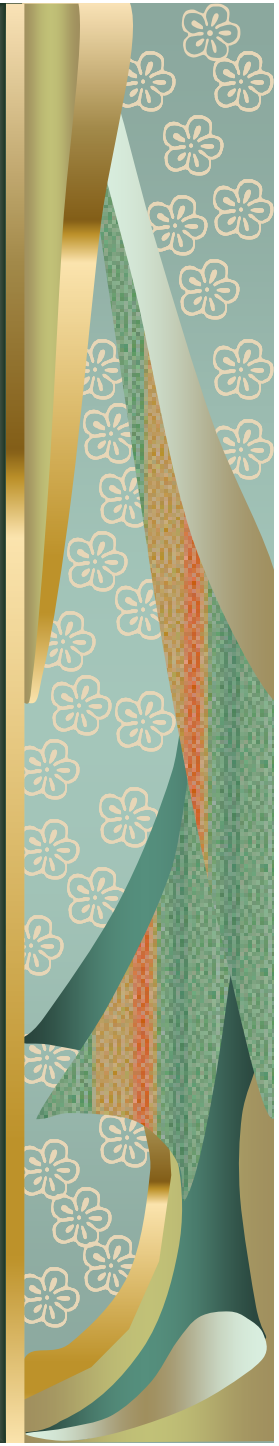
Economic Modelling: With especial reference to HIV/AIDS

Senelani Dorothy Hove-Musekwa

NUST
Bulawayo
Zimbabwe

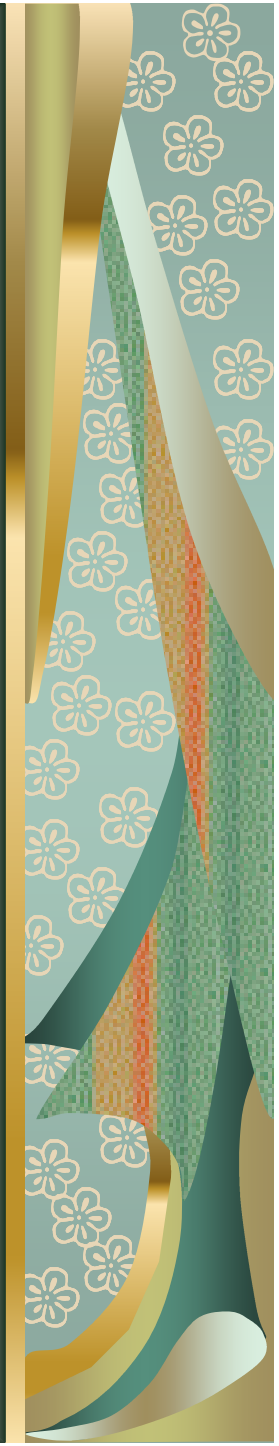
AIMS
Cape Town
South Africa

Advanced Study Institute- Uganda: 22 July 2009

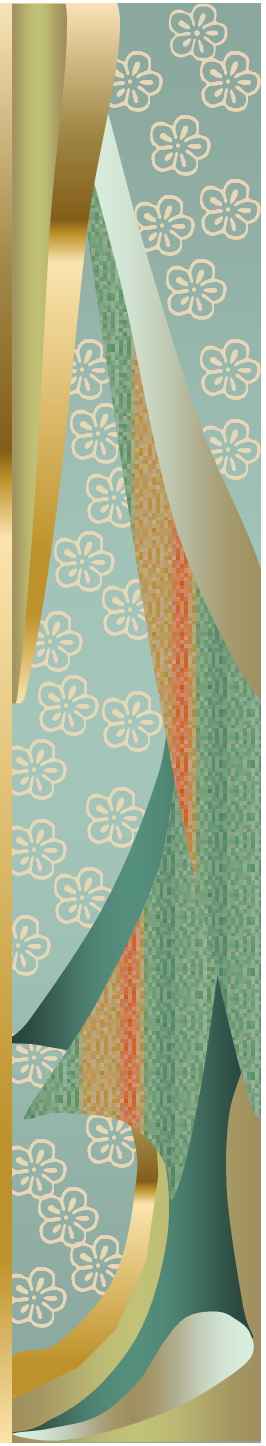


Outline of lecture

- Introduction to Economic Epidemiology
- Prevalence dependence
- Trend/Aim/Benefit
- Economic impact of HIV/AIDS
- Measuring economic impact



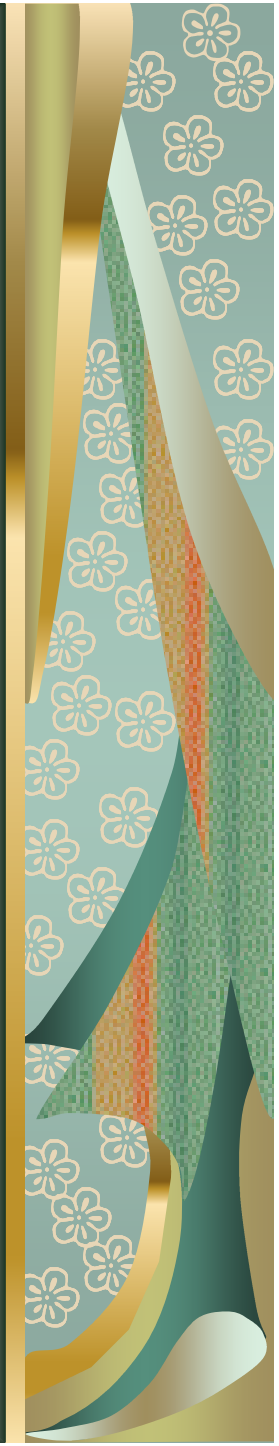
- Example of ART therapy- benefits
- Example of multiple strategies for HIV/AIDS- cost
- Other Economic evaluation to be considered
- Conclusion



What is Economic Epidemiology?

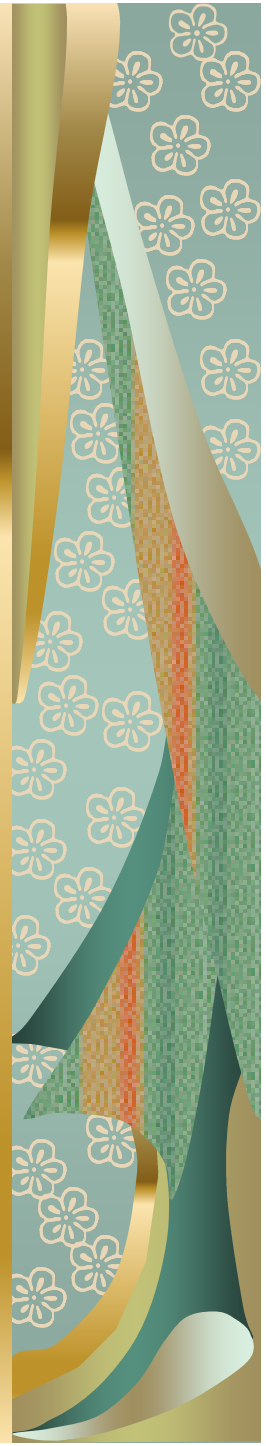
- **Economic epidemiology** is a field at the intersection of epidemiology and economics
- Its premise is to incorporate
  - principles of individual behavior
  - incentives for healthy behavior
  - resource optimization
  - simple economics

into epidemiological models



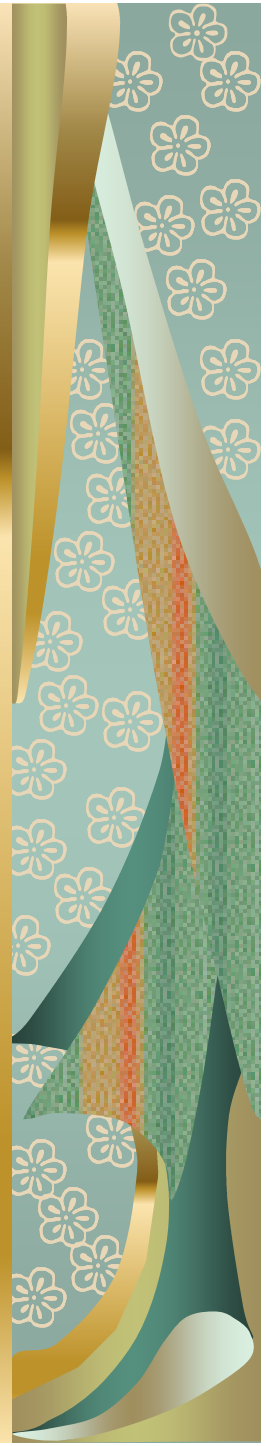
EPIDEMIOLOGY

- **DEFINITION:-** The **study** of the **distribution**, **frequency** and **determinants** of health problems and disease in human population
- **PURPOSE:- To obtain, interpret and use health information to promote health and reduce disease**



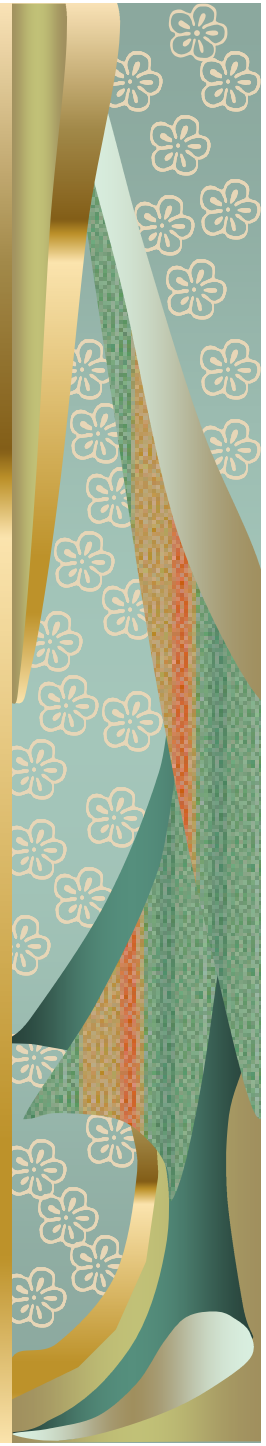
Prevalence dependence

- The field is dependent on the idea of prevalence or disinhibition
- Limiting the spread of a disease at the population level requires changing individual behavior,
- This depends on what information individuals have about the level of risk because individuals change their behavior as the prevalence of a disease changes

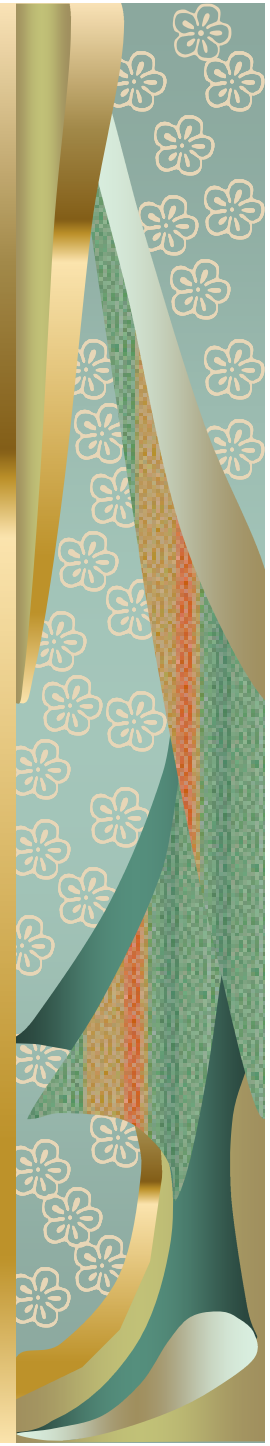


Example

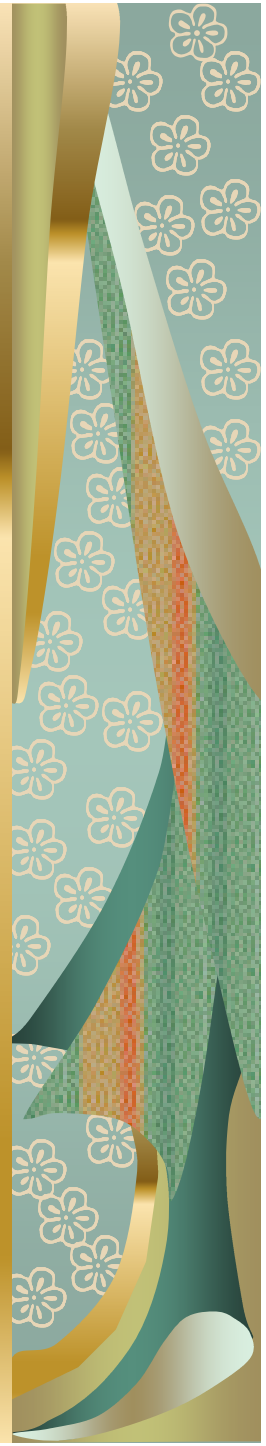
- Mass spraying to reduce malaria transmission can reduce the effects of mosquitoe bites and this might lead to reduction in the use use of bednets.



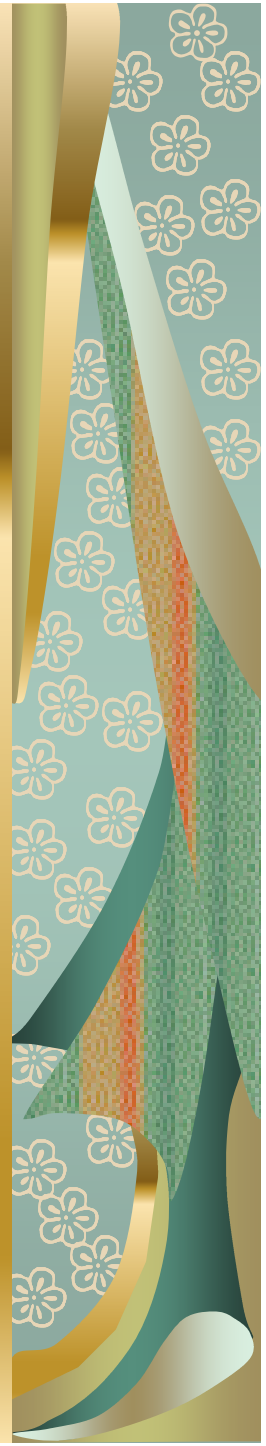
- People tend to ignore a disease if risk is low, but if the risk of infection is higher, individuals are more likely to take preventive action.
- If the pathogen is more transmissible, like HIV, the greater the incentive is to make personal investments for control.
- Similarly if there is a lowered risk of disease, either through some interventions like vaccination or because of lowered prevalence, individuals may increase their risk-taking behavior.



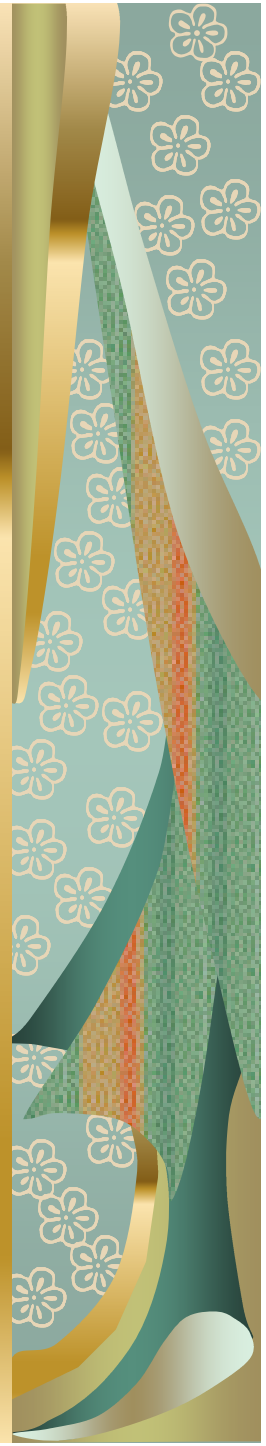
- Models suggested that the introduction of highly active antiretroviral therapy (ART), which significantly reduced the morbidity and mortality associated with HIV/AIDS, may lead to increases in the incidence of HIV as the perceived risk of HIV/AIDS decreased (Blower SM et al, 2000)



- Behavioral response have important implications for the timing of public interventions, because prevalence and public subsidies may compete to induce protective behavior (Geoffard, et al 1996).

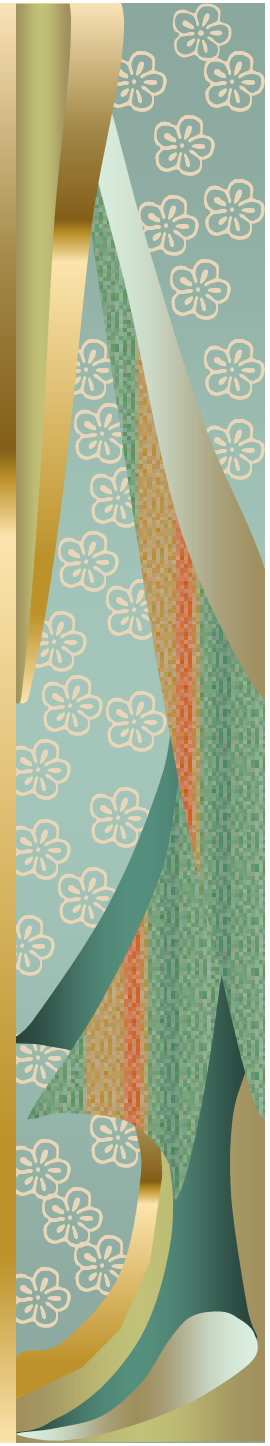


- If prevalence induces the same sort of protective behavior as public subsidies, the subsidies become irrelevant because people will choose to protect themselves when prevalence is high, regardless of the subsidy, and subsidies may not be helpful at the times when they are typically applied.



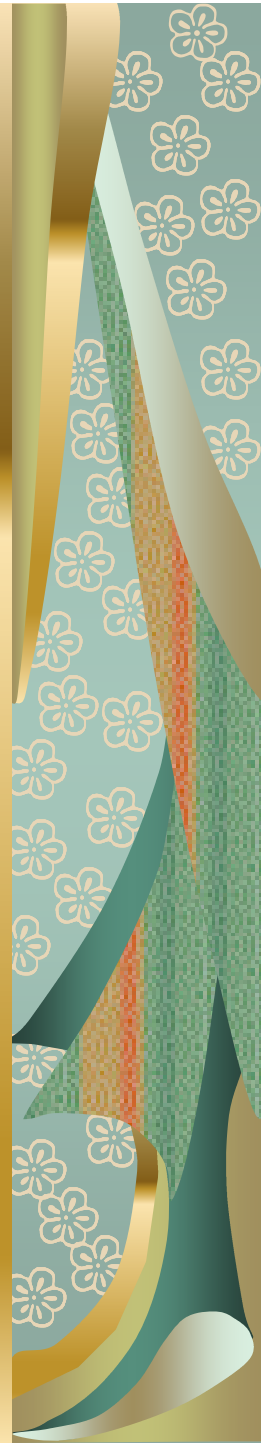
Factors influencing behaviour responses

- Environmental factors- services and policies
- Social factors – peers, family, role models
- Personal factors – knowledge, self-efficacy, risk, risk perception



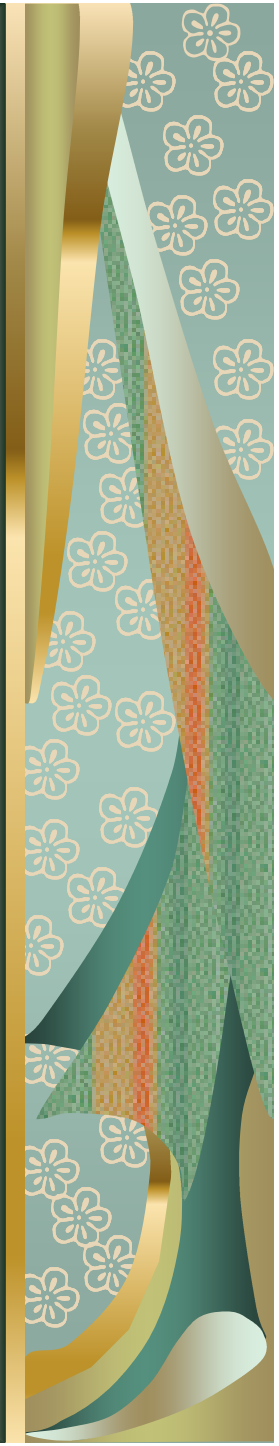
What is the trend?

- Epidemiological models do not real take account of economic constraints or incentives faced by individuals and policy makers
- Economic models mostly do not incorporate the dynamics of disease.



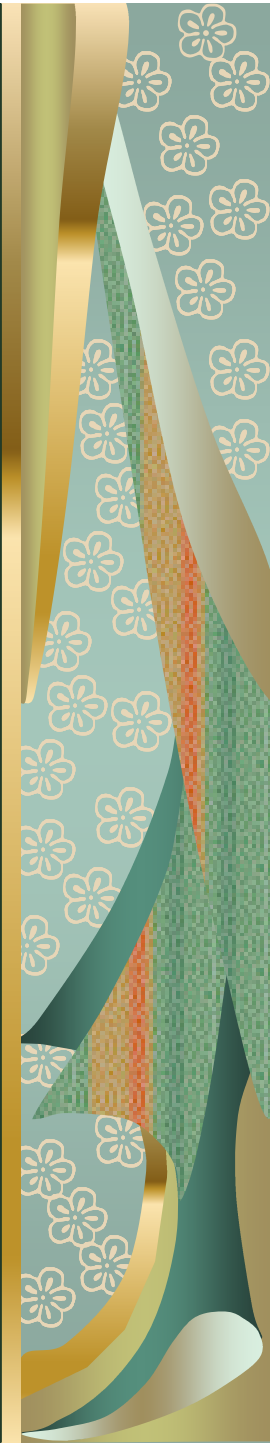
Aim

- Have an interdisciplinary approach to manage the complex interaction of mathematical, economical, epidemiological and statistical considerations in the emergence, persistence and spread of infectious diseases

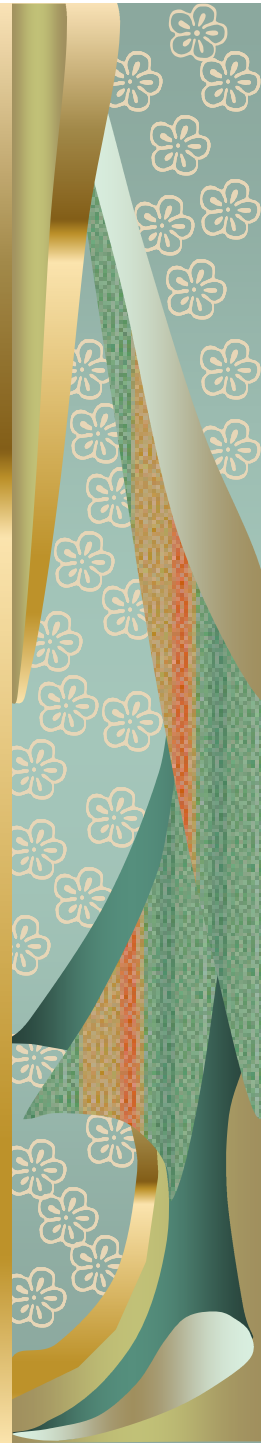


Benefits

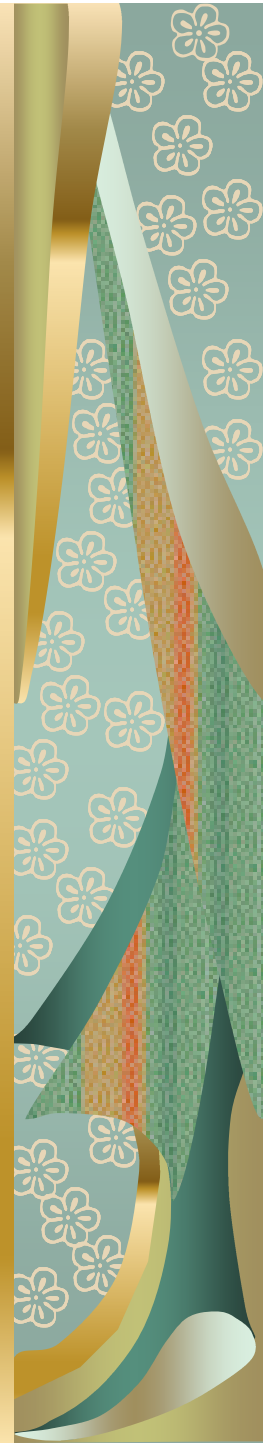
- Epidemiological models provide a foundation for policy models
- Governments, health-care providers must determine how best to allocate scarce resources for prevention and treatment
- Which prevention and which treatment that produces the greatest attainable reduction in infections, morbidity and mortality under the given constraints of the resources?



- Reasonable assessments of program costs and benefits are required to make rational policy decisions
- Optimal strategies and policies are needed to control the spread of diseases

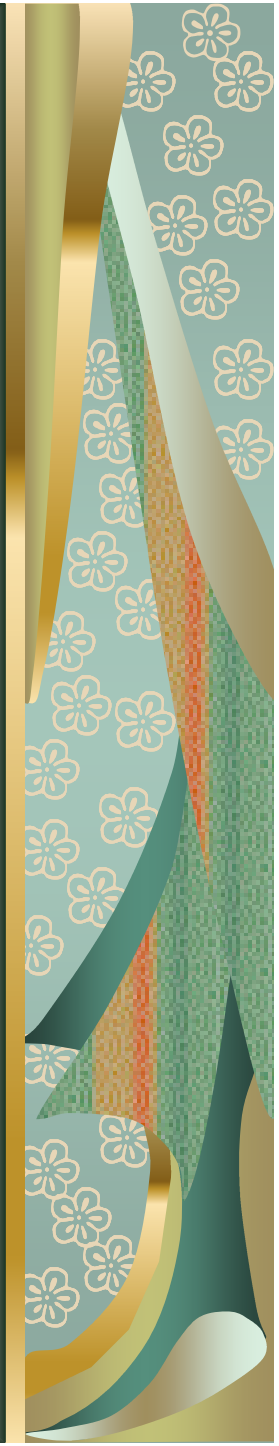


- Improves policy responses to epidemic diseases by providing clear tools for thinking about how certain actions can influence the spread of disease transmission.



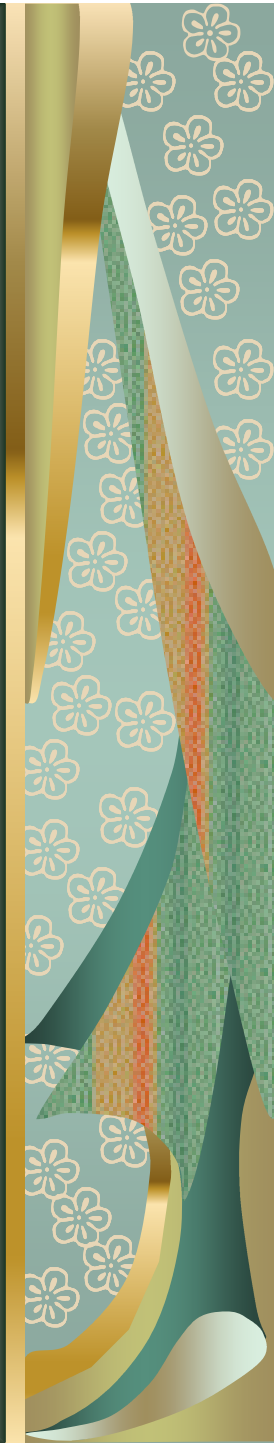
So what?

- Economic epidemiology strives to incorporate these types of behavior responses into epidemiological models to enhance a model's utility in evaluating control measures.

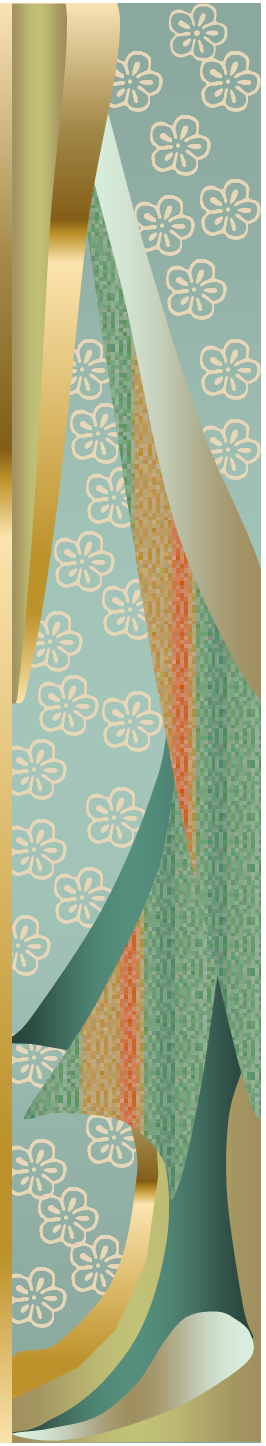


Economic Impact of HIV/AIDS

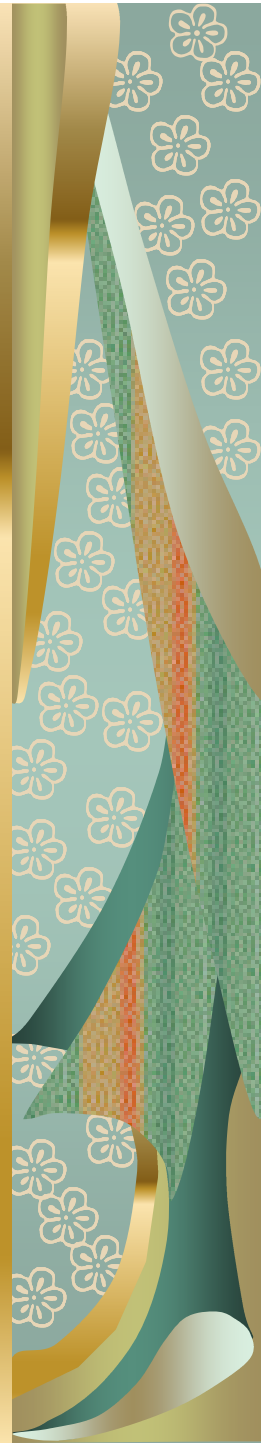
- Economic impact of HIV/AIDS is based on the direct monetary values that are incurred as the epidemic runs its course.
- Costs involved affects the patient, the worker the government



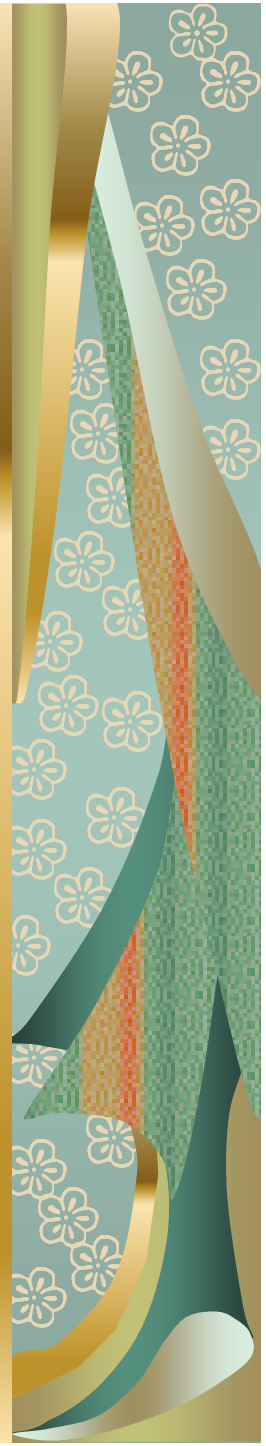
- A decline in savings and investment (from the relocation of expenditures towards medical care),
- Consequently, there is net effect on the growth rate of per-capita GDP



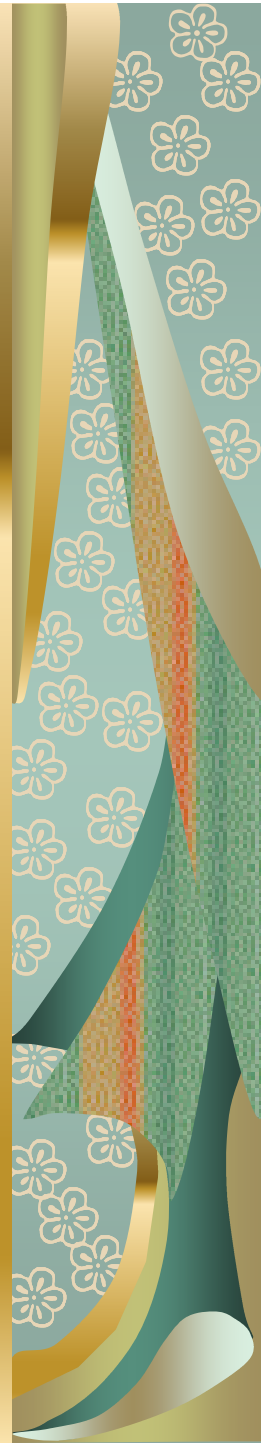
- The long-run economic costs of AIDS are almost certain to be much higher and possibly devastating if we emphasize the importance of human capital and transmission mechanism across generations in any economy.



- The formation of human capital, which should be thought of as the entire stock of knowledge and abilities embodied in the population, plays a leading role in promoting economic growth.
- AIDS can severely retard economic growth even to the point of leading to an economic collapse since AIDS is primarily a disease of young adults.

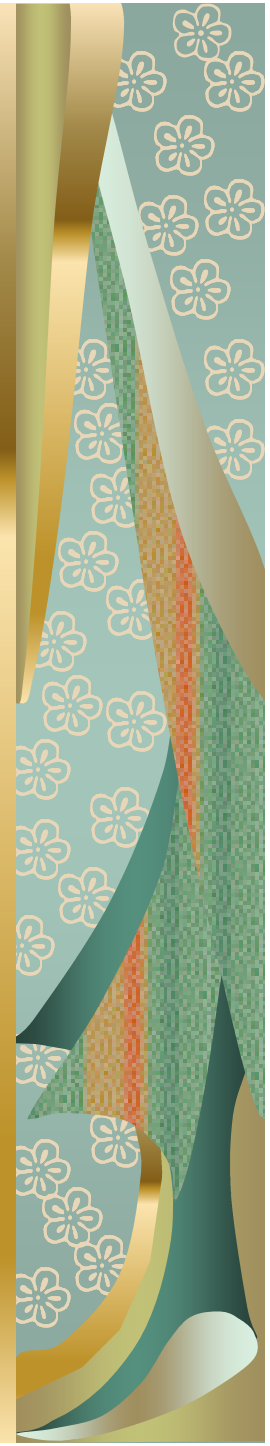


- A few years after they become infected, it reduces their productivity by making them sick and weak, and then kills them in their prime time, thereby destroying the human capital progressively built up in them through child-rearing, formal education, and learning on the job.

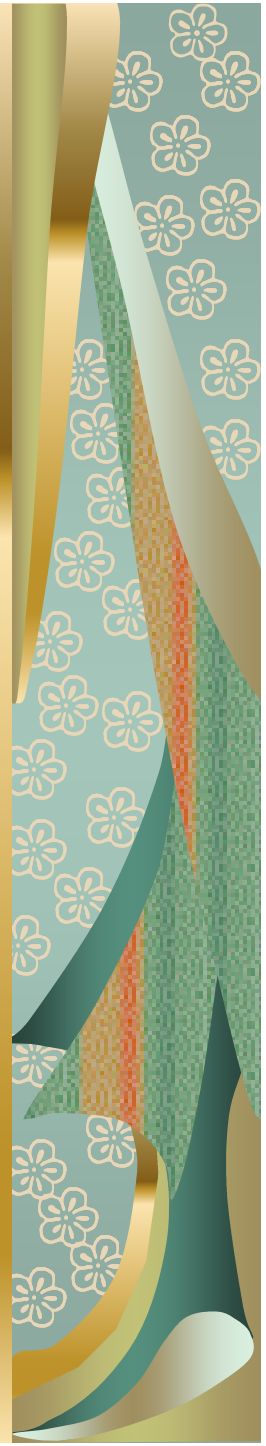


- In terms of the economic policy, AIDS has particularly two important implications.

➢ By killing off mainly young adults, AIDS also seriously weakens the tax base, and so reduces the resources available to meet the demands for public expenditures, including those aimed at accumulating human capital, such as education and health services not related to AIDS - pressure on economy.

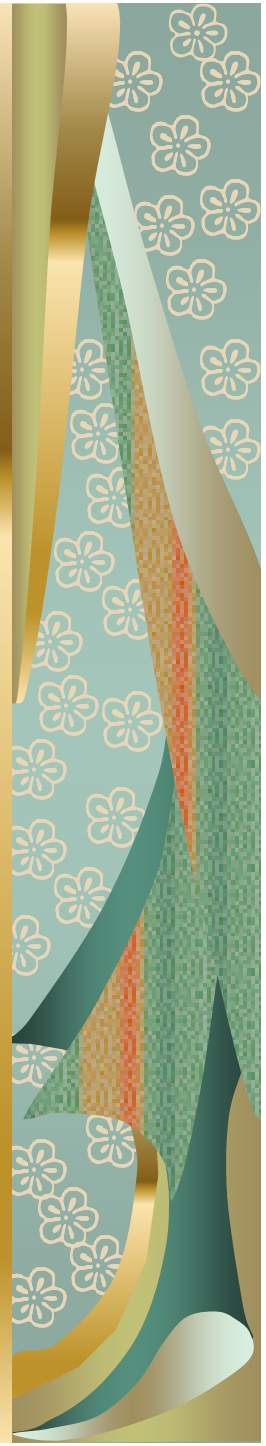


- Slower growth of the economy means slower growth of the tax base, an effect that will be reinforced if there are growing expenditures on treating the sick and caring for orphans.
- As a result, the state's finances will come under increasing pressure.



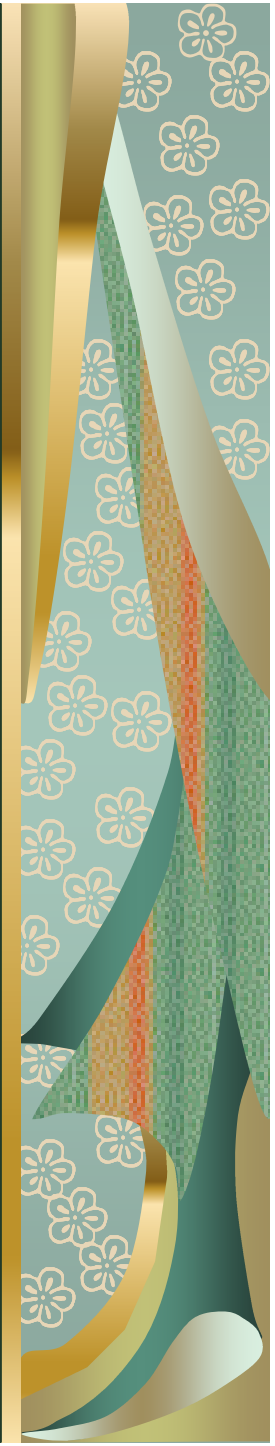
- Orphans are not given the care and education enjoyed by those whose parents remain uninfected,

  →government is likely to experience increasing fiscal difficulties, and so lack the resources to assume this additional burden in full.



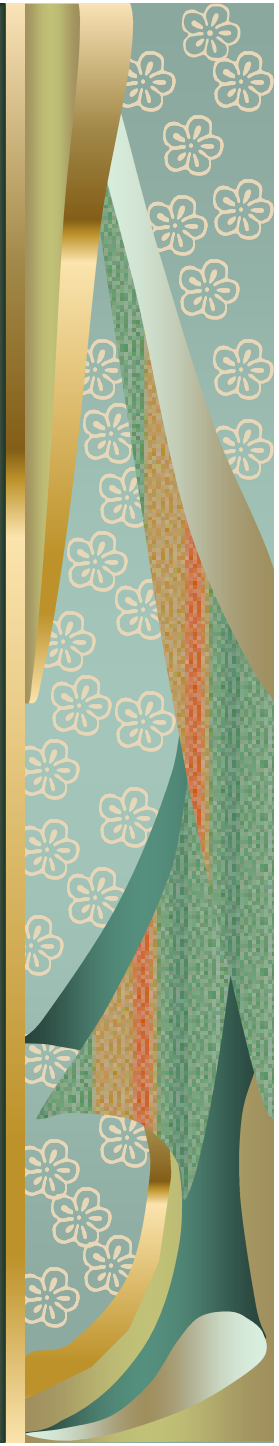
Measuring the Economic Impact

- Base all our analysis on the a mathematical model, where prevention and treatment have been augmented in the fight against the pandemic.
- Develop the cost function model which captures the all costs of therapy and progression to AIDS for all those who are infected at the beginning of treatment



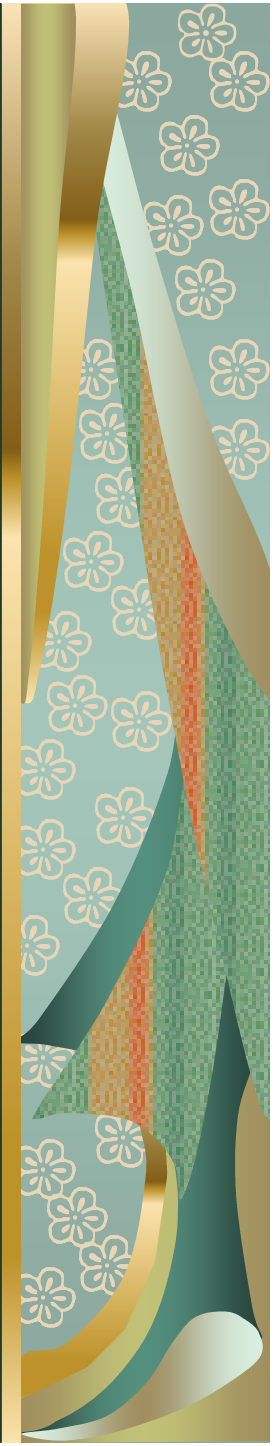
The Costs

- treatment of patients
- loss of productivity due to
  - premature death of infected individuals
  - sickness of infected individuals
  - time lost to the care giver
- Strengthening the health care system to prevent spread



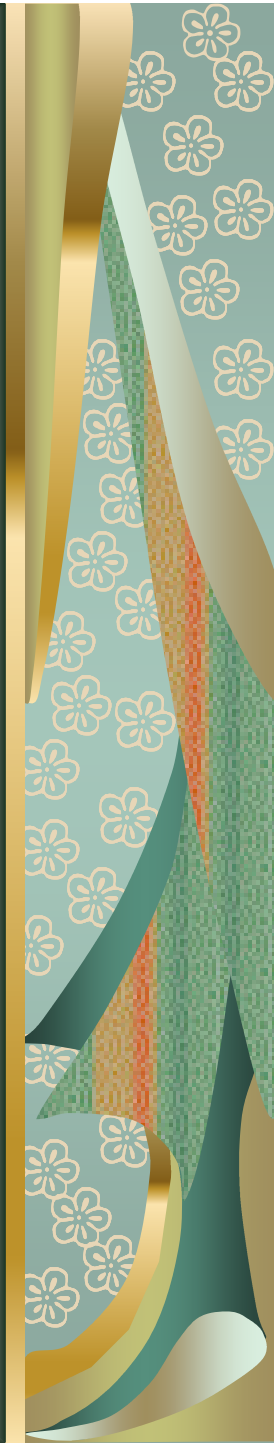
Costs

- Loss of skilled work force
- Retraining a new work force
- Screening people for the infection
- Screening of blood products
- Preventions eg vertical transmission, educational campaigns
- Hospitalization
- Pain of suffering to the patients and their families - intangible



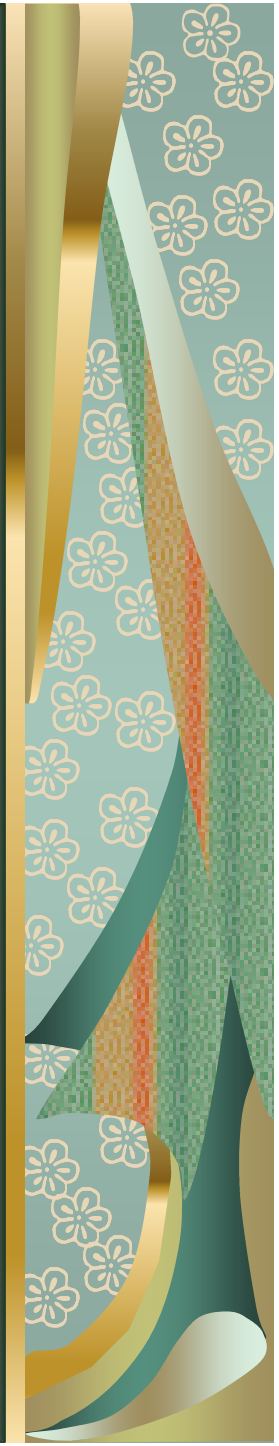
Costs

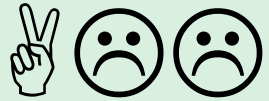
- Post infection counseling,
- Training peer educators, printing booklets and other related material.
- Home based care
- Running the clinic and other related administrative issues such as follow up of defaulters by phoning
- Research and development

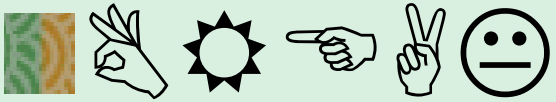


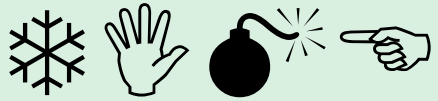
Measuring the Economic Impact: The Cost Function

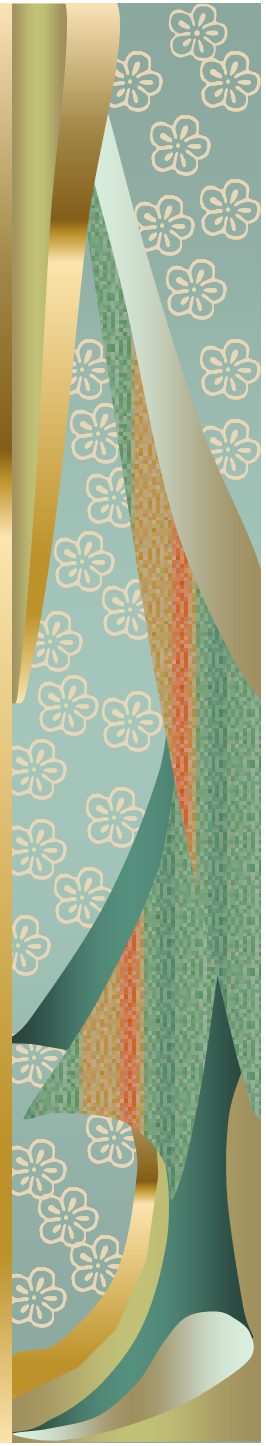
- Measurements to gauge the severity of the epidemic and the performance of public interventions to reduce its spread.
- Consider the total number of life years in the active population as a measure of epidemiological impact





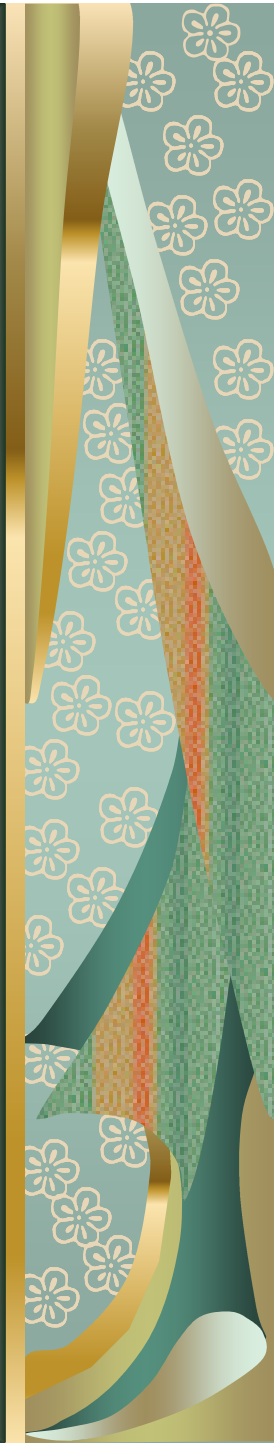






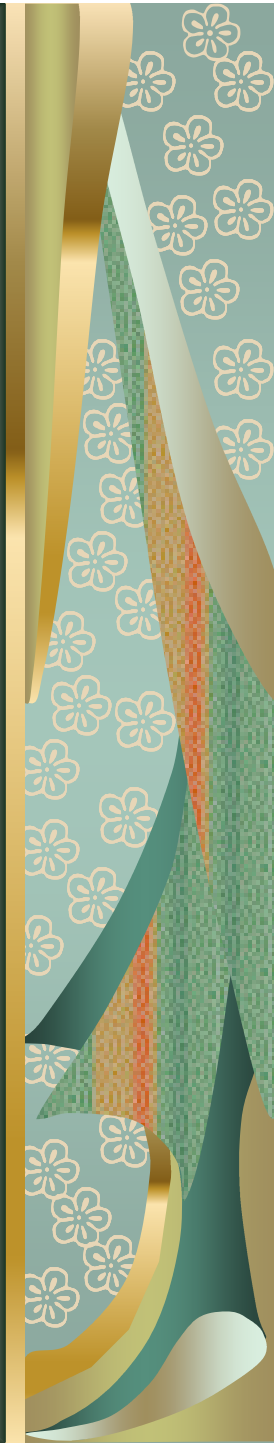
Example1: Cost function: S.D. Hove-Musekwa, Vengai Runyowa, Zindoga Mukandavire,2008

- Mathematical model incorporating all the prevention and treatment strategies which are
  - condom use – behaviour change
  - screening and pre-and post counselling
  - treatment



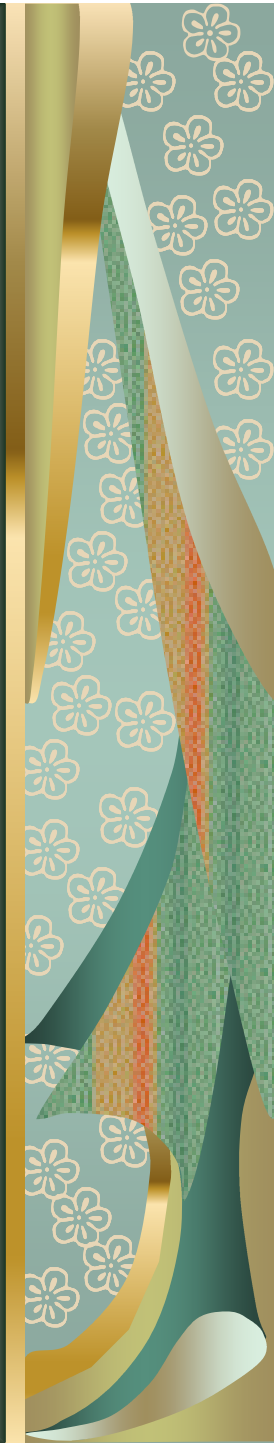
Model Formulation: Notation

- S - Susceptible individuals
- I - HIV-only infected asymptomatic individuals
- T - treated individuals
- T_c- treated individuals given post-treatment counselling
- A -individuals with full blown AIDS
- A_c-treated individuals with full blown AIDS given post-treatment counselling
- N is the total population



Notations: Demographic parameters

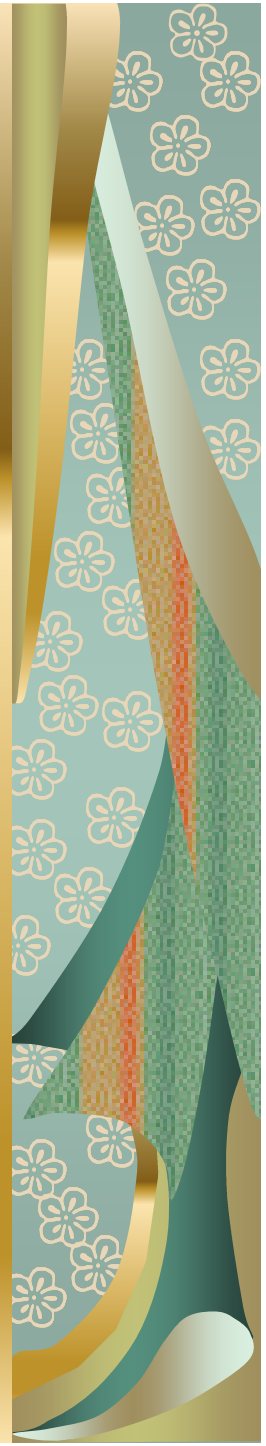
- Π - is the recruitment rate of sexually mature (+16 years) susceptible individuals admitted into the community per unit time.
- Death rates μ - We assume that natural death rate for all individuals is constant, the same and proportional to the number in the class and is independent of other diseases.



Demographic parameters contd-

- Death rates δ_i- We also assume that the AIDS individuals

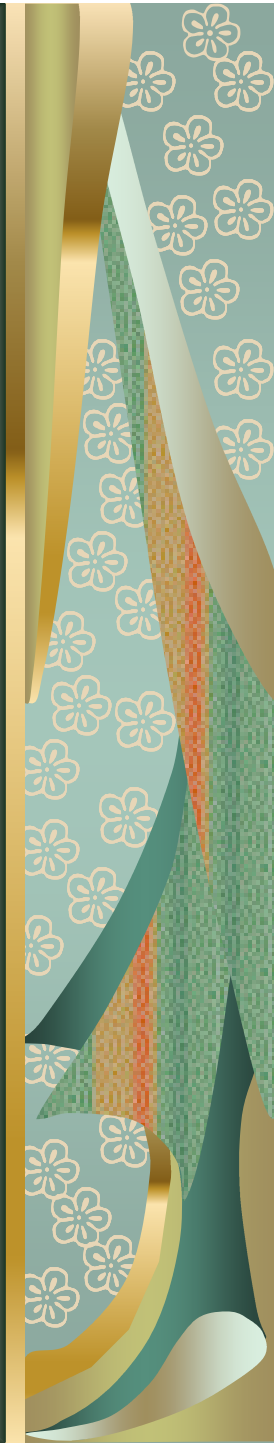
  suffer a disease-caused mortality at a constant rate δ_i: i = 1; 2
- depending whether the individual is under treatment only or both treatment and post counselling respectively.



Epidemiological parameters

- β^{-} is probability of transmission from an infected individual to a susceptible individual
- r_i is the vulnerability constant- is the factor by which the

  probability of transmission is raised in the case of the AIDS group having close contact with the susceptible group.
- Average number of sexual partners c -depends largely on social and environmental factors that determine the living conditions, resources and social opportunities. Culture and religion also have an influence on the number of new partners one can acquire.

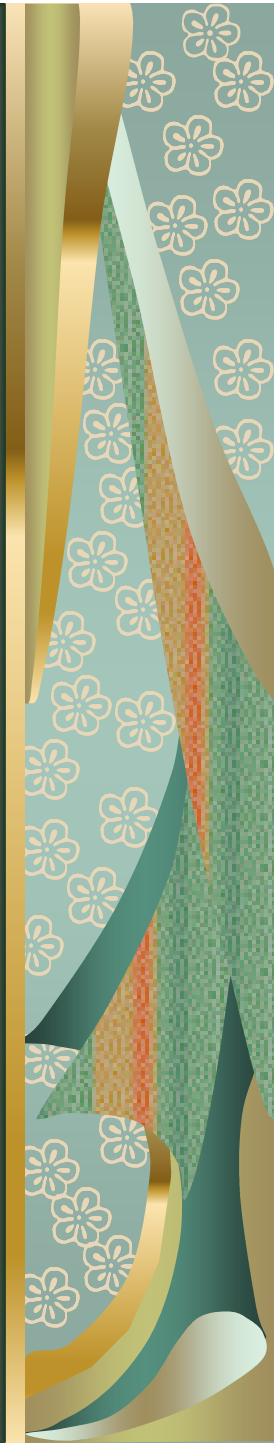


Progression rates $\sigma,\eta,\ \rho_i,v_i;\ i=1;\ 2;$

- $\rho_i v_i$ where ρ_i is the rate of seeking treatment and v_i is the progression rate from the normal infectives and AIDS class respectively after treatment to the treated class.
- **Intervention rates ($\omega;\ \psi_i\ ,\alpha_i;\ \epsilon_i;\ i = 1;\ 2$)**

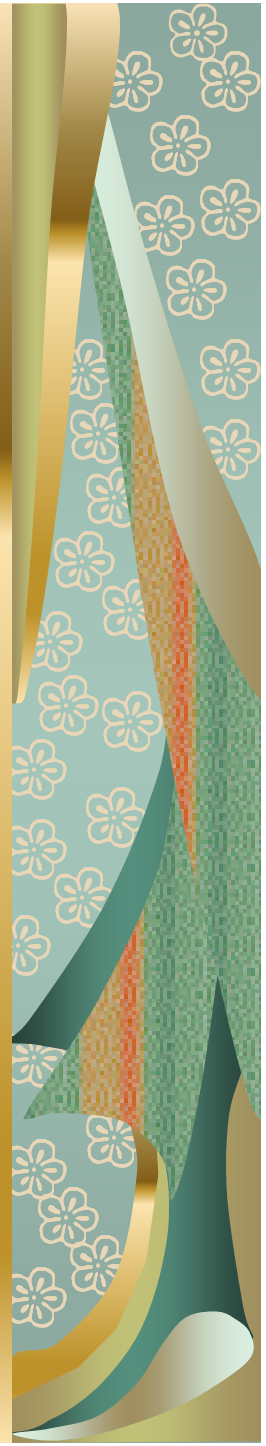
  - $\omega = \alpha_1\epsilon_1$ - the condom induced preventability which is the product

  of α_1 (compliance rate) and condom efficacy of ϵ_1 and such that $0 \leq \alpha_1\epsilon_1 \leq 1$



- $p = \alpha_2 \epsilon_2$ - measurement of the level of reduction in the severity of HIV when an individual is taking treatment which is given by the product of the rate of adhering to treatment α_2 with a drug efficacy

  ϵ_2 so that p is the drug induced preventability of progression to AIDS.
- ψ_i - rate at which the treated infectives and AIDS individuals receive post treatment counselling and progress to the AIDS counselled class.



Model equations

$$\frac{dS}{dt} = \pi - (1 - \varpi)\lambda S - \mu S$$

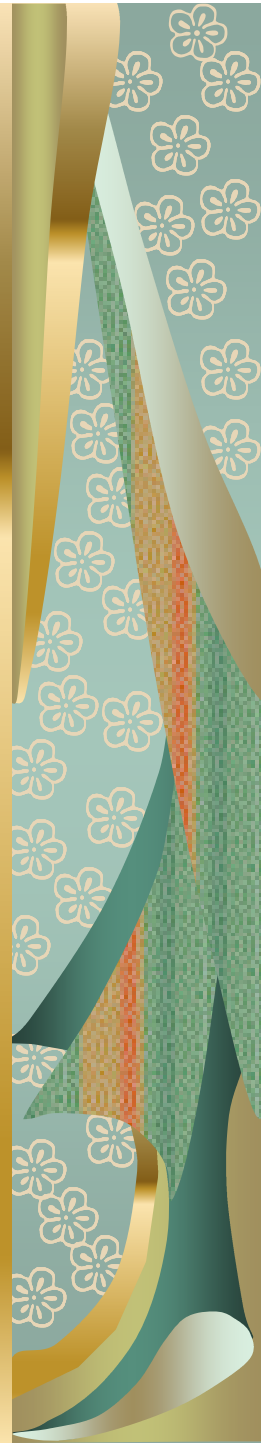
$$\frac{dI}{dt} = (1 - \varpi)\lambda S - (\nu_1 \rho_1 + \nu\rho + \mu)I$$

$$\frac{dT}{dt} = \nu_1 \rho_1 I + \nu_2 \rho_2 A - [\gamma(1 - \pi) + \psi_1 + \mu]T$$

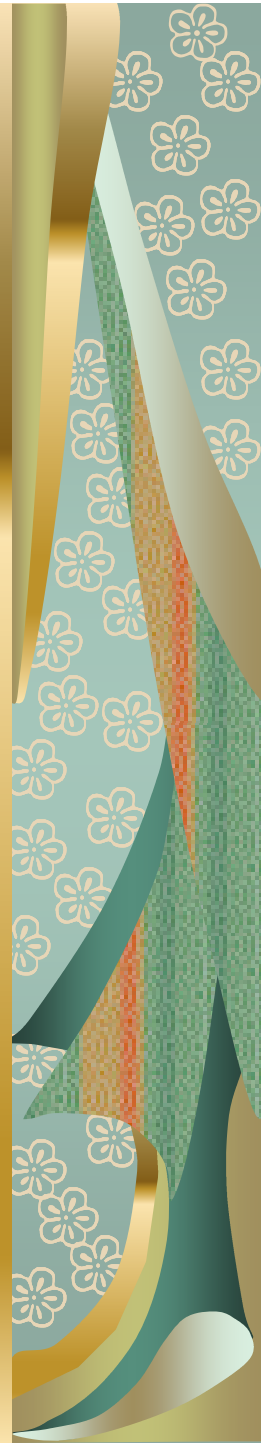
$$\frac{dT_c}{dt} = \psi_1 T + \nu_3 \rho_3 A_c - (\eta + \mu)T_c$$

$$\frac{dA}{dt} = \nu\rho I + \gamma(1 - \pi)T - (\delta + \nu_2 \rho_2 + \psi_2 + \mu)A$$

$$\frac{dA_c}{dt} = \eta T_c + \psi_2 A - (\delta + \nu_3 \rho_3 + \mu)A_c$$

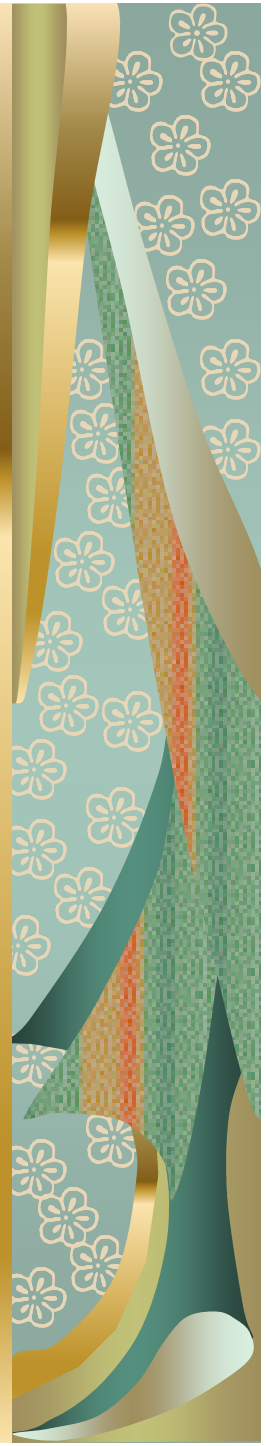


- where $$\lambda = \frac{\beta c(I(t) + r_1 A(t) + r_2 T(t))}{N(t)}$$
- r_1 and r_2 –vulnerability constant,



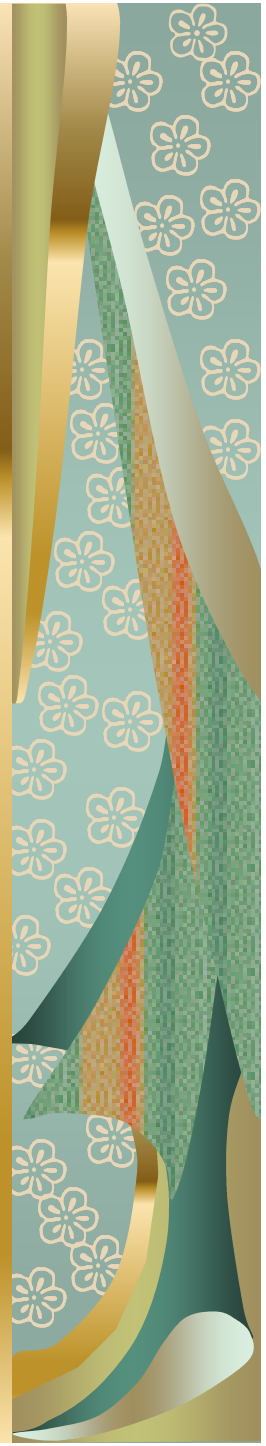
Invariant regions

- It can be shown that for the system the region
- $\Gamma = \{(S; I; T; T_c; A; A_c)\} \in R^{6+} \leq \Pi / \mu\}$ is positive invariant, making sure that the model is well posed and biologically meaningful.



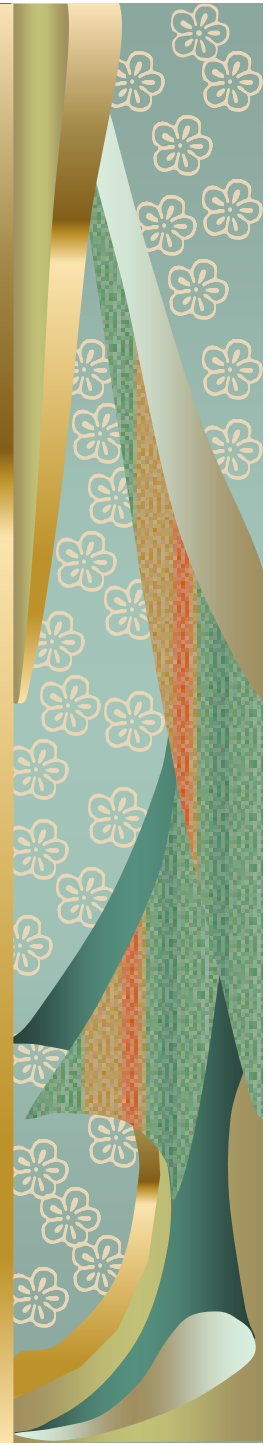
Equilibrium States

- The model has a DFE
- $E_0 = (S^*, I^*, T^*, T_c^*, A^*, A_c^*)$
  $= (\Pi/\mu, 0, 0, 0, 0, 0)$
- The reproduction number R_e is



$$R_e = R_{0I} + \left[\frac{\rho_1 \nu_1}{\rho_1 \nu_1 + \sigma_1 \nu + \mu} + \left(\frac{\sigma_1 \nu}{\sigma_1 \nu + \rho_1 \nu_1 + \mu} \right) \left(\frac{\rho_2 \nu_2}{\rho_2 \nu_2 + \sigma_1 \nu + \mu} \right) \right] R_{0T}$$

$$\left[\frac{\sigma_1 \nu}{\sigma_1 \nu + \rho_1 \nu_1 + \mu} + \left(\frac{\rho_1 \nu_1}{\rho_1 \nu_1 + \sigma_1 \nu + \mu} \right) \left(\frac{\sigma_2}{\sigma_2 + \psi_1 + \mu} \right) \right] R_{0A}$$

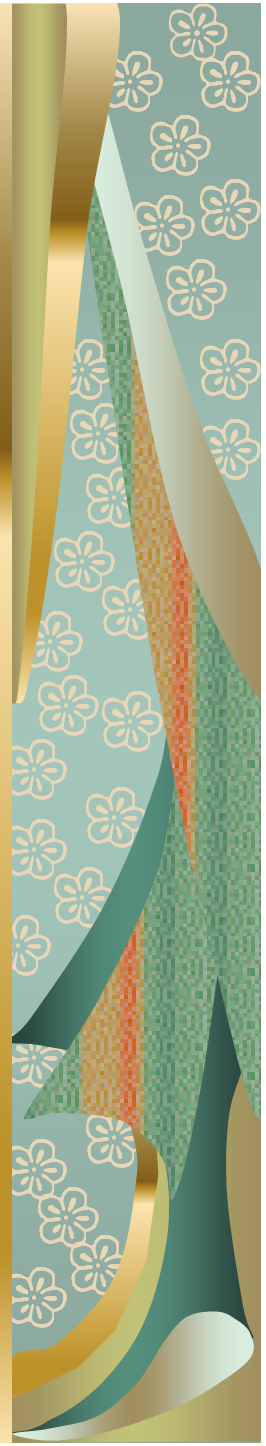


- where

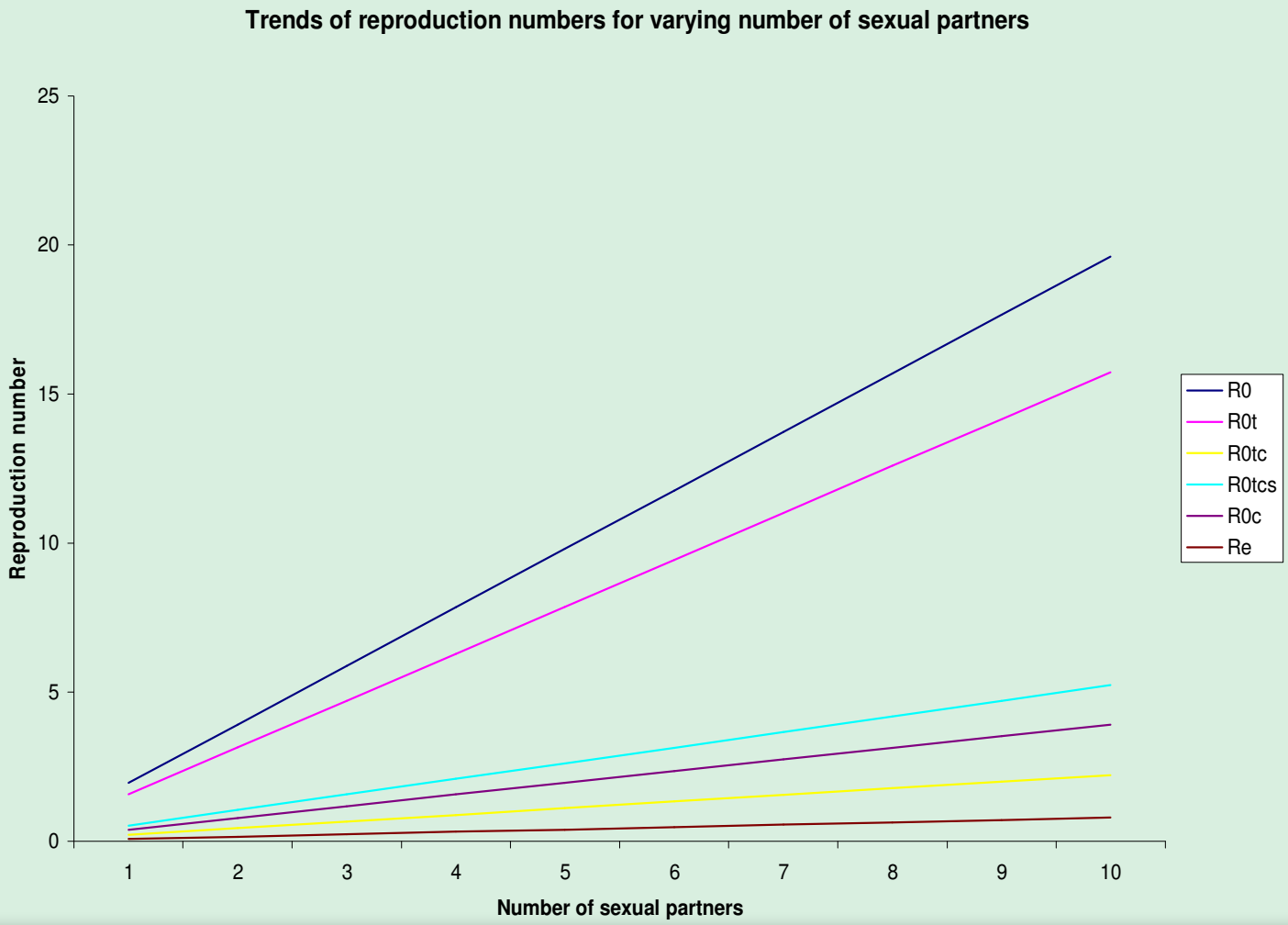
$$R_{0I} = \frac{c\beta(1-\omega)}{\nu_1\rho_1 + \nu\sigma_1 + \mu}, R_{0T} = \frac{cr_1\beta(1-\omega)}{(\sigma_2 + \psi_1 + \mu)(1-R_p)}$$

$$R_{0A} = \frac{cr_2\beta(1-\omega)}{(\rho_2\nu_2 + \psi_2 + \mu + \delta_1)(1-R_p)}$$

$$R_p = \left(\frac{\sigma_2}{\sigma_2 + \psi_1 + \mu}\right)\left(\frac{\rho_2\nu_2}{\rho_2\nu_2 + \psi_2 + \mu + \delta_1}\right) < 1$$

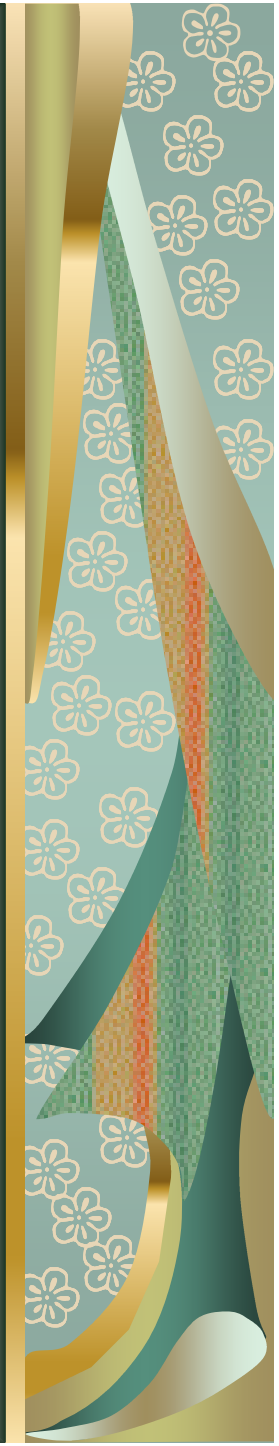


Sensitivity Analysis: Trends of reproduction numbers



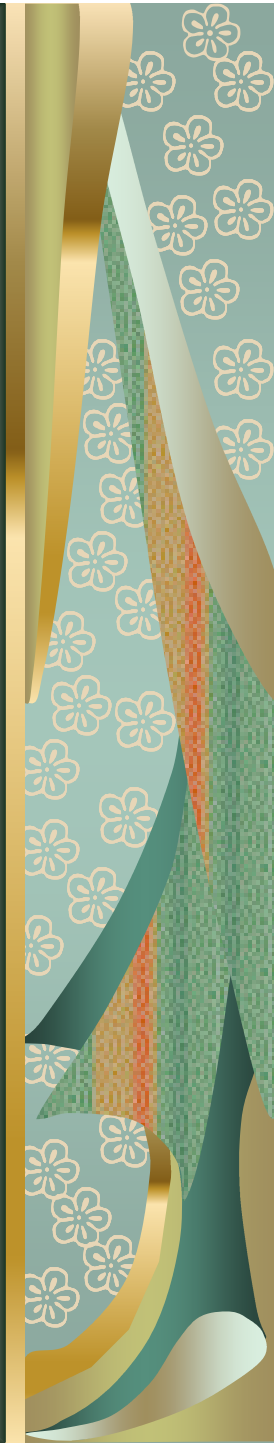
Trends of reproduction numbers

- Treatment alone worsens the epidemic
- Condom use alone is better than treatment alone
- Post treatment counselling together with the other strategies reduces the epidemic
- More interventions reduce the basic reproduction number showing the importance of multiple strategies being used.
- $R_e < R_{0c} < R_{0tcs} < R_{0t} < R_0$:



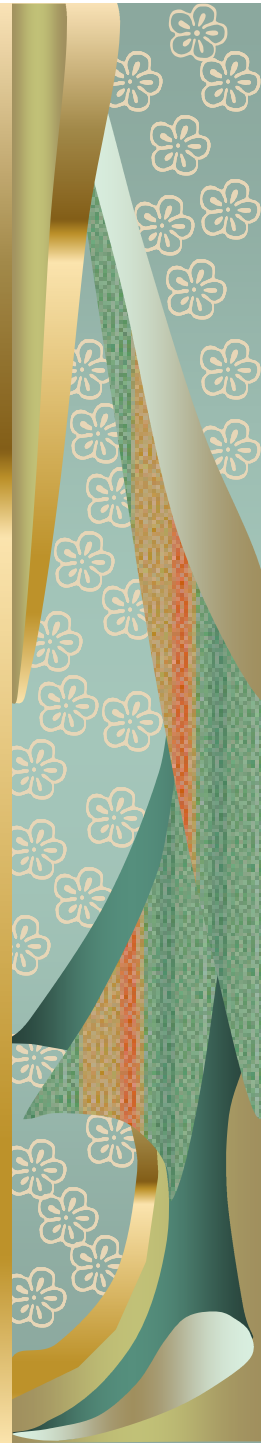
Stability Analysis of the Disease-Free Equilibrium, E_0

- E_0 is locally asymptotically stable if $R_0 < 1$ and unstable if $R_0 > 1$:
- The globally stability of E_0 follows from Thieme (1993) can be summarized in the following theorem
- **Theorem:** E_0 is globally asymptotically stable if $R_0 < 1$ and unstable if $R_0 > 1$:

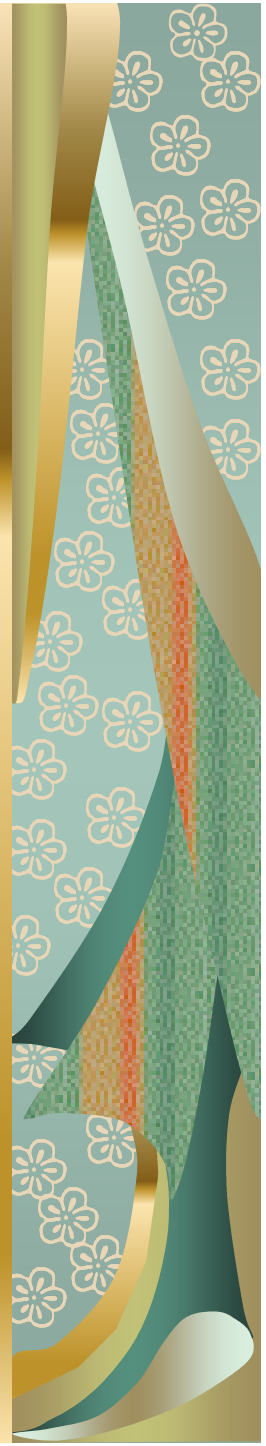


Measuring the Economic Impact

- Develop the cost function model which captures the cost of therapy and progression to AIDS for all those who are infected at the beginning of treatment
- Model developed using concepts drawn from the previous work of Paltiel and Kaplan (1992)



- Economic impact of HIV/AIDS in Zimbabwe based on the direct
- monetary values that are incurred as the epidemic runs its course.
- Base all our analysis on the model, where prevention and treatment have been augmented in the fight against the pandemic.



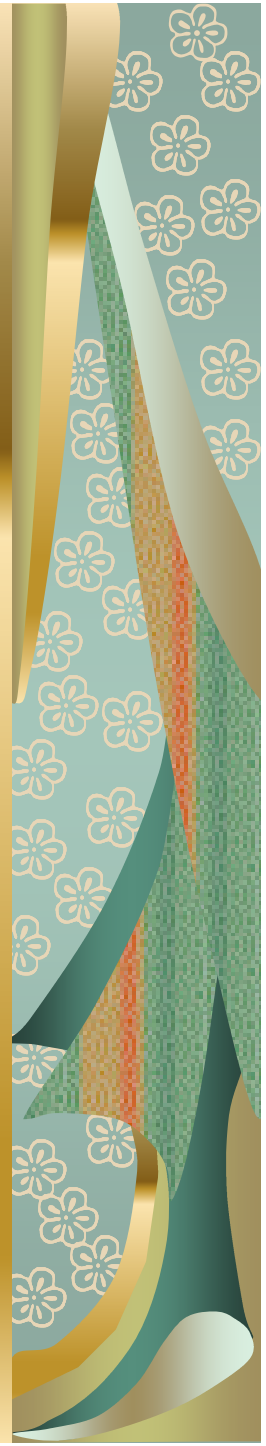
- Assumptions

- Using the condom consistently (i.e. correctly and constantly)

  gives 100% prevention of HIV transmission.

- Treatment/Therapy of the relevant form commences once the

  person has been identified to be positive.

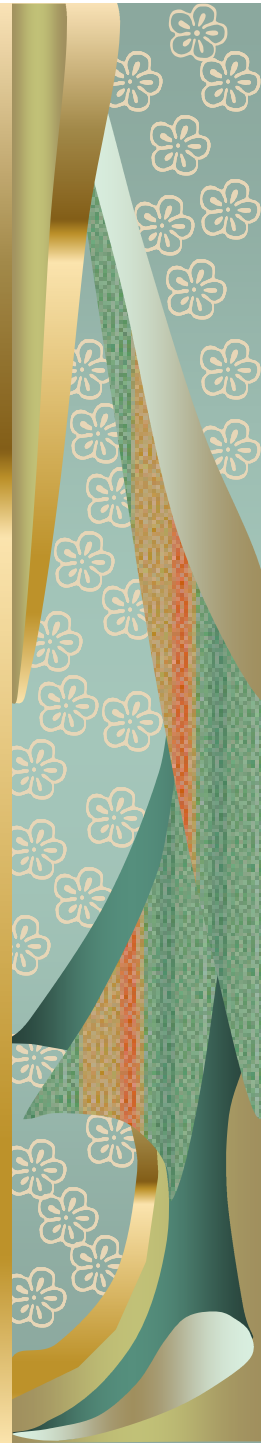


The Cost Function

- Costs involved affects the patient, the worker the government

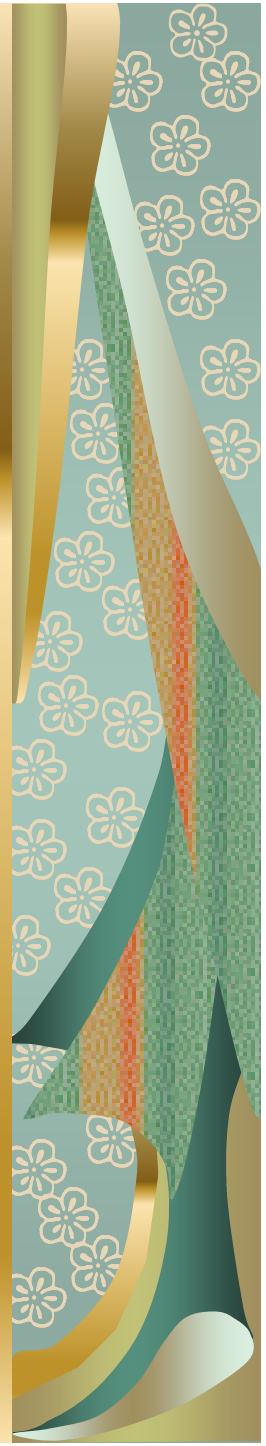
- The cost of condoms C_c, this is proportional to the total number of susceptibles, infectives and AIDS individuals, ie, sexually active population, at any given time

- The cost of screening C_s

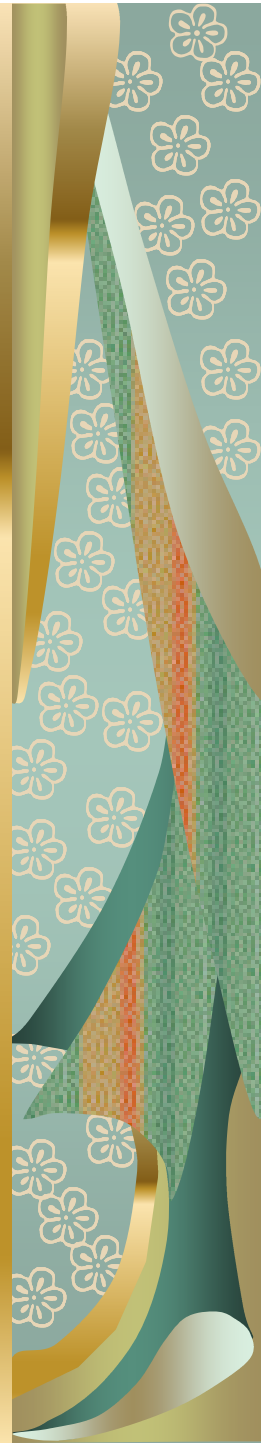


- The costs C_{TI} of fighting opportunistic infections like Tuberculosis, pneumonia, the cost of the different prophylaxis on the said population and the cost of CD4 cell counts, viral load

- important where there is drug resistant or treatment failure.

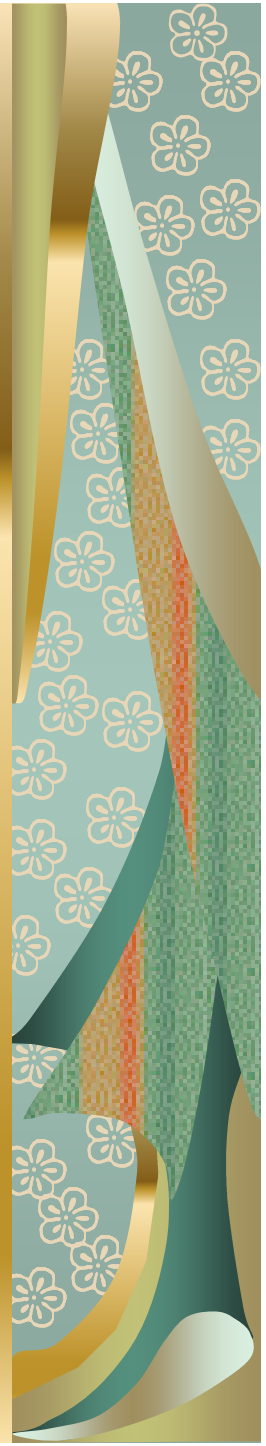


- The cost C_{TA} of treating those who have developed full blown AIDS by the proportion of the treated who go on to develop full blown AIDS - such costs as home based care, hospitalization, supply of structured ARV treatment, home nursing about Z$2m a month patient paying Z$50.



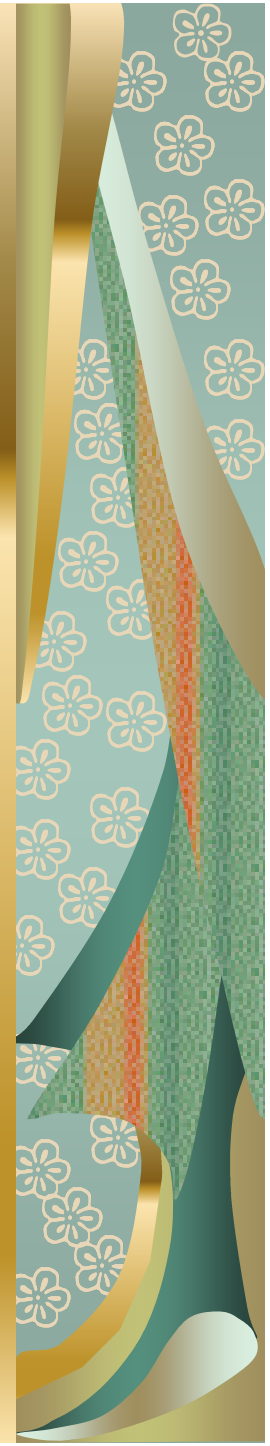
- The cost C_{PC} of post infection counseling, included are the cost training peer educators, printing booklets and other related material.

- The cost C_R of running the clinic and other related administrative issues such as follow-up of defaulters, etc.



Summary of Costs

- Condom costs – C_C.
- Screening cost – C_S
- Treating the infectives I – C_{TI}.
- Treating AIDS individuals – C_{TA}.
- Treating post-counselling individuals – C_{PC}.
- Running costs – C_R.

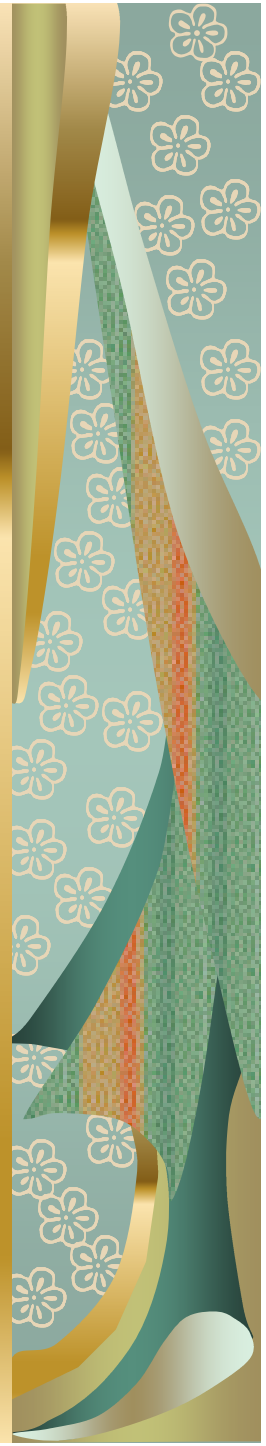


- The total cost C_{TC} is given by

$$C_{TC} = \int_0^n C \, dt$$

for n years

$$C = C_c[S(t)+I(t)+T(t)] + C_s[v_1\rho_1 I(t) + v_2\rho_2 A(t)] + C_{TI} I(t) + C_{TA}\sigma_2 T(t) + C_{CP}[\psi_1 I(t) + \psi_2 A(t)] + C_R$$



Simulating treatment of varying proportion: Infectives

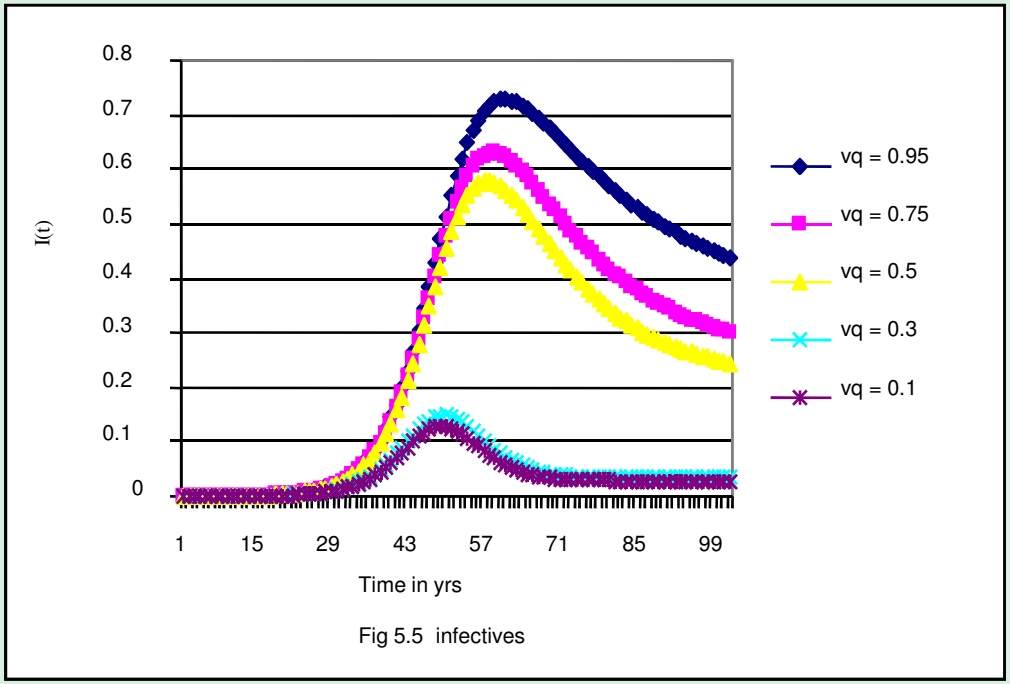


Fig 5.5 infectives

- Figure 1: Treating the stated proportions of HIV victims: Its effect on the adult infectives: vq is the proportion of individuals receiving treatment.

Simulating treatment of varying proportion: AIDS individuals

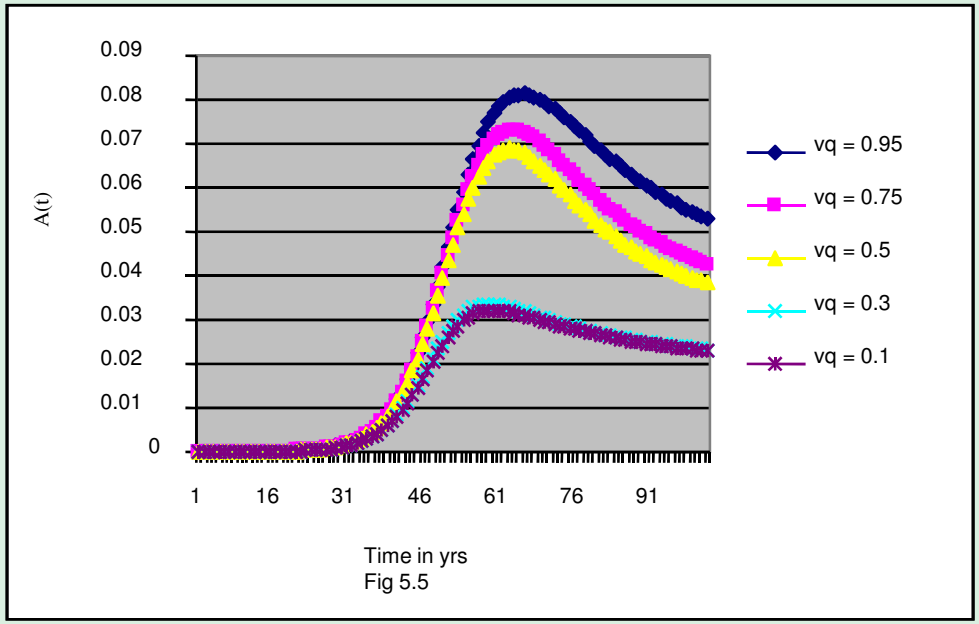
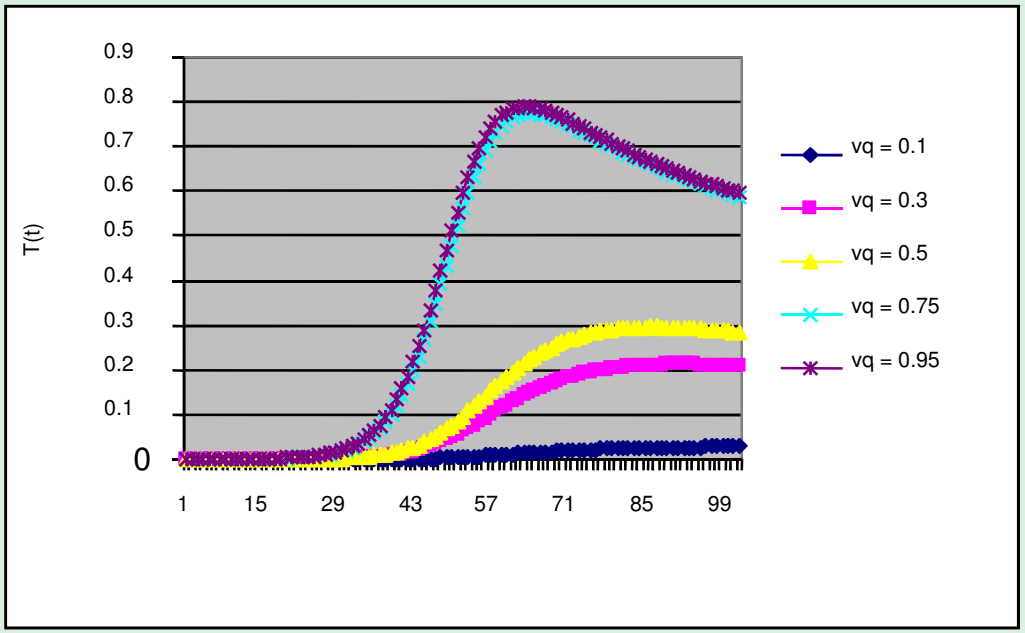


Fig 5.5

- Fig 2: Treating the stated proportions of HIV victims: Its effect on adult AIDS cases: vq is the proportion of adults population

receiving treatment

Simulating treatment of varying proportion: Treated individuals



- Fig 3: Treating the stated proportions of HIV victims: Its effect on adult Treated cases: vq is the proportion of adults population receiving treatment

Varying the incubation period with treatment: Infectives

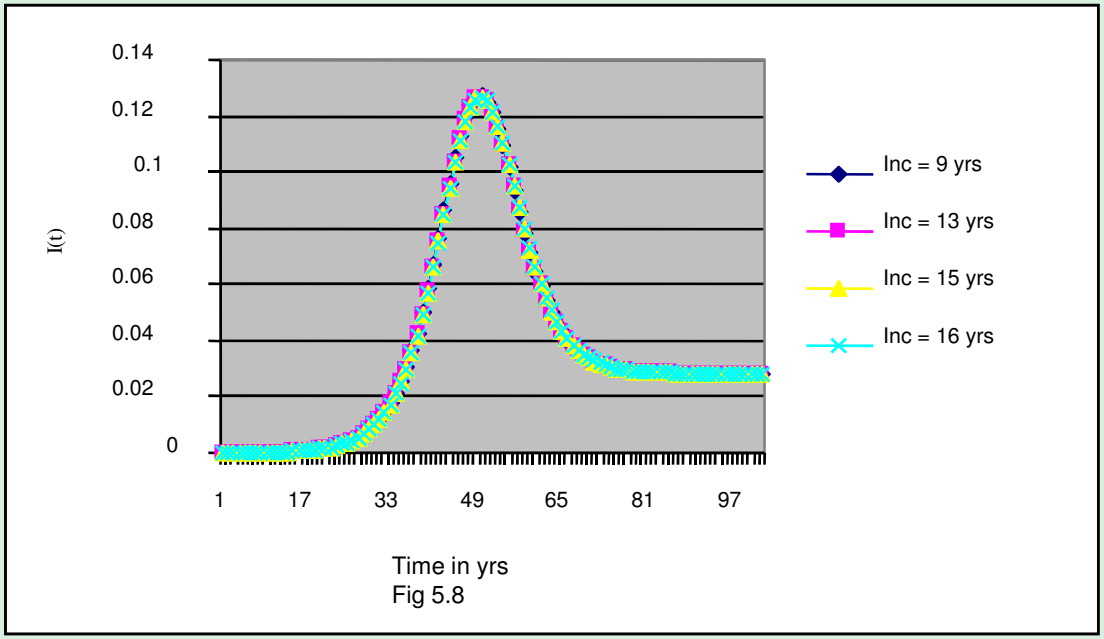


Fig 5.8

- Figure 4: Varying the incubation period and effective treatment of infectives: Its effect on the infected population: Inc: is the incubation period (average time an individual spends in the infected class before fully developing full blown AIDS

Varying the incubation period with treatment: Treated individuals

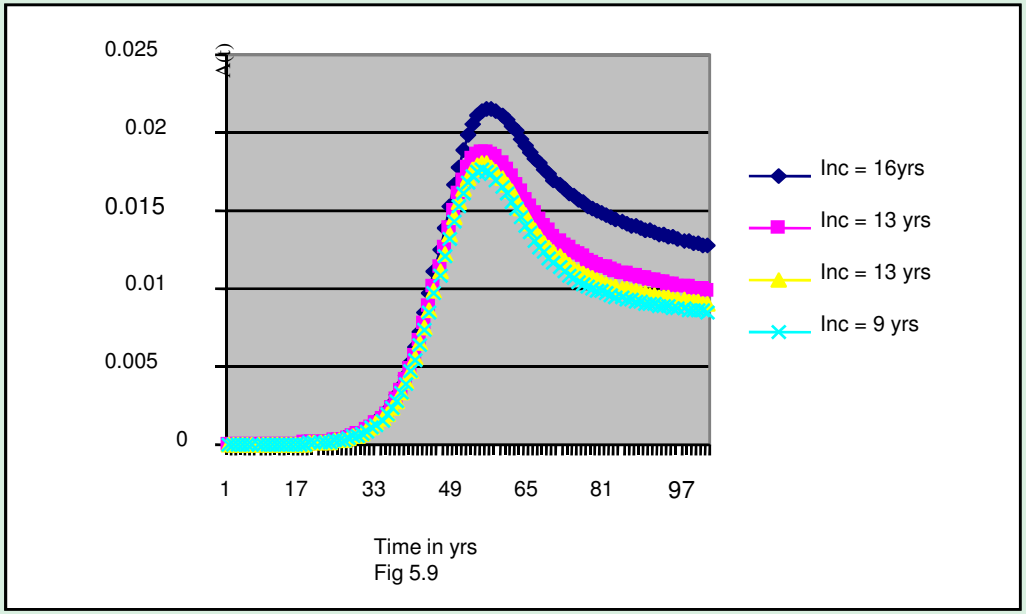


Fig 5.9

- Figure 4: Varying the incubation period and effective treatment of Treated infectives: Its effect on the treated infected population: Inc: is the incubation period (average time an individual spends in the infected class before fully developing full blown AIDS

Varying the incubation period with treatment: AIDS individuals

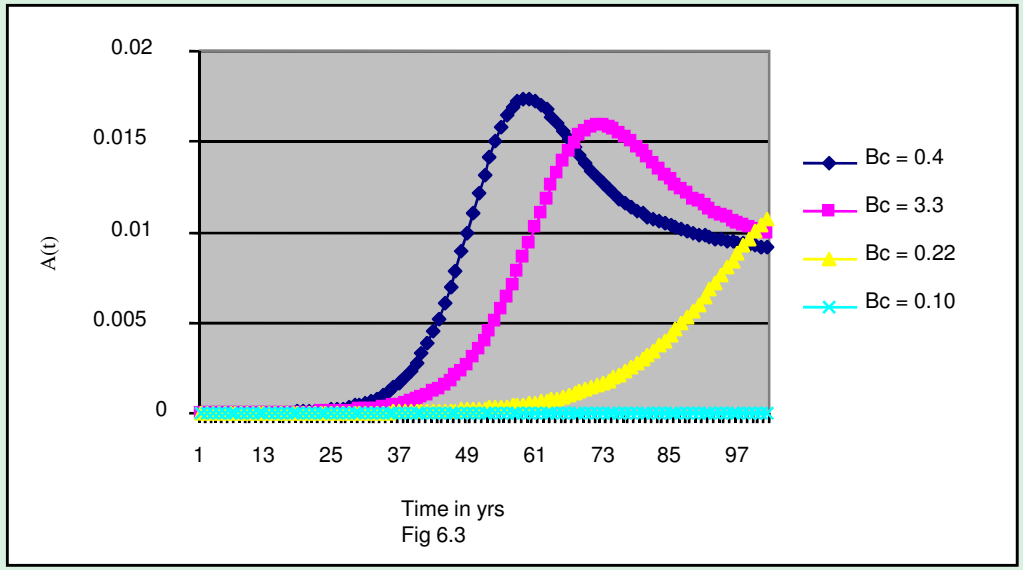


Fig 6.3

- Figure 5: Varying the incubation period and effective treatment of infectives: Its effect on the AIDS population. Inc: is the incubation period (average time an individual spends in the infected class before fully developing full blown AIDS

Simulating Total Cost: Varying the incubation period with no post-counselling

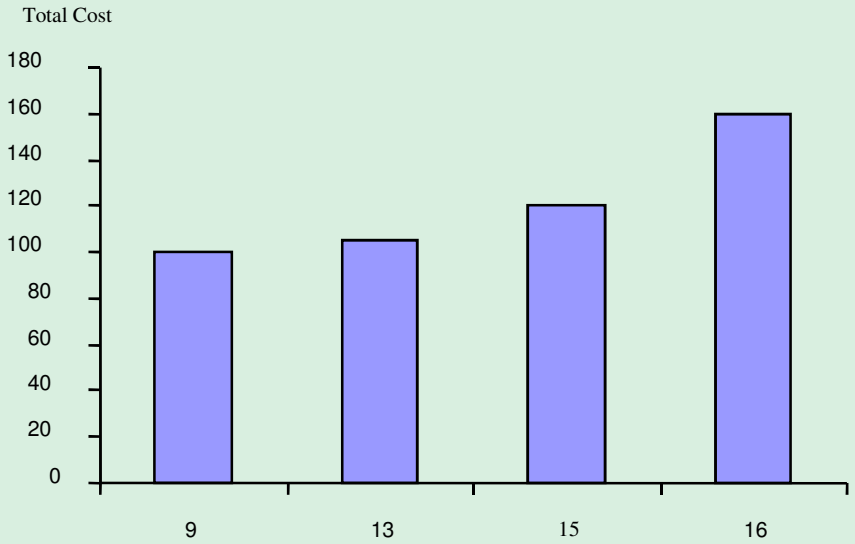
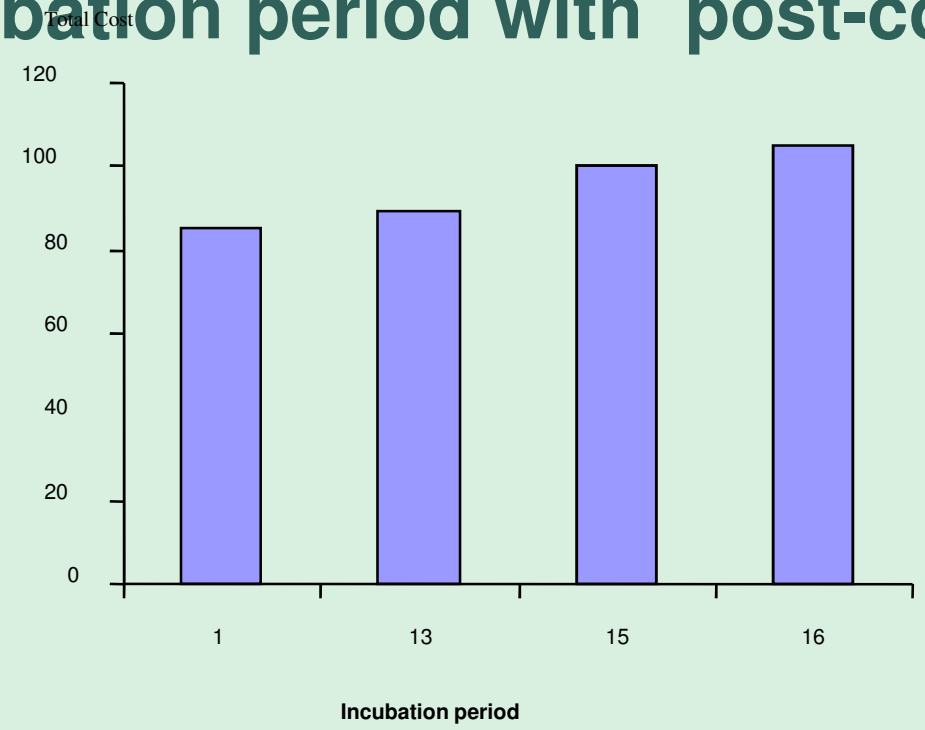


Figure 6.0 Incubation time in years

- Figure 6 The increase in the number of the infective population maybe attributed to the increase in the incubation period (i.e. more healthy years more sexual contacts for the infected).

Simulating Total Cost: Varying the incubation period with post-counselling



- Figure 7: The cost when there is post-counselling

Simulating effective treatment of infectives: Varying levels of behavioral

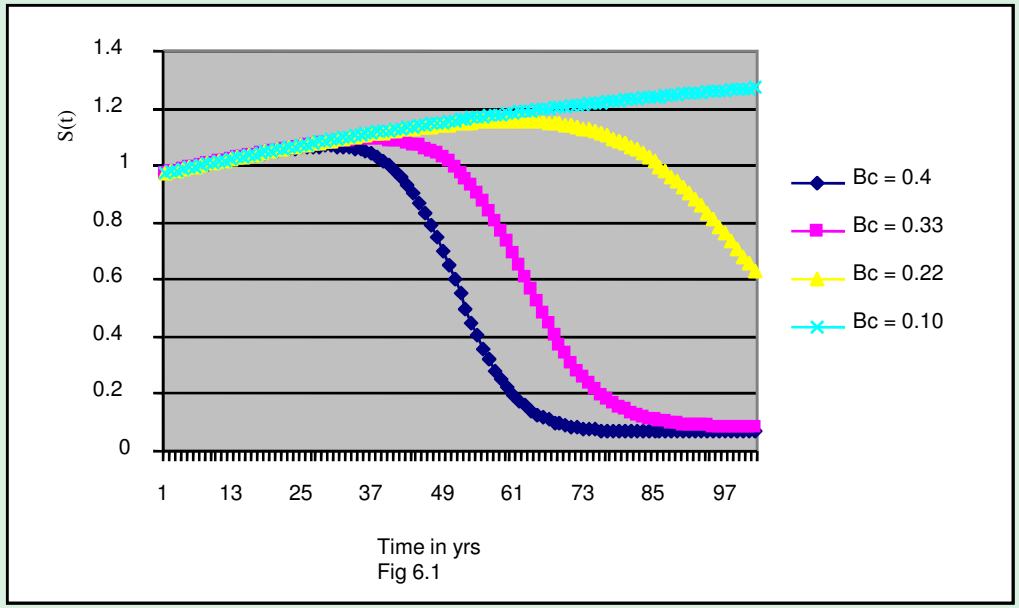


Figure 8 Effective treatment with a change in social behavior, : The distribution of the susceptible population. Bc: the change in social behavior, smaller values of Bc indicate positive change i.e. less partners per individual while large values indicate the converse.

Simulating effective treatment of infectives: Varying levels of behavioral

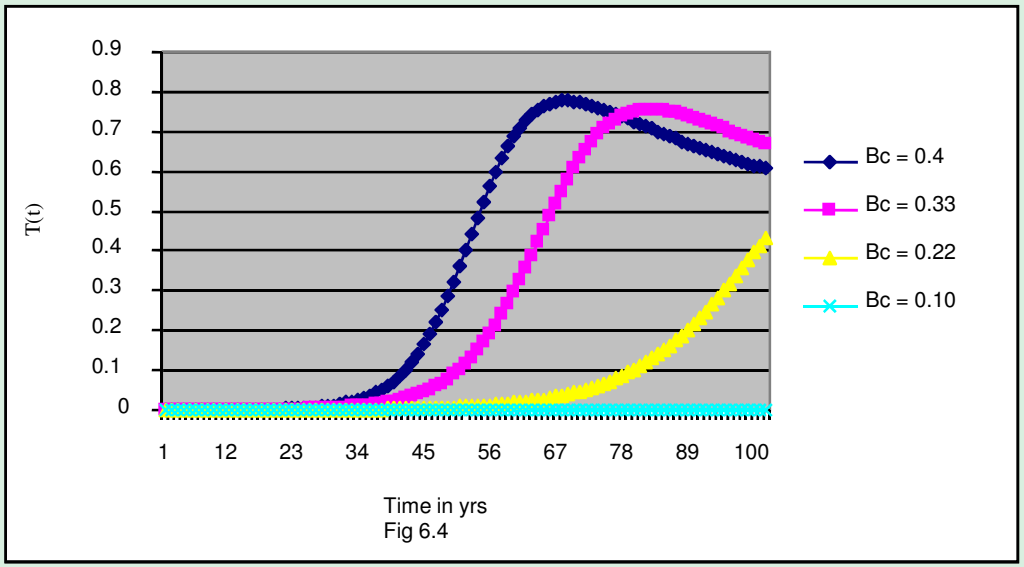


Fig 6.4

Figure 9 Effective treatment with a change in social behavior, : The distribution of the treated population. Bc: the change in social behavior, smaller values of Bc indicate positive change i.e. less partners per individual while large values indicate the converse.

Simulating effective treatment of infectives: Varying levels of behavioral

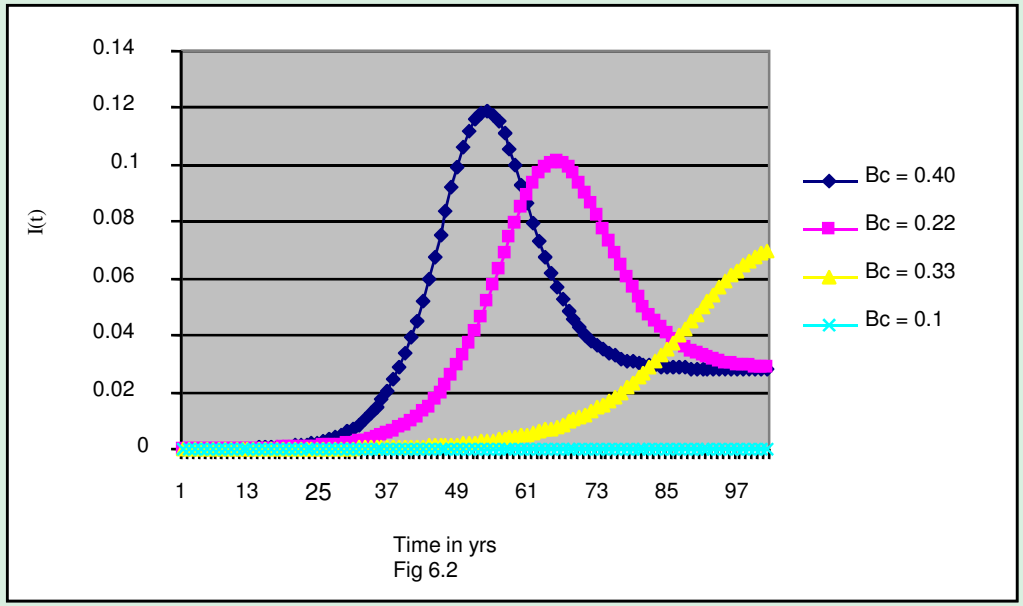


Figure 10 : Effective treatment and effect of change in social behavior : The distribution of infected adults. Bc: the change in social behavior, smaller values of Bc indicate positive change i.e. less partners per individual while large values indicate the converse.

Simulating effective treatment of infectives: Varying levels of behavioral

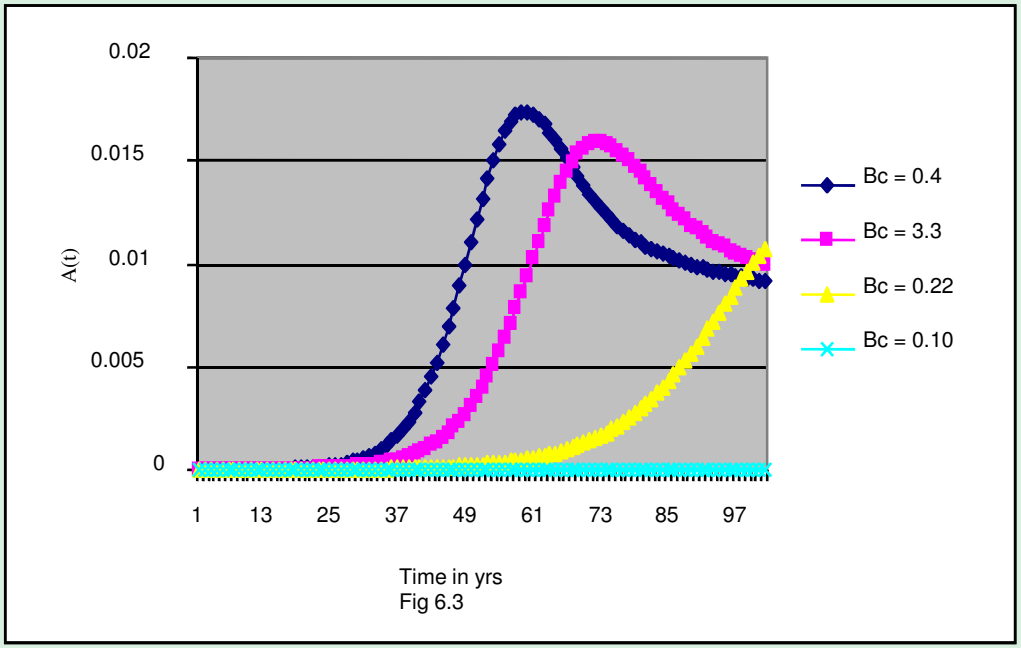


Figure 11 : Effective treatment and effect of change in social behavior : The distribution of AIDS individuals. Bc: the change in social behavior, smaller values of Bc indicate positive change i.e. less partners per individual while large values indicate the converse.

Simulating Total cost

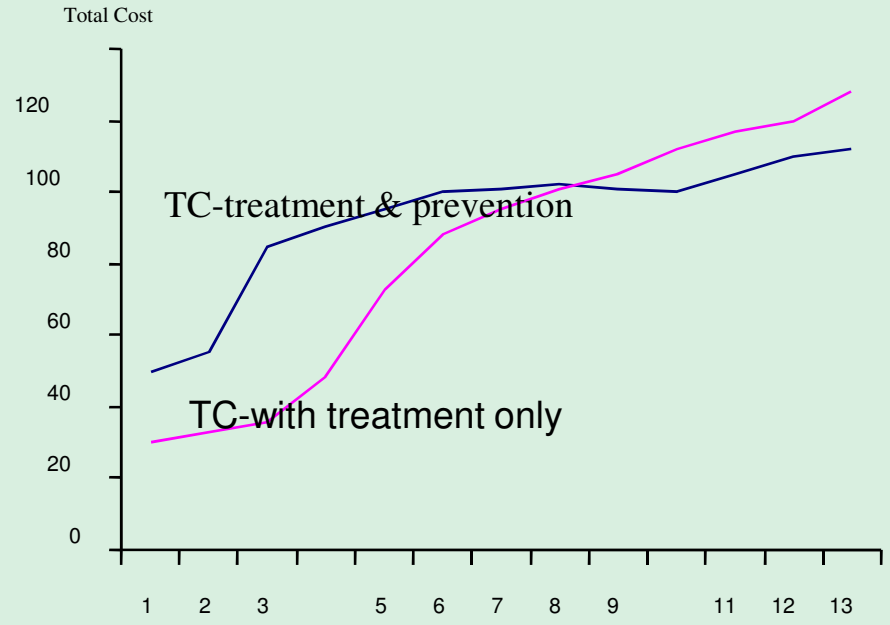
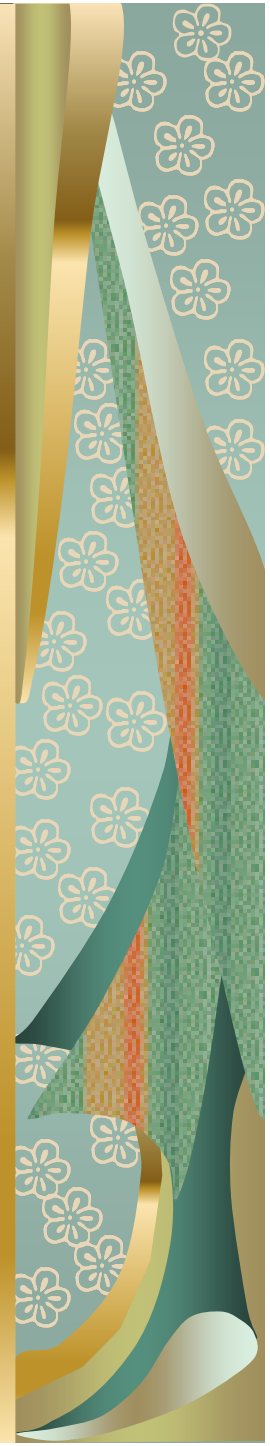


Figure 6.6 Time in years

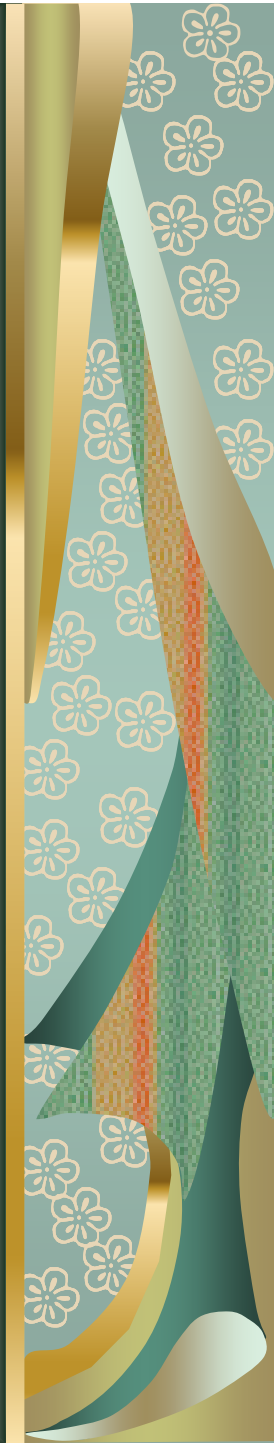
- Figure 12 : The total cost incurred in treating the infected population over time in two scenarios i.e. 1. Treatment coupled by preventive measures, 2. Treatment only.



Results

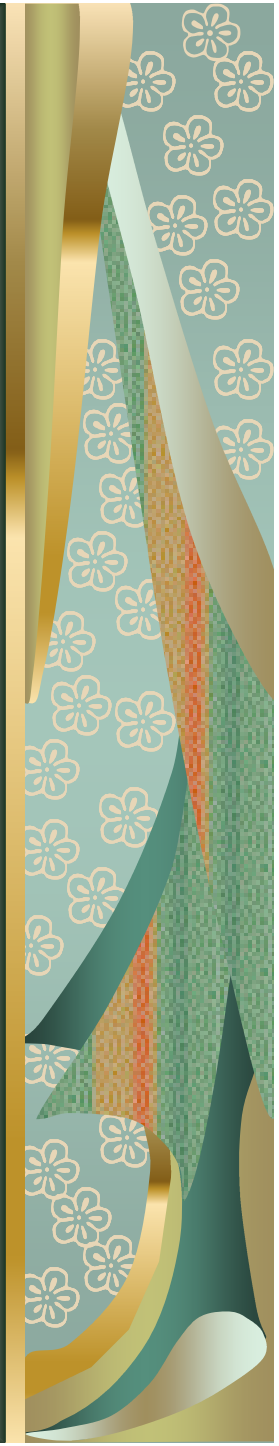
The following information can be obtained

- Save maximum number of person-years
- Max efficiency: number of person-years per years on ART
- How many life-years could be saved
- How many CD4 tests would this need
- How many years would be spent on ART
- How many orphans and child deaths would there be?
- How many person years lost to HIV/AIDS
- Morbidity and mortality issues – sick days and number of deaths



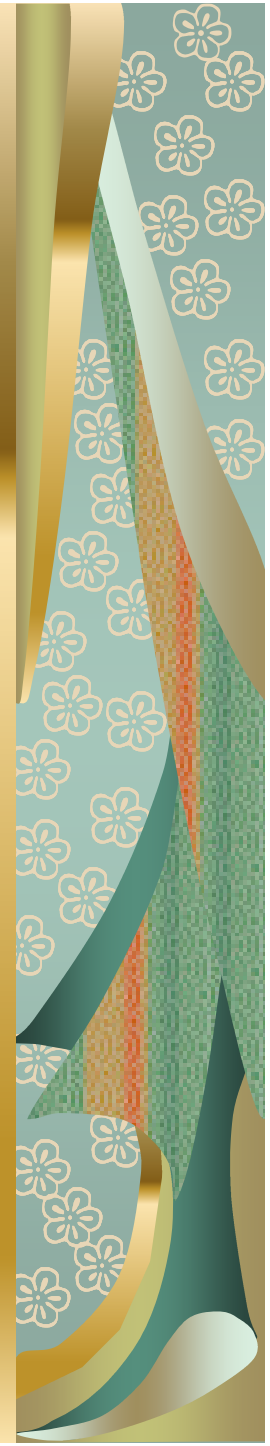
Results

- The total costs incurred in fighting the pandemic are lower when treatment is accompanied by educative programs.
- Change of behaviour reduces the economic impact of the epidemic
- Better position to advise policy makers



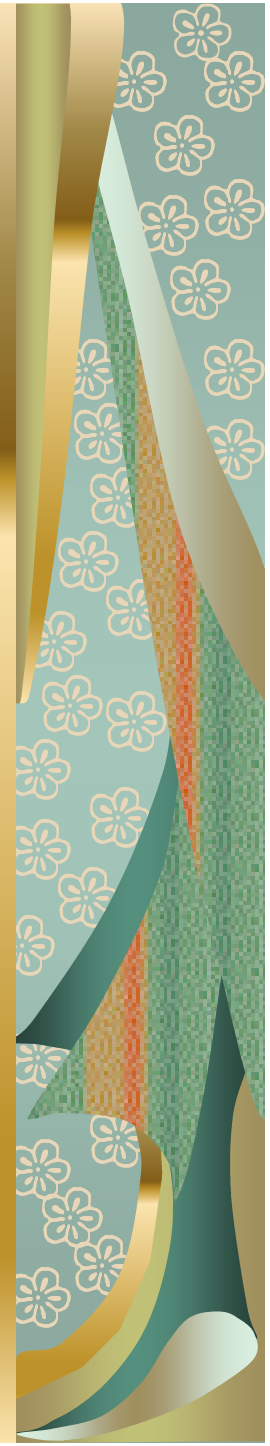
Modifications to the cost function which can be done

- Planned for a horizon of n years in the example
- Plan for beyond the horizon
- Suppose a new vaccine/treatment is found which changes the active population's behaviour
- More people come for testing
- Have a lump sum which captures the costs at beyond the planning horizon



- Let C_n = cost beyond the planning period depends on the individual living beyond life expectancy (lump sum).

$$C_{TC} = \int_0^n C dt + C_n$$

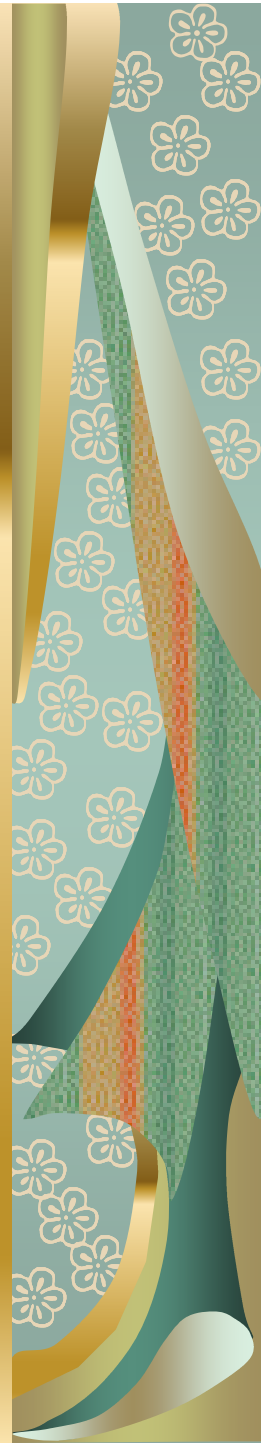


Adjusting for timing

- Discounted economic costs
- - per-person direct costs of treatment and prevention

$$C_D = \int_0^n [C_c S(t) + C_s(S(t) + \nu_1 \rho_1 I(t) + \nu_2 \rho_2 A(t)) + c_i [C_{TI} I(t) \\ \ldots\ldots + C_{TA}(\gamma(1-\pi)T(t)) + C_{PC}(\psi_1 T(t) + \psi_2 A(t))]] e^{-rt} dt$$

- r is the discount rate normal between 3% and 5%
- c_i annual cost to treat an individual in a particular disease stage i

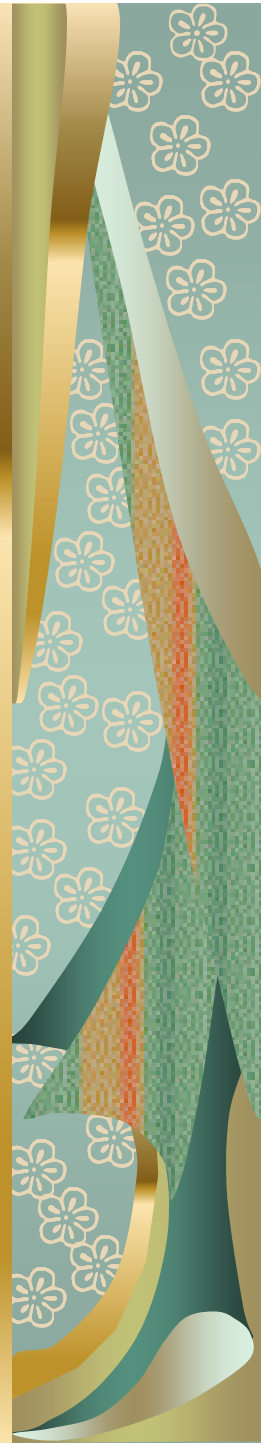


Discounted QALYs lived by the population

- This is given by

$$C_D = \int_0^n [q_i[C_{TI} I(t) + C_{TA}(\gamma(1-\pi)T(t)) + C_{PC}(\psi_1 T(t) + \psi_2 A(t))]]e^{-rt} dt$$

- q_i the QALY adjustment for a year of life in disease stage i

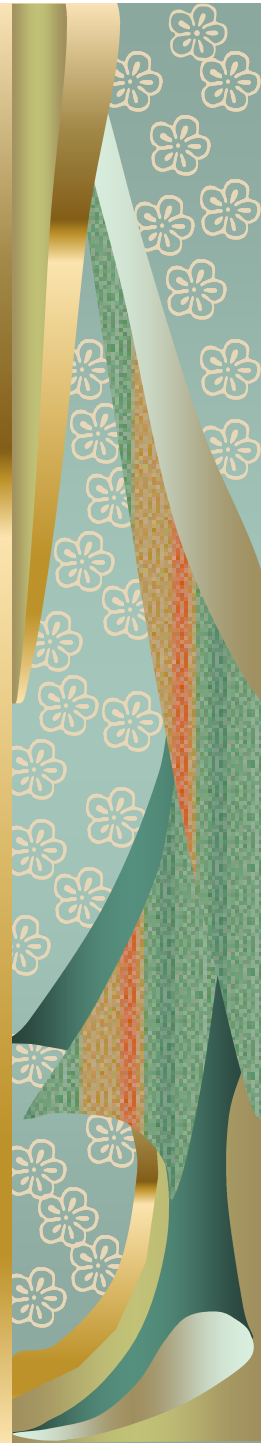


Epidemiological impact

- Epidemiological effectiveness – total number of life-years spent in the active population
- Total life-years within the planning period

$$TLy = \int_0^n [S(t) + I(t) + T(t) + A(t)]dt$$

- Beyond the planning period- natural life expectance, eg for S it will be S(n)/μ

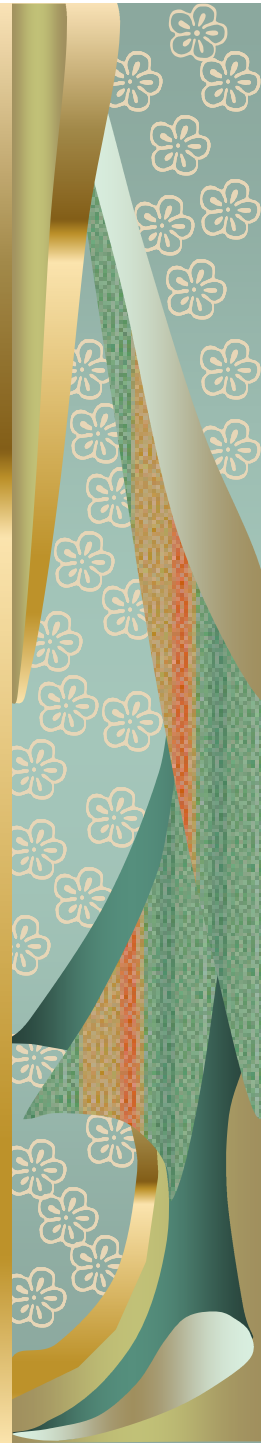


- This gives

$$TLy = \int_0^n [S(t) + I(t) + T(t) + A(t)]dt + \frac{S(n)}{\mu} + \frac{I(n)}{\nu_1\rho_1 + \nu\sigma + \mu}$$

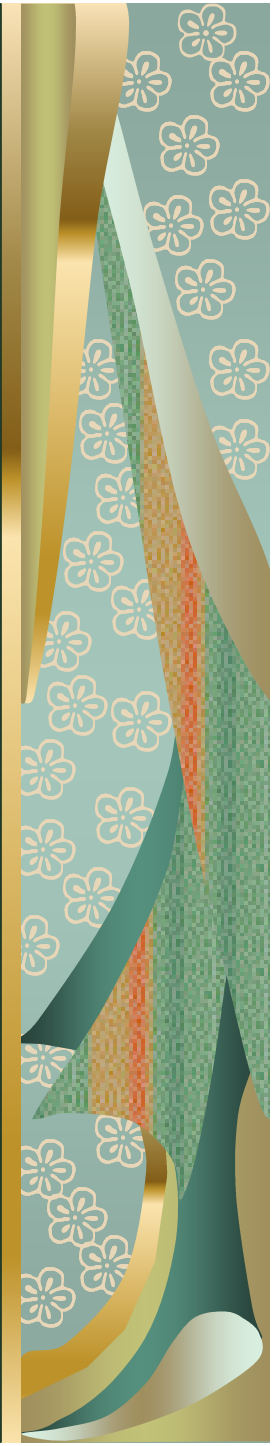
$$+ \frac{T(n)}{\sigma_2 + \psi_1 + \mu} + \frac{A(n)}{\nu_2\rho_2 + \psi_2 + \delta_1 + \mu}$$

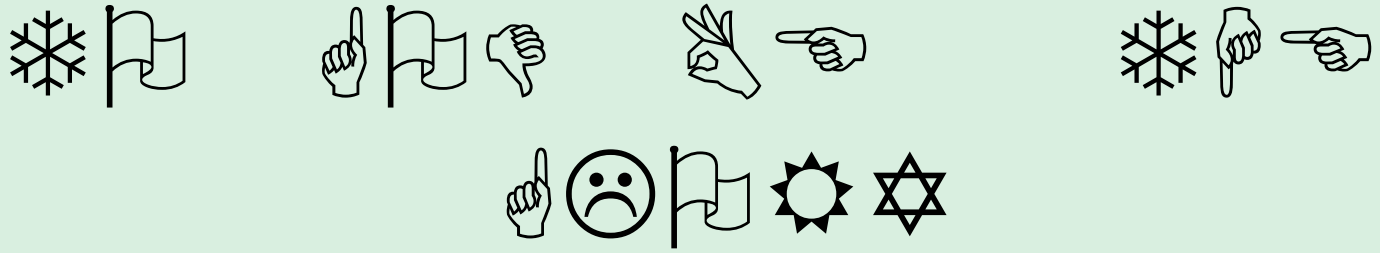
- Intended benefit is the life years spent in the population
- We note that not only the costs of prevention and treatment can be calculated but also its attendant benefits by assigning quality adjusted life-year values spent in each of the different population compartments.

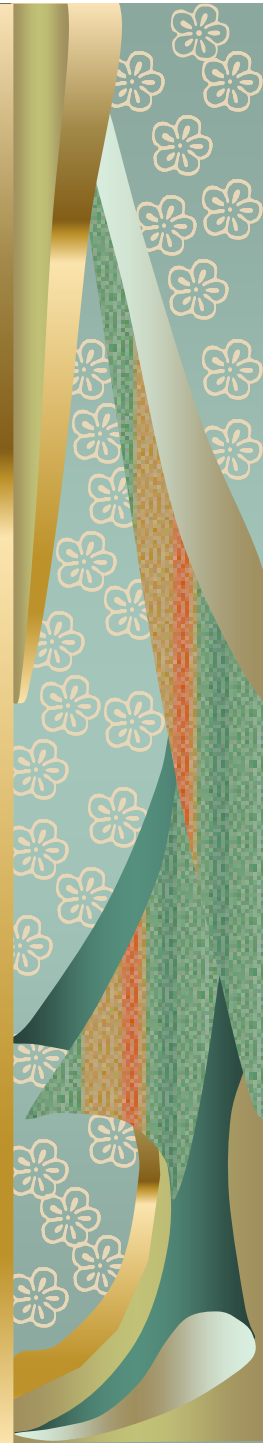


Conclusion

- Epidemiological models taking account of economic constraints or incentives faced by individuals or institutions will be helpful
- Economic models taking into account the spatial and temporal dynamics of disease will be more practical.
- Therefore there is need to strengthen the **marriage** between Economics and Epidemiology to enable policy makers to make informed decisions



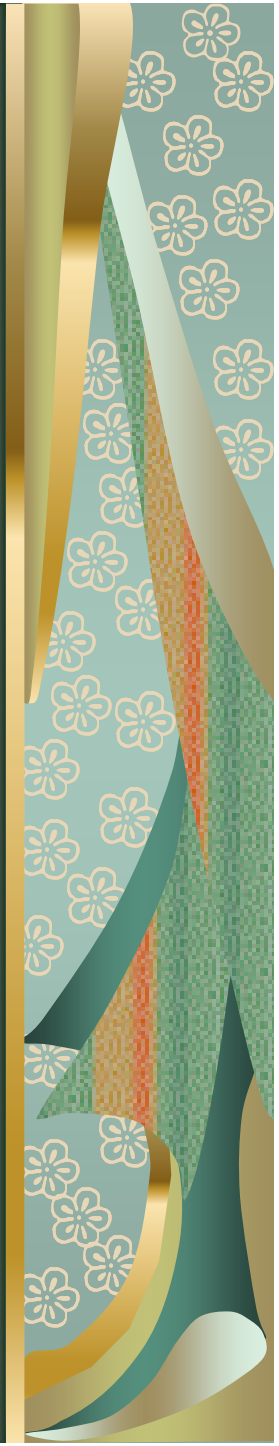




Economic Modelling: With especial reference to HIV/AIDS

Senelani Dorothy Hove-Musekwa

NUST
Bulawayo
Zimbabwe

AIMS
Cape Town
South Africa

Advanced Study Institute- Uganda: 22 July 2009