

Using System Dynamics to model the HIV/AIDS epidemic in Botswana and Uganda

R. Howell¹, O. Wesselink², E. Pruyt

Delft University of Technology
Faculty of Technology, Policy and Management
P.O. Box 5015, NL-2600 GA Delft, The Netherlands

16 August 2013

¹R.J.Howell@student.tudelft.nl, ²O.J.H.Wesselink@student.tudelft.nl

Abstract

Uganda and Botswana present two interesting and contrasting cases in the AIDS epidemic. System dynamics models of the AIDS epidemic in Botswana and Uganda were created to examine the future development of the virus in both countries and evaluate existing and future policy measures. The effect of existing and new policies such as abstinence only, educational campaigns, increased availability of anti-retroviral therapy (ARTs) and condoms, and circumcision were tested on key social and economic indicators. The most effective policy in both countries is a combination of scaling up prevention of mother to child transmission (PMTCT), condom use and availability, circumcision, and ART coverage. The epidemic in Botswana seems to have leveled out; therefore, alternative policies such as circumcision will be necessary to fight HIV in the future. In Uganda there is great need for improvement in dealing with the AIDS epidemic. The model shows that HIV prevalence will increase without drastic policy measures.

Key Words: Public health, public policy, economic development, Sub-Saharan Africa

1 Introduction

1.1 Problem Description

In June 2001 Botswana president Festus Mogae when speaking about AIDS/HIV stated: “*We are threatened with extinction. People are dying in chillingly high numbers. It is a crisis of the first magnitude.*”

Sub-Saharan Africa has some of the highest HIV/AIDS rates in the world, a problem that is decreasing life expectancies, leaving children without parents, and placing significant economic burden on already developing economies. As the world watches as the tragedy of AIDS unfolds and ravages countries already often plagued with disease, corruption, poor infrastructure and health services, Uganda and Botswana present two interesting and contrasting cases in the AIDS epidemic. Botswana has the most stable and transparent government in Africa, but also one of the highest HIV rates in the world at almost 25% (UN AIDS). It is unclear why Botswana’s HIV prevalence is so high but since the prevalence rate is a percentage of the population, its high magnitude could also be attributed to Botswana’s small population. Unlike most African countries Botswana has been open about the AIDS problem and created aggressive policies to both reduce the number of infections and increase the life expectancy of those living with AIDS. While these policies have dramatically reduced the HIV prevalence, it has created a financial burden to the Botswana government. In Botswana's National Development Plan 10 (NDP 10) report, outlining government goals

through 2016, the AIDS epidemic was a large focus. In NDP 10 Botswana has set targets of annual GDP growth rates, targets that in a 2012 progress report have not been reached. The AIDS epidemic has decreased both the productivity of the workforce in Botswana and the number of working adults (also a result of the reduced life expectancy), factors that may influence Botswana's future economic growth . Although Botswana has achieved universal coverage of anti-retroviral therapy (ART) (ie: more than 80% of the population having access to ARTs), they have the challenging 2016 target of zero new HIV infections (NDP 10 Report). Since Botswana already has wide coverage of ARTs, high acceptance and use of condoms, and a relatively low birth rate, it is predicted that the HIV prevalence rate will simply level out but not exhibit the dramatic decrease experienced at the beginning of the century (Avert, 2012).

Uganda has a much lower AIDS rate at 6.7% (UN AIDS) than Botswana but a different set of problems. As the country where the first HIV case was discovered, Uganda enjoyed early success in fighting the AIDS epidemic. It is unclear however whether their early decrease in HIV prevalence was actually due to policy measures taken or due to outside factors such as deaths due to AIDS and civil war. Currently, Uganda has one of the highest population growths in the world, a phenomena which could increase the AIDS epidemic without policies directed at reducing the number of new infections. Over the last ten years the HIV prevalence rate has stayed constant/increased in Uganda. Additionally, although nearly 50% of Uganda's population is under 18, Uganda's government is encouraging the rapid population growth in the country, stating that the growth will be the country's strength rather than addressing the potential scale up of HIV infections resulting from the population increase (Avert, 2012). Much of the infected population lacks access to anti-retroviral therapy, the relatively easy treatment for mother to child transmission of AIDS (MTCT) is lacking, and wide acceptance and availability of condoms is absent. Uganda's lack of coherent policies regarding family planning and AIDS is a large cause for concern within the development community. Presently, Uganda spends a minimal amount of government spending on the AIDS epidemic; most spending is from international organizations (UN AIDS). Modeling the dramatic population growth that is expected, and the financial and societal burden that an increase in AIDS will cause can be used to foresee possible futures and to test appropriate policy responses.

1.2 Research Goals

The system dynamics model of the AIDS epidemic in Botswana and Uganda proposed here will be used to look at the key economic and social indicators of labor force, the societal burden resulting from a decreased workforce (burden per uninfected adult), the infected population, AIDS spending per person, percentage of orphans, AIDS related deaths, and the effect of AIDS on life expectancy to better visualize the effect that the AIDS has and will have on the two countries. The effect of existing and new policies such as abstinence only, educational campaigns, increased availability of ARTs and condoms, circumcision, and family planning will be tested on the key indicators.

2 Methodology

2.1 Boundaries

Although there are many ways to contract the HIV virus, this study will focus on infections resulting from sexual activity and mother to child transmission (MTCT). Also, the study only focuses on Botswana and Uganda. The dynamics of contracting the HIV virus, and later

developing AIDS is very complex and should involve several separate stock flow structures for different stages of the disease as well as different age structures. The complexity of the HIV virus was simplified for this model and the effect of early detection and treatment of HIV was left out. Since the year 2030 is a key year for Millennium Development Goals, the time span of the model is from the approximate start of the AIDS epidemic in 1980 to 2030.

2.2 The model

In figure 3.2 on the next page, the complete structure of the model is shown as it was modeled in Vensim. Some variables were given a background color, to indicate their function as a policy tool (blue) or key performance indicator (yellow). There are some hidden layers in the model that are not shown in Figure 2.1.

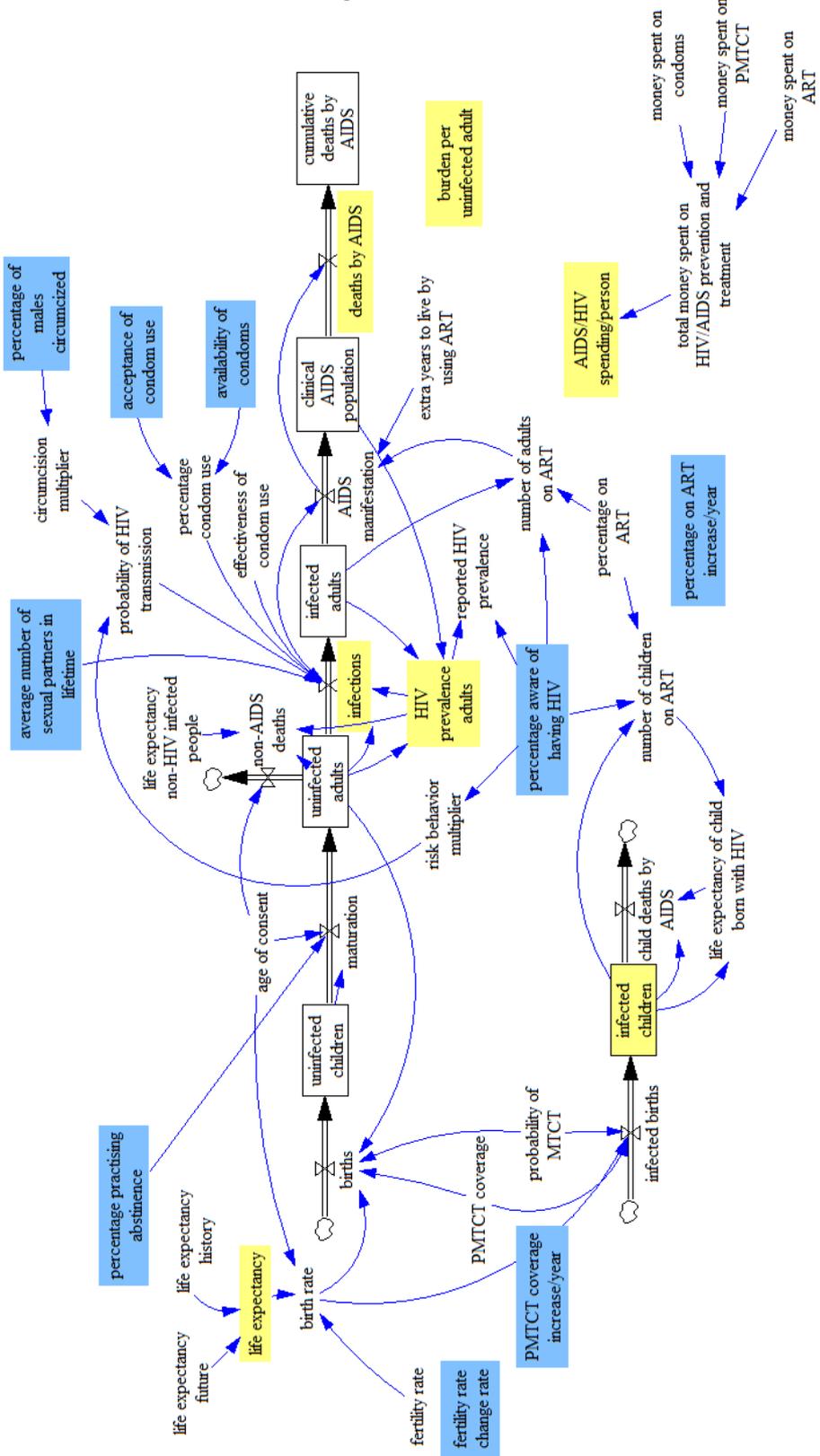


Figure 2.1 Complete System Dynamics model. Hidden variables are not shown.

2.3 Main structure

As adapted from , the main structure of the HIV/AIDS epidemiology model consists of a susceptible population stock (*uninfected adults*), from which people flow via *infections* to an HIV-infected population stock (*infected adults*), and then through an *AIDS manifestation* flow to a *clinical AIDS population* stock, after which they die (*deaths by AIDS*). Since the entire population does not die from AIDS, in addition to the Dangerfield model (which is used for HIV/AIDS in the UK), there is another outflow from *uninfected adults*, namely *non-AIDS deaths*. Also, in contrast to the Dangerfield model, *births*, *uninfected children* and *maturation* were taken into account. The main stock-flow structure can be seen in Figure 2.2.

HIV-infected adults can pass the HIV virus on to their newborn children during pregnancy, labor and delivery, or breastfeeding (if the infant comes in contact with its mother's body fluids such as blood through a cut on the breast). The passing of the HIV virus from mothers to children is called mother-to-child-transmission (MTCT) and the probability of MTCT is estimated at between 20% and 50% . In the current model, the median value of 35% was taken as the *probability of MTCT*. The most important implication of MTCT for the model structure is that it requires an additional *infected births* flow into an *infected children* stock. For simplicity, and because most of the infected children die before they mature, there was no connection made between infected children and infected adults. It was assumed that the infected children die (*child deaths by AIDS*) at an average age of *life expectancy of child born with HIV*.

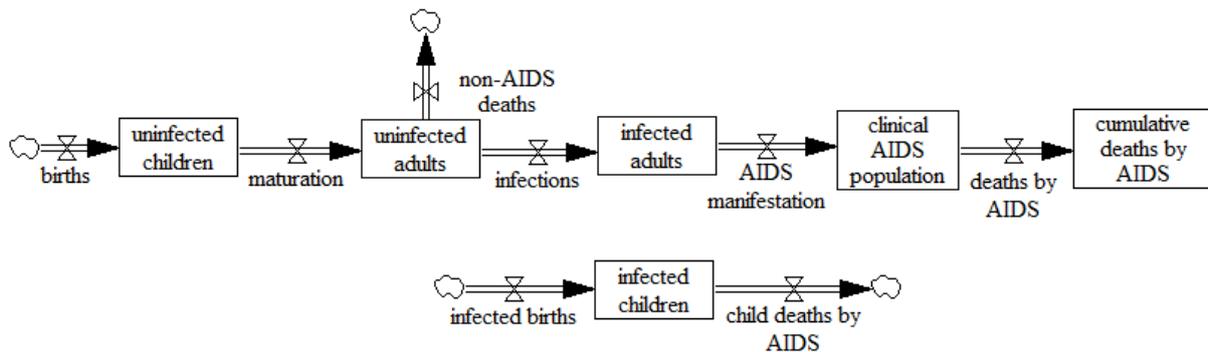


Figure 2.2 Main stock-flow structure of the HIV/AIDS epidemiology model

This model is dealing with a timespan that is partially historical and partly in the future. Variables of which the historical values are known (e.g. *fertility rate*) start as an exogenous lookup function, and continue from 2012 on endogenous variables. Therefore, a *lookup switch* was used to let the historic data overflow into the model-calculated data for the future. This *lookup switch* function goes from 0 in 2010 to 1 in 2012. Every variable that uses historic data was made up of a [*variable name*] *history* multiplied by $(1 - \text{lookup switch})$, and a [*variable name*] *future* multiplied by *lookup switch*.

Although the basic structure of the HIV/AIDS models are the same, the initial values and lookup functions for history are different for Uganda and Botswana. Besides this difference, the model works the same for both countries and could be modified for other countries with high HIV prevalence.

2.4 Infections flow

The most sophisticated and perhaps most important formula used in the model is the one used for the *infections* flow. For this formula we were inspired by the paper by ; the formula is shown below.

$$I = N_{uninf} F_{inf} \frac{N_{partners}}{A_{life} - A_{consent}} \left(1 - (1 - P_{trans}) \left(1 - F_{condom} E_{condom} \frac{N_{acts} (A_{life} - A_{consent})}{N_{partners}} \right) \right)$$

where:

I = *infections*

$A_{consent}$ = *age of consent*

A_{life} = *life expectancy*

E_{condom} = *effectivity of condom use*

F_{condom} = *percentage condom use*

F_{inf} = *HIV prevalence adults*

N_{acts} = *average number of sexual acts per year*

$N_{partners}$ = *average number of sexual partners in lifetime*

N_{uninf} = *uninfected adults*

P_{trans} = *probability of HIV transmission*

The average life expectancy of people in Botswana and Uganda lies between 50 and 60 years and for simplicity the sexually active lifetime is taken as *life expectancy – age of consent*, the latter of which a value of 17 years was used. Thus it was assumed that adults remain sexually active until they die.

2.5 Factors influencing the infections rate

It was assumed that the *probability of HIV transmission* during heterosexual intercourse is between 0.2% and 1.0% per act, depending on the degree of risk behavior. The *risk behavior multiplier* is modeled as a linear function of the awareness of HIV (*percentage aware of having HIV*). For Uganda, this percentage gradually increases from 0% in 1980 to 80% in 2012, following an asymptotic curve. For Botswana, the percentage aware of having HIV in 2012 was assumed to be 90%. Since this is a strong assumption, sensitivity testing on this variable was performed (see section 4: Validation).

Circumcision lowers the *probability of HIV transmission* by 60%. A higher *percentage circumcised* therefore serves as a policy tool to lower the infections rate. Another important factor is *percentage condom use*, in the current model calculated by *acceptance of condom use times availability of condoms*. The *effectiveness of condom use* was shown through research to equal 80%. Finally, the *average number of sexual partners in lifetime* was set to 4.5 and the *average number of sexual acts per year* was calibrated to 100, to fit the actual infections rate data.

2.6 Treatment of HIV

As of 2004, anti-retroviral treatment (ART) has become available to lengthen the incubation time of HIV . In other words, ART postpones the manifestation of AIDS symptoms in HIV patients. Before ART became available, the average incubation time of HIV was estimated at 8 years . The value of the variable *extra years to live by using ART* is uncertain and cannot be proven since the treatment exists for only 9 years now. A value of 20 years was taken as a starting point since it results in the closest fit of the model-calculated deaths by AIDS with the numbers of deaths by AIDS reported by the .

With the introduction of ART, MTCT can also be prevented. An increase in prevention of mother-to-child-transmission (PMTCT), e.g. a higher *PMTCT coverage*, leads to a lower rate of *infected births*.

The World Bank provides data for the development of the *percentage on ART* and *PMTCT coverage* . From 2012 on, different future scenarios can be tested by adjusting the values of *percentage on ART increase/year* and *PMTCT coverage increase/year*. For the base run, a status quo was simulated by setting these values to 0%.

2.7 Life expectancy

The historic data of life expectancy in Uganda and Botswana is known, and it can be observed in earlier years that life expectancy declines when HIV prevalence increases. Since life expectancy serves as an important performance indicator, there is a need to acquire values for future life expectancies dependent on HIV prevalence. By reasoning, a function for life expectancy can be obtained in which the total population is divided by the total number of deaths per year:

$$\textit{life expectancy future} = \frac{\textit{total population}}{\textit{total deaths per year}}$$

After comparing the course of this function to actual life expectancy data, it was observed that this function follows the pattern of history closely. However, the value of this endogeneously calculated life expectancy was at every point higher than the actual life expectancy. After calibration of *life expectancy history* with *life expectancy future*, a multiplier with a value of 0.73 was found for Uganda that corrects for the unwanted upward shift. The result can be seen in Figure 2.3. The multiplier also worked for the Botswana data.

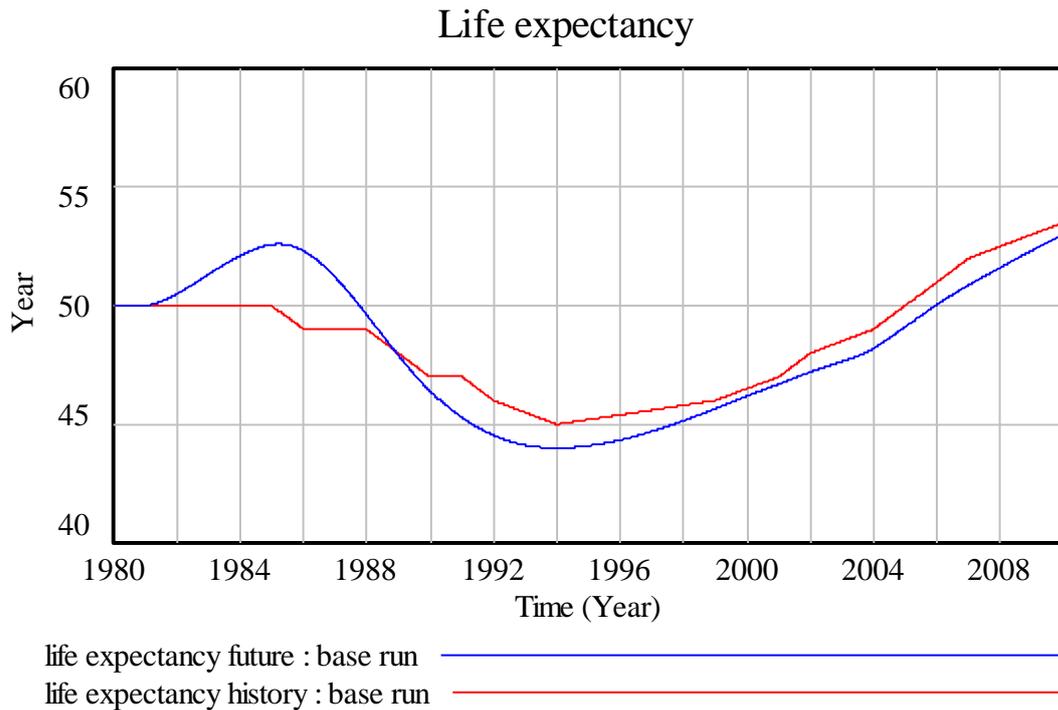


Figure 2.3 Comparison of life expectancy history and model-calculated life expectancy

2.8 Abstinence

Abstinence is considered an important policy in fighting AIDS, especially in Uganda. Young people are promoted to practice abstinence, i.e. to save sex for marriage and to stay with only one partner during their lifetime. Although “abstinence only” is controversial among the development and international community, it is strongly promoted by the Ugandan government. Therefore, a structure was added to the model in which a variable percentage of children flow to an *abstinent population* after maturing (see Figure 2.4). The assumption was made that people in this *abstinent population* will never get HIV. Initially, the *percentage practising abstinence* was set to 0%.

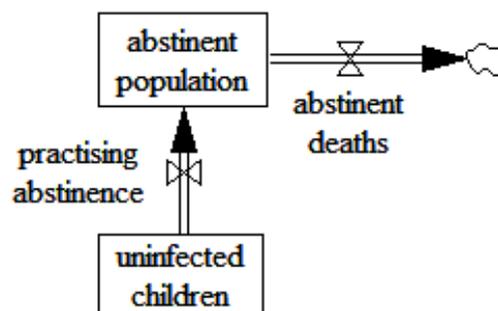


Figure 2.4 Structure for abstinent population

2.9 Financial burden of HIV/AIDS

All measures to fight the HIV/AIDS epidemic cost significant money either from governmental or private sources. This includes money for ART and PMTCT, and money for making condoms more available. Numbers for the costs of these measures are estimated based on different sources or guesses, to examine how different policy measures increase financial burden. Since the costs are estimates a sensitivity analysis was performed to examine how changes in the estimations affect model behavior (see section 4: model behavior).

2.10 Burden per uninfected adult

The burden per uninfected adult is a performance indicator calculated by:

$$\frac{\text{infected adults} + \text{infected children} + \text{uninfected children} + \text{clinical AIDS population}}{\text{uninfected adults} + \text{abstinent population}}$$

In short, it divides the help-demanding population by the help-giving population.

3 Validation

3.1 Comparison with real data

The most logical first validation test would be a comparison between the numbers obtained by running the model and the numbers found in databases. As a first test, the reported HIV prevalence in Uganda was compared (see Figure 3.1) and corresponds well with existing data.

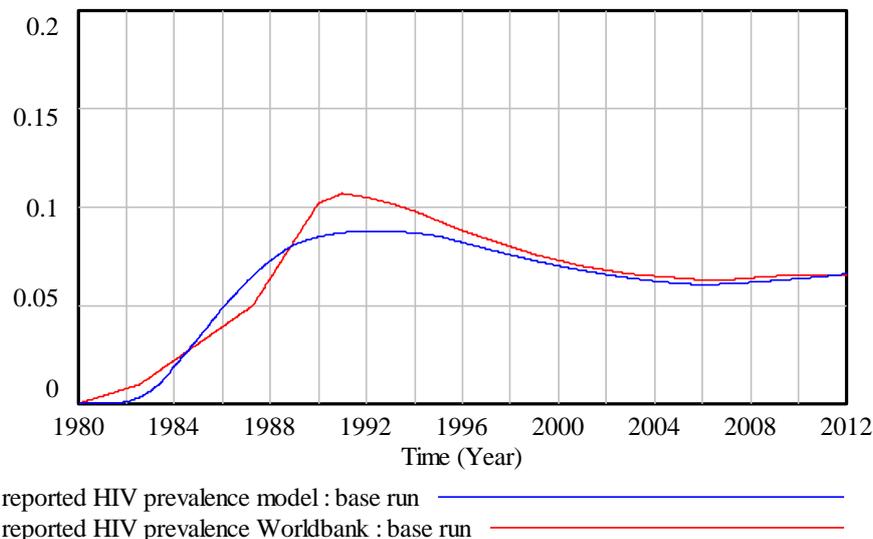


Figure 3.1 Comparison of model-calculated HIV prevalence and actual HIV prevalence in Uganda

Variables were compared with actual data, for both Uganda and Botswana, and the overall fit between the model and the available statistics was sufficient for exploratory and policy analysis within the model.

3.2 Extreme value testing

Since the effect of changes to the system on future outcomes is important, extreme value testing was done to check for unrealistic behavior. The Botswana model was used for an extreme value test in which all policies are suddenly ceased in 2010, by setting the availability of condoms, ARTs, and PMTCT to zero. As expected, the model-calculated *infections* go up drastically in response to this cease of policies (Figure 3.2).

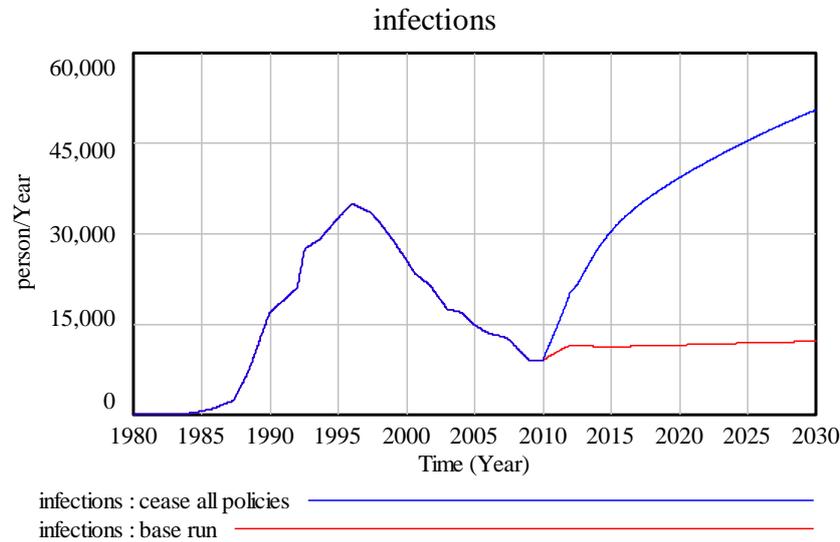


Figure 3.2 New infections per year in Botswana after ceasing all HIV policies

3.3 Sensitivity analysis

One of the most uncertain parameters in the model is *percentage aware of having HIV*; therefore a sensitivity analysis was performed, using the Uganda model. Since it is a lookup function, a direct Monte Carlo simulation is not possible in Vensim. Instead, five different scenarios were tested. For every scenario, a different course of the graph for *percentage aware of having HIV* was chosen. The different lookup functions used are plotted in Figure 3.3.

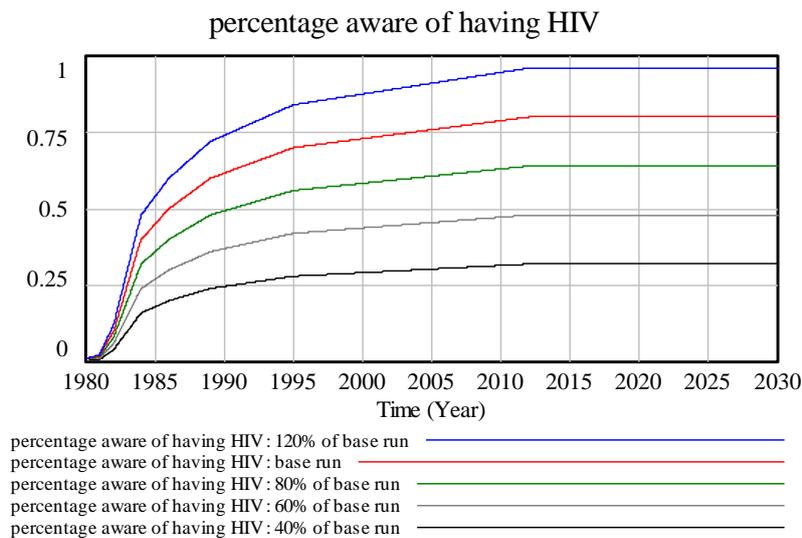


Figure 3.3 Five courses of percentage aware of having HIV for five different scenarios

The effects of these different scenarios on Ugandan society were checked by looking at the important performance indicator *infections* (Figure 3.4). Obviously, different assumptions about the uncertain parameter of *percentage aware of having HIV* (and especially its value after 2012) can have large consequences for the future behavior of the model. Although the infections flow displays similar behavior for all tested values (i.e. it shows no behavioral sensitivity), different values result in different numerical values for infections per year (it shows numerical sensitivity).

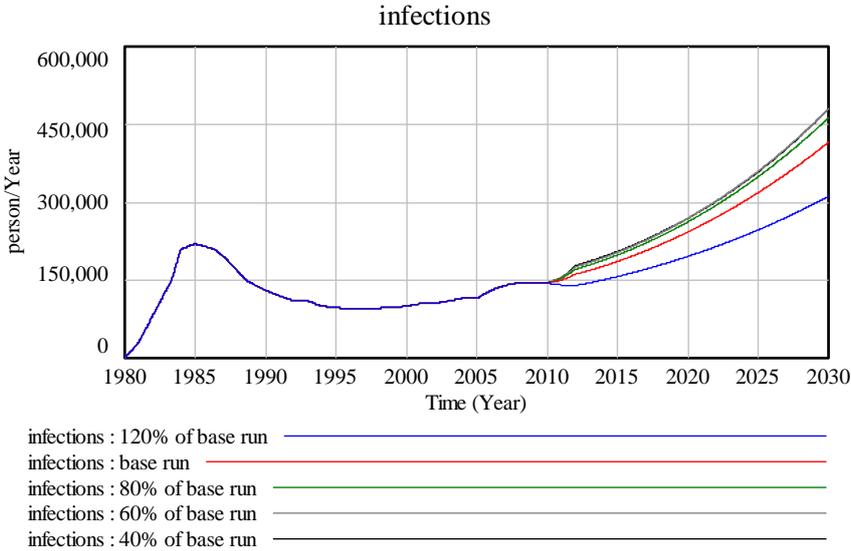


Figure 3.4 Infections flow for five different scenarios

A check for the plausibility of these scenarios can be done by looking at the graph of *reported HIV prevalence* (Figure 3.5), which is also a function of the *percentage aware of having HIV* (since people who are unaware of their HIV status may not be reported). In this graph, the historic data of reported HIV prevalence is added. The *base run* scenario (red line) matches most closely with the historical data (light blue line). The closeness of fit can be a slight justification for the use of the *base run* values for *percentage aware of having HIV* as described in the previous section on specification.

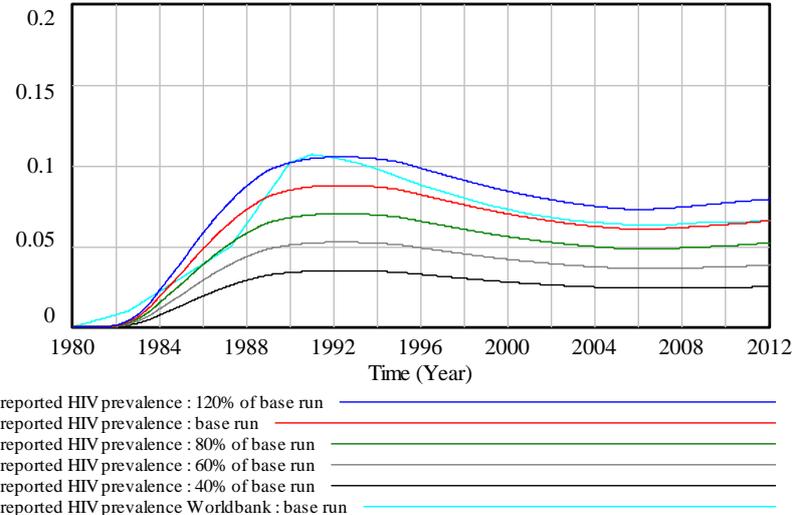


Figure 3.5 Reported HIV prevalence for five different scenarios, compared to real reported HIV prevalence as provided by WorldBank, 2012)

4 Model behavior

4.1 Infections and HIV prevalence

A Latin Hypercube uncertainty analysis is performed to check the influence of variations in values for uncertain parameters that are used to calculate the infections flow. These values also indirectly affect the evolution of HIV prevalence. A range of values (see Table 4-1) was chosen for the variables *acceptance of condom use*, *availability of condom use*, *percentage of males circumcised*, *average number of sexual acts per year*, and *average number of sexual partners in lifetime*, according to a random uniform distribution. The results are shown in figures 4.1-4.4. As shown by the graphs, the future AIDS epidemic in Uganda may dramatically increase regardless of values chosen.

Table 4-1 Parameter ranges used in sensitivity analysis

Parameter	Uganda	Botswana
Acceptance of condoms	30% – 50%	70% – 100%
Availability of condoms	30% – 50%	80% – 100%
Percentage males circumcised	0% – 20%	0% – 20%
Average no. of sexual acts per year	50 – 150	50 – 150
Average no. of partners	4 – 5	4 – 5

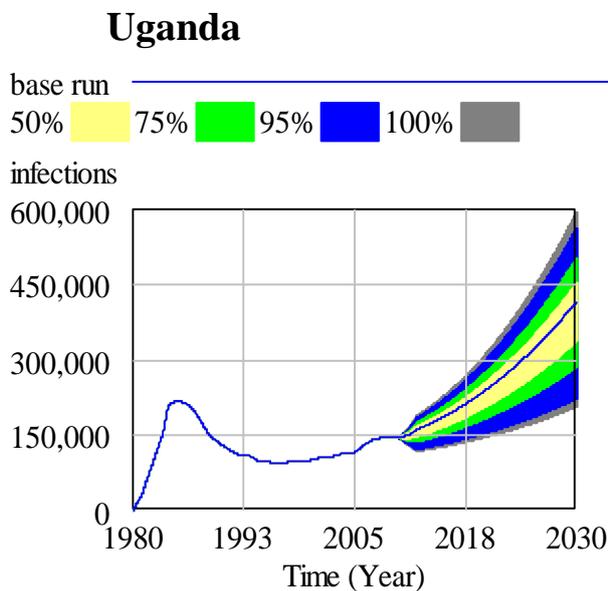


Figure 4.1 Sensitivity graph for infections in Uganda

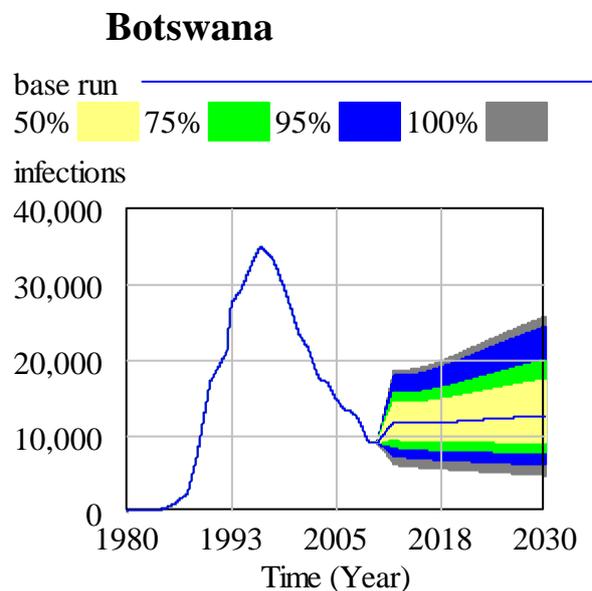


Figure 4.2 Sensitivity graph for infections in Botswana

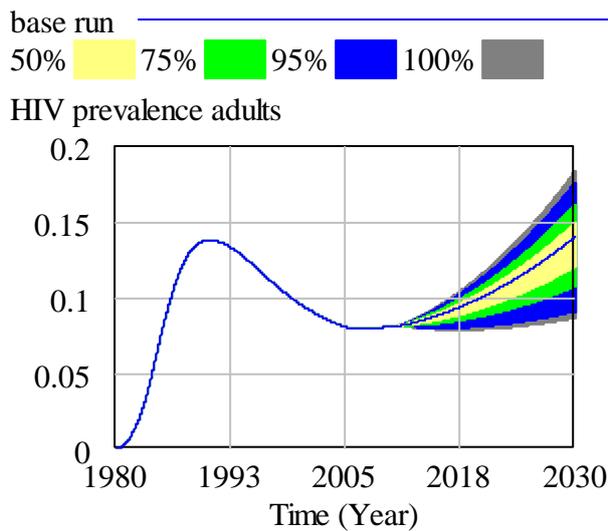


Figure 4.3 Sensitivity graph for HIV prevalence in Uganda

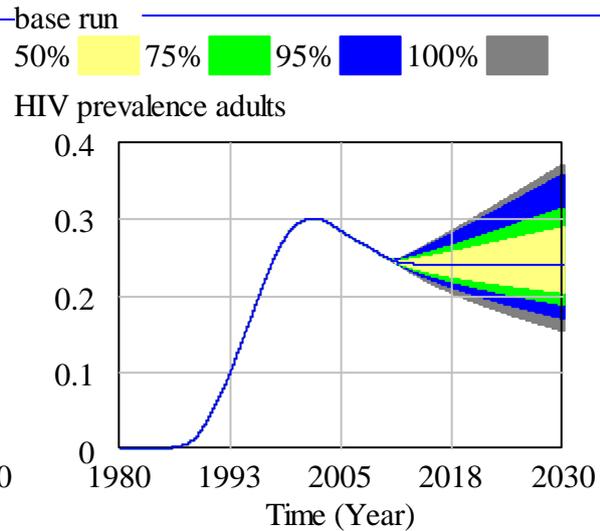


Figure 4.4 Sensitivity graph for HIV prevalence in Botswana

4.2 Financial burden of HIV/AIDS in Botswana

The exact costs of HIV/AIDS prevention and treatment practices are not known, so an uncertainty analysis was performed on the values determining these costs, using the ranges depicted in Table 4-2. The sensitivity graph for Botswana is shown in Figure 4.5. The estimated spending per capita lies between 75 and 125 US dollars per year, and will increase slowly in the next 20 years if there is no major change in HIV prevalence. The average values for the costs of HIV/AIDS prevention and treatment practices were used in the rest of the analysis.

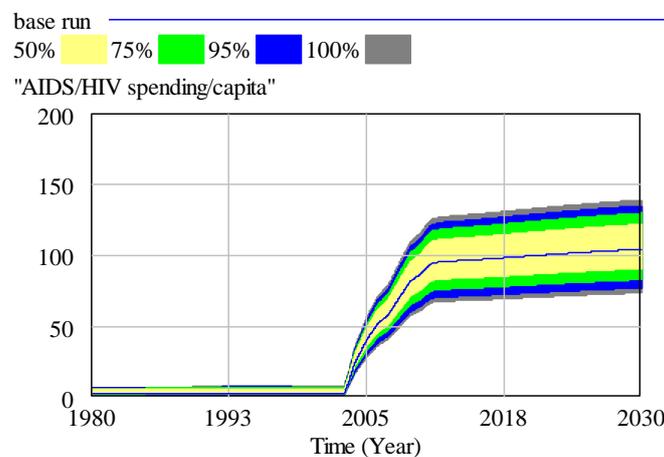


Figure 4.5 Sensitivity graph for AIDS/HIV spending per capita (US dollars per year) in Botswana

Table 4-2 Parameter ranges used in sensitivity analysis

Costs in US dollar per person per year

Condoms	3 – 15
ART	500 – 1000
PMTCT	1500 – 2500

Since the availability of ART, PMTCT and condoms is already close to 100% in Botswana, the future spending on HIV/AIDS is highly dependent on the HIV prevalence in the future; therefore sensitivity analysis was also done on HIV/AIDS spending/capita in Botswana, using the same range of values on the same parameters as for the infections and HIV prevalence sensitivity graphs (Figure 4.6).

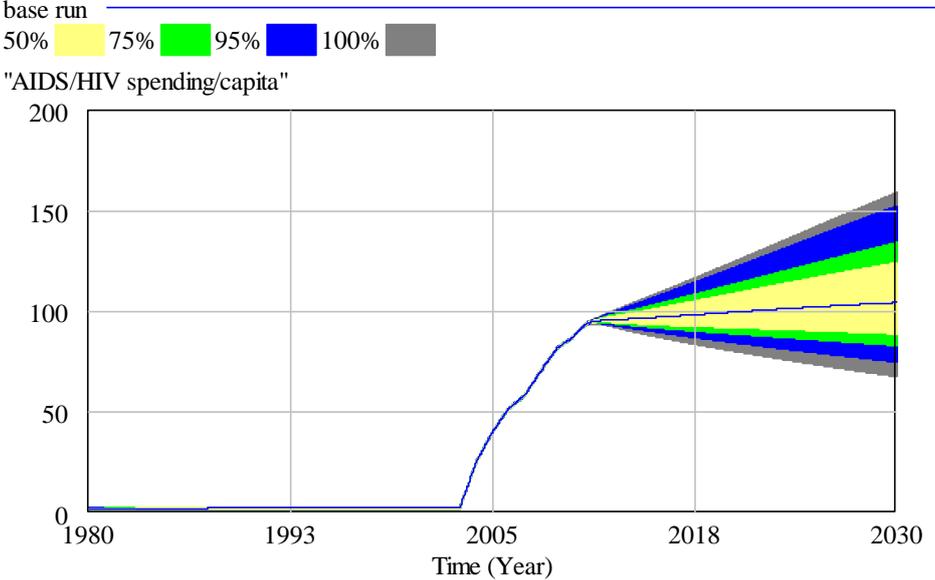


Figure 4.6 Sensitivity graph of AIDS/HIV spending per capita (US dollar per year) in Botswana

4.3 Infected children

The uncertainty analysis for infected children shows that without policy measures the number of infected children in Uganda will increase (Figure 4.7).

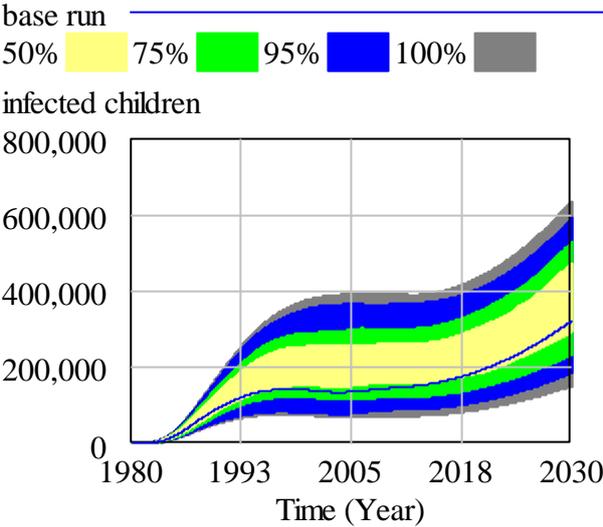


Figure 4.7 Sensitivity graph for infected children in Uganda

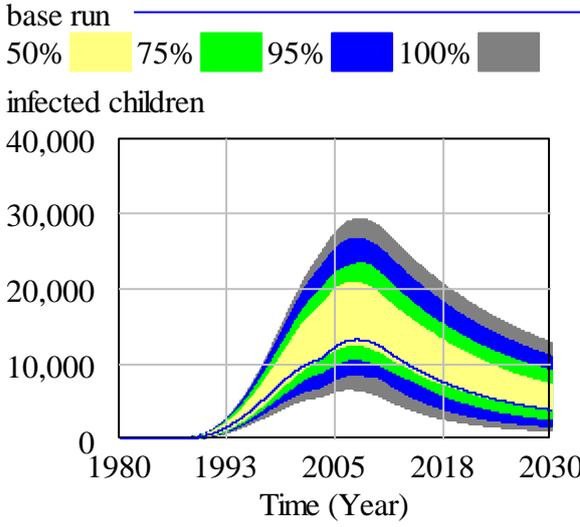


Figure 4.8 Sensitivity graph for infected children in Botswana

5 Policy Analysis

In the past and present, both Uganda and Botswana have been hailed as success stories in their reduction of HIV prevalence. In the early 2000s Botswana aggressively attacked the AIDS problem through a combination of international and governmental funding, resulting in a decrease of new infections and HIV prevalence. Both Botswana and Uganda have promoted the policy of ABC—Abstinence, Be Faithful, and Condom Use. In recent years Uganda has focused mainly on the abstinence portion of this policy, a move that has drawn much criticism from the international community (Avert, 2012). Some studies speculate that the focus on abstinence only has resulted in Uganda’s increase in total infected population and constant HIV prevalence rate over the last ten years.

Another new area in AIDS research is the effect of circumcision on the spread of AIDS. New studies have shown that circumcision can reduce the chances of contracting HIV by approximately 60% (WHO, 2012). The effect of circumcision on the epidemiology of AIDS was tested here to evaluate its effectiveness as an AIDS reduction policy.

Lastly, three other crucial policy responses are deployment of ART, the prevention of mother to child transmission, and reduction of fertility rate (more applicable for Uganda). Full availability of ART and Prevention of MTCT have almost been achieved in Botswana, but in Uganda treatment is lacking; therefore one appropriate policy response would be to scale up ART and PMTCT services. Also for Uganda, creating national family planning policies to reduce the astronomical population growth has potential to decrease the HIV prevalence. Currently, contraceptive use and availability is extremely low (WHO, 2012). Unfortunately, due to the non-ideal way of modeling delays in population flows, and the lack of a distinction between different age groups in the adult population, the current model is not suited to test this policy appropriately.

Table 5-1 Values used for policy variables

Values used in policy analysis	Uganda	Botswana
Abstinent population	30%	30%
Acceptance of condoms	90%	100%
Availability of condoms	90%	100%
Percentage males circumcised	80%	80%
Average no. of partners	3	3
ART increase	NA	5%
PMTCT increase	NA	5%

To test policies, realistic values were chosen for the various policy variables. Since abstinence only is a highly controversial policy, the percentage of those practicing abstinence was set to 30%. As shown in the following figures abstinence has a positive impact on reducing infections, and a low cost per person. The number of partners was reduced from 4.5 to 3 to test the policy of promoting faithfulness. Condom use was tested with different values for Botswana and Uganda since Botswana already has high availability and acceptance. Acceptance and availability were set to 100% for Botswana and 90% for Uganda (a big

increase from the current value of 40%). For both countries the percentage of the male population circumcised was set to 80%. Lastly, for Uganda, ART and PMTCT coverage was increased 5% per year. The effect of these policies on the key performance indicators is shown in the following graphs. Table 5-1 summarizes the policy values used in the policy analysis.

5.1 ABC Policies on KPIs Botswana

Infections & HIV Prevalence

Figure 5.1 shows how Botswana's new infections have mostly leveled out regardless of policies, but in order to achieve the nearly impossible target of no new infections in 2016, Botswana will need to scale up their existing policies. Figure 5.2 shows that Botswana's HIV prevalence has mostly leveled out unless all existing policies are combined and scaled up.

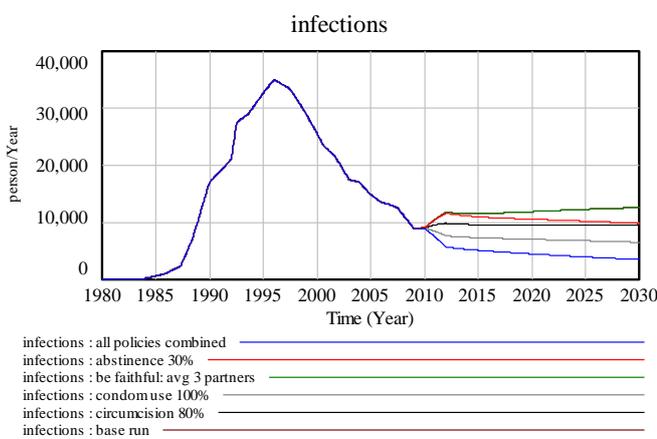


Figure 5.1 Effect of policies on new infections per year in Botswana

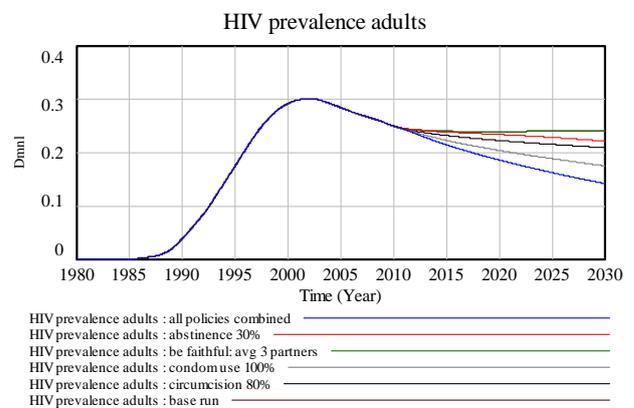


Figure 5.2 Effect of policies on HIV prevalence in Botswana

Burden per Uninfected Adult

The burden per uninfected adult shows a decrease in the future, likely due to the positive population growth in both countries. However, the curve follows a similar pattern to the HIV prevalence and number of infections.

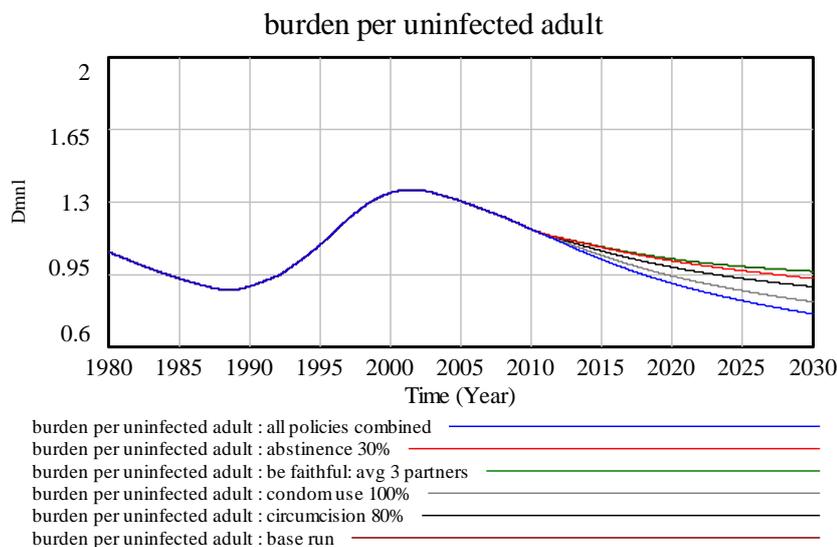


Figure 5.3 Effect of policies on burden per uninfected adult in Botswana

AIDS spending per capita

Since Botswana already spends a large portion of government money on AIDS prevention Figure 5.4 shows that there isn't a large difference in cost per person for the different policies and overall spending will go down per person.

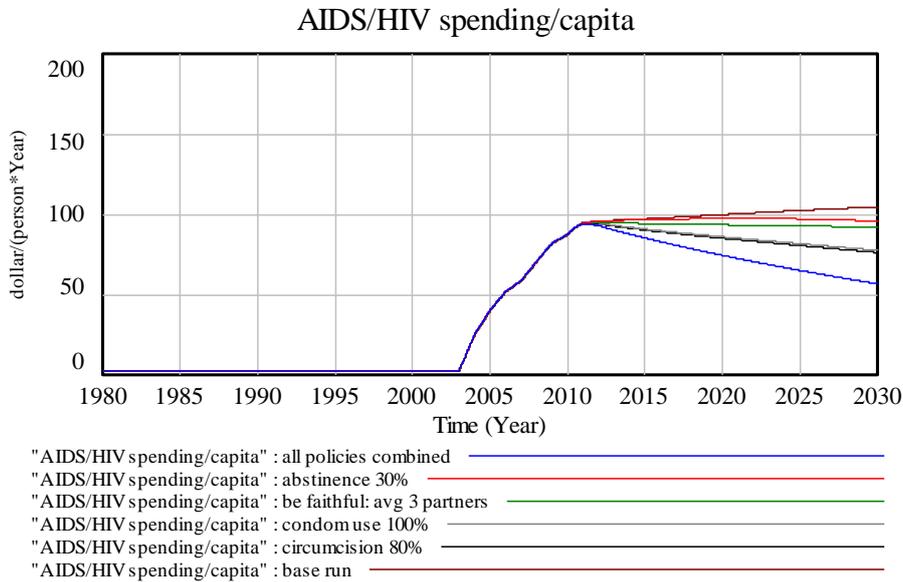


Figure 5.4 Effect of policies on AIDS/HIV spending/capita in Botswana

5.2 ABC Policies on KPIs in Uganda

Infections & HIV prevalence

Unlike Botswana, there is significant room for policy improvements in Uganda's minimal existing HIV prevention policies. Figure 5.5 shows that unless Uganda starts creating aggressive AIDS reduction policies an increase in new HIV infections could be expected.

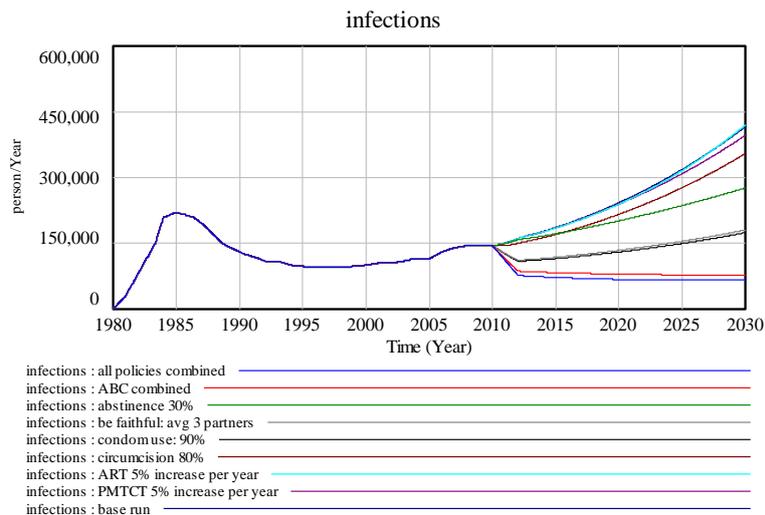


Figure 5.5 Effect of policies on new infections per year in Uganda

Similar to the results from new infections, Figure 5.6 shows that if Uganda fails to update their HIV policies the HIV prevalence will increase.

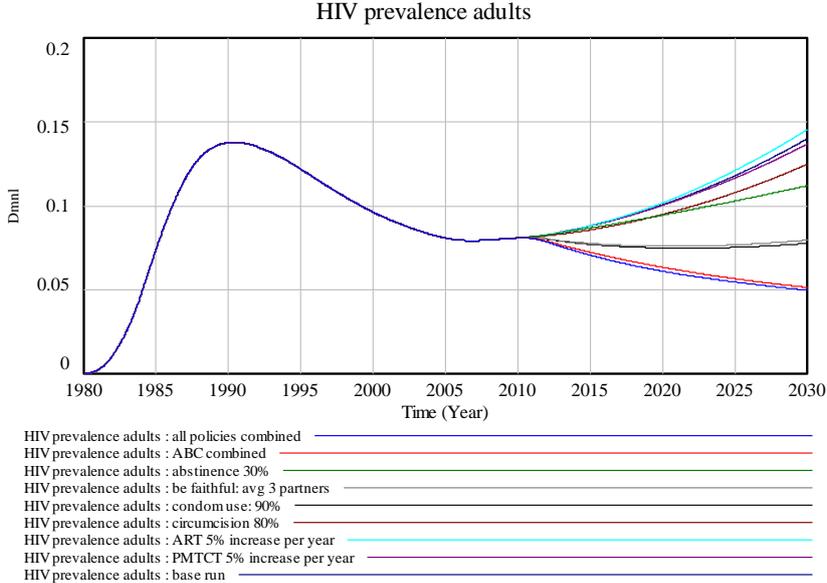


Figure 5.6 Effect of policies on HIV prevalence Uganda

Burden per uninfected adult

The burden per uninfected adult in Uganda also shows (Figure 5.7) a slow decrease in the future, probably due to Uganda’s continually growing population. However, without policy measures the decrease is less severe and mostly levels out.

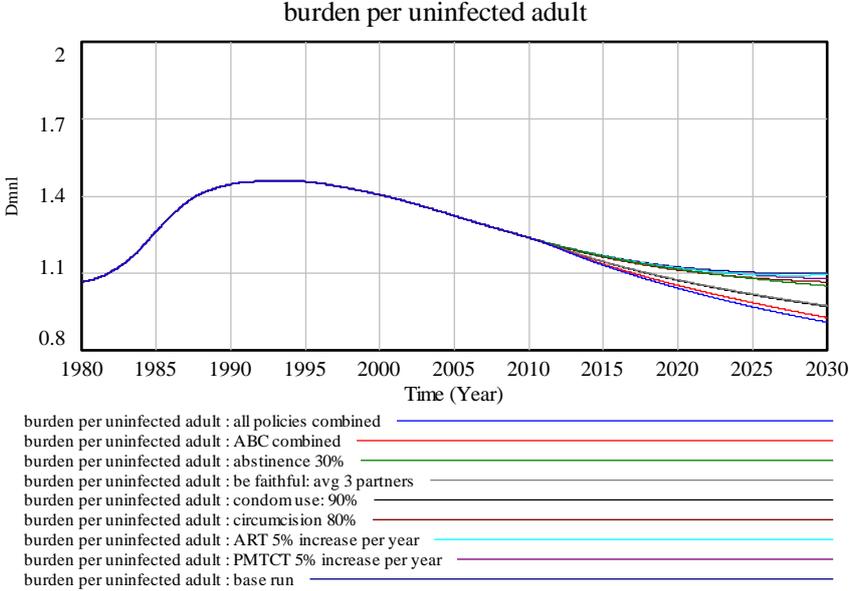


Figure 5.7 Effect of policies on burden per uninfected adult in Uganda

AIDS spending per capita

Conversely to Botswana, Figure 5.8 demonstrates that AIDS spending in Uganda will increase (again could be attributed to the population increase). In particular, increasing coverage of ARTs (an expensive treatment option) will greatly increase spending. The need for more AIDS spending in Uganda predicted by experts is matched by the behavior of this model.

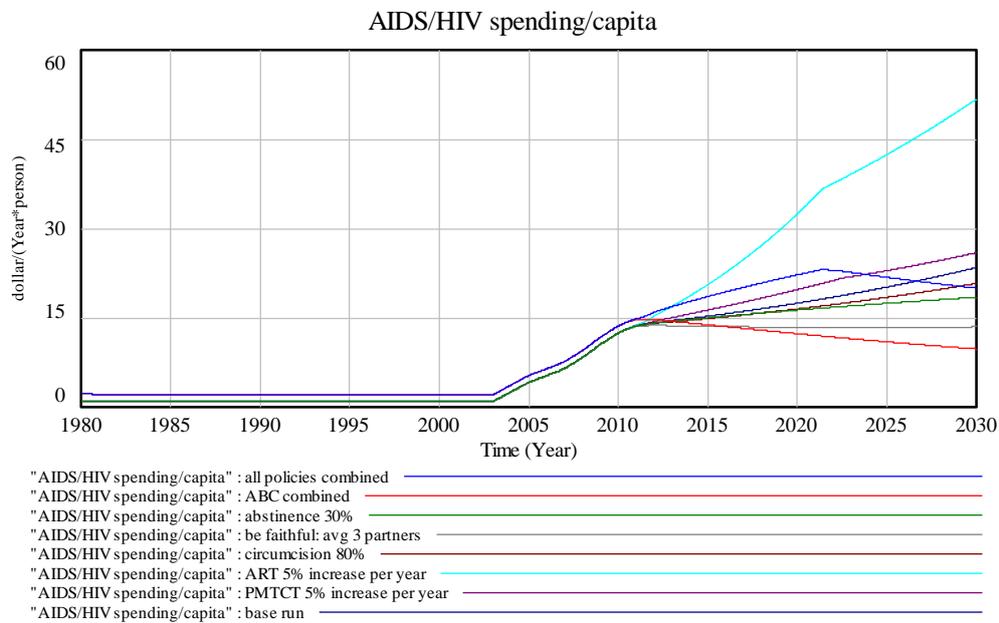


Figure 5.8 Effect of policies on AIDS/HIV spending per capita (US dollar per year) in Uganda

Deaths by AIDS

Since Uganda does not have universal coverage of ARTs it is interesting to examine how the deaths by AIDS flow changes given changes in policies. Like the previous graphs Figure 5.9 shows how the most effective policy is a combination of AIDS prevention measures (blue line).

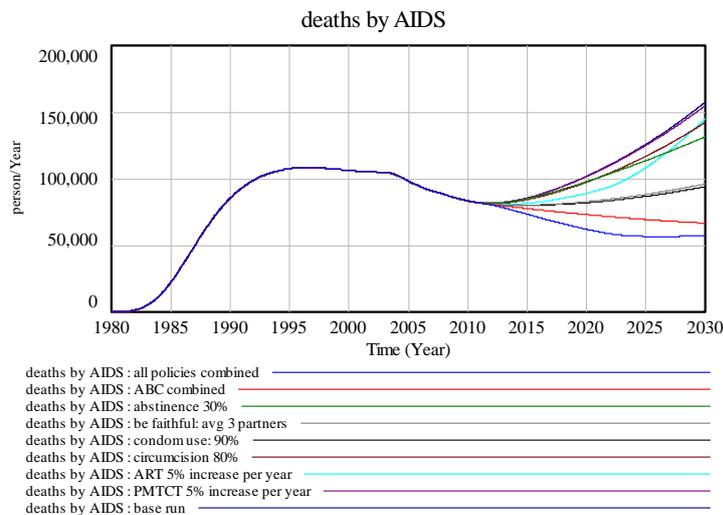


Figure 5.9 Effect of policies on deaths by AIDS in Uganda

Infected Children

Uganda has very low PMTCT coverage, therefore the effects of increasing PMTCT or simply increasing AIDS prevention has large impacts on the growth of infected children (shown in Figure 5.10).

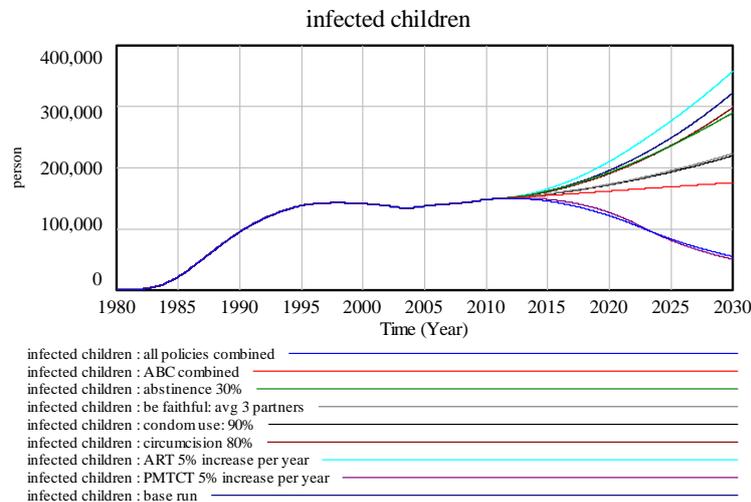


Figure 5.10 Effect of policies on number of infected children in Uganda

5.3 Policy Conclusions

As expected, the AIDS epidemic in Botswana has leveled out and even with increased policy action the, positive effects on the epidemic will not be as pronounced. Maximizing existing policies and introducing new policies such as circumcision will assist Botswana in reaching the unlikely goal of no new infections by 2016.

As exhibited consistently in the model behavior, the AIDS epidemic in Uganda is going to increase and will only slow given strong policy action. In a more positive light, since Uganda is lacking strong and effective prevention policies there is significant room for expansion in the AIDS fight. If Uganda combines all existing policies and introduces circumcision, the HIV prevalence will decrease and other negative effects of the epidemic will be less pronounced.

6 Conclusions and Discussion

6.1 Conclusions & Recommendations

Based on the model behavior several conclusions can be made regarding the dynamics of the future AIDS epidemic and appropriate policy responses. It seems likely that the HIV prevalence and number of infections in Uganda will increase. Although the popular policy in Uganda of abstinence shows some improvements in the key performance indicators, it is difficult to appropriately test since it depends on the assumption of the percentage of people who are actually practicing abstinence. The most effective policy in both countries is a combination of scaling up PMTCT, condom use and availability, circumcision, and ART coverage. For Botswana the effects of scaling up HIV prevention are not as extreme since universal coverage of PMTCT and ARTs have already been reached. It might be useful for Botswana to invest more in new prevention methods such as circumcision on top of existing policies. In Uganda there is much room and need for increased development in addressing the

AIDS epidemic. Universal coverage of ARTs and PMTCT has potential to slow the AIDS epidemic in Uganda but currently coverage is severely lacking. Additionally, as Uganda's population increases, redirecting HIV prevention away from simply abstinence only will be essential in order to address the potential increase in infections and HIV prevalence.

Lastly, all policy efforts to fight AIDS come at a cost. Botswana already invests significant funds in HIV prevention but the difficulty in the future will be balancing the social cost that the AIDS epidemic presents with the economic burden it places on a country that seeks to slow the reach of the virus. Furthermore as international aid will possibly decrease in the coming years with the advent of the global financial crisis, as a result, both Uganda and Botswana will feel an increased financial burden due to AIDS. In order to stop the inevitable spread of the virus Uganda will certainly need to expand HIV treatment and prevention and Botswana will need to begin reevaluating existing policies for both their effectiveness and affordability, rather than solely letting the government absorb the cost of AIDS.

Ultimately, the devastating effect of AIDS on the social and economic development of Botswana and Uganda creates the need for both countries to radically attack the spread of the virus through concerted policy efforts. In addition to simply improving implementation of existing and new HIV prevention policies, focusing on reducing the fertility rate in Uganda could have a positive impact on the development of HIV. Finally, although Botswana has been praised for their success in reducing HIV, future improvements to meet their set targets will be difficult and increasingly costly to the government.

6.2 Future research

In the current model, different methods were used to model outflows from the population stocks. In some cases, a first-order delay was used, while in other cases the value of the stock was divided by the average time after people leave the stock. The inconsistency in modeling outflows was necessary for the current model to function, but is not ideal.

Another limitation of the current model is that there is only one stock for adults, meaning the fact that partners are usually about the same age is not taken into account. It is assumed that 17 year olds will have sex with 50 year olds, as frequently as 24 year olds will have sex with 24 year olds. In a more sophisticated model, a split up of the adult population into different age groups is recommended. The two limitations of the current model explain why the effects of family planning policies (as discussed in chapter 6) cannot be tested reliably. A fix of both limitations in a future study would solve these problems and broaden the possibilities for policy testing.

Furthermore, the HIV/AIDS epidemic has huge effects on the labor force and ultimately productivity of a country. Using the Cobb-Douglas production function as a guide to examine how changes in labor force and productivity affect GDP growth, future work on the dynamic of GDP/capita with respect to AIDS should be done. Since both Botswana and Uganda have high growth rates as their economies are still growing, it would be valuable to explore how AIDS will affect their future economic growth.

Another important aspect of AIDS prevention and treatment that was overlooked in this model is the timely testing and follow-up treatment of potential HIV positive people (Highly Active Antiretroviral Therapy-HAART). In Uganda, availability of testing services is extremely low and an increase in testing could have a positive impact on reducing the HIV prevalence (or conversely cause an increase in the reported HIV prevalence). For future

models adding an additional stock-flow structure to model HIV testing and HAART treatment would provide a more thorough policy analysis of the AIDS epidemic.

Much of HIV research has focused on prevention and treatment but steered away from the possibility of a cure for AIDS. It could be beneficial to examine the social and economic effects of curing AIDS in Uganda and Botswana since a cure for AIDS could not only positive but negative effects (with regards to un-damped population growth) on the future development of both countries.

Finally, since many of the values and assumptions used in this analysis are highly uncertain and should be tested under deep uncertainty, future work will be done using the Exploratory Modelling and Analysis (EMA) tool developed by E. Pruyt and J.H. Kwakkel.

7 References

- Avert. (2012). *The HIV and AIDS epidemic in Africa*. Retrieved from <http://avert.org/AIDS-hiv-africa.htm>
- Auvert, Bertran, Dirk Taljaard, Emmanuel Lagarde, Joëlle Sobngwi-Tambekou, Rémi Sitta, and Adrian Puren. "Randomized, Controlled Intervention Trial of Male Circumcision for Reduction of Hiv Infection Risk: The Anrs 1265 Trial." *PLoS Med* 2, no. 11 (2005): e298.
- Boily, Marie-Claude, Rebecca F. Baggaley, Lei Wang, Benoit Masse, Richard G. White, Richard J. Hayes, and Michel Alary. "Heterosexual Risk of Hiv-1 Infection Per Sexual Act: Systematic Review and Meta-Analysis of Observational Studies." *The Lancet Infectious Diseases* 9, no. 2 (2009): 118-29.
- Dangerfield, Brian, and Carole Roberts. "A Role for System Dynamics in Modelling the Spread of Aids." *Transactions of the Institute of Measurement and Control* 11, no. 4 (November 1, 1989 1989): 187-95.
- De Cock, K.M., M. Fowler, E. Mercier, I. De Vincenzi, J. Saba, E Hoff, D.J. Alnwick, M. Rogers, and N. Shaffer. "Prevention of Mother-to-Child Hiv Transmission in Resource-Poor Countries: Translating Research into Policy and Practice." *JAMA: The Journal of the American Medical Association* 283, no. 9 (2000): 1175-82.
- Johnson, Leigh. "An Introduction to the Mathematics of Hiv/Aids Modelling." In, (2004). http://www.commerce.uct.ac.za/Research_Units/CARE/RESEARCH/PAPERS/Maths_Intro.pdf.
- Lule, Elizabeth, and Markus Haacker. *The Fiscal Dimension of Hiv/Aids in Botswana, South Africa, Swaziland, and Uganda*. Washington, D.C.: The World Bank, 2012.
- Weller, S. C., and K. Davis-Beaty. "Condom Effectiveness in Reducing Heterosexual Hiv Transmission." *Cochrane Database of Systematic Reviews* 2007, no. 4 (2007).
- WorldBank. "World Databank: World Development Indicators (Wdi) & Global Development Finance (Gdf)." The World Bank Group, 2012.