end of the wealth distribution, while still having to be sufficiently wealthy, do not have to be as wealthy as in the economy with high externalities to choose safe sex.

It follows that if the economy is sufficiently rich relative to the level of human-capital externalities, $\Psi(w^*(x))$ intersects the 45 degree line at a unique and interior point (see Figure 1). Below this point are relatively poor people who engage in unsafe sex and above it are the relatively wealthy individuals who opt for safe sex. Given that $w^*(x)$ is non-increasing for low human-capital externalities, it is straightforward that the equilibrium is unique if there are no human-capital externalities.

Proposition 3 (Multiple equilibria) *If human-capital externalities are sufficiently high and the economy is not too rich, there exist multiple equilibria.*

If the human-capital externalities effect is sufficiently high, then the *income* effect on a relatively rich individual when many people choose unsafe sex is strong. This individual has a lower opportunity cost of unsafe sex, and so even rich individuals may be enticed into unsafe sex. In this case multiple equilibria may exist as illustrated in Figure 1. If individuals believe many others are engaging in unsafe sex, they will be more likely to choose unsafe sex–this is a *high unsafe sex equilibrium.* If individuals believe few others are engaging in unsafe sex, then they will more likely engage in safe sex–this is a *low unsafe sex equilibrium.*

[10]More formally, $\overline{w} > w^\dagger$, where $w^\dagger$ is given by (15) in the appendix.

4.3 Comparing equilibria

Proposition 4 (Poverty) *If human-capital externalities are low, richer economies have a lower HIV/AIDS prevalence. If human-capital externalities are high, richer countries may have a higher or lower HIV/AIDS prevalence.*

Consider an economy where there are no human-capital externalities. If everyone in the economy becomes wealthier, it follows that for every x^e their second-period expected utility increases. This increases the incentives to choose safe sex and in equilibrium a larger share of individuals do so (see Figure 1). It follows that in equilibrium a smaller share of the population engages in unsafe sex in the rich economy (x_r) than in the poor (x_p) economy.

Next consider an economy in which human-capital externalities are important and that is not too wealthy (Proposition 3). This economy will have multiple interior equilibria. Its *high unsafe sex equilibrium* could feature a larger share of the population engaged in unsafe sex than in the unique interior equilibrium of a poorer economy with low human-capital externalities. If we compare two economies in which human-capital externalities are important and that are not too wealthy such that each has multiple interior equilibria as illustrated in Figure 2, we see that the share of the population engaged in unsafe sex is higher in the rich economy's *high unsafe sex equilibrium* (x_r^h) than in the poor economy's (x_p^h) and the share of the population engaged in unsafe sex is lower in the rich economy's *low unsafe sex equilibrium* (x_r^l) than in the poor economy's (x_p^l),

Finally, consider two economies in which human-capital externalities are high. Suppose one of them is rich enough that there is a unique interior equilibrium while the other features multiple interior equilibria. The share of the population engaged in unsafe sex is lower in the richer economy's *low unsafe sex equilibrium* than in the poorer economy's.

It is also of interest to compare how the unsafe sex equilibrium varies with wealth inequality. Barnett and Whiteside (2002) conjecture that a highly unequal wealth distribution combined with a low social cohesion, such as in South Africa, could explain the rapid spread of HIV. Consider two economies where the wealth distribution in the first, denoted by the cumulated wealth distribution Ψ_{ε}, is more equal than in the second, Ψ_u. The following proposition compares the equilibria across those two economies and is illustrated in Figures 3 (no human-capital externalities) and 4 (with human-capital externalities).

Proposition 5 (Inequality) *Assume there are no human-capital externalities and denote the unsafe sex equilibrium in the unequal economy by x_u . If $\Psi_{\varepsilon}(w^*(x_u)) < \Psi_u(w^*(x_u))$, then, in equilibrium, fewer individuals have unsafe sex in the equal economy than in the unequal one. If there are human-capital externalities, a more unequal economy can select a higher or lower HIV/AIDS prevalence than an equal one.*

A lower unique equilibrium is generated in economies with no (or low) externalities because redistributing income from the rich to the poor induces fewer individuals to choose unprotected sex. However, for the same reason as in Proposition 4, when there are sufficiently high human-capital externalities, the comparison depends on which equilibrium is selected. To see this, assume that Proposition 3 holds and that both the equal and unequal economies generate two interior equilibria as illustrated in Figure 4.[11] If the more equal economy selects the high equilibrium x_{ε}^h and the unequal one selects the low equilibrium x_u^l, then HIV prevalence is higher in economies with lower wealth inequality. However, the more equal economy may select the low equilibrium, x_{ε}^l, while the unequal one selects the high equilibrium x_u^h.

In the next section we discuss policy issues that arise from these results. We first suggest possible explanations for why some countries end up at the high unsafe sex equilibrium while others do not. Then we examine the implications of greater life expectancy on HIV prevalence. Finally we discuss the merits of providing a free antiretroviral drug plan.

[11] We perform a mean preserving Dalton transfer as above to construct a new economy with a less unequal wealth distribution. The more equal economy will also generate two interior equilibria.

5 Policy Issues

Our model suggests that alleviating poverty may be important in the fight against HIV/AIDS, not just because poverty is correlated with a lack of education. Even if they are aware of the disease, understand how it is transmitted and have access to condoms, sufficiently poor individuals may opt for the utility gain provided by unprotected sex. So poor countries are at risk even if they educate their population about HIV transmission and provide access to condoms.

The existence of human-capital externalities can lead to even greater prevalence of HIV if economies are not sufficiently wealthy. Intermediate economies which are industrial or service-based could have very high HIV prevalence depending on which equilibrium is selected. Why do some intermediate economies (in particular in Southern Africa) end up with very high rates of HIV, while others (for example Mexico) do not?

5.1 Equilibrium Selection

While we do not model equilibrium selection in this paper, we can propose some potential explanations for the fact that some developing countries (in Sub-Saharan Africa in particular) select the high unsafe-sex equilibrium. These explanations include: religious views on the use of contraceptives, the stated opinion of the country's political leader on the means of transmission of the AIDS virus, the prevalence of witchcraft and beliefs about the effectiveness of unscientific cures for HIV/AIDS.

The rate of HIV prevalence in Kenya which stands at 15% may be attributed at least in part to the mixed messages voiced by public figures about the disease. For example, in August of 1996, the head of the Catholic church in Kenya, Cardinal Maurice Otunga, denounced sex education and set fire to a pile of condoms. Similarly, South African President Thabo Mbeki has repeatedly downplayed the HIV epidemic in his country and stated that HIV does not cause AIDS. Currently over 20% of South Africans have HIV. In many Sub-Saharan Africa countries, traditional healers are prescribing sexual intercourse with virgins as a cure for HIV leading to increases in the number of young women affected with the disease. While clearly other factors, which are not accounted for in our model (e.g. internal migration), are at play, beliefs coordination should be viewed as important for ending up at the low equilibrium.

5.2 Life Expectancy

Poor countries have a low life expectancy even in the absence of HIV. In our model, life expectancy is captured by the parameter α. *Ceteris paribus*, a higher α means the likelihood of surviving into the second period increases if one has safe sex but does not affect the likelihood of survival in the case of unsafe sex. Hence, the opportunity cost of unsafe sex increases. As a result, more people choose safe sex for every given expectation level x^e, and the function $\Psi(w(x))$ shifts downwards. If there are no human-capital externalities, an economy with a higher life expectancy selects a lower unique equilibrium than a poor one with a low life expectancy. In economies which exhibit two interior equilibria, a higher life expectancy may not necessarily imply a lower equilibrium because of the way that human-capital externalities affect incomes when expectations about x are high. However, if α increases enough, and the richest individual in the economy is sufficiently wealthy, then a unique lower equilibrium exists. Hence, incremental changes in lifetime expectancy may not reduce the HIV prevalence in some economies, while a single large change might.

5.3 A free antiretroviral drug plan

An important policy question is whether the antiretroviral drug should be made available to AIDS patients. Some countries (for instance Brazil) have chosen to make the drug freely available, while others (for instance South Africa) have refused to do so. There has been much debate about the efficiency and equity of such a policy since, if they are not free, most AIDS patients cannot afford the drug. Levy shows that providing the drug for free has an adverse effect on the containment of AIDS. He refers to this as the complacency assertion. Individuals are more likely to engage in unsafe sex since the risk is reduced. In what follows we construct an example in which a free antiretroviral drug plan can in fact reduce the spread of HIV/AIDS.

Consider a benchmark economy which verifies Proposition 3 and exhibits two equilibria: one interior and another one where everyone has unsafe sex. Assume this economy selects the high unsafe equilibrium. Moreover, let the probability of survival into the second period if one chooses safe sex equal 1 ($\alpha = 1$), assume a linear second-period utility function ($v(y_2) = y_2$), and a specialized AK production technology as in Barro, Mankiw and Sala-i-Martin (1995) given by:

$$y_2 = w\varphi_2(x) \tag{6}$$

Equation (6) imbeds the no human-capital externalities if $\varphi_2(x)$ equals a constant for all x. A free antiretroviral drug plan increases the likelihood of survival into the second period of those who have unsafe sex. Denoting the new survival rate function by $\tilde{g}$, and $\tilde{g}(1) \equiv \tilde{\gamma} > \gamma$.

Proposition 6 (Free Drug) *If the economy is sufficiently rich and*

$$\gamma < \tilde{\gamma} < 1 - \gamma, \tag{7}$$

a free antiretroviral drug plan leads the benchmark economy to select a lower unsafe sex equilibrium than the current one.

An increase in the likelihood of survival has two opposite effects as γ increases. First, *ceteris paribus*, the utility cost of having safe sex decreases because the likelihood of survival increases with the AIDS drug. Hence more people are drawn into unsafe sex. Second, as γ increases, the second-period human capital increases, and consequently, second period income increases. Therefore the benefit of being alive in the second period increases and fewer individuals are drawn into unsafe sex. Condition (7) states that the increase in the likelihood of survival when having unsafe sex must not be too high otherwise the negative effect dominates.[12]

Finally, a corollary of (7) is that the introduction of a free AIDS drug plan in the absence of human-capital externalities always increases the share of the population having unsafe sex. In such an economy there is no *income* effect. The benefits of unsafe sex increase but the cost remains unchanged. Hence in equilibrium more people have unsafe sex.

6 Conclusion

This paper investigates the link between economic development and HIV/AIDS prevalence. There are two crucial elements in our analysis. First, for there to be some economic explanation for the HIV/AIDS epidemic, agents must derive some instantaneous utility benefit from sex without a condom. Second, the share of the population engaging in unsafe sex has conflicting effects on individual willingness to have unsafe sex. On the one hand, as the share of individuals having unsafe sex increases, an agent has a greater incentive to protect himself because of the increased riskiness from unsafe sex–the *survival* effect. On the other hand, when a large share of the population is engaged in unsafe sex, next-period aggregate human capital may be reduced. If individual incomes depend on aggregate human capital, even richer individuals' incomes may be sufficiently lowered that they opt for the utility gain from unsafe sex–the *income* effect.

We show that in economies which use technologies where human-capital externalities do not matter, there exists a unique equilibrium. We then derive conditions under which, when there are human-capital externalities, multiple unsafe sex equilibria arise. There are a number of important

[12] A necessary condition for (7) is that $\gamma < 1/2$. In this example, we assume the economy is sufficiently rich to generate a unique equilibrium under the free drug plan. This assumption makes equilibria comparison easier. We also abstract from how HIV prevalence rate varies if individuals anticipate whether the antiretroviral drug will be made available. Auld (2003) shows that if the release of a prophylactic vaccine was announced beforehand "infections rise in the period in which the vaccine was released if the release was anticipated, and fall otherwise".

policy implications stemming from these results. The first is that if there are no human-capital externalities, richer countries should have a lower prevalence of HIV/AIDS. However, in the presence of human-capital externalities, richer countries may have a higher HIV/AIDS prevalence than poorer ones as observed in Sub Saharan Africa. If economies are sufficiently rich, then they exhibit a unique equilibrium with low HIV/AIDS prevalence. We therefore argue that incremental development may not always be effective in reducing HIV/AIDS prevalence. However, if these countries can be made sufficiently wealthy, only a very small share of their population will engage in unsafe sex and so HIV/AIDS prevalence should be reduced.

Similarly, our results for wealth inequality depend on the nature of the production technology. If human-capital externalities are sufficiently low, for instance in agrarian economies, then income redistribution reduces HIV/AIDS prevalence. The opportunity cost of unsafe sex increases for the individuals at the bottom of the wealth distribution who benefit from the income redistribution. Hence, more individuals choose safe sex. However, when there are human-capital externalities, multiple externalities may arise. In this case a cross-country comparison depends on which equilibrium is selected.

The fact that some relatively rich countries may select a high HIV/AIDS equilibrium poses an important beliefs coordination problem for some developing countries. Unless an economy can transition to a point where it is sufficiently wealthy, moving from an agrarian to an industrial/service-based economy could lead to a high unsafe-sex equilibrium and a larger fraction of the population engaged in unsafe sex. In other words, economic development is not sufficient in some cases to ensure a low HIV/AIDS prevalence. Selecting a low unsafe sex equilibrium is crucial. This can be accomplished by using education to properly coordinate beliefs.

Future work should set up a fully dynamic model with matching and side payments to investigate policies which can affect the dynamics of the system. Such an analysis would fall in the class of dynamic games as in Breton et al. (2003) and would require the use of numerical solutions. We plan to pursue this avenue in future research.

References

Agha, Sohail, Thankian Kusanthan, Kim Longfield, Megan Klein, and John Berman (2002) 'Reasons for non-use of condoms in eight countries in Sub-Saharan Africa.' Working Paper 49, Population Service International, Washington D.C., October

Arndt, C., and J. D. Lewis (2000) 'The macro implications of HIV/AIDS in South Africa: A preliminary assessment.' *South African Journal of Economics* 68(5), 856–87

— (2001) 'The HIV/AIDS pandemic in South Africa: Sectoral impacts and unemployment.' *Journal of International Development* 13(4), 427–449

Auld, M. Christopher (2003) 'Choices, beliefs, and infectious disease dynamics.' *Journal of Health Economics* 22, 361–377

Barnett, Tony, and Alan Whiteside (2002) *AIDS in the Twenty-First Century. Disease and Globalization* (New York, N.Y.: Palgrave Macmillan)

Barro, Robert, Gregory Mankiw, and Xavier Sala-i-Martin (1995) 'Capital mobility in neoclassical models of growth.' *American Economic Review* 85(1), 103–15

Bonda, Virginia, and Paul Dover (1997) 'Men, women and the trouble with condoms: problems associated with condom use by migrant workers in rural zambia.' *Health Transition Review* 7(Supplement), 377–391

Booysen, F., and J. Summerton (1990) 'HIV/AIDS, poverty and risky sexual behavior: Evidence from South Africa.' University of the Free State, South Africa

Bowles, Samuel (1972) 'Investment in education: The equity-efficiency quandary.' *Journal of Political Economy* 80(2), S219–S251

Breton, Michèle, Pascal St-Amour, and D. Vencatachellum (2003) 'Dynamic production teams with strategic behavior.' *Journal of Economc Dynamics and Control* 27(5), 875–905

Checchi, Daniele (2000) 'Does educational achievement help to explain income inequality?' Working Paper 208, World Institute for Development Research

Geoffard, Pierre-Yves, and Tomas Philipson (1996) 'Rational epidemics and their public control.' *International Economic Review* 37(3), 603–624

Husain, Ishrat Z., and Petr Badcock-Walters (2002) 'Economics of HIV/AIDS impact mitigation: Responding to problems of systemic dysfunction and sectoral capacity.' United States Agency for International Development

Katz, Michael L., and Carl Shapiro (1985) 'Network externalities, competition, and compatibility.' *American Economic Review* 75(3), 424–440

Levy, Amnon (2002) 'A lifetime portfolio of risky and risk-free sexual.' *Journal of Health Economics* 21, 993–1007

Lucas, Jr. Robert E. (1988) 'On the mechanics of economic development.' *Journal of Monetary Economics* 22(1), 3–42

— (1990) 'Why doesn't capital flow from rich to poor countries.' *American Economic Review* 80(2), 92–96

Michaud, Pierre-Carl, and Désiré Vencatachellum (2003) 'Human capital externalities in South Africa.' *Economic Development and Cultural Change.* Forthcoming

Philipson, Thomas, and Richard A. Posner (1993) *Private Choices and Public Health: the AIDS Epidemic in an Economic Perspective* (Cambridge: Harvard University Press)

— (1995) 'The microeconomics of the aids epidemic in Africa.' *Population and Development Review* 21(4), 835–848

Ramjee, Gita, Eleanor Gouws, Amy Andrews, Landon Myer, and Amy E. Weber (2001) 'The acceptability of a vaginal microbicide among South African men.' *International Family Planning Perspectives* 27(4), 164–170

Rao, Vijayendra, Indrani Gupta, Michael Lokshin, and Smarajit Jana (2003) 'Sex workers and the cost of safe sex: The compensating differential for condom use in calcutta.' *Journal of Development Economics.* Forthcoming

Ray, Debraj (1998) *Development Economics* (Princeton, New Jersey: Princeton University Press)

Renne, Elisha P. (1993) 'Condom use and the popular press in Nigeria.' *Health Transition Review* 3(1), 41–56

Skordis, Jolene, and Nicoli Nattrass (2002) 'Paying to waste lives: the affordability of reducing mother-to-child transmission of HIV in South Africa.' *Journal of Health Economics* 21(21), 495–421

UNAIDS (2002) 'Report on the global HIV/AIDS epidemic.' Geneva, Switzerland

United Nations Development Programme (2002) 'Human development report 2002.' Oxford University Press 198 Madison Avenue, New York, New York, 10016

USAID (2000) 'Community and personal perception of risk and vulnerablity to HIV infection and AIDS.' United Management Consultants, USAID Polity Project Ethiopia

Varga, Christine A. (1997) 'Sexual decision-making and negotiation in the midst of AIDS: youth in KwaZulu-Natal South Africa,.' *South Africa* 7(Supplement 3), 45–67

World-Bank (1999) 'Consultations with the poor. national synthesis reports.' National Report Washington D.C.

7 Appendix

7.1 Proof of Lemma 1

If $x^e = 0$, then by assumption 2,

$$\alpha - g(0) = \alpha - \alpha = 0. \tag{8}$$

Substituting (8) in (4), we obtain that for all w, $B(w, 0) = -\Delta < 0$.

7.2 Proof of Proposition 1

Differentiate (4) with respect to x^e and w respectively gives:

$$B_{x^e} = v' y_{2\varphi} \varphi_{2x^e} [\alpha - g(x^e)] - vg', \tag{9}$$

$$B_w = [\alpha - g(x^e)] v' y_{2w}. \tag{10}$$

First, as $B_w \neq 0$ for all $x \in (0, 1]$ and both derivatives are continuous, the implicit theorem holds and there exists a function $w^*(x)$ such that $B(w^*(x), x) = 0$. Since the functions u, v and g are by assumption continuous, it follows that the implicit function $w^*(x)$ is also continuous. Second, by Lemma 1, if x equals to 0, then all individuals choose unsafe sex. Since (i) $[0, 1]$ is by definition non empty, compact and convex, (ii) $\Psi : [0, 1] \longrightarrow [0, 1]$, and (iii) Ψ is continuous, we can appeal to Brouwer's fixed point theorem which guarantees a solution to (5).

7.3 Proof of Lemma 2

We formally derive the explicit conditions for $w^*(x)$ to be convex. Equate (4) to 0 and differentiate totally to get:

$$\frac{d\mathsf{w}^*}{d\mathsf{x}^e} = \frac{-B_{\mathsf{x}^e}}{B_{\mathsf{w}}}, \tag{11}$$

where B_{x^e} and B_w are given by (9) and (10) respectively. By assumption 2a, $\alpha > g(x)$ for all $x \in (0,1]$, and hence from (10), $B_{\mathsf{w}} > 0$ for $x \in (0,1]$. Therefore, (11) is of the same sign as $-B_{\mathsf{x}^e}$.

First we establish that $w^*(x)$ is downward sloping when x tends to 0.[13] Using (9), then

$$\lim_{\mathsf{x}^e \longrightarrow 0+} B_{\mathsf{x}^e}(\mathsf{w}, 0) \quad = \quad \lim_{x^e \longrightarrow 0+} v' y_{2\varphi} \varphi_{2x^e}[\alpha - g(\mathsf{x}^e)] - \lim_{x^e \longrightarrow 0+} v(y_2) g'(\mathsf{x}^e) \tag{12}$$

Aslim$_{x^e \longrightarrow 0+} v(y_2(\mathsf{w}, \varphi(\varphi, \mathsf{x}^e))) > 0$, as $v \in \Re_+$; $\lim_{x^e \longrightarrow 0+}[\alpha - g(\mathsf{x}^e)] = 0$ by assumption 2b, and $\lim_{x^e \longrightarrow 0+} g'(\mathsf{x}^e) < 0$ by assumption 2c, it follows that (12) is negative. Given that B_w is unambiguously positive, using (11) we conclude that:

$$\lim_{\mathsf{x}^e \longrightarrow 0+} \frac{dw^*}{dx} < 0 \tag{13}$$

Second we derive a sufficient condition for $w^*(x)$ to be increasing when $x = 1$. Evaluating (9) at $x = 1$, we obtain that $B_x(w, 1) > 0$ if:

$$v' y_{2\varphi} \varphi_{2x}[\alpha - \gamma] < v g_x. \tag{14}$$

where $\gamma \equiv g(1)$. Hence, (14) guarantees that $\frac{dw^*(1)}{dx^e} > 0$.

Putting (13) and (14) together, imply that $w^*(x)$ reaches a minimum at $\widetilde{x} \in (0,1]$ and is convex. Intuitively, there are at least three ways to rationalize why (14) is sufficient and necessary for $w^*(x)$ to be convex. First, when x equals 1, if the marginal utility from consumption (v') and the marginal effect of unsafe sex on aggregate human capital (φ_{2x}) are not equal to 0, and g_x is finite, then condition (14) holds if $y_{2\varphi}$ tends to infinity when it is evaluated at $x = 1$. In other words, (14) is more likely the larger the marginal effect of human-capital externalities on income. Even the richest individual anticipates an important income loss as x^e is close to 1 such that the opportunity

[13] Note that we cannot evaluate B_{x^e} at $x^e = 0$ because of Lemma 1.

cost of unsafe sex becomes small. Second, (14) also holds as φ_{2x} tends to minus infinity. This means that the marginal effect of the share of the population engaged in unsafe sex on aggregate human capital accumulation is very large. Third, a sufficient condition for (14) to hold is for $g_x(1) = 0$. In other words, if the likelihood of not surviving into the second period is constant when everyone in the population engages in unsafe sex, then the condition holds and $-B_x > 0$. Note that (16) is violated if (14) does not hold because the right hand side of condition (16) is positive for $x \in (0, 1]$.

7.4 Proof of Proposition 2

We first compute the threshold wealth for which an agent is indifferent between safe and unsafe sex when $x^e = 1$. Next we investigate how it varies with human-capital externalities. We then consider how the unsafe sex equilibrium varies with the extent of human-capital externalities and the economy's wealth.

Threshold wealth Equate (4) to 0 when it is evaluated at $w^\dagger$ and $x^e = 1$, and simplify to obtain:

$$w^\dagger = \tilde{v}^{-1}\left[\frac{\Delta}{\alpha - \gamma}\right], \tag{15}$$

where $\gamma \equiv g(1)$, and $v\left[y_2(w^\dagger, \varphi_1\gamma)\right] \equiv \tilde{v}(w^\dagger)$. We now investigate how, $w^\dagger$ changes with human-capital externalities increase. On the one hand, if $x^e = 1$, the negative impact y_2 is greater the higher the human-capital externalities. On the other hand $\Delta/(\alpha - \gamma)$ is independent of human-capital externalities. Consequently, as v is a monotone increasing function, using (15) we can conclude that $w^\dagger$ increases with the extent of human-capital externalities. Note that from (15), $w^\dagger$ is decreasing in α and increasing in γ and Δ.

Extent of human-capital externalities We consider two cases:

i) No human-capital externalities.

By definition, $y_{2\varphi} = 0$ if there are no human-capital externalities while $g_x > 0$. Therefore (14) is violated and $w^*(x)$ is decreasing for all $x \in (0, 1]$. From Lemma 1 for there to exist an indifferent agent who is in the wealth support it is necessary that at least $B(\overline{w}, 1) \geq 0$. Otherwise, if $w^*(x) \ni [\underline{w}, \overline{w}]$ for all $x \in [0, 1]$ then we have a unique corner equilibrium $x^* = 1$. Now assume $\overline{w} > w^\dagger$. Therefore there exists an $\hat{x}$ such that $B(\hat{x}, \overline{w}) = 0$. Hence, $\Psi(w(x)) = 1$ for all $x < \hat{x}$, while $w^*(x)$ and $\Psi(w^*(x)$ are decreasing for $x \in (\hat{x}, 1]$. As $\Psi(\cdot) \in [0, 1]$, there exists a unique $x^* \in (\hat{x}, 1)$ such that $x^* = \Psi(w^*(x^*))$. Hence the equilibrium is unique and interior if $w(x)$ is non-increasing (no human-capital externalities) and $\overline{w} > w^\dagger$.

ii) Human-capital externalities.

If (14) holds, $w(x)$ is monotone increasing for $x \in (\tilde{x}, 1]$. Assume there exists an $\tilde{x} \in (0, 1]$ such that $\Psi(w^*(\tilde{x})) < \tilde{x}$ then there exists at least one equilibrium.

(a) If the slope of $w(x)$ is less than 1 at $x = 1$, then by monotonicity, its slope is less than 1 for all $x \in (\tilde{x}, 1]$. Using (9) and (10) to evaluate dw/dx at $x = 1$, and rearranging terms, $w^*(x)$ has a slope which is smaller than 1 if and only if:

$$vg_x - v' y_{2\varphi} \varphi_{2x} (\alpha - \gamma) < (\alpha - \gamma) v' y_{2w} \tag{16}$$

where all functions are evaluated at 1. If (16) holds, $\Psi(w^*(\widetilde{x})) < \widetilde{x}$, $\Psi(w^*(x)$ does not cross the 45-degree line a second time and the equilibrium is unique and interior. We say that human-capital externalities are sufficiently low if (16) holds.

(b) Similarly, if (14) holds, (16) does not, $\Psi(w(\widetilde{x})) < \tilde{x}$ and $\overline{w} > w^\dagger$, the equilibrium is unique and interior. However, following our above discussion, if (14) holds but (16) does not, human-capital externalities must be quite high. Hence the wealth of the richest individual must be greater than when there are no or low human-capital externalities.

7.5 Proof of Proposition 3

A necessary condition for multiple equilibria is that $\Psi(w(x))$ is convex, i.e. (14) holds. Let $\tilde{x} = \arg\min w^*(x)$, and define $\widetilde{w} = w(\widetilde{x})$. $\Psi(w(x))$ is decreasing in x over $[\underline{w}, \widetilde{w})$, and increasing in x over $(\widetilde{w}, \overline{w}]$. So if $\Psi(w(x))$ is convex, then, $\tilde{x}$, human-capital externalities, and the economy's wealth, combine to generate multiple equilibria.

Assume (14) holds, (16) does not, and $\Psi(w(\tilde{x})) \leq \tilde{x}$. Then there are two possible cases:

i) three equilibria if $\overline{w} < w^\dagger$: two interior equilibria and one equilibrium where everyone chooses unsafe sex. If the richest individual is poorer than $w^\dagger$ then $B(\overline{w}, 1) < 0$. Therefore, there exists some expectations level $\hat{x} < 1$ such that $B(\overline{w}, \hat{x}) = 0$. Finally that $\Psi(w^*(\tilde{x})) \leq \tilde{x}$ completes the proof.

ii) two equilibria if $\overline{w} = w^\dagger$: one interior and one where everyone chooses unsafe sex. This follows directly from i) and noting that if $\overline{w} = w^\dagger$ then $B(\overline{w}, 1) = 0$.

Hence, by not 'too' rich economies we mean that $\overline{w} \leq w^\dagger$, and if (14) holds while (16) does not, capture 'sufficiently' high human-capital externalities.

7.6 Proof of Proposition 4

First, consider a situation in which human-capital externalities are not important and where $B(\overline{w}, 1) > 0$. Hence there is a unique interior equilibrium. Suppose there are two economies; a poor one, denoted p, and a rich one, denoted r, characterized by Ψ_p and Ψ_r respectively. Assume that Ψ_r first order stochastically dominates Ψ_p and both use the same technology. Then Ψ_r shifts the distribution of individuals to the right. For $x \in (0, 1]$ and for a given $w^*(x)$, $\Psi_r(w^*(x)) < \Psi_p(w^*(x))$ as illustrated in Figure 1. This implies that, if human-capital externalities are low and a positive measure of individuals are rich enough to benefit from safe sex when $x^e = 1$, richer economies have a smaller share of their population engaged in unsafe sex.

Next consider a situation in which human-capital externalities are sufficiently high such that there are multiple equilibria. Just as when there are no human-capital externalities, and as illustrated in Figure 2, $\Psi_r(w^*(x)) < \Psi_p(w^*(x))$ for all $x \in [0, 1]$. However, each economy generates three equilibria and all depends on which equilibrium is selected.

7.7 Proof of Proposition 5

We first consider an economy where there are no human-capital externalities. Let the unequal economy be characterized by the wealth distribution Ψ_u with support $[w_u, w^u]$, and assume $w^u > w^\dagger$, where $w^\dagger$ is given by (15). In this case, by Proposition 2 there exists a unique interior equilibrium denoted by x_u in Figure 3. Moreover, from (4) there exists a $\hat{x}_u \in (0, 1)$ such that $B(w^u, \hat{x}_u) = 0$.

The equal economy, is constructed by a mean-preserving Dalton transfers from Ψ_u (see Ray (1998)). It is characterized by the wealth distribution Ψ_ε with wealth support $[w_\varepsilon, w^\varepsilon]$.

i) Given that $w^\varepsilon = w^u - a$, with $a \in \Re_+$, and $B_w > 0$, it follows that $B(w^\varepsilon, \hat{x}_u) < 0$ and therefore $\Psi_\varepsilon(w(\hat{x}_u)) = 1$. Hence, there exists another $\hat{x}_\varepsilon > \hat{x}_u$ such that $B(w^u, \hat{x}_\varepsilon) = 0$.

ii) As the poorest individuals in the equal economy benefit from the wealth redistribution, some become rich enough to choose safe sex. Hence, when $x^e = 1$, $\Psi_\varepsilon(w^*(1)) < \Psi_u(w^*(1))$.

Using *i)* and *ii)*, and assuming that $\Psi_\varepsilon(w^*(x_u)) < \Psi_u(w^*(x_u))$ implies that the share of individuals who choose unsafe is as illustrated in Figure 3. By monotonicity of w^* and the cumulative wealth distribution, the equilibrium population-share who has unprotected sex is smaller in the equal than in the unequal economy.

Second, consider an unequal economy where there are human-capital externalities and which exhibits three equilibria. In the same manner as above, we can construct an equal economy from the unequal one. Given the Dalton sequence of transfers, the new economy also generates three equilibria as illustrated in Figure 4. The comparison across the two economies depends on which equilibrium is selected.

7.8 Proof of Proposition 6

If everyone has unsafe sex, then, by the law of large numbers, the share of individuals who survive in the second period equals $g(1) \equiv \gamma$. Consequently, $\varphi_2 = \gamma\varphi_1$. We implicitly assume that HIV infection is purely random among those who have unsafe sex. Making use of (6) in (15), the richest individual in the economy who is indifferent between safe and unsafe sex has a wealth endowment:

$$w_0^{\dagger} = \frac{\Delta}{(1-\gamma)\gamma\varphi_1}. \tag{17}$$

It follows that the new richest individual who is indifferent between safe and unsafe sex if the antiretroviral drug is freely available is given by:

$$\tilde{w}_0^{\dagger} = \frac{\Delta}{(1-\tilde{\gamma})\tilde{\gamma}\varphi_1}. \tag{18}$$

Using (17) and (18), $w_0^{\dagger} > \tilde{w}_0^{\dagger}$ if an only if (7) holds. If (7) holds, and in the benchmark economy $\tilde{w}_0^{\dagger} < \overline{w} = w_0^{\dagger}$, the free drug plan generates a unique interior equilibrium. It follows that the share of individuals who have unsafe sex is smaller than prior to the introduction of the free drug plan.

In the absence of human-capital externalities $w_0^{\dagger} > \tilde{w}_0^{\dagger}$ if and only if $\tilde{\gamma} < \gamma$. However, that condition never holds because by assumption the free drug plan increases the likelihood of survival. Hence, even richer individuals are induced into unsafe sex. Consequently, the free drug plan unambiguously leads to a higher unsafe-sex equilibrium if there are no human-capital externalities.

Table 1: Bivariate correlations between economic development, income inequality and HIV incidence

	Sample of countries	Gross domestic product per capita [a]	GINI Index [b]	Agricultural Share [c]
HIV prevalence [a] (as a share of the 15-49 age group)	All countries	-0.29	0.42	
		(0.00)	(0.00)	
	Sub-Saharan Africa	0.21	0.49	-0.42
		(0.20)	(0.05)	(0.01)

Notes

[a] HIV prevalence and pre capita gross domestic product (purchasing power parity in US$ for 2000) are from the UNDP Human Development Report (2002)

[b] The GINI index of income inequality is from Checchi (2000)

[c] The Agricultural share in GDP is from the World Bank at http://www.worldbank.org/data/countrydata/countrydata.html

[d] P-values are in parentheses under each correlation coefficient

Number of countries by data availibility.

	Sample	
	All countries	Sub-Saharan Africa
HIV prevalence and GDP per capita	117	37
HIV prevalence and GINI index	64	16

Figure 1: Economic Development with No human-capital externalities

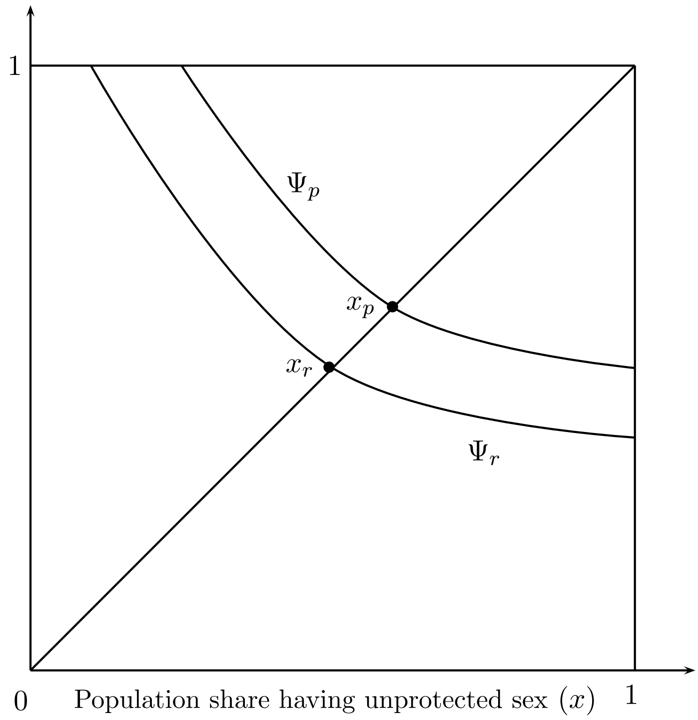
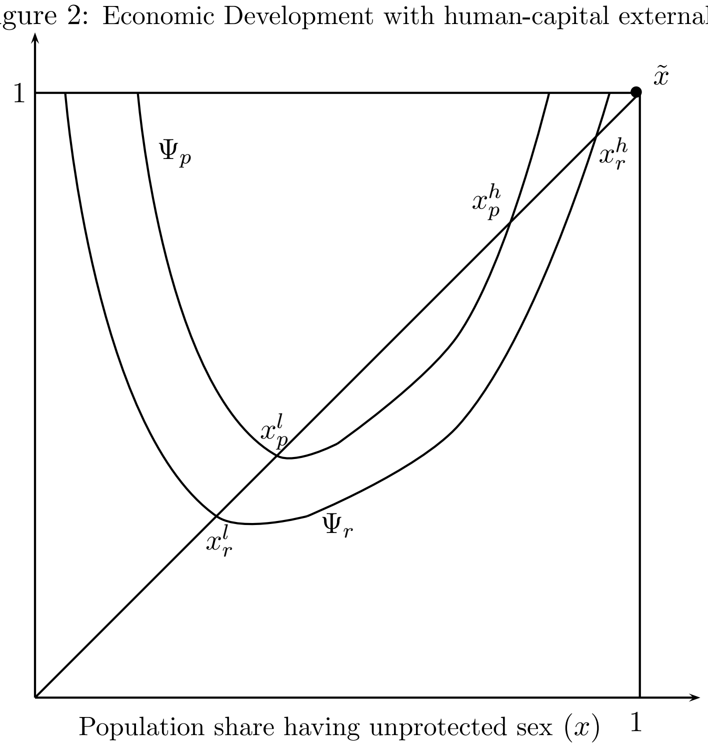


Figure 2: Economic Development with human-capital externalities



Note for Figures 1 and 2: Ψ_r and Ψ_p are the cumulative wealth distributions in the rich and poor economies respectively, with Ψ_r stochastically dominating Ψ_p. In Figure 1 x_p (x_r) denotes the equilibrium in the poor (rich) economy. In Figure 2 x_j^i, $i \in \{h, l\}$ and $j \in \{p, r\}$, denotes a high or low equilibrium for a poor or rich economy; $\tilde{x}$ is the equilibrium where everyone choses unprotected sex.

Figure 3: Inequality with No human-capital externalities

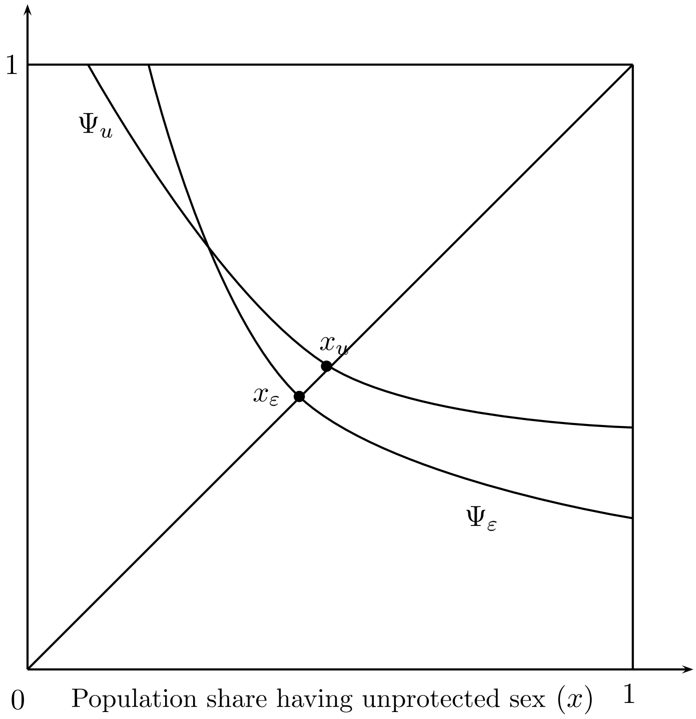
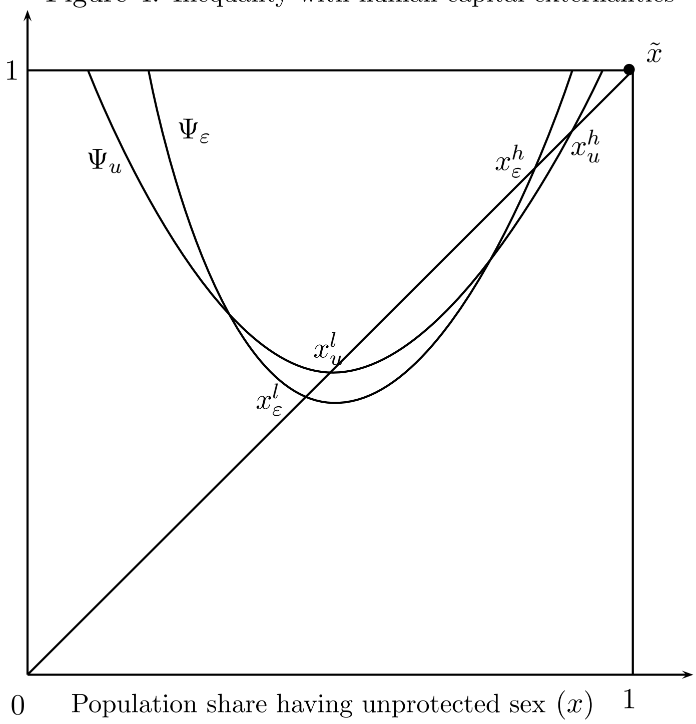


Figure 4: Inequality with human-capital externalities



Note for Figures 3 and 4: Ψ_ε is the cumulative wealth distribution (CWD) in the equal economy. It is constructed from the CWD Ψ_u of the unequal economy by performing Dalton transfers (Ray 1998). In Figure 3 x_ε (x_u) is the equilibrium in the equal (unequal) economy. In Figure 4 x^i_j, where $i \in \{h, l\}$ and $j \in \{\varepsilon, u\}$, denotes a high or low equilibrium for an equal or unequal economy; $\tilde{x}$ is the equilibrium where everyone choses unprotected sex.