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Cocktails of hope: simulating the effects of HIV/AIDS intervention strategies in Botswana, Mozambique and Namibia 2000-2020

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1 Introduction

The news about AIDS in Africa is grim, but not entirely devoid of signs of hope. Education programs seem to have been successful in Uganda and Senegal. The price of HIV medications is falling and those medications are slowly finding there way to those who need them. Large scale (phase 3) testing of an AIDS vaccine is in progress, with results expected next year (2002, NYT, 2001). Microbices, a potentially inexpensive and simple means for women protect themselves are also promising (JAMA, 2000). In this paper, we investigate some of the effects of educational policies aimed at changing risky sexual behavior and of distribution of HIV medication in three highly affected countries, Botswana, Mozambique, and Namibia. We consider population size, AIDS deaths, HIV incidence and prevalence, the population distribution over urban and rural areas, and some of the effects on the educational system. For this purpose, we use a newly developed model of the evolution of populations that significantly affected by HIV, developed at the International Institute for Applied Systems Analysis (IIASA). The new model is described in Section 2. In Section 3, we discuss the results of simulations of the implications of various policy options. We conclude, in Section 4, with some thoughts about the future.

2 IIASA's integrated HIV/AIDS model

The work on our model started as part of a three country population-development-environment (PDE) project funded by the European Commission at the International Institute of Applied System Analysis (IIASA). The aim of the project was to provide

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comprehensive long-term strategies for sustainable development in Namibia, Botswana, and Mozambique. Early in the project stage, it became apparent that HIV/AIDS was one of the most important challenges in these three countries and the project team decided to focus a major part of the research efforts on this problem. In line with the approach of the project in general, our HIV/AIDS model is completely integrated, meaning that historical HIV estimates, and the annual incidence and prevalence are modeled simultaneously with population growth, vertical transmission, AIDS deaths, population distribution, education, and GDP. The model is highly detailed, and remains as close to empirical data as possible. We also included a number of different policy intervention strategies.

There are many types of HIV/AIDS models that can be created. The design of this model reflects our desire to stay as close as possible to the best available data, namely HIV prevalence levels from the sentinel surveillance sites. The model corrects for the important biases of these data sources.

2.1 Basic structure

The population flows through four HIV-subgroups: the *population without HIV*; the *population with HIV*, which is asymptomatic but infected by years since infection; the *population with HIV on medication*; and the *population with AIDS* with full-blown symptoms (see Figure 1). Within the sub-groups, the population is divided into 100 one-year age categories, sex, HIV susceptibility, and education. For each cohort, the model allows for there to be education-specific proportions who are not susceptible to HIV, either biologically or more likely because of their behavior. These proportions of people who are nonsusceptible are allowed to remain constant or change over time as part of the scenario setting. Education results from assumptions about school entry and departure[2]. Babies are born into the *without HIV*, *HIV* or *AIDS* categories, according to assumptions about fertility, fecundity reduction of HIV-positive mothers, and vertical transmission. The non-AIDS categories are subject to a normal, age specific non-AIDS death rate. We have used the death rates projected by the national agencies of Namibia, Botswana, and Mozambique. Once a person has AIDS and is not medicated, the annual death rates are very high, from 50-80 percent annually.

The *population without HIV* flows into the *population with HIV* according to incidence rates, which can vary depending on susceptibility and education and are described below. Once a person has HIV he or she remains a-symptomatic for what in Africa this is estimated to be about 7 years. The model tracks the years since infection, and as the time since infection increases, so does the probability that AIDS symptoms will develop. Once this happens, the person either flows into the *population with AIDS* category, or into the *population with HIV on medication* group, where he or she will remain for a random length of time with a mean duration set by the model user.

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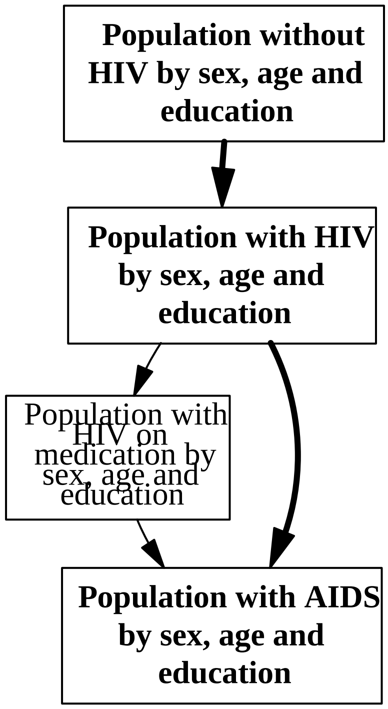
[2] There is a different design for education in the Mozambique model as compared to the Botswana and Namibia model, which we return to below.

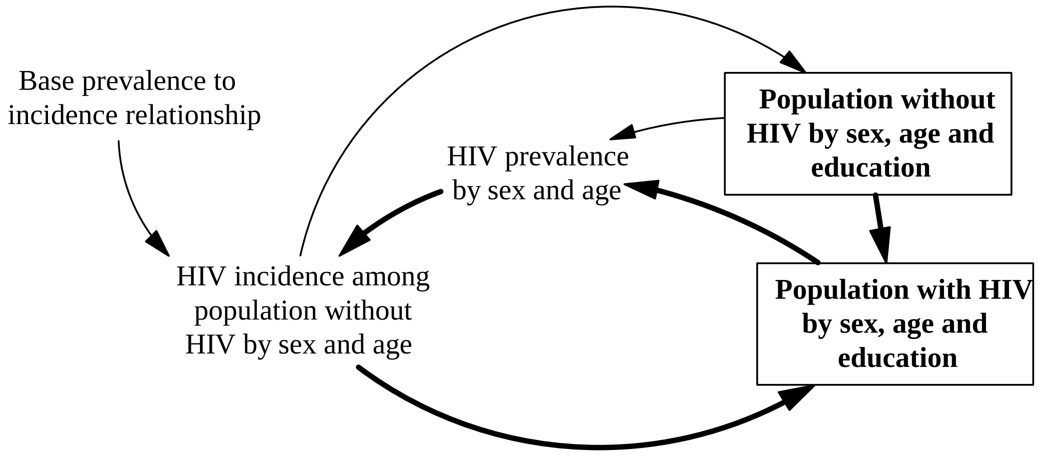
Figure 1. Flow of population through four HIV-subgroups in IIASA's integrated HIV/AIDS model.



New infections determine the movement from the population without HIV to those with HIV. They are a function of the level of prevalence (in other words, the general level of possible exposure to HIV), the proportion of people susceptible to HIV[3], and intervening factors, such as risky behavior, the pattern of sexual behavior in the country, and medical interventions discussed below. The intervening factors are collected in the *Base prevalence-to-incidence relationship* as shown in Figure 2. The term "base" is added because as we shall see below, behavior changes and medical interventions can modify the prevalence-to-incidence relationship. The dark lines in the figure, linking prevalence to incidence, to the HIV positive population and back to prevalence show the vicious cycle of the disease (not taking into account factors which will level off prevalence such as AIDS deaths and an exhaustion of at-risk population).

[3] Set to 90 percent in Namibia and Botswana, and 100 percent in Mozambique.

Figure 2. Prevalence and incidence in IIASA's integrated HIV/AIDS model.



New HIV infections for women in Botswana and Namibia are a function what we call the *dynamic prevalence-incidence relationship*:

$IR(age,education,year) = k(age,education) \cdot MAMPR(age,education,year)^{\beta}$.

IR(age,education,year) is the fraction of uninfected, susceptible women in a particular age and education group in a given year who become infected during that year. *k(age,education)* is a set of age- and education-specific constants that are derived from two observations on HIV prevalence rates. In the case of Botswana, these observations are from 1993 and 1997. *MAMPR(age,education,year)* is a moving-average modified prevalence rate. It takes into account the prevalence rates in a five-year window centered on the specified age and takes into account differences in risky sexual behavior of population groups and differences in the likelihood of spreading HIV depending on whether the infected person is on medication or not. β is a parameter that is determined by the distribution of risky sexual behavior in the population[4]. The male incidence rates are derived from female incidence. The user can set the ratio of male:female incidence. In the scenarios for Botswana and Namibia below it is set to .8.

For Mozambique, we use what we can call the *simple prevalence-to-incidence relationship*. The AIDS Action Group in the Ministry of Health provided an historical time series of prevalence from 1986-1997. From this and historical simulations of AIDS deaths with the model, we found incidence among non-HIV infected and therewith an historical relationship between prevalence and incidence rates for 11 years[5] for men and women together. As expected the higher the

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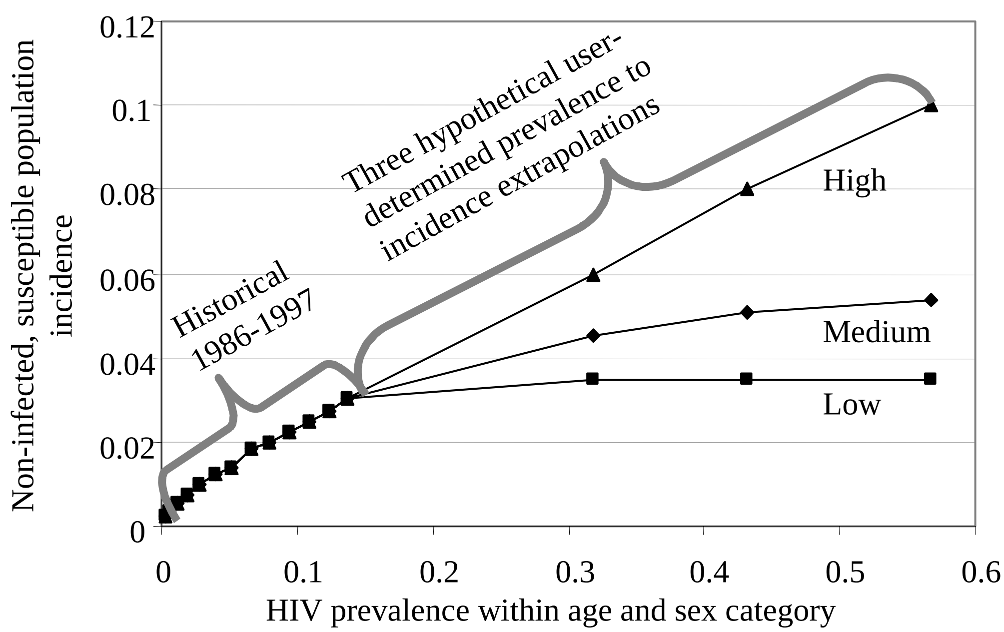
[4] Changing the betas will cause different levels of prevalence in the projection period. However, it will not change the estimations of prevalence in the historical period, because there are compensating changes in the k's.

[5] The two simplifications compared to the dynamic prevalence-incidence relationship are that the rates are averaged and identical for all age groups 15-49, and there is no distinction between sexually active and non-sexually active teenagers. However, because the non-infected population shrinks with increasing age, overall incidence by age group declines with age, as it does for Botswana and Namibia. The sexual activity effect of teenagers is not included in the Mozambique model.

prevalence rate, the higher the historical incidence rates among non-infected persons (see Figure 3). The historical relationship between prevalence and incidence indicates something about the type of sexual behavior pattern that is prevalent in the country. A country with more risky sexual behavior would have higher incidence rates among the non-infected persons at each level of prevalence than one with less risky behavior.

The historical prevalence and incidence pairs take us up to the highest prevalence level given by the Ministry of Health, namely, 13.76 percent among adults age 15-49 in 1997. In the future, higher prevalence levels are likely to occur. To include these higher levels, and the likely higher levels of incidence, the historical curve is extrapolated. There are three extrapolation curves used in this paper, conveniently called low, medium, and high to account for uncertainty. The user can set any curve when using the model.

Figure 3. Incidence-prevalence relationship in Mozambique, using historical data from 1986-1997 and three extrapolated trend-lines for higher than observed prevalence rates.



2.2 HIV/AIDS intervention policies

We can group the policy measures into two categories: those, which change behavior and medication. These policies are set per year, in other words, the model user can determine in what year the policies take effect, the effectiveness and changes thereto over time.

The results below show that an essential policy is one that is geared towards behavioral change. In the model, behavioral change is simply expressed as a reduction of the incidence at each level of prevalence or an increase in the non-susceptible population, without specifying the precise cause. Research has found that effective behavioral changes include condom use during risky sex, for example with commercial sex workers or during early adulthood when the partner flux might be greater. They can also include having of non-HIV sexually transmitted diseases, which facilitate the transmission of HIV, treated or the introduction of microbicides to reduce transmission when they become available. We do not specify the particular measures. A general use of condoms by the whole population is less effective than targeted use. Examples from Thailand, Uganda (U.S. Census, 1999) and case studies in Kenya and Malawi (Sweat et.al. 2000) show that the significant incidence reduction can be realistically attained.

Two of the medication strategies focus on antiretroviral drugs. One is a prevention strategy, which targets pregnant women to reduce vertical transmission. The use of drugs during pregnancy and labor, has been shown to reduce transmission by about 30-50 percent (Wood et.al. 2000c). The user can specify the rate and the proportion of pregnant women receiving the treatment. In the scenarios below, a 40 percent reduction is assumed.

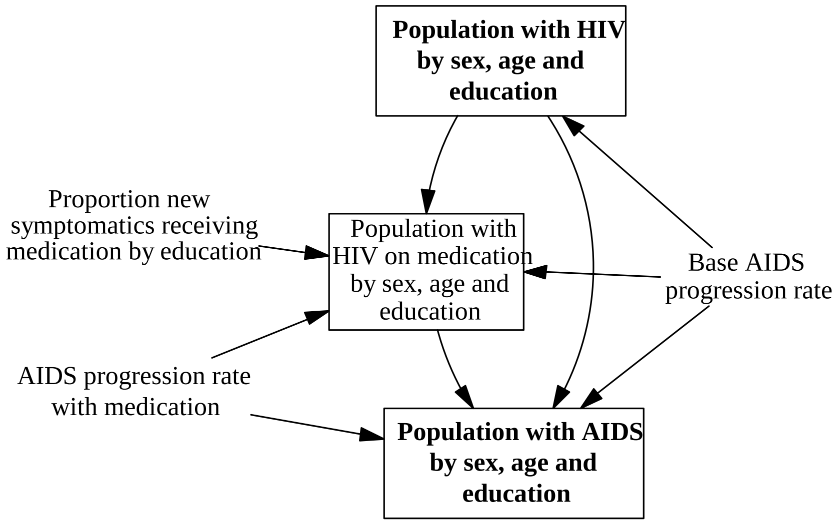
Second, antiretroviral drugs can be administered to people who begin to develop AIDS symptoms, to postpone the full onset of AIDS. The socio-demographic impact of the drugs will depend on the length of effectiveness and on the proportion of people developing symptoms who receive them. In our model the cocktail is administered to those who develop AIDS symptoms (according to the base AIDS progression rate). In Figure 4, these are the *proportion new symptomatics receiving medication*. There is no way of knowing the extent to which medication will increase the life expectancy, but the constant mutation of the HIV virus suggests that medical research will be in a race with the mutations to maintain or increase the length of effectiveness. Wood et.al. (2001) estimate an extra 5-7 years resulted from therapy based on studies such as Hogg et.al. (1998). Recent information (McKinney, 2001) indicates that the drugs now available might be less effective in sub-Saharan Africa because different strains of the HIV virus dominate there compared to North-America.

It is likely that there is a public health side effect of the antiretroviral drugs. Through reducing the virus count in the blood it is possible that the infectivity of those on medication is also reduced (Operalski et.al. 1997; King, 1997; Curtis, 2001). If indeed, the drugs reduce infectivity to a large extent, a considerable drop in infection rates (compared to a scenario with no drugs) results. At present, many institutes are devoting more of their research funds to answer this important question (for example, NIH, 2001). The model allows the user to set the infectivity reduction.

A third medical intervention would be a vaccine against the disease. Such a vaccine is not on the market although some vaccines are presently being tested (NYT, 2001). The scenarios discussed below don't include this option, but the model does have a time dependent variable that the user can set which determines the proportion of the population who have received the vaccine.

Three of the interventions mentioned here modify the base prevalence-to-incidence relationship, namely, behavioral change, lower infectivity of those on antiretroviral drugs, and the vaccine. The *Actual prevalence-to-incidence relationship* is the product of the base prevalence-to-incidence relationship and the effects of behavioral and medical modifications.

Figure 4. Effects of drugs, which increase the life expectancy of those who develop AIDS symptoms.



2.3 Education and urban-rural distribution effects

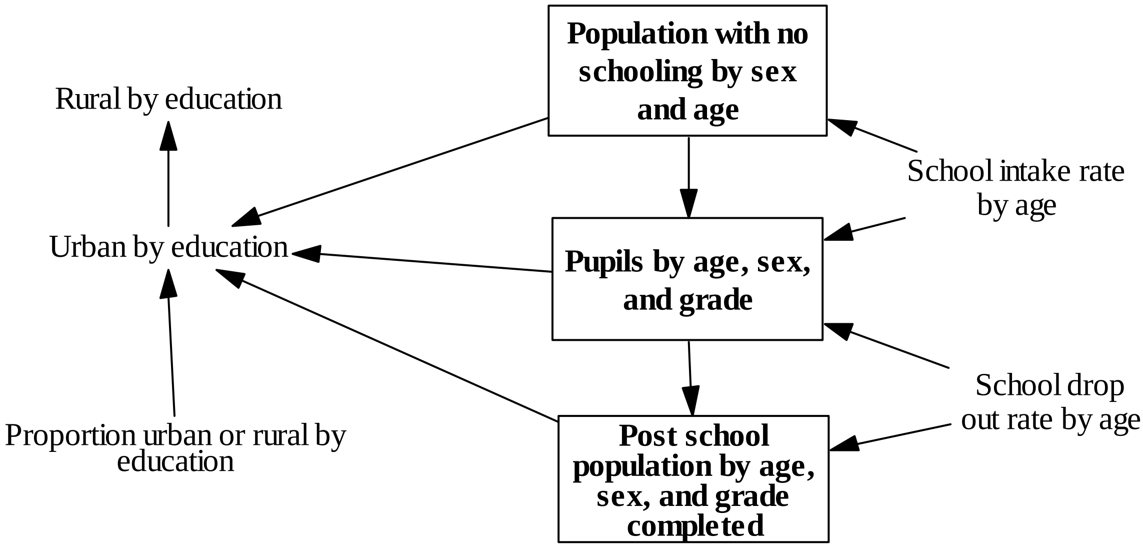
The adult level of education and the distribution of the population over rural and urban areas are both important indicators of the level of development and the development paths open to the country. HIV/AIDS and policies will impact these variables.

The model calculates school enrollment the level of adult education (starting with the most recent census data) based on assumptions about school entry and departure. The model for Mozambique includes a single year of age and grade simulation of school enrollment and teachers. The model used for Botswana and Namibia simply allows the user to set what proportion of each cohort will receive primary, secondary and tertiary education.

For Mozambique, school entry and departure rates are taken from census and school enrollment data. Basically, people are born into the *Population with no schooling* group. The proportions of children age 5-13 who enter school are set by the model user. Of the *Pupils by age, sex, and grade*, some will leave school at each age and enter into the *Post school population by age, sex, and grade completed*. The user also sets school departure by age. The *Post school population* is the basis for the calculation of adult education (see Figure 5).

It is expected that HIV/AIDS will reduce the demand for schooling because fewer children are born, some die of AIDS before reaching school age, and orphans (whose parents have died of AIDS) generally have lower school enrollment rates than children with parents (for example, Ainsworth and Over, 2001). Teachers will also die of AIDS, and an important question is whether the rate of teacher deaths compared to the reduction of pupils will result in a deterioration of the pupil: teacher ratio and school quality.

Figure 5. Transition to school and post-school population according to school intake and school drop out, and the distribution of population in urban and rural areas.



In general, the higher the level of education, the greater the probability that a person resides in an urban area. For example, in Mozambique for example, 14 percent of those with no or very low levels of education lived in urban areas; compared to 92 percent of those who had completed secondary school or higher. Thus, as a population becomes more educated, it will automatically shift to a more urban concentration, even barring rural-urban migration *within* education categories. The model distributes the population to urban and rural areas depending on the education profile and the user-determined proportions urban within each education category.

Another factor that will probably benefit population distribution is greater urban access to medical services, condoms, and public education efforts. Any program to reduce HIV and AIDS – such as the provision of antiretroviral drugs, condoms, non-HIV STD treatment, education of risk-groups, treatment of pregnant women – will be easier in the cities, and probably more cost-effective (although studies do not exist to prove this). UNAIDS country reports of Uganda found that condom use for risky sex or condom availability is higher in urban than rural areas. Moreover, those with higher education are more likely to be able to afford treatment or to be in jobs that offer treatment. On the other hand, in most countries, the likelihood of having risky sex and the HIV prevalence rates are higher in urban areas, which might cancel out the beneficial effects of better access to condoms and treatment.

2.4 Comparison to other models

In scope, the integrated model goes beyond the HIV/AIDS models that we know because of the inclusion of policy interventions, education, and the population distribution (the model also includes economic impacts but we do not discuss those here). In our view, the integration is one of the model's most important contributions to the field. Secondly the inclusion of a wide range of policy options, which can be easily implemented by the user is a unique feature. Third, the behavior and data based incidence calculation (in the prevalence-to-incidence relationship) is, in our view, an improvement over calculations based on regression or extrapolation of the prevalence curves, such as are used in other models.

The most similar effort to ours is that of the group led by Evan Wood in British Columbia, Canada (Wood et.al. 2000a, 2000b, 2000c). Wood and his group have modeled the socio-demographic impact of various scenarios of antiretroviral drug intervention in Canada and South Africa for a 5 and 10 year time horizon using the Spectrum software from the Futures Group (www.tfgi.com). We use the some of the same parameters as theirs for our drug intervention simulations, namely the vertical transmission rate reduction from antiretroviral drugs and a six-year life extension for HIV patients on those drugs[6]. Their published work does not include a longer time horizon, the effects of other interventions, such as safer sex, nor HIV/AIDS impacts on population distribution and education.

The model of Botswana and Namibia includes three sexual activity groups: non-active, active and at-risk, and active not at-risk. There are other models which include much greater detail in this respect, such as the ASSA model presented by Dorrington today (Dorrington, 2001), the micro-simulation model by van Vliet et.al. (1998), the Bulatao (Bos and Bulatao, 1992) model used by the World Bank, and the Interagency Working Group (iwg) model used by the US Census Bureau (Stanley et.al. 1991).

3 Simulation results

On the basis of empirical data from population censuses (Botswana 1991; Mozambique 1997; Namibia 1991) and other national sources, we obtained or estimated the starting year population age structure, age-specific fertility rates, mortality rates, education by age, and urban-rural distribution by education. The population is disaggregated by 100 single years of age, sex, 3 or 14 education levels[7], four HIV statuses (see section 2.1), 15 single years since infection (for those HIV-positive, asymptomatic and unmedicated). The Botswana and Namibia models also consider whether a young person has initiated sexual activity or not and two types of sexual behavior (risky and not risky).

Starting year HIV prevalence rates were calculated for Namibia and Botswana from the sentinel survey sites. The Sentinel Surveillance Survey data come from small, nonrepresentative, and geographically biased samples with no information on the women except their ages and the fact that they are pregnant. We corrected for this bias by including in our calculations fertility patterns, fecundity reductions due to HIV, and sexual activity rates. For Mozambique, a time series of HIV prevalence was given by the Ministry of Health, which had made its own calculations, based on its sparse data collection at sentinel sites, and we used this series as historical input.

3.1 Results with no interventions

Figure 6 shows the baseline, No Change population projection with HIV/AIDS for Namibia, Botswana, and Mozambique. The No Change population projection assumes a medium prevalence-to-incidence relationship, and no interventions to

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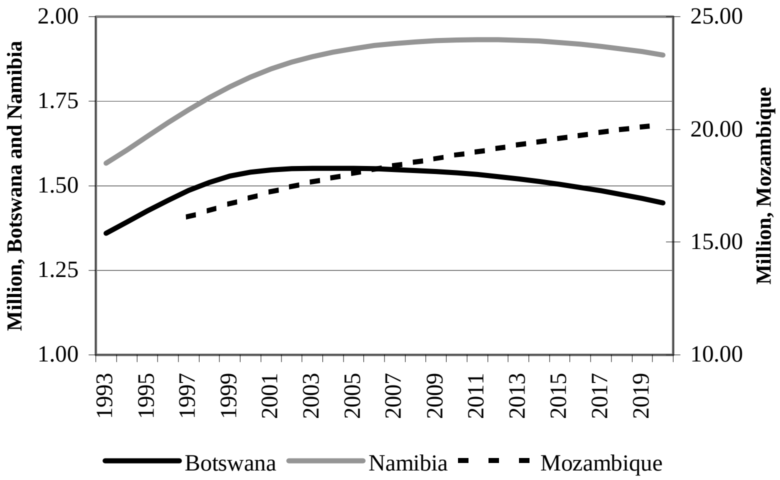
[6] For Mozambique only. For Botswana and Namibia, a 10-year life extension is assumed.

[7] Low, Medium, High for Botswana and Namibia; 12 grades, no schooling, plus university degree for Mozambique.

change behavior or administer medications. In both Botswana and Namibia, population begins to decline. The population of Botswana is currently (2001) around 1.55 million people. Ten years from now, Botswana's population will be 1.53 million in the baseline scenario and 1.45 million in 2020. The population of Namibia is currently around 1.82 million people. It would continue to increase for another ten years from now, to 1.93 million before starting to decline to 1.90 by 2020. The population of Mozambique would increase throughout the projection period, from 17.22 million in 2001 to 20.22 million in 2020, mainly because of higher observed and assumed future fertility in Mozambique. These figures are very similar to the most recent projections produced by the US Census Bureau[8].

Figure 6. Baseline, No Change population projection with HIV/AIDS for Namibia, Botswana, and Mozambique until 2020.



Projected population depends on prevalence rates and the prevalence-incidence path chosen. A sensitivity analysis shows the differences in projected population and prevalence rates depending on a high incidence, medium incidence, and low prevalence to incidence relationship. For Mozambique, the three simulations reflect the curves in Figure 3; for Namibia and Botswana, β is .5, .35 and .2 respectively. In 2001, the estimated prevalence rates vary depending on the relationship chosen because these numbers are already "projections" from the data, which goes only to 1997.

The simulations all show that even in the absence of interventions, the rapid increase of prevalence ends. In Botswana, the rise in prevalence rates tapers off as of 2001; in Namibia as of 2006; in Mozambique as of 2008. When prevalence becomes quasi stable, the epidemic has reached a mature stage where AIDS deaths cancel new incidence. The difference between the highest and lowest stable prevalence rates by 2020 is 5 percentage points in Botswana, see Table 1. In Mozambique and Namibia

[8] In 2020 the projected population in projections that include AIDS were 20.63 million in Mozambique, 1.96 in Namibia, and 1.29 in Botswana. We are grateful for the Excel files with these figures provided by Peter D. Johnson of the US Census Bureau International Division.

the difference is 6 and 9 percentage points respectively. The relatively small differences stem from the fact that the epidemics in these countries appear to be close to maturity. This means most prevalence-incidence pairs have already been observed – prevalence does not reach much higher levels because AIDS deaths catch up with incidence. The population size differences between scenarios are even smaller than prevalence because there is a long period between infection with HIV and death.

Table 1. Estimated adult HIV prevalence rate (proportion of population age 15-49) and population (in million) in 2000 and in 2020 for Botswana, Mozambique, and Namibia according to high, medium and low prevalence-incidence relationships.

	Prevalence among adults 15-49, both sexes			Population size in millions		
	Botswana	Namibia	Mozambique	Botswana	Namibia	Mozambique
2001	.29-.31	.18-.21	.17-.18	1.55	1.82	17.22
2020						
Simulations with a high prevalence-to-incidence relationship	.36	.31	.25	1.39	1.75	19.82
Medium prevalence-to-incidence	.33	.26	.22	1.45	1.90	20.22
Low prevalence-to-incidence	.31	.22	.19	1.48	1.99	20.84

3.2 Results with behavioral change to reduce incidence

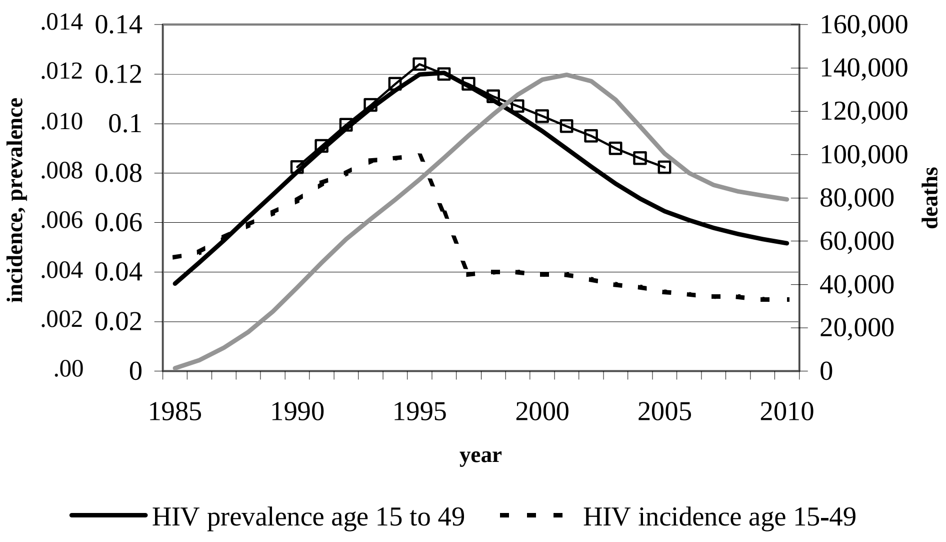
Uganda had one of the earliest AIDS epidemics and among the highest HIV prevalence rates in the early 1990s, around 12 percent of the adult population in 1992 (US Census, 1999). It is also the only country to have experienced a turn-around in prevalence rates: in 1999 the estimated prevalence was 8.3 percent (WHO, 2000), while in 1994 it was over 10 percent. The cause of this remarkable decline appears to be an aggressive government policy to enlighten the population about the causes of AIDS and a campaign to promote safer sexual behavior. Among the changes that have occurred in Uganda are more monogamy, fewer risky sexual encounters, higher use of condom during risky sex, and a later age of sexual initiation (.   It is important to know how much behavior change in Uganda reduced incidence in order to have a gage by which to measure our own assumptions for Botswana, Namibia, and Mozambique.

We estimated the Uganda experience by doing an historical simulation from 1985-2001, and calibrating model calculations of prevalence 1985-1999 to estimations provided by the US Census Bureau. To calibrate, we had to shift the prevalence-to-incidence relationship slightly from the one used for Mozambique, insert Uganda population figures, and make assumptions about how effective the government policy was in changing behavior over time. The US Census gives an abrupt turn-around the prevalence trend in 1995 and a linear decline from 12 percent prevalence in that year to a little over 10 percent by 2000. This decline is more conservative than the one published in *World Population Profile: 1998* in which national adult prevalence was estimated to be under 9 percent by 1998. It is also more cautious than the estimate by UNAIDS, which puts 1999 prevalence at 8.3 in its latest country report (WHO, 2000). We mention this to emphasize that the prevalence and incidence drops we simulated are probably on the moderate side. To replicate the turn-around in prevalence rates, incidence rates have to decline. We achieve this by lowering the base prevalence-to-incidence relationship with a behavioral change factor of 10 percent by 1994; 60 percent by 1996; and gradual slippage to 55 percent by 2010. More gradual or smaller impacts did not produce the prevalence turn-around given by the US Census. This means that the government's policies produced a massive incidence reduction in a very short time-span. So why is the impact on prevalence and AIDS deaths not massive?

The figure shows that a visible impact of the government policy on prevalence rates and in particular, on AIDS deaths, is considerably delayed. While safer sex was on the increase from 1994 (at least) on, prevalence in our simulation does not decline until 1997 and AIDS deaths continue to rise until 2001. This is because of the enormous delays in the epidemic and epidemiological momentum. Lower incidence rates reduce the inflow to the HIV positive population; but the stock of that population is only reduced through AIDS deaths after some time, which is why prevalence does not change as radically as incidence. The AIDS deaths themselves basically lag 7 years behind the prevalence rates because of the long incubation time.

The US Census also assumes prevalence remains constant at 8 percent from 2005 on, whereas our simulations show that unless the population regresses back to more risky sex, it is more likely to continue falling. This is because behavioral changes have a cumulative effect. If fewer people engage in risky behavior, fewer people become infected with HIV and consequently there are fewer HIV-positive people around to infect others in the future.

Figure 7. HIV prevalence, incidence and AIDS deaths in Uganda 1985-2010 calibrated to US Census estimates for HIV prevalence 1990-2005. We are grateful to the US Census Bureau for providing the spreadsheet with prevalence.

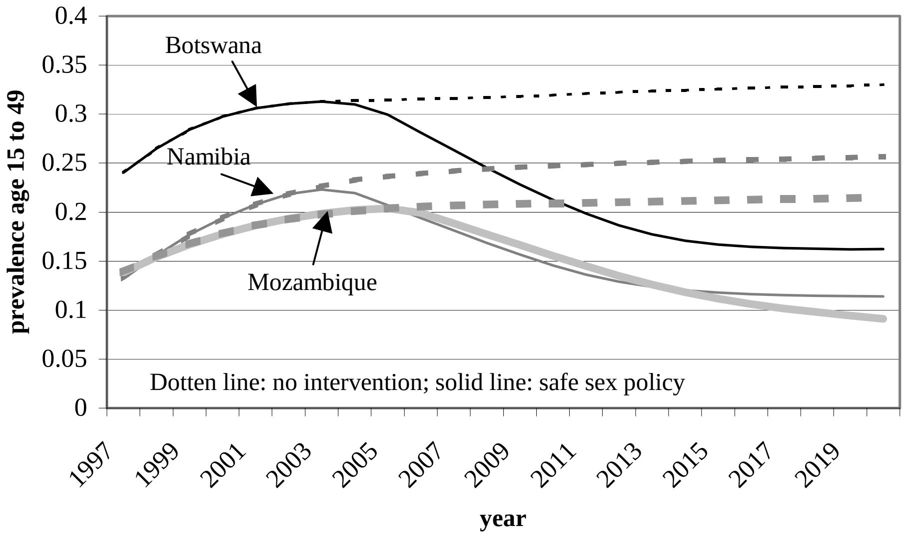


We do not know to what extent the Uganda experience can be replicated nor perhaps whether there were other factors at play not included in the above simulation. The simulation should be seen as one possible scenario among many others. It is however, the only empirical starting point for Africa that exists, and as such is an important guide for policies that seek to lower incidence rates. The simulations for Botswana, Namibia, and Mozambique shown in Figure 8 follow the simulations for Uganda. Behavioral change causes the incidence rates to be 10 percent lower (than they would be in the absence of change) two years after the initialization of a public campaign program, and 50 percent lower another two years later. In Botswana and Namibia, the policy is initiated in 2000, reflecting recent efforts there, and in Mozambique in 2002. The changes are identically applied to all education and age groups.

In examining the results it is important to remember that each of these cultures is different, and one cannot assume that any policy or intervention which works in one country will do so in another one. In 1993, Malawi, Zambia, Zimbabwe, Botswana and Uganda had similar HIV prevalence rates, in excess of 10 percent (US Census, 2001), but it was only in Uganda that an intervention was deemed possible and necessary and only there that behavior shifted significantly enough to impact the epidemic.

Figure 8 shows the HIV prevalence rates among adults 15-49 in the No Change scenario from the previous section, and with the Behavioral Change scenario described above. With No Change, prevalence rates stabilize at a high level. With Behavioral Change, all three countries experience a turn-around in prevalence, which would not have occurred with a continuation, shown in Figure 8. By 2020, the prevalence rate in Botswana is only 16 percent compared to the 33 percent it would otherwise be; in Namibia prevalence is 11 percent compared to 25; and in Mozambique it is 9 percent compared to 22. In each case, prevalence is more than 50 percent lower than it would have been without any intervention. For Mozambique, it appears that by 2020 prevalence is still declining, but this is not true for Namibia and Botswana. There the epidemic seems to have reached a new stability at a lower, but still significant level.

Figure 8. Prevalence rates in Botswana, Mozambique, and Namibia 1997-2020 according to the baseline scenario and the behavioral change scenario.



We tested the sensitivity of the prevalence level, and the number of AIDS deaths in 2020 to various interventions plateaus: no change, behavior change leading to a 20 percent incidence reduction, a 50 percent reduction (as above) and an 80 percent reduction. As Table 2 shows, bigger behavior changes lead to higher impact in the form of lower prevalence rates and fewer AIDS deaths. The impact is almost linear: 20 percent lower incidence leads to about 20 percent lower prevalence; 50 percent lower incidence to a little more than 50 percent lower prevalence; and 80 percent to 85-90 percent lower prevalence than without interventions.

The life expectancy gains from behavioral change are high. With no change, for example, life expectancy for women in Mozambique in 2020 would be only 36.5 years, lower than the present level of 37.0. With modest behavior changes, there would be a 1.9-year life expectancy gain, with medium changes an 8.2-year gain, and with 80 percent lower incidence, life expectancy would be 16.3 years longer than with no changes. The gains in Botswana and Namibia are similarly large.

We would like to note again, that behavioral change might mean very different types of changes. It could mean a rather small decline in unprotected risky sex among a specific population group for example, or it could be a change that affects the whole population[9]. Safer sex does not necessarily mean abstinence or condom use only; it could also mean treatment of non-HIV STD's to reduce the rate of transmission. Indeed recent research shows that a successful prevention policy first targets specific risk-groups and risky behavior within those groups, rather than the general population (Ainsworth and Over, 1997).

[9] For example, Ainsworth, et.al. (1997) estimated that if 500 sex workers used condoms 80 percent of the time, 10,000 new infections would be averted, whereas if 500 low-income men used condoms 80 percent of the time, this would only avert 88 new infections.

Table 2. Prevalence, AIDS deaths (in 1000), and life expectancy at birth in 2020 according to 4 scenarios with different sexual behavior.

		No Change	20 % incidence reduction	50 % incidence reduction	80 % incidence reduction
Botswana	Prevalence (%)	.33	.27	.16	.05
	AIDS deaths (x1000)	32	28	17	6
	Life Exp. (yr. at birth)	32.6	37.0	45.5	57.4
Namibia	Prevalence	.26	.20	.11	.03
	AIDS deaths	36	30	18	6
	Life Exp.	38.9	42.5	49.2	56.9
Mozambique	Prevalence	.21	.18	.09	.02
	AIDS deaths	272	232	136	34
	Life Exp.	36.5	38.6	44.7	52.8

3.3 Results with antiretroviral intervention.

Antiretroviral drugs have successfully reduced vertical transmission when administered prophylactically to pregnant women, and have extended the life of HIV-positive adults. The drugs, which reduce the virus load in the blood, might also reduce the infectivity of the HIV-positive adult, thus providing a public benefit also in the form of fewer new HIV infections.

In the early months of 2001, various decisions from pharmaceutical companies and action by governments (in particular the South African government) led to an enormous reduction in the cost of the drugs for Africa and other developing countries. Our earlier calculations (Sanderson et.al. 2001a, 2001b) show that under the new circumstances, public provision of the drugs for free is financially feasible for Botswana and Namibia. Some companies in Botswana have begun to include the in their employees' health plans, since the costs of the drugs are now lower than the cost of losing valuable workers.

However, it will be difficult to administer the drugs on a wide scale in countries with a weak health system, such as Mozambique, because of organizational difficulties (Wood et.al. 2000c, suggest the same for South Africa). Moreover, while the drugs do extend life expectancy, it is only by about 6 years in North America. In Africa it might be shorter because of the difficult drug-regime, intermittent shortages, and because of different HIV strains.

With these circumstances in mind, we explore antiretroviral scenarios with three variable parameters. The three parameters are the proportion of pregnant women receiving the drugs to reduce vertical transmission, the proportion of adults developing symptoms who receive the drugs and third, the reduction in infectivity. Only the results for Mozambique are shown for the sake of brevity.

Table 3 shows adult HIV prevalence rates, AIDS deaths, and life expectancy at birth for a large number of simulations. All treatment is assumed to start at zero percent in 2002. First, there is a simulation with no intervention. Second, there is a simulation called Universal, run for comparative purposes, where the drugs are universally given to those who develop symptoms, *and* if the infectivity is reduced by 100 percent. There is also a set of nine simulations which cross-simulate three levels of the proportion of adults developing symptoms who receive antiretroviral treatment with three levels of infectivity reduction. The proportions receiving treatment are assumed to be 25 percent by 2005 and constant thereafter in the lowest treatment simulations; 50 percent by 2008 (and subsequently constant) in the medium treatment simulation; and 75 percent in the high treatment simulation. The three levels of infectivity reductions are 0, 50, and 90 percent. Finally, there are three simulations in which pregnant women only receive the drugs, namely 25 percent by 2005; 50 percent by 2008; and in the last simulation, 75 percent by 2008. The drugs are assumed to post-pone the onset of full-blown AIDS by 6 years.

The results for Mozambique are shown in Table 3. In the No Change simulation, adult HIV prevalence in 2020 would be 21 percent, there would be 272 thousand AIDS deaths and life expectancy would be 36.5 years. In the Universal simulation, life expectancy would be 43.4 years, almost six years longer (there is a slightly confounding effect from deaths of children born with HIV or AIDS, who do not receive the treatment in the simulation). Prevalence would be lower than in the no intervention case, because the pool of non-infectious people is larger, as it now includes those who are on treatment. This causes the probability of having sex with an infectious person to be lower. AIDS deaths would be 175 thousand, almost a third lower than with no intervention.

The actual situation is not likely to be the universal one, but rather something less perfect. In the most effective non-universal antiretroviral drug simulation 75 percent of those developing symptoms receive the treatment by 2008 and beyond and the infectivity is reduced by 90 percent. In this simulation, adult HIV prevalence would be almost unchanged, 22 percent, but there would be only 213 thousand deaths, and life expectancy would be 40.8, years a gain of 4.3 years compared to no intervention. In the least effective intervention, with only 25 percent receiving treatment and no reduction in infectivity, HIV prevalence would be 24 percent, there would be 273 thousand AIDS deaths, and life-expectancy would only be half a year longer than in the case with no intervention.

Whether or not the antiretroviral drugs reduce infectivity has a large impact on the results. In those simulations with a 90 percent reduction, the HIV prevalence is 21 to 22 percent, whereas if there is no infectivity reduction, prevalence ranges from 24 to 29 percent.

Second, prevalence is higher in those simulations where more people receive the drugs because people in the HIV positive population have a longer lifetime. Because of the higher prevalence, a portion of the gain in life expectancy and AIDS deaths reduction is lost if we assume no reduction in infectivity. Life expectancy gains are .5, 1.2 and 1.9 years in the three variations of treatment administration and constant infectivity, while the gains are 1.9, 3.1, and 4.3 years with a 90 percent infectivity reduction.

The short-term prophylactic treatment of pregnant women to reduce vertical transmission leads to small life-expectancy gains of .2, .4 and .6 years depending on how many women are reached. However, this intervention might still be the most cost-effective one, as found in Wood et.al. (2000c) in terms of dollars per person year gained.

Table 3. HIV prevalence, AIDS deaths, and life expectancy at birth in 2020 in 12 scenarios with varying degrees of antiretroviral drug administration.

		Horizontal infectivity reduction				Pregnant women receiving short-term treatment
		100 %	0 %	50 %	90 %	
Prevalence	No Change	.21				
	Universal	.19				
	25 % by 2005		.24	.23	.21	.21
	50 % by 2008		.27	.24	.21.	.21
	75 % by 2008		.29	.25	.22	.21
AIDS deaths	None	272				
	Universal	175				
	25 % by 2005		273	257	244	269
	50 % by 2008		266	246	229	265
	75 % by 2008		261	235	213	262
Life Exp.	None	36.5				
	Universal	43.4				
	25 % by 2005		37.0	37.7	38.4	36.7
	50 % by 2008		37.7	38.7	39.6	36.9
	75 % by 2008		38.4	39.7	40.8	37.1

4 Effect of HIV/AIDS and policies on population distribution and education system.

4.1 School enrollment and teachers in Mozambique

School enrollment and the number of teachers will be heavily hit by HIV/AIDS, which causes a pupil reduction due to fewer births and early deaths, and removes teachers from the schools. A detailed examination can be made with the model for Mozambique[10].

[10] The model for Botswana and Namibia includes the proportions of children who receive primary, secondary, and tertiary education, but calculates neither the number of pupils nor the number of teachers.

In Mozambique, school entry occurs at many ages, starting at age 5, and ranging up to young adulthood. Similarly, school departure occurs throughout the school cycle. In each grade between 6% and 47% of the students leave (the higher drop-out rates occur at transitions from one school level to the next). Most, but not all, people who leave school are teenagers. This rather complex situation is captured in a model with school enrollment by single-year age groups and single grades from 1–12, as well as university enrollment (see Figure 5).

A particular concern for the country is whether or not there will be enough teachers, particularly at the lower primary school level. This concern is more acute in the face of the HIV/AIDS epidemic. To capture this, the model also calculates the number of teachers in primary school based on the general adult education level and mortality rates among teachers.

Table 4 shows the total number of pupils in primary school, the number of teaches, and the pupil: teacher ratio in four scenarios: one without HIV/AIDS, with HIV/AIDS, medium incidence but no policy intervention, as previous but with behavior change leading to a 50 percent lower incidence, and as previous with 75 percent antiretroviral administration and 90 percent reduction of infectivity. The table shows that by 2020 the epidemic would the number of pupils and teachers by about three-quarters with HIV/AIDS compared to a situation with no HI/AIDS. The two policies do not have any appreciable effect by 2020. The number of primary school pupils with no intervention is 2.33 million, and with the assumed behavioral change or antiretroviral treatment it is 2.37, or 2.37 million respectively. This is because, although prevalence and AIDS deaths are much lower in the two intervention scenarios (as shown in sections 3.2 and 3.3), there is such a long lag in from infection to death, the population effects are not appreciable by 2020. If we extend the simulations out to 203O, larger effects emerge. With no interventions, there are 2.23 pupils, while the safe sex, and antiretroviral treatments produce 2.48, and 2.34 pupils.

Interestingly, the ratio of pupil: teacher is virtually the same without HIV/AIDS, with the epidemic but no intervention, and with interventions. If enrollment continues at the present level, the pupil: teacher ratio is set to decline significantly over the next decades, regardless of the epidemic, because of big increases in the education levels of young adults, who typically teach lower primary school. It turns out that HIV/AIDS reduces the number of pupils at the same rate as it reduces teachers. The interventions tend to reduce the loss of teachers more than pupils, so the pupil: teacher ratio is a little better in the two intervention scenarios. The model does not include the disruptive effects of AIDS, such as a higher turnover of teachers or an overall loss of population, so there might be other negative effects that are not included here.

Table 4. Lower primary school pupils and teachers, as well as pupil: teacher ratio in four scenarios: with no HIV/AIDS; with HIV/AIDS, medium incidence but no intervention; as above with 50 percent incidence reduction through safe sex by 2006; and as above with 75 percent antiretroviral treatment and 90 percent reduction of infectivity.

	Pupils xMillion	Teachers x1000	Pupil: teacher ratio
2001	2.19	37.9	57.8
2020			
No HIV/AIDS (I)	2.95	91.9	32.1
With HIV/AIDS, medium incidence (II)	2.33	69.1	33.7
As II, with 50% incidence reduction through safe sex (III)	2.37	72.8	32.6
As II, with 75% antiretroviral treatment of symptomatics and pregnant women, 90% reduction of infectivity (IV)	2.37	74.0	32.0
2030			
Scenario I	3.14	141.7	22.1
Scenario II	2.23	93.3	23.9
Scenario III	2.48	108.2	22.9
Scenario IV	2.34	105.9	22.1

4.2 Effect if HIV/AIDS and policies on population distribution in rural and urban areas: scenarios for Botswana and Namibia.

HIV/AIDS and education will have an impact on the both the size and the distribution of the population between the urban and rural areas of Botswana, Mozambique, and Namibia. HIV/AIDS will cause the population to be smaller than it would otherwise be, and to the extent that policies reach urban population more than rural ones, will also shift the population distribution to cities. Second, rising education levels will cause a larger proportion of the total population to live in urban areas, because the average education level in all three countries is rising and urbanization is positively correlated to level of schooling. Together, HIV/AIDS and education lead to a stagnant or declining rural population size for all three countries, while the urban population continues to expand (albeit at a slower pace than it would in the absence of HIV/AIDS).

Botswana and Namibia are in the midst of an era of rapid increase in the number of people with secondary and tertiary education thanks to past high enrollment rates. The HIV epidemic will not change this. Indeed, if more-educated people are more likely to change their behavior, or if they are more likely to receive medication for their infections, HIV could increase proportion of the population with higher education even more. By 2020, In Mozambique, the proportions of people with secondary and tertiary education will also rise because of improvements in school enrollment, although the overall level of education will remain far behind that of Botswana and Namibia.

Secondly, in the simulations below on policy interventions for Botswana and Namibia, we assumed that more highly educated adults are 1) more likely to change their behavior and 2) more likely to receive antiretroviral treatment[11]. This produces a second bias in favor of urban populations. We include this bias in the simulations presented in Table 5. In the Behavior Change scenarios for Botswana and Namibia, the HIV incidence drops 25 percent (compared to what it would be without change) among adults with primary education, 40 percent among those with secondary, and 50 percent among those with tertiary education. In the Medication scenarios, antiretroviral treatment for those who develop AIDS symptoms rises from 0 in 2001 to 30 percent in 2004 among adults with primary education; 45 percent among adults with secondary; and 60 percent among those with tertiary. The infectivity reduction is set at .9, regardless of education. For comparison, the No Change scenario from above is included in Table 5 with the results.

In the Continuation scenarios, the urban population of Botswana rises from 784 thousand to 848, while the rural population declines from 762 thousand to only 602. As a result the proportion urban increases from .51 to .58. Similarly in Namibia, the urban population rises, from 810 thousand to 1.045 million, while the rural population declines. The proportion urban in Namibia grows from .44 in 2001 to .55 in 2020. The reason the urban population grows in these scenarios is because of inflow from the rural areas to replace those who die of AIDS (in the absence of such migration, the urban populations would decline). Meanwhile, the rural population is severely depleted because it is doubly hit by out-migration of the better-educated adults and AIDS deaths.

The two policy intervention scenarios, Behavior Change and Partial Medication, lead to higher populations (compared to No Change) in *both* urban and rural areas, but the urban areas receive a greater benefit. As a result, in 2020 the proportion urban in Botswana is .59 in both policy intervention scenarios compared to .58 without intervention, and .56 in Namibia as compared to .55. These differences, while they appear small, do mean the urban areas experience thousands of AIDS deaths fewer and the rural areas thousands more, simply because of the bias. These scenarios are only one of an infinite set of potential combinations of biased or unbiased responses to policies and as such are only an indication of the possible direction of changes. It is, however, likely that there is some urban bias in the policy response (perhaps more, perhaps less than we assumed here).

[11] The present version of the Mozambique model does not allow this differentiation.

Table 5. Urban population, rural population, and percentage urban in Botswana and Namibia, 2001 and 2020 in the Continuation scenario, and two policy scenarios with stronger policy impacts on groups with higher education.

Botswana

Population in 1000	Urban population	Rural population	Percent urban
2001	784	762	.51
2020			
Continuation	848	602	.58
Behavior Change	919	631	.59
Partial Medication	929	639	.59

Namibia

Population in 1000	Urban population	Rural population	Percent urban
2001	810	1011	.44
2020			
Base	1045	852	.55
Behavior Change	1123	893	.56
Partial Medication	1124	898	.56

5 Discussion

Policy-makers in Africa have generally been slow to responding to the enormous challenge facing them because of the HIV/AIDS pandemic. In a short while, their task will be made much more complex. It is possible that as early as next year (2002), there is evidence of a partially effective vaccine. Questions are emerging as to what to do about the HIV medications that already exist, such as antiretroviral drugs cocktails, and how to proceed simultaneously with behavioral change programs. Donor agencies also need to make decisions about what kinds of interventions to fund.

Our goal in this paper is to help decision-makers understand their options by providing a realistic forecasting tool that allows them to see the implications of various policies and policy mixes. In essence, we have provided some of the elements of the benefit side of a cost-benefit analysis here. Other benefits are discussed elsewhere (see Sanderson et al (2001a and b) and Wils et al (2001)). The costs of various policies are changing rapidly. For the moment, we leave these for future

It is clear that extending life of sick people is a moral imperative whenever possible and therefore, the provision of antiretroviral drugs will and must proceed. Overall, life expectancy gains of .5-4.3 years were simulated with successful drug programs for Botswana, Namibia, and Mozambique by 2020. These results show that the drugs are not a panacea, even if it would be possible to make them universally available.

The best cure for HIV/AIDS is prevention. This is shown by the high gains in life expectancy when a reduction of incidence occurs. There are a number of options open to reduce incidence today, such as protection during risky sex, the treatment of non-HIV sexually transmitted diseases, and interventions to reduce vertical transmission[12]. Our simulations show life expectancy gains from a successful prevention program, similar to those in Uganda or Thailand, can be 8-24 years by 2020. Although we do not specify the types of behavioral changes in this model, other studies have shown that targeted risk-reduction is more effective than a diffuse general change (Ainsworth and Over, 1997).

It is possible that more prevention options, such as a vaccine, and a cheap method for women to protect themselves with so-called microbicides will become available in the near future. As they do so, it will be possible to include them in further simulations.

[12] Our historical simulation of Uganda shows that the prevalence decline in that country was only possible with a considerable lowering of incidence rates. The change occurred in a relatively short time, in a voluntary manner acceptable to the public.

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