

Evolution of HIV/AIDS in Southern Africa

L. Lauwers & E. Pruyt* & L. Hens** & J.P. Brans

*Delft University of Technology, Policy Analysis Section
Faculty of Technology, Policy and Management
P.O. Box 5015, 2600 GA Delft, The Netherlands
E-mail address: E.Pruyt@tudelft.nl

**Vrije Universiteit Brussel and Vesalius College
Schoofslaan 8, B-1160 Brussels, Belgium
E-mail address: luc.hens@skynet.be

March 20, 2008

Abstract

This paper presents a system dynamics model to study the spread of HIV/AIDS in Southern Africa. The HIV/AIDS model includes important feedback mechanisms of the spread of HIV/AIDS, and partly explains the dynamics of the epidemic in a representative Southern African country. The HIV/AIDS model indicates that prevention to reduce risk behavior is crucial in all stages of the epidemic, but is most efficient in an early stage. Financial relief is most appropriate in a more advanced stage of the epidemic.

Keywords: System Dynamics, HIV/AIDS, Southern Africa

1 Introduction

1.1 Current Status of the HIV/AIDS epidemic

AIDS is one of the most destructive epidemics in the history of humanity and claimed 3.1 million lives in 2005 alone, bringing the total number of worldwide victims -since the first reported cases in 1981- to 25 million (UNAIDS/WHO 2005). And the epidemic is far from defeated, as almost 5 million got infected with HIV in 2005. This increases the number of people living with HIV to 40.3 million, the highest ever and more than double the 1995 level of 19.9 million (UNAIDS/WHO 2005).

Sub-Sahara Africa is the hardest hit region in the world: although it accounts for a small part of the world population, the region accounts for 65% of all people living with HIV and accounts for more than 75% of all AIDS victims; 7.2% of adults are infected with HIV. The scale to which the epidemic has spread across the countries in Sub Saharan Africa varies largely.

The impact of the HIV virus is not limited to the individuals who become infected and eventually die from AIDS; HIV affects all aspects of social and economic development. Moreover, the burden of the epidemic disproportionately falls on the developing countries, which together account for over 95% of HIV infections and for 95% of the lives claimed by AIDS since the start of this devastating epidemic (UNAIDS 1999). In 1991, the United Nations predicted that by the end of the decade, 9 million people would be infected and 5 million would have died in Sub Saharan Africa; it appeared to be a threefold underestimation (UNAIDS 2000).

Whereas a handful of countries succeed in stabilizing or reversing the spread of new infections, the HIV/AIDS epidemic is still expanding and is growing out of control in most of Sub Saharan

Africa -and especially in Southern Africa. Therefore, in this paper, we will focus on the HIV/AIDS epidemic in Southern Africa.

1.2 Objectives and Method

Many studies have tried to monitor the demographical, socio-economic or macroeconomic impact of AIDS in various countries in the region south of the Sahara. Pioneering research to uncover the link between HIV/AIDS and economic growth has been done by Kambou, Devarajan, and Over (1992), Cuddington (1993), Cuddington and Hancock (1995) and Bloom and Mahal (1997). These first-generations studies take a 'cautiously optimistic view' (Gaffeo 2003, p.35) and typically show a rather small impact on the level and growth rate of GDP per capita. However, these outcomes should be taken with a pinch of salt because in the 1990s, the full scale of the HIV/AIDS epidemic was not yet acknowledged and the channels through which AIDS would affect the economy were poorly understood. More recent studies that also address the economic impact channels of the HIV/AIDS epidemic, such as Arndt and Lewis (2000) and Bonnel (2000) use more sophisticated and realistic models as the knowledge about HIV/AIDS grew. For example, Bonnel (2000) runs cross-country regressions that do take the effects on the accumulation of social capital into account. Kambou, Devarajan, and Over (1992) assess the economic implications of AIDS with a computable general equilibrium model of Cameroon in which AIDS decreases the supply of labor. Arndt and Lewis (2000) extend and refine the model by Kambou, Devarajan, and Over (1992) and incorporate the effects of HIV/AIDS on labor supply, labor productivity, total factor productivity, household spending, and government spending into their computable general equilibrium model of the South African economy. These more recent contributions point out that HIV/AIDS does have a substantial macroeconomic impact on aggregate and on per capita output.

The above studies have one thing in common: their main purpose is to provide a quantitative assessment of the (macro)economic implications posed by the HIV/AIDS epidemic. Although all of these models are firmly grounded in economic theory and undoubtedly increase the knowledge on the impacts of HIV/AIDS, they take the presence of the epidemic as a given and do not go deeper into its causes. Another interesting starting point would be to identify the causes of the rapid spread of HIV/AIDS in Southern Africa and the ways the consequences of this disease are actually linked with these causes, in other words, to include feedback, which is the objective of this study.

2 The HIV/AIDS Model

2.1 Reference Mode

The HIV/AIDS model presented here, focuses exclusively on Southern Africa, because the region is at the center of a HIV epidemic. The first cases of the HIV virus were reported in the 1980s, and therefore the starting point of the model is set in 1980. The time horizon is 50 years.

In the mid 1980s, little was known about the HIV virus and its effects. At that time hardly nobody would have predicted that the epidemic would grow out into a devastating development crisis in only a few decades. Consequently, in the early stages of the epidemic, data collection on HIV/AIDS was poor, making the start of HIV/AIDS in Southern Africa hard to reconstruct. The US Census HIV/AIDS Surveillance Data Base (US Census Bureau 2004) compiles worldwide information on HIV prevalence, HIV incidence and reported AIDS cases. For developing countries, the database lists data from small-scale surveys, mostly conducted in specific geographic areas, for different population subgroups and for small sample sizes. The HIV prevalence may vary significantly between urban or rural areas, between high- or low-risk population groups, between age groups and between sexes. The large variation together with the small scope and size of the conducted surveys make it difficult to come to reliable and comparable data for the entire population.

Whiteside (2002) and the World Bank (1997) suggest that the evolution of the HIV prevalence

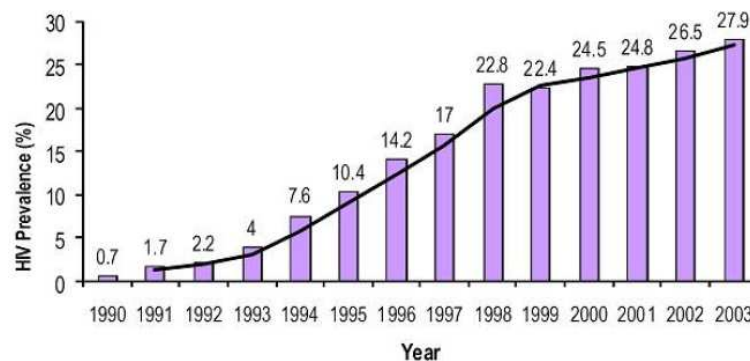


Figure 1: Prevalence of HIV among antenatal care attendees in South Africa, 1990–2003. Source: Department of Health (2003, p.6).

follows an S-shaped pattern -in its up-going phase. The prevalence level is expected to reach a peak and eventually to start declining. The UN predicts that the peak will occur between 2005 and 2010 for most countries (Nations 2004). With the current prevalence levels, it is assumed, in the reference mode, that the HIV prevalence peak will fluctuate between 25 and 30% of the population for a representative Southern African country.

In sum, in the assumed reference mode the HIV prevalence follows an S-shaped growth path, which reaches a peak between 25 and 30% and then gradually declines. Empirical data of the evolution of HIV prevalence in South Africa between 1990 and 2003 supports the S-shaped pattern (see figure 1).

This figure shows that the HIV prevalence was very low in the early 1990s. From 1994 to 1998 the epidemic rose exponentially, with an average annual growth of 2.94%. In 1999, the growth rate lowered to about 1.1% and the following years the growth rate remained low. This evolution indicates that the HIV epidemic stabilizes, not that the level of HIV infections has started to decline. On the contrary, HIV prevalence rates in South Africa are high and keep on rising (of Health 2003). These gloomy findings are confirmed in the latest UNAIDS report: in 2004, the HIV prevalence level among pregnant women reached 29.5%, the highest level ever (UNAIDS/WHO 2005).

Predictions about the decline of HIV prevalence remain guesswork. The evolution will depend on the effectiveness and intensity of the prevention measures. Time will tell how the HIV/AIDS epidemic will evolve, but as stated before, the model not only tries to understand the course of the epidemic but to use this knowledge to tackle the seemingly unbridled spread of HIV/AIDS.

2.2 Assumptions

2.2.1 HIV Characteristics

HIV prevalence is affected by the interaction of the infected population multiplier, the biological risk multiplier and the behavioral risk multiplier (see further). In the model, it is assumed that HIV transmission only occurs via heterosexual intercourse and by vertical transmission: it excludes drug use and blood transfusions. The population is divided into four age cohorts ([0-14], [15-44], [45-64] and [65+]) but is not stratified by sex, income class or degree of sexual risk behavior. A person's economic situation only feeds back into HIV prevalence via health. An additional link could be added between the economic situation and the risk behavior, when a decline in income forces people to engage in high risk behavior (sex workers, migrant workers, ...).

2.2.2 Micro-economic impact

It is assumed that the expenditures to cover the basic needs for food and shelter are constant over time. This assumption excludes price effects. Inter-temporal constraints are not modeled, and

people and governments cannot borrow or save. As a result, the household's and government's budget constraints then imply that total expenditures are exactly matched by total income. Ultimately, abstraction is made from taxes, which means that a household's average income exactly equals the disposable income. The government is not explicitly included in the model because of several previous simplifications. First, the model does not include taxes, which would leave the government without its major source of income. Second, productive investments in human or physical capital are not modeled as endogenous variables (see below), so on the side of government's expenditures similar problems would arise. Therefore, the existence and allocation of a government budget is left out altogether. However, government intervention is included in the model for the sole purpose of assessing and evaluating intervention strategies (see 4).

2.2.3 Macro-economic impact

In the model, growth of GDP is only affected by HIV/AIDS via growth of the labor force. It is assumed that HIV/AIDS reduces the pool of skilled and unskilled labor equally. Other constituents of GDP growth (growth of total factor productivity and investments in physical capital) are assumed to be unaffected by HIV/AIDS. The omission of investments in human capital (education) underestimates the impact of HIV/AIDS on GDP growth, particularly in the long run. That total factor productivity growth is assumed constant does not account for possible higher growth rates due to technological progress or higher efficiency. Physical capital remains unchanged: investments in physical capital are excluded and it is assumed that physical capital does not depreciate. The assumptions about GDP growth are highly restrictive but keep the model understandable.

2.3 The General Model Structure

The HIV prevalence is the most important variable in the model. Its level is determined by a set of key influential factors. At the same time, the HIV prevalence has a direct or indirect impact on a wide range of other variables in the model. The variables feed back into the HIV prevalence. As a result multiple feedback loops arise, that alter the HIV prevalence and related variables in a positive or negative way and give cause to complex dynamic behavior.

2.3.1 Factors that influence HIV prevalence

The HIV prevalence (ranging from 0 to 100%) is influenced by the infected population multiplier, the behavioral risk multiplier and the biological risk multiplier.

The infected population multiplier: The infected population multiplier is part of a positive feedback loop, which embodies the mechanism that the number of new HIV infections (and the HIV prevalence) rises as the population already infected with HIV grows larger. The infected population multiplier matches the description of the epidemiological determinant from the HIV/AIDS framework.

The behavioral risk multiplier: Risky sexual behavior takes many forms and can be discouraged or stimulated through multiple channels, as discussed in section 3. AIDS awareness is defined as the percentage of the population that is aware of HIV/AIDS and the protective measures against it. AIDS awareness is endogenously determined and gives shape to the ζ 'HIV/AIDS experience loop'. The mechanism behind this stabilizing loop is as follows: the higher the HIV prevalence, the more people will become aware of the existence and consequences of the disease -either from being infected themselves or from an infected relative or friend. The increased awareness in turn reduces risky behavior and tempers the further spread of HIV/AIDS.

The risky behaviour could also be reduced through preventive measures. The exogenous variable *prevention impact* represents prevention mechanisms that reduce risk behavior, such as the use of condoms and the perception of infection risk. This variable provides opportunities for assessing and designing alternative prevention measures to curb the spread of HIV/AIDS (see 4).

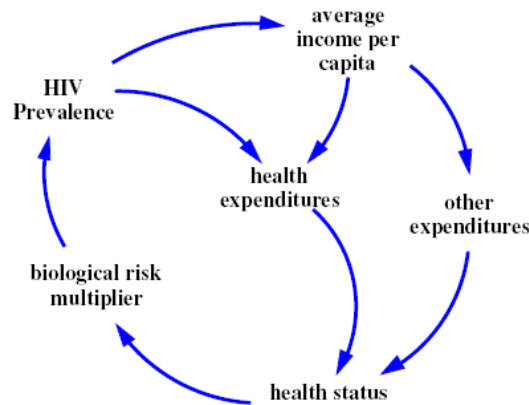


Figure 2: The biological risk multiplier

The biological risk multiplier The third multiplier is a crucial parameter that closes an important feedback loop in the model, by providing a link between the HIV prevalence and health (see figure 2). The biological risk multiplier reflects the reasoning that better health and nutrition decreases the susceptibility of the host. In short, HIV prevalence reduces the growth rate of GDP, which reduces income per capita. In a next stage, expenditures on health care increase due to higher HIV prevalence and (indirectly) due to lower income per capita (see figure 2).

Both the health care and the other expenditures -the latter serve as proxy for the standard of living- have a direct impact on health. Child mortality is used as a measure of health, as is also commonly adopted by the World Health Organization: increasing child mortality indicates a deterioration of general health conditions and vice versa. The link between health and the HIV prevalence is captured by the biological risk multiplier (see figure 2). To connect health to the biological risk multiplier, a lookup function is used. Subsequently, the biological risk multiplier affects the HIV prevalence and the feedback loop is closed.

2.4 Sub-Structures of the HIV/AIDS Model

2.4.1 Demographics

The foundations of the population dynamics in this HIV/AIDS model are based on the population structure of the World3 model (Meadows, Behrens III, Meadows, Naill, Randers, and Zahn 1974). In the population sub-structure (see figure 3), the population is divided into four age cohorts. The flows between the cohorts include the births, the deaths and the maturation from one age group to the next.

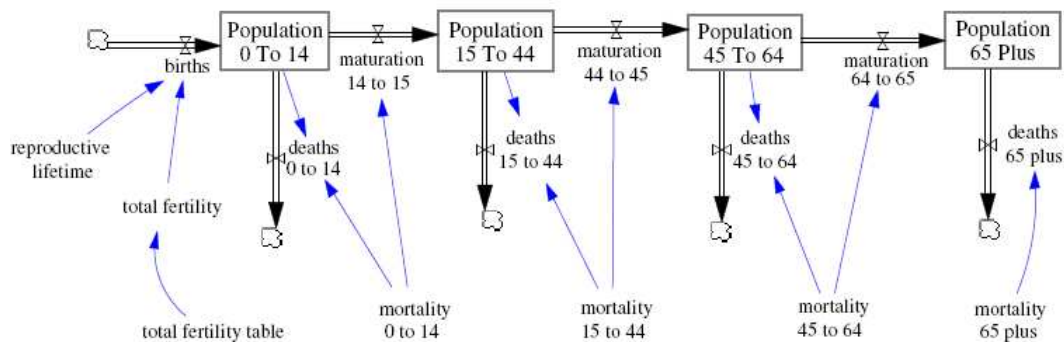


Figure 3: The population structure

The total fertility is assumed to be exogenous and thus not influenced by AIDS. However, the number of births are indirectly affected by AIDS through the changing population size: $Births = (total\ fertility * Population_{15To44} * 0.5 / reproductive\ lifetime)$. Hence, it is assumed that women constitute exactly 50% of the total population. HIV/AIDS results in higher mortality among women of the age group 15-44 and consequently, the total births are lower in an AIDS scenario. The mortality rates for the different age cohorts depend on the life expectancy, and this relationship is captured by four age-specific lookup tables, with values equal to those used in the World3 Model. To incorporate that HIV/AIDS increases mortality, the life expectancy is multiplied by an 'AIDS lifetime multiplier', directly linked to the HIV prevalence.

To express that HIV/AIDS selectively 'targets' the two middle age categories (15- 44 and 45-64), an additional factor is included: AIDS life expectancy is replaced by two new variables: the 'high AIDS life expectancy' and the 'low AIDS life expectancy'. In addition, the AIDS lifetime multiplier is split up in a high and a low variant: the HIV/AIDS virus alters the life expectancy of the age groups [15-44] and [45-64] more severely than for the other age groups.

The population's health also influences the life expectancy. To include this link, follow a similar approach as for the link between HIV prevalence and life expectancy. The health lifetime multiplier (recorded in a lookup table) links the health status to the life expectancy. The underlying mechanism is easy to comprehend: the health multiplier raises the life expectancy when health improves.

This part of the model structure also allows for the calculation of the cumulative AIDS deaths, albeit in an indirect way. In a first step, the deaths for the age cohorts are re-calculated. To rule out the effects of HIV/AIDS on mortality at this point, the life expectancy (instead of the low and high AIDS life expectancy) directly influences the different mortality rates. The sum of all deaths in this non AIDS scenario represents the total non- AIDS deaths. Next, the total AIDS deaths are determined by subtracting the total non-AIDS deaths from the total deaths. Ultimately, the cumulative stock is obtained by accumulating all these AIDS deaths.

2.4.2 Impact of Labor Force

The labor force is defined as the sum of the [15-44] and the [45-64] age cohorts, times the labor participation fraction. The impact of HIV/AIDS on the labor force is twofold. A first influence channel works on the size of both age cohorts: a higher HIV prevalence leads to higher mortality rates and hence slows down or reverses in an extreme case the population growth rates. Secondly, higher HIV prevalence lowers health and lowers the labor participation fraction, thereby closing another feedback loop.

The combination of both impacts results in a change of the labor force. To quantify the change in labor force, the size of the labor force in the presence of HIV/AIDS is compared to its size in a non AIDS scenario. To obtain the non-AIDS scenario, a 'shadow' population structure is added to the model, which is completely similar to the population structure discussed above, except for the mortality rates and the labor participation fraction.

In the shadow population structure, mortality rates for each cohort are related to the life expectancy and not to the low and high AIDS life expectancy parameters, as in the basic population structure. The shadow population structure also contains a labor participation fraction, which remains constant. In the HIV/AIDS model structure, this labor participation fraction is affected by a multiplier that is linked to health.

2.4.3 Impact on GDP

Aggregate output follows a Cobb-Douglas production function $Y = AL^{1-\alpha}K^\alpha$ where Y is total output, A the total factor productivity, L the number of workers, K the quantity of capital and α capital's share of income (Weil 2005). In terms of growth rates, the production function becomes: $\hat{Y} = \alpha\hat{A} + (1-\alpha)\hat{L} + \alpha\hat{K}$. The effect of HIV/AIDS on the growth rate of GDP (\hat{Y}) will only play through the growth rate of the labor force (\hat{L}). It is assumed that the growth rate of total factor productivity (\hat{A}) is exogenous (constant at 1.0%). The growth rate of physical capital (\hat{K}) equals

zero by assumption. Capital's share of income (α) is set at 1/3. The growth rate of GDP (\hat{Y}) is: $\hat{Y} = \hat{A} + 2/3\hat{L}$.

2.4.4 Impact on Spending

In the model, income is spent on food and shelter, health and other expenditures. The expenditures on food and shelter (in order to survive at subsistence level) represent the largest outflow of income and are constant. A household cannot cut expenditures on food and shelter below this level. Spending on health care comprises expenses for basic health care and costs for medical care due to HIV/AIDS. Other expenditures range from luxury articles (such as a car, television or radio) to more varied and expensive food items such as meat. These other expenditures allow an individual to eat better or otherwise to increase the standard of living. It is assumed that an increase in other expenditures improves health.

The budget allocation changes over time due to changes in the HIV prevalence and the growth rate of GDP. It is assumed that households initially spend 65% of income on food and shelter, 25% on health and 10% on other expenditures. At any time, the budget allocation must satisfy two conditions: (i) Food & Shelter expenditures remain unchanged, and (ii) Total income = Total expenditures. The prevalence of HIV has a double impact on spending: it lowers the income via its impact on GDP per capita and increases medical expenses (see figure 4).

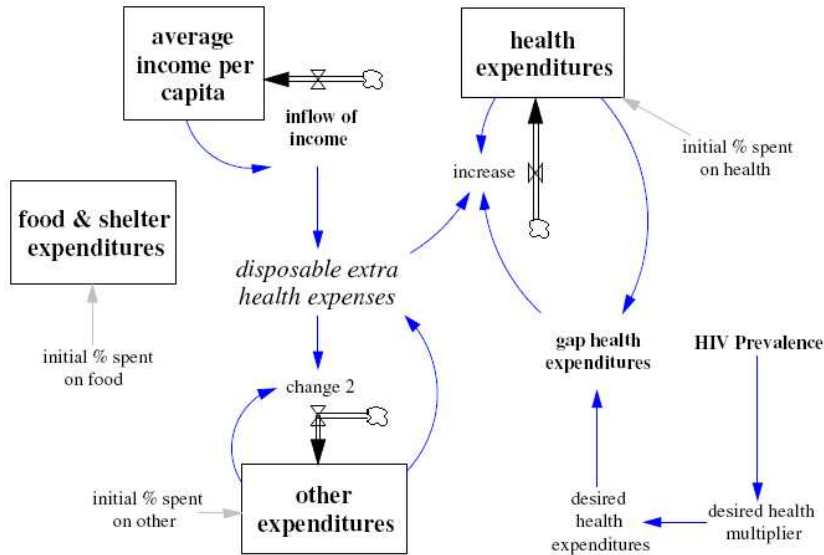


Figure 4: The budget allocation structure

The food & shelter expenditures are a stock without an in- or outflow, because this budget post remains constant throughout the run time. Other expenditure types are not constant. A flow is therefore included into the stock of the health expenditures and of the other expenditures (see figure 4). The desired health expenditures are made up of a desired level of basic expenses and a supplement for AIDS-related health expenses, which increases with HIV prevalence. The relationship between the HIV prevalence and the AIDS-related health expenditures is captured by the 'desired health multiplier' recorded in a lookup table. The inflow into the stock of health expenditures is directly linked with two important variables: gap health expenditures and disposable extra health expenses. The 'gap health expenditures' is the difference between the desired health expenditures what an individual would like to spend- and the actual health expenditures. The 'disposable extra health expenses' reflect the additional resources that can be spent on health care, and is defined as the sum of the inflow of income and the other expenditures. To put things more simply: the gap health expenditures represent what an individual wants to spend extra on

health care, whereas the disposable extra health expenses show what he or she is able to spend extra and is the maximum additional spending on health.

A second important mechanism of the budget allocation is how changes in health expenditures and other expenditures are related. The change in other expenditures is expressed by an if-then-else function: *If* disposable extra health expenses-gap health expenditures ≥ 0 , *Then* Change 2 = disposable extra health expenses-gap health expenditures-other expenditures, *Else* Change 2 = - other expenditures. This function means that when health expenditures are below their maximum level, the other expenditures will either grow or decline. To grasp this mechanism, it is necessary to go back to the budget constraint and the definition of 'disposable extra health expenses'. The increased expenses for health care must be offset by a combination of more income or lower other expenditures. When income increases faster than the health expenditures, other expenditures rise as well. However, when the income increases slower than health expenditures, a part of other expenditures will have to be diverted towards health care to satisfy the budget constraint. The 'else-' part of the function sets the stock of other expenditures equal to zero when the condition does not hold.

2.4.5 Impact on Health Status

The last part of the HIV/AIDS model includes all the mechanisms that feed back into health. Starting from an initial value, health changes over time. The changes are induced by two sources: the 'total health expenditures' and the 'other expenditures'. The total health expenditures comprise both the private and the external expenditures on health. The external health expenditures will be treated in section 4. The absolute level of total health expenses is positively linked to the health status: more money spent on health leads to better health, albeit after a certain time delay. The level of other expenditures is associated with an individual's standard of living which is positively correlated with health. The link between the expenditure type and health is modeled in both cases by a health multiplier recorded in a lookup table. Ultimately, health is altered -after a time delay by the interaction of the two health multipliers.

2.5 Beyond the HIV/AIDS Model

Most of the structural assumptions act as a double-edged sword. On the one hand, they may oversimplify the model and reduce its practical use. On the other hand, more complicated models are more difficult to understand and require more data. An important question is which model generates the best results: a detailed model that closely reflects reality but includes poor data or parameter values, or a more simplified model with reliable data. The difficulty is to find a good balance between the simplifications in the model structure and the reliability of the parameter values.

That population is not stratified is a shortcoming, because the HIV/AIDS epidemic unequally affects different groups. Technically the population can be stratified by gender, by sexual risk behavior, and by income class (by using 'subscripts'), but reliable data for the strata are hard to find.

The growth of GDP is also seriously simplified. The impact of HIV/AIDS on total factor productivity is not modeled (for example through investments in human capital, impact on education). It is assumed that physical capital does not depreciate and investments in physical capital are excluded.

3 Behavior of the HIV/AIDS Model

3.1 Model Outcomes

The base-run simulation aims to generate a plausible course for the HIV/AIDS epidemic as it could unroll in a representative Southern African country. The parameter values for the base-run have been set to fit the specific Southern African context and can be retrieved in the accompanying

Vensim model. In this section, the main parameter values of the base-run are summarized. The outcomes of the base-run simulation are presented and links are drawn between different evolutions to demonstrate that the HIV/AIDS model exists in a succession of logic and consistent parts.

3.1.1 Main Parameter Values

The representative Southern African country in this model counts 7.362.645 inhabitants in 1980. This is the average of the population in Botswana, Lesotho, Namibia, South Africa, Swaziland, Zambia and Zimbabwe in 1980 (US Census Bureau).

The country's gross domestic product in 1980 is US\$9.066.607.183 (in 2000 dollars), the average from Botswana, Lesotho, Namibia, South Africa, Swaziland, Zambia and Zimbabwe between 1980 and 1985 (Programme 2006). GDP per capita in 1980 then equals US\$ 1.231. The labor participation fraction is 75% and this percentage is based on the economically active population in Botswana, Kenya, Malawi, Mozambique, Tanzania, Zambia and Zimbabwe between 1977 and 1989 (US Census Bureau). It is assumed that the annual growth rate of total factor productivity is 1.0%. The growth rate is based on the average growth rate of total factor productivity between 1981 and 2000 for Botswana, Lesotho, Swaziland, Uganda, Zambia and Zimbabwe (average = 1.37% according to the FAO (2004)).

In 1980, the life expectancy is 50 years; this value is calculated from the life expectancy in Kenya, Lesotho, Malawi, Mozambique, Namibia, South Africa, Swaziland, Tanzania, Uganda and Zambia in 1980 (US Census Bureau). Health is expressed in child mortality and amounts to 160 deaths per 1000 children under five years in 1980, the average for Angola, Botswana, Kenya, Lesotho, Malawi, Mozambique, Namibia, South Africa, Swaziland, Tanzania, Uganda, Zambia and Zimbabwe in 1980 (Bank 2002).

3.1.2 Course of the HIV/AIDS Epidemic

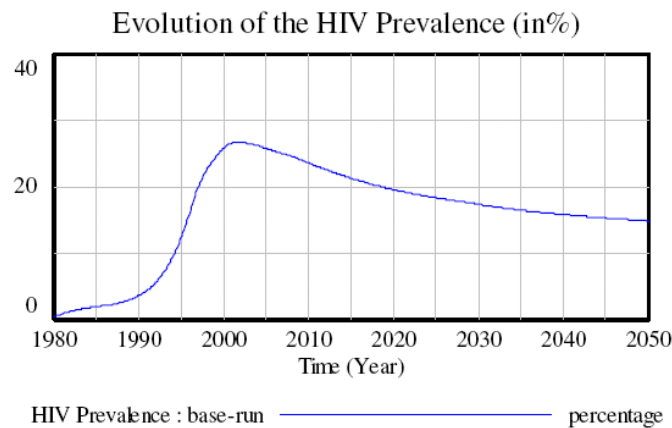


Figure 5: Evolution of HIV prevalence

Figure 5 presents the evolution of the HIV prevalence generated by the baserun of the HIV/AIDS model. The evolution resembles the reference mode (see figure 1) to a large extent: a slow rise in HIV prevalence in the initial phase, followed by a strong upswing in the mid- 1990s and a peak between 2000 and 2010. The later course of the epidemic cannot be compared to empirical data; according to this model, the HIV prevalence will slowly decline. Figure 6 provides a clearer insight into the driving forces behind this evolution of the HIV/AIDS epidemic by showing the causes strip of the HIV prevalence.

The causes strip illustrates the dynamics of HIV prevalence. The bottom panel of figure 6 shows that the infected population multiplier contributes most to the course of HIV. But this effect is misleading: although the other two multipliers do not change much, they actually have a

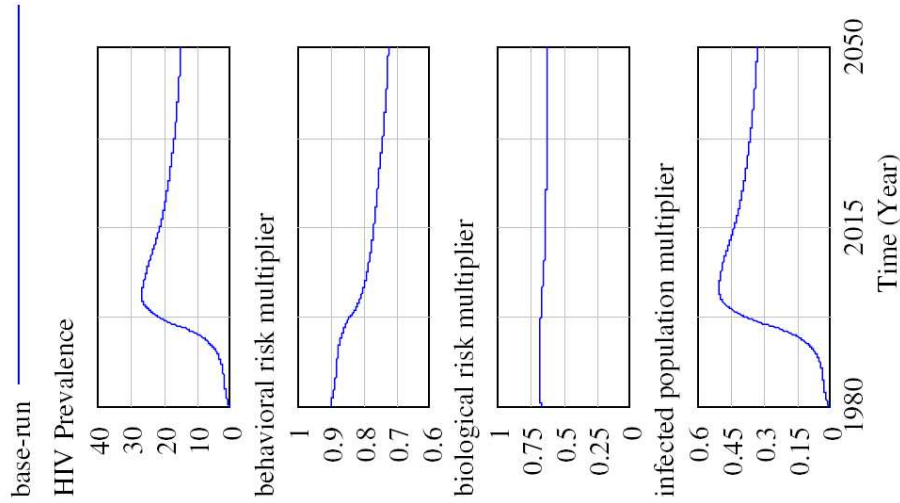


Figure 6: Causes of the evolution of HIV prevalence

key role in the evolution of the HIV prevalence. To understand the mechanisms that determine the path of the HIV level, we must go back to the model structure. The infected population multiplier is 'stuck' in a strong positive feedback loop that runs from the HIV prevalence into the multiplier and then back into HIV prevalence. So, if we assume the two other multipliers constant at value 1, the 'explosions of infections loop' leads to an extremely rapid spread of HIV, until 100% of the population is infected. This outcome is logical because the positive loop cannot be tempered by any 'external' mechanism. Hence, the other multipliers have a crucial impact on the course of the HIV prevalence. The behavioral risk multiplier is part of a negative feedback loop (the HIV/AIDS experience loop) and gradually declines from the start (see figure 6). The experience loop acts as a counterweight to the 'explosion of infections loop' and manages to contain the epidemic up to a certain extent. The behavior of the biological risk multiplier (and its feedback loop), however, is more complicated as the third panel in figure 6 reveals: the biological multiplier first increases and then gradually decreases. So whereas the biological multiplier initially contributes to the further spread of HIV, at some point it reaches a peak value and slowly starts to decrease. From this moment on, both the behavioral and the biological risk multiplier start reducing the HIV prevalence (see figure 6). This effect is strengthened by the positive feedback of the infected population multiplier. The interaction of the three multipliers causes the HIV prevalence to go down slowly.

3.1.3 Cumulative AIDS Deaths

A second outcome of the model simulation is the evolution of the AIDS deaths. Figure 7 shows the course of HIV prevalence and the cumulative number of deaths due to AIDS over time, matching the so-called 'two epidemic curves' introduced by Whiteside (2002). Figure 7 confirms that even if the HIV prevalence is on the rebound, the epidemic will continue to take a high death toll for many years to come.

3.1.4 Demographic Impact

The HIV/AIDS epidemic also has a visible impact on the population. Figure 8 compares the evolution of the population in a scenario without HIV/AIDS -the baseline- to the case in which the population suffers from the adverse effects of the epidemic. In general, the population stabilizes mostly because fertility rates decline. In the model, fertility drops from 6.67 children in 1980 to a mere 2.39 children in 2050 (based on average fertility rates between 1980 and 2050 for Botswana,

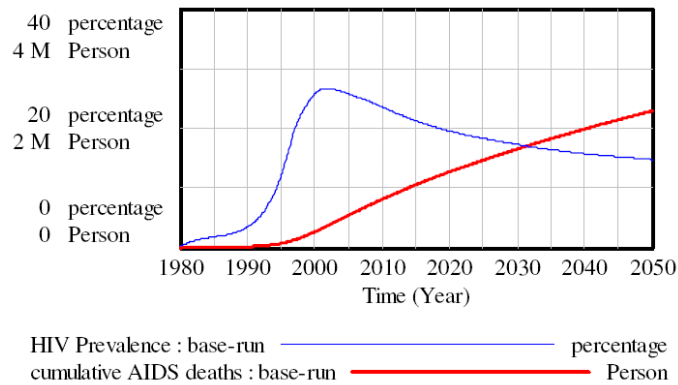


Figure 7: Two epidemic curves

Kenya, Lesotho, Malawi, Mozambique, Namibia, Swaziland, South Africa, Tanzania, Uganda, Zambia and Zimbabwe; (US Census Bureau).

Figure 8 also reveals that for the first 20 years into the epidemic, the impact on the population size is virtually zero. This result can be put down to the fact that the AIDS virus only started to claim its first victims halfway the 1990s, as can be deduced from figure 7. Nevertheless, the gap between an AIDS and a non AIDS affected population grows larger over time. The evolution of the population in the AIDS and the non-AIDS scenario matches UN predictions (Nations 2004, p20).

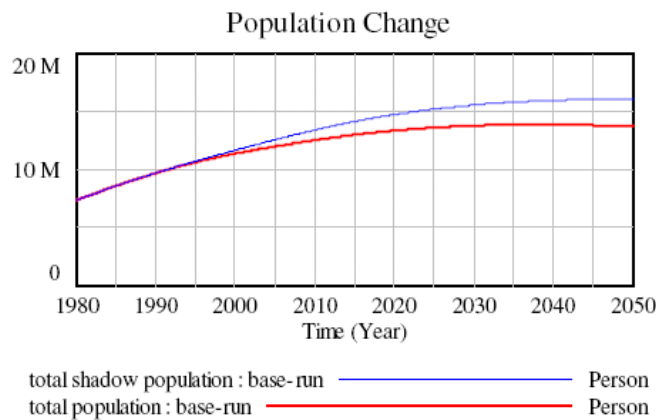


Figure 8: The demographic impact of the HIV/AIDS epidemic

The adverse impact on population is even more pronounced for the labor force (see figure 9). The difference in working age population in both scenarios is more pronounced, because HIV/AIDS has a greater impact on the mortality rates of the working age population than for the young (aged [0-14]) and the old (aged 65 and over).

The GDP growth rate slowly declines but still remains positive (see figure 10). The GDP growth rate lowers with the growth rate of the labor force. The growth rate of total factor productivity (TFP) is set exogenously at 1.0%. The growth rate of labor declines because fertility declines and mortality is higher due to HIV/AIDS. As a result, the labor force stabilizes (see base-run in figure 9).

Figure 11 shows the causes strip of GDP per capita. Absolute GDP rises because the GDP growth rate remains positive. The impact on GDP per capita is less pronounced because the population also changes. The initial rise in GDP does not translate into higher GDP per capita,

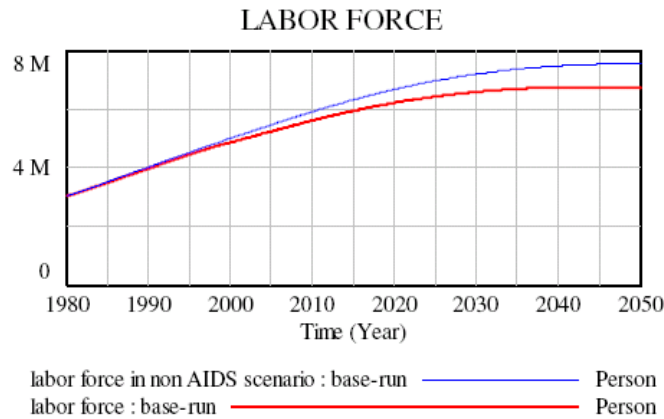


Figure 9: The evolution of the labor force in the AIDS and non AIDS scenario

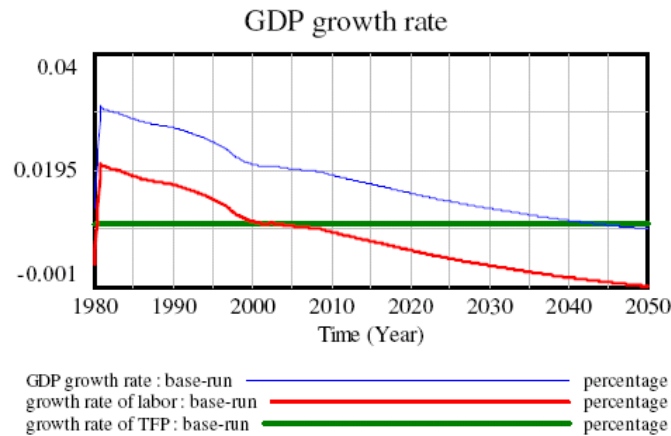


Figure 10: Evolution of the GDP growth rate. Note. The units on the Y-axis are percentages (for example: 0.0196 is 1.96%)

since the population grows more or less at the same rate. After 2010, a combination of a increasing output and a stabilizing population results in increasing GDP per capita (see the upper panel of 11).

3.1.5 Macro-Economic Impact

The model includes two interventions that cushion a part of the burden of AIDS on households: cash transfers that raise average income per capita and subsidies for medical expenditures. In the base-run, these interventions are set equal to zero. Section 5.3.3 evaluates the impact of cash transfers and subsidies for health care.

Figure 12 shows the evolution of the income per capita and the different expenditures. The food and shelter expenditures remain constant over time because they satisfy the basic human needs that an individual cannot live without. Health expenditures rise a little in parallel with the HIV/AIDS epidemic and then slowly decrease. The other expenditures first decrease to zero and from 2000, other expenditures increase as average income increases.

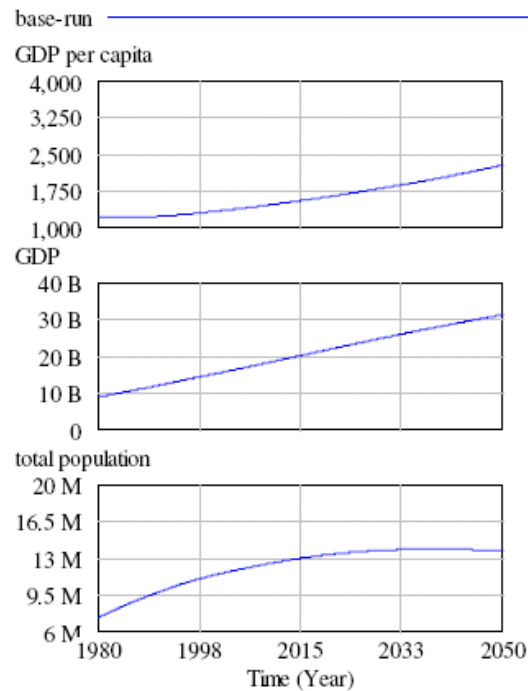


Figure 11: Evolution of GDP per capita and its constituent parts. Note. GDP and GDP per capita are expressed in US dollars

3.1.6 Impact on Health

The shifting spending patterns affect health in two ways (see figure 46). 'Other expenditures' are a proxy for the standard of living: better housing conditions, safer drinking water and a more balanced food pattern. A higher standard of living is associated with a better health. The total health expenditures also are a good indication for health.

Figure 13 demonstrates that health seriously worsened between 1980 and mid-1990 as households reduced spending on 'other' goods and insufficiently increased health expenditures. After 1995, health gradually improved because households increased total health expenditures a little. After 2000, health improved significantly because the other expenditures increased (figure 46). The evolution of health is the final link in a feedback loop that accounts for the dynamic behavior of the biological risk multiplier, one of the main determinants of the HIV prevalence.

3.1.7 Risk Behavior

Another major influence on the HIV prevalence is the behavioral risk multiplier (see figure 38), which depends on the change in risk behavior. Risk behavior can be reduced by the cumulative effect of two different model variables: AIDS awareness and prevention (by government or non-governmental organizations). When HIV prevalence rises, so will the AIDS awareness. A second determinant of the risk behavior is exogenous prevention. In the base-run, it is assumed that the effectiveness of prevention gradually increases (see figure 14), which reduces risk behavior over time. Figure 14 presents the course of the risk behavior influence, the prevention impact and their combined effect on the risk behavior.

Figure 14 requires some further explanation. The 'risk behavior influence' represents the percentage of the population that adopts safer sexual practices as a direct result of better AIDS awareness. Although more people are aware of AIDS, it does not reduce risk behavior by much, because the awareness of HIV/AIDS does not change sexual risk behavior if it is not accompanied by prevention.

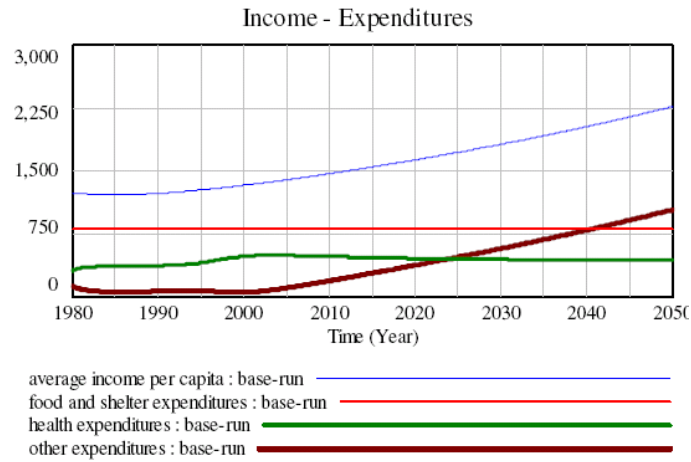


Figure 12: Evolution of Average Income and Different types of expenditures

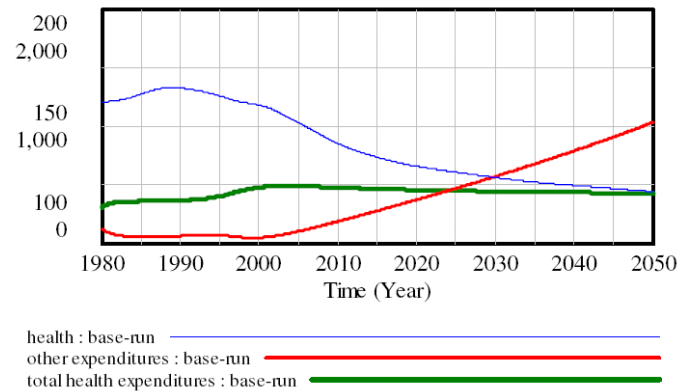


Figure 13: Evolution of health and its main determinants. Note. Health is expressed by child mortality, expenditures are in US dollars

The prevention impact shows the percentage of the population that changed their risk behavior after preventive efforts. Figure 14 also shows how risk behavior declines. Risk behavior refers to the percentage of the population that engages in risky sexual practices. It is obtained by subtracting the prevention impact and the risk behavior influence from a maximum degree of risk behavior (100)

Initially, only the risk behavior influence reduces risk behavior, but from the mid 1990s onwards, the prevention impact steadily increases and becomes the main cause of safer sexual practices. The path of risk behavior fully determines the path of the behavioral risk multiplier and thereby provides the last link in the causal chain of the general course of the HIV epidemic.

3.2 Validity of the Model

A first essential criterion is the model’s ability to replicate historically observed behavior. When comparing figure 5 to figure 1 for the HIV prevalence from 1980 until present, the HIV/AIDS model fits with the reference mode.

A second criterion is the outcome of the sensitivity analysis. It is essential to distinguish between numerical and behavioral sensitivity. Numerical sensitivity means that when assumptions change, the numerical values of the model’s outcomes change. Behavioral sensitivity means that

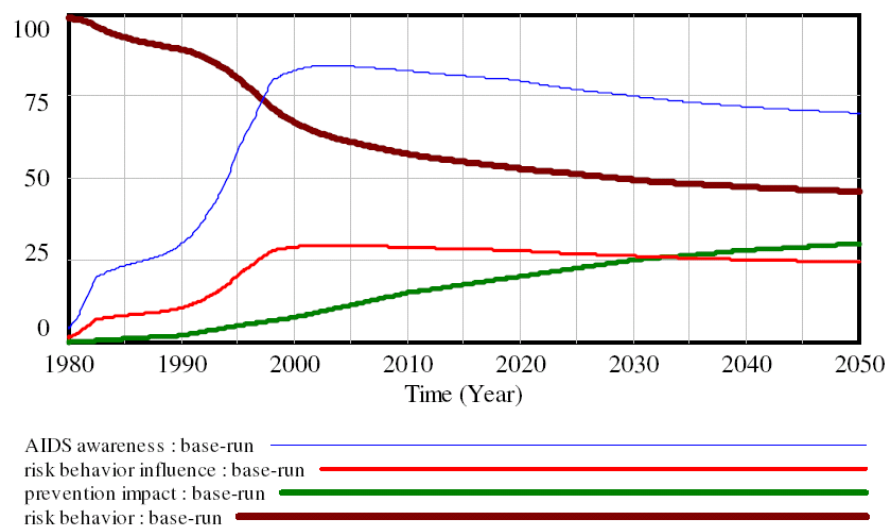


Figure 14: Evolution of the risk behavior and its determinants. Note: The Y-axis represents the percentage of the population that (i) is aware of HIV/AIDS (AIDS awareness) (ii) changes its risk behavior (risk behavior influence and prevention impact) (iii) engages in risky sexual behavior (risk behavior)

when assumptions change, the patterns of behavior generated by the model change (Sterman 2000). Extensive sensitivity analyses revealed that the model shows a considerable degree of numerical sensitivity. In order to improve the validity of the model, the highly sensitive numerical links (especially the lookup table of change in risk behavior as a function of AIDS awareness) should be reviewed and improved.

However, the HIV/AIDS model shows little behavioral sensitivity: a different parameter value changes the numerical values of the outcomes but does not substantially change the behavior of the model's outcomes. For example, when a household spends more on health care, health improves and HIV prevalence lowers. But higher health expenditures do not suddenly change the pattern of the HIV prevalence. The model does not show unexpected or inexplicable behavior. The low behavioral sensitivity confirms that the HIV/AIDS model is relatively robust.

The HIV/AIDS model scores well on behavioral sensitivity but shows a relatively high degree of numerical sensitivity. To judge the HIV/AIDS model on overall sensitivity, the objectives of the system dynamics model are decisive. The main objective of the HIV/AIDS model is to understand the spread of HIV/AIDS (in Southern Africa) and to evaluate prevention measures, not to make accurate predictions about the future course of the epidemic. Hence, a low behavioral sensitivity is more important than a low numerical sensitivity. For this reason, the relatively high degree of numerical sensitivity does not detract much from the validity of the model.

The sensitivity analysis on the budget allocation reveals that a changing allocation of the budget has a substantial impact on health and consequently also on the HIV prevalence. The sensitivity to changes in budget allocation justifies government intervention to smoothen the spending pattern. Cash transfers or subsidies for health care will avoid large changes in the spending pattern and guarantee that health does not suffer from a changing budget allocation. These paths will be further explored in section 4.

The growth rate of total factor productivity does affect the HIV prevalence but in the long run a higher growth rate of total factor productivity does not lower HIV prevalence by much. Moreover, the government cannot easily manipulate growth rate of total factor productivity, making this parameter not a suitable instrument to curb HIV/AIDS.

The third criterion involves the model's robustness. In the extensive sensitivity analyses, the

model's behavior has been studied for a range of extreme input values. The HIV/AIDS model returns logical outcomes and although the results are not always realistic (because the inputs are extreme), the results are predictable. This finding supports the conclusion that the HIV/AIDS model is robust.

In sum, the HIV/AIDS model scores relatively good on all three criteria: it is a simple but robust model which can be used to evaluate policy interventions. Of course, the model can still be improved.

4 Policy Measures

4.1 Prevention to reduce Risk Behavior

A first intervention is oriented to reduce sexual risk behavior. This can be achieved in various ways, for example by facilitating and promoting the use of condoms, by removing the social barriers and the stigma that impede the adoption of safer sexual practices, or by empowering women. The 'prevention impact' (a part of the 'HIV/AIDS experience loop') represents the external prevention and operates with a lookup function that is linked to time. The model easily permits the testing of alternative prevention measures.

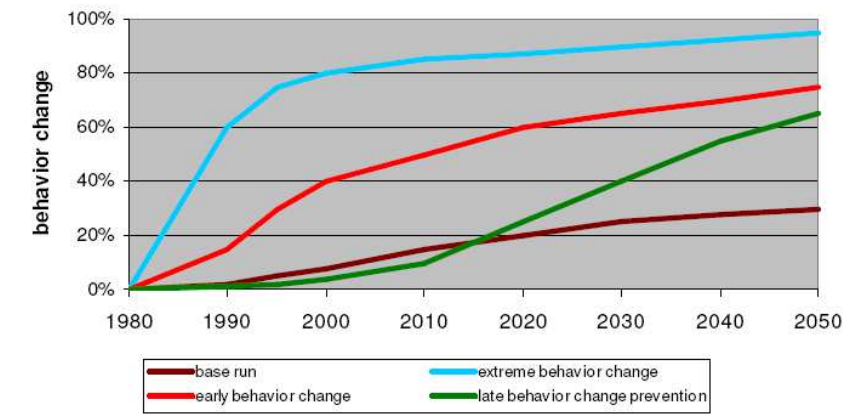


Figure 15: Behavior change prevention measures: base run versus alternative runs. Note. The Y-axis represents the % of the population that changes risk behavior as a result of prevention.

The base-run simulation assumes a low effectiveness of prevention: sustained prevention induces only 20% of the population to change their risk behavior by 2020 (see figure 15). In the simulations, the effectiveness of prevention varies between an extreme, an early and a late behavior change. Figure 16 shows the lookup tables for the base-run and the three alternative simulations. The 'extreme behavior change' induces 80% of the population to change risk behavior by 2000, 'early behavior change' 40%, and 'late behavior change' only 4%. Figure 16 shows the risk behavior and the HIV prevalence for the base run and the three behavior change scenarios.

The base run assumes that prevention is not very effective, which results in a HIV prevalence that declines very slowly. The 'late behavior change' scenario follows the same course as the base-run until 2020 but then HIV prevalence goes down faster. The more intensive prevention after 2010 in the 'late behavior change' simulation causes the HIV prevalence to go down -although there is a time lag of several years before prevention translates into a decline in HIV prevalence. In the 'early behavior change' scenario, the HIV prevalence follows a bell-shaped curve that reaches a peak value around 10%. The 'extreme behavior change' scenario represents a case in which prevention starts early and results in a quick and high adoption of safe sexual practices. This swift behavior change does not allow the epidemic to spread (upper graph of figure 16).

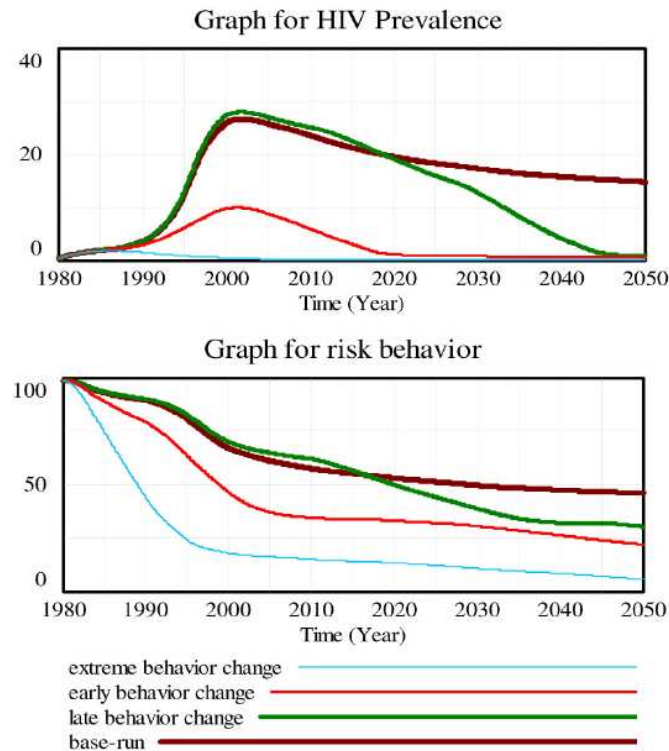


Figure 16: Outcomes of alternative prevention measures aimed at behavior change. Note. The Y-axis of the graph for risk behavior represents the % of the population that engages in sexual risk behavior

4.2 Financial and Health Care Support

Another channel to curb HIV/AIDS involves per capita income and expenditures. The model includes two intervention mechanisms to design and test different preventive action (by government or donor organizations): cash transfers (that increase per capita income) or subsidies for health care (that raise the total health expenditures).

The base-run simulation sets both equal to zero. Two policy measures are explored that combine cash transfers and health subsidies: 'intensive prevention 1980' and 'intensive prevention 1990'.

In the 'intensive prevention 1980' package a donor gives both cash transfers and health subsidies to every individual. The cash transfers and health subsidies start in 1980 and gradually increase (cash transfers increase to \$300 per year in 2050 and health subsidies to \$400 per year in 2050). In the 'intensive prevention 1990' scenario, the first cash transfers and health subsidies are given in 1990 (see figure 17). Figure 18 shows the outcomes of the prevention measures on the HIV prevalence and the cumulative number of AIDS deaths.

The two 'intensive' prevention measures do not have a huge impact on the spread of HIV/AIDS in its initial phase. However, with the 'intensive prevention 1980'-campaign, the HIV prevalence peaks at a lower top, which calls for a prevention as early as possible (20%, compared to 26% in the base-run). The intensive prevention measures have a substantial impact in a later phase of the epidemic, by steadily bringing down the level of HIV prevalence: by 2050, HIV prevalence has dropped to 9%, compared to 15% in the base-run.

Conclusions The simulations suggest that the HIV/AIDS epidemic can be suppressed if appropriate measures are taken. First, all policies have better results if implemented early. Early and successful interventions to curb the spread of HIV hinder the different positive feedback loops to

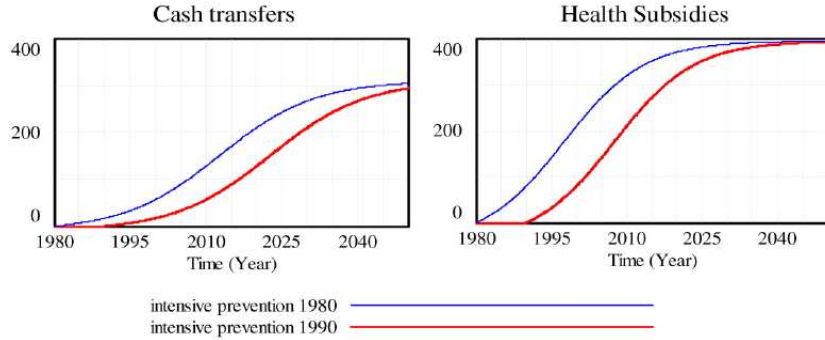


Figure 17: Cash transfers and health subsidies (per capita, in US dollars)

play out their full potential. Second, more intensive measures in terms of effort or budget lead to better results. In reality, policy makers are forced to set priorities because of inertia and scarce resources. The simulations provide some guidelines, in this regard. The financial relief measures are less effective in a early stage of the epidemic, because in this stage the adverse effects of HIV/AIDS on income per capita remain modest (see figure 11 and Figure 18). Conversely, prevention aimed at sexual risk behavior is crucial in the initial breakthrough of the HIV/AIDS epidemic but less effective to bring down the HIV prevalence once the virus is widespread (see figure 16). In sum, as long as the epidemic is in a nascent or concentrated stage, the focus should be on behavior change. But when the epidemic is generalized, measures to change behavior should be supplemented with direct financial relief.

5 Conclusions

5.1 Policy Recommendations

An HIV/AIDS epidemic of the size and seriousness of the current epidemic in Southern Africa is not inescapable. A set of efficient and well designed policies can avert a human disaster caused by HIV/AIDS.

The effectiveness of policy measures varies with the stage of the epidemic; policy measures should be designed and implemented accordingly. Early and extensive measures yield the best results in curbing the epidemic, but this 'full' package is not feasible. Policy measures to change sexual risk behavior are most efficient in the early stages, but are successful and necessary throughout all stages of the epidemic. The adverse effects of HIV/AIDS on income and health only become fully apparent when the epidemic has grown to large proportions. Therefore, in a more advanced stage of the epidemic, efficient policy intervention should also include financial relief to improve health and supplement households' budgets. In an advanced stage of the epidemic, the main challenge is to find a good balance between prevention and relief.

5.2 Paths for Future Research

The HIV/AIDS model is a rough description of reality: every model is a simplification. The HIV/AIDS epidemic proves so complex that it is hard to capture all the mechanisms of the spread of the HIV/AIDS virus in a simple model. The available time for building the HIV/AIDS model was also limited. Hence, several restrictive assumptions had to be made.

The objectives of the HIV/AIDS model focus on behavioral rather than numerical outcomes. More realistic structural assumptions may change the model's behavior and imply different policy recommendations. Therefore, the structural shortcomings of the HIV/AIDS model must be addressed first.

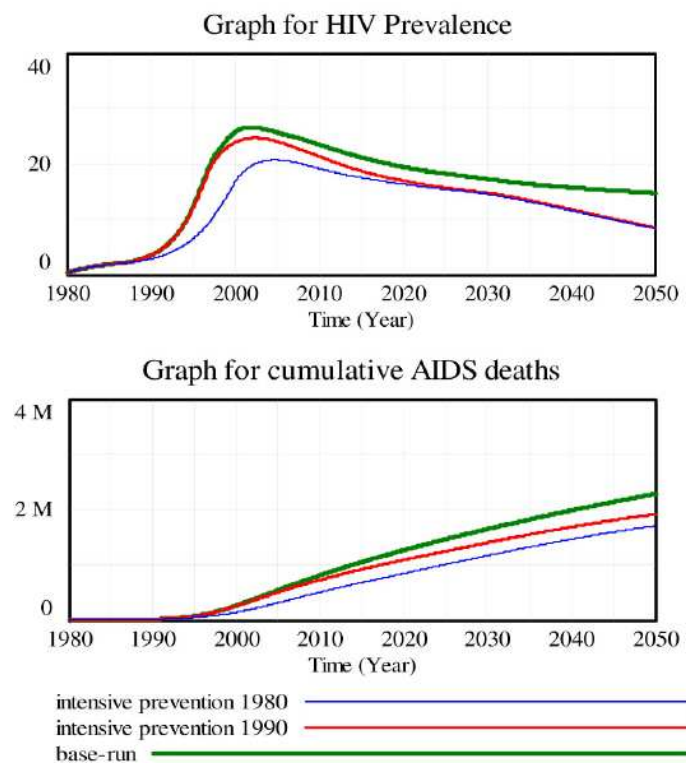


Figure 18: Effects of cash transfers and health subsidies

The most limiting structural assumption concerns the growth rate of GDP. The growth rate of labor is endogenous but the growth rates of total factor productivity and physical capital are exogenous (the growth rate of physical capital even equals zero). In addition, the model does not account for the adverse effects of HIV/AIDS on human capital (education), investments, savings and productivity: the variables are either exogenous or not included in the model.

A second 'round' of improvements should reexamine the numerical assumptions. The outcomes of the model are sensitive to changes in parameter values and lookup tables (the budget allocation, the growth rate of total factor productivity, the impact of AIDS awareness on the change in risk behavior and the impact of a change in the labor force on the growth rate of labor). More accurate values would improve the validity of the model.

References

- Arndt, C. and J. Lewis (2000). The macro implications of HIV/AIDS in south africa: A preliminary assessment. *South African Journal of Economics* 68(5), 856–887. 2
- Bank, W. (2002). The world banks health, nutrition and population data platform (HNPSStats). [data base]. Technical report, World Bank. 9
- Bloom, D. and A. Mahal (1997). Does the aids epidemic threaten economic growth? *Journal of Econometrics* 77(1), 105–124. 2
- Bonnell, R. (2000). *HIV/AIDS: Does It Increase or Decrease Growth in Africa?* Washington, D.C.: World Bank. 2

- Cuddington, J. (1993). Modeling the macroeconomic effects of AIDS, with an application to Tanzania. *World Bank Economic Review* 7(2), 173–789. 2
- Cuddington, J. and J. Hancock (1995). The macroeconomic impact of AIDS in malawi: a dualistic, labour surplus economy. *Journal of African Economies* 4(1), 1–18. 2
- FAO (2004). *The State of Food and Agriculture - 2003–04*. Rome: Food and Agriculture Organization of the United Nations (FAO). 9
- Gaffeo, E. (2003). The economics of HIV/AIDS: A survey. *Development Policy Review* 21(1), 27–49. 2
- Kambou, G., S. Devarajan, and M. Over (1992). The economic impact of AIDS in an African country: Simulations with a computable general equilibrium model of Cameroon. *Journal of African Economies* 109–130. 2
- Meadows, D., W. Behrens III, D. Meadows, R. Naill, J. Randers, and E. Zahn (1974). *Dynamics of Growth in a Finit World*. Cambridge: Wright-Allen Press. 637 p. 5
- Nations, U. (2004). *The Impact of AIDS*. New York: United Nations, Department of Economic and Social Affairs, Population Division. 3, 11
- of Health, D. (2003). *National HIV and Syphilis Antenatal Seroprevalence Survey South Africa, 2003*. South Africa: Department of Health, Republic of South Africa. 3
- Programme, U. N. E. (2006). *GEO Data Portal [Data Base]*. Consulted on March 29, 2006, from <http://geodata.grid.unep.ch>. 9
- Sterman, J. (2000). *Business dynamics: systems thinking and modeling for a complex world*. Irwin/McGraw-Hill: Boston. 982 p. 15
- UNAIDS (1999). *The UNAIDS report*. Geneva: Joint United Nations Programme on HIV/AIDS (UNAIDS). 1
- UNAIDS (2000). *Report on the Global HIV/AIDS Epidemic June 2000*. Geneva: Joint United Nations Programme on HIV/AIDS. 1
- UNAIDS/WHO (December 2005). *AIDS Epidemic Update*. Geneva: Joint United Nations Programme on HIV/AIDS and World Health Organization. 1, 3
- US Census Bureau. *International Data Base*. April 2005 Release. 9, 11
- US Census Bureau (2004). *HIV/AIDS Surveillance Data Base*. 2
- Weil, D. (2005). *Economic Growth*. Boston: Pearson Addison Wesley. 6
- Whiteside, A. (2002). Poverty and HIV/AIDS in Africa. *Third World Quarterly* 23(2), 313–332. 2, 10
- World Bank (1997). *Confronting AIDS: Public Priorities in a Global Epidemic*. New York: Oxford University Press. 2