Modelling hospitalization, home-based care and individual withdrawal for people living with HIV/AIDS in high prevalence areas

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Outline of presentation

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- Objectives
- Introduction
- The Model
- The Model Analysis
- Stability analysis of equilibrium states
- Numerical simulations
- Results and Discussion

Aim

Qualitatively study the dynamics of HIV/AIDS holistically from the current situation in developing countries

Objectives

- To evaluate and quantify the efficacy of Community Home-Based Care (CHBC) for people living with HIV/AIDS (PLWHA)
- To identify the most effective intervention strategy.
- To validate the model with the actual data.

Introduction

- The number of PLWHA has increased over the last decade due to the availability of antiretrovirals (ARVs)
- Majority of people seek medical treatment at hospitals
- Shortage of staff and space at hospitals and other patient referral systems to care for HIV patients
- PLWHA - early discharge from the hospitals or not admitted at all

Introduction contd.....

- The model of care of PLWHA has shifted from hospital care to CHBC(Akintola, 2006)
- In response, policies to promote home-based care of patients had to be implemented by hospitals, health departments and non-governmental organizations (NGOs).
- What is home-based care?

Home-based care

- An approach to care provision that combines **clinical services, nursing care, counselling, psycho-spiritual care and social support**
- (WHO) defines CHBC, as ‘the provision of health services by **formal** and **informal caregivers in the home** in order to **promote, restore and maintain a person’s maximum level of comfort, function and health including care towards a dignified death**
- Not a replacement for hospital care- comprehensive continuation of prevention, care, treatment and support services

Home-based care classification

- Preventive - further infections,
- Promotive - change of behaviour,
- Therapeutic- ARVS,
- Rehabilitative,
- Long-term maintenance and
- An extension of services

CHBC Objectives

- To enhance the quality of life of PLWHA by
  - facilitating health care from the hospitals to homes
  - raising awareness of HIV/AIDS
  - reducing overcrowding in health care facilities
- This work is based on the first two authors personal experiences about CHBC in Zimbabwe.

Model Formulation

- Model is a modification of a multi-strategy model by Nyabadza (2006)
- Model takes into account hospitalization of symptomatic AIDS patients and their release into CHBC
- Screened infectives seek more help fom CHBC
- Force of infection λ, incorporates behaviour change, individual withdrawal from risky sexual activities and the efficacy of CHBC.

Model Formulation

- Adjustment factors to β, which are $\eta_i, i = 1, 2, 3$ intended to reflect the influence of pre- and post-counselling on biological and behavioural processes that pushes the risk of HIV transmission
- The natural history of HIV infection is represented by the model diagram shown in Figure 1.

Model diagram

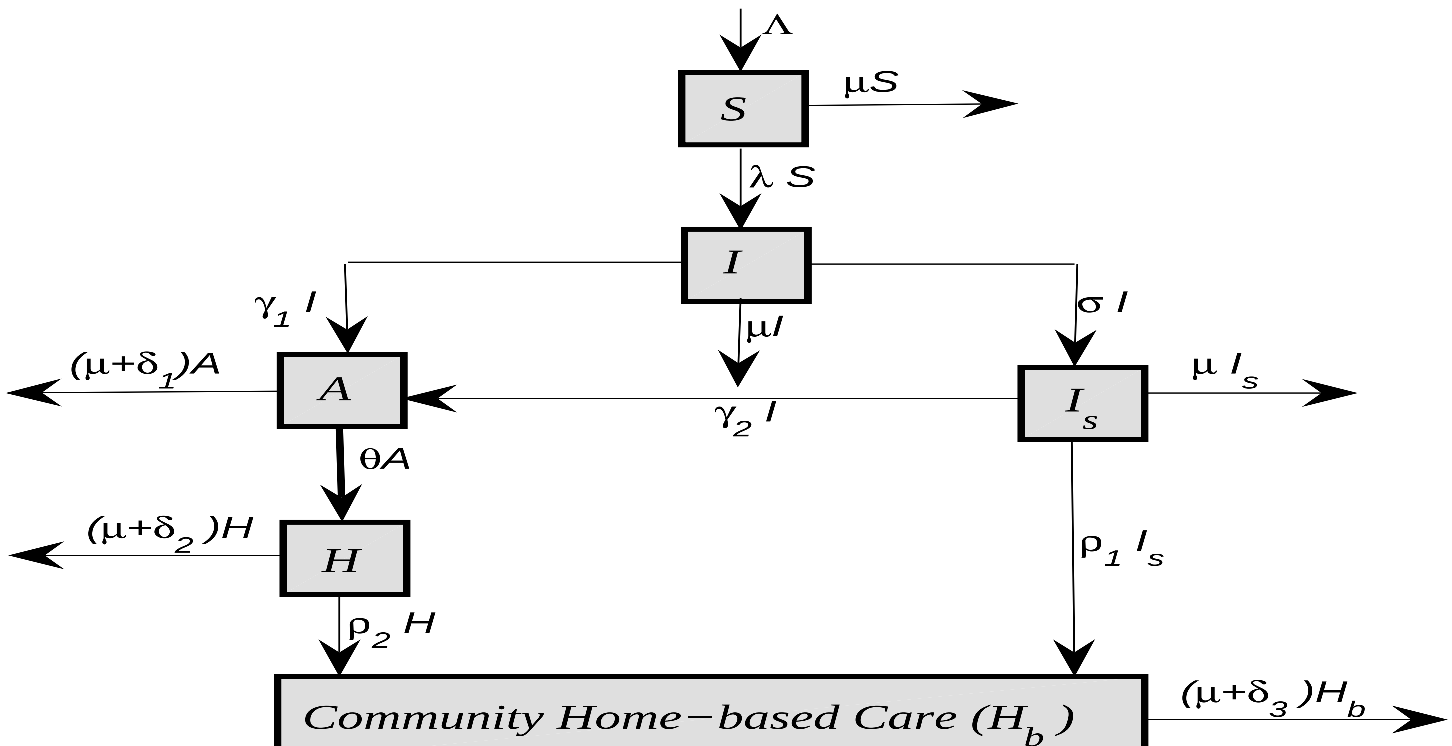


Figure 1: Model diagram showing movements of individuals between compartments.

Model Equations

$$
\left.
\begin{aligned}
\dot{S} &= \Lambda - \lambda S - \mu S, \\
\dot{I} &= \lambda S - (\mu + \sigma + \gamma_1) I, \\
\dot{I}_s &= \sigma I - (\mu + \gamma_2 + \rho_1) I_s, \\
\dot{A} &= \gamma_1 I + \gamma_2 I_s - (\mu + \theta + \delta_1) A, \\
\dot{H} &= \theta A - (\mu + \rho_2 + \delta_2) H, \\
\dot{H}_b &= \rho_1 I_s + \rho_2 H - (\mu + \delta_3) H_b,
\end{aligned}
\right\} \qquad (1)
$$

$$\lambda = \beta e^{-m(\delta_1 A + \delta_2 H + \delta_3 H_b)} \left(\frac{I + (1-p)(\eta_1 I_s + \eta_2 A + \eta_3 (1-\phi) H_b)}{N} \right),$$

$$\Omega = \left\{ (S(t), I(t), I_s(t), A(t), H(t)), H_B(t) \in \mathbb{R}^6_+ : N \leq \frac{\Lambda}{\mu} = N^* \right\}.$$

Measure of behaviour change

- The exponential function that measures behavior change encompasses the use of condoms, serial monogamy, reduction in concurrent partnerships, resulting from observed mortality due to HIV/AIDS.
- The response parameter m, measures how individuals respond to the increase or decrease of mortality due to HIV/AIDS

Equilibrium Points

- We begin our analysis by considering the case $m = 0$ and leave the case $m \neq 0$ for the numerical simulations.
- The disease-free equilibrium given by,

$$E_0 = \left(\frac{\Lambda}{\mu}, 0, 0, 0, 0, 0\right).$$

- The endemic equilibrium point is give by

$$S^* = \frac{N^*}{R_e}$$

Equilibrium Points

$$
\begin{aligned}
I^* &= \frac{\mu}{R_e(\mu+\gamma_1+\sigma_1)}(R_e-1) \\
I_s^* &= \frac{\sigma}{\rho_1+\gamma_2+\mu} I^*, \\
A^* &= \frac{(\gamma_1(\rho_1+\gamma_2+\mu)+\gamma_2\sigma_1)}{(\rho_1+\gamma_2+\mu)(\theta+\mu+\delta_1)} I^* \\
H^* &= \frac{\theta(\gamma_1(\rho_1+\gamma_2+\mu)+\gamma_2\sigma)}{(\rho_1+\gamma_2+\mu)(\theta+\mu+\delta_1)(\rho_2+\mu+\delta_2)} I^* \\
H_B^* &= \Big[\frac{\rho_1\sigma}{(\rho_1+\gamma_2+\mu)(\delta_3+\mu)} \\
&+ \frac{\rho_2\theta(\gamma_1(\rho_1+\gamma_2+\mu)+\gamma_2\sigma)}{(\rho_1+\gamma_2+\mu)(\mu+\delta_3)(\theta+\mu+\delta_1)(\rho_2+\mu+\delta_2)}\Big] I^* \\
\lambda* &= \frac{(\mu+\gamma_1+\sigma_1)}{N^*} R_e I_1^*.
\end{aligned}
$$

The effective reproduction number,

$$
\begin{aligned}
R_e \quad = \quad & R_I + \frac{(1-p)\sigma}{\sigma+\gamma_1+\mu} R_{I_s} + (1-p)\Big[\frac{\gamma_1}{\gamma_1+\sigma+\mu} \\
& + \frac{\sigma\gamma_2}{(\sigma+\gamma_1+\mu)(\gamma_2+\rho_1+\mu)}\Big] R_A \\
& + (1-p)\Big[\Big(\frac{\sigma\rho_1}{(\sigma+\gamma_1+\mu)(\rho_1+\gamma_2+\mu)} \\
& + \frac{\gamma_1\theta\rho_2}{(\gamma_1+\sigma+\mu)(\theta+\delta_1+\mu)(\rho_2+\delta_2+\mu)} \\
& + \frac{\sigma\gamma_2\theta\rho_2}{(\sigma+\gamma_1+\mu)(\gamma_2+\rho_1+\mu)(\theta+\delta_1+\mu)(\rho_2+\delta_2+\mu)}\Big)\Big] R_H
\end{aligned}
$$

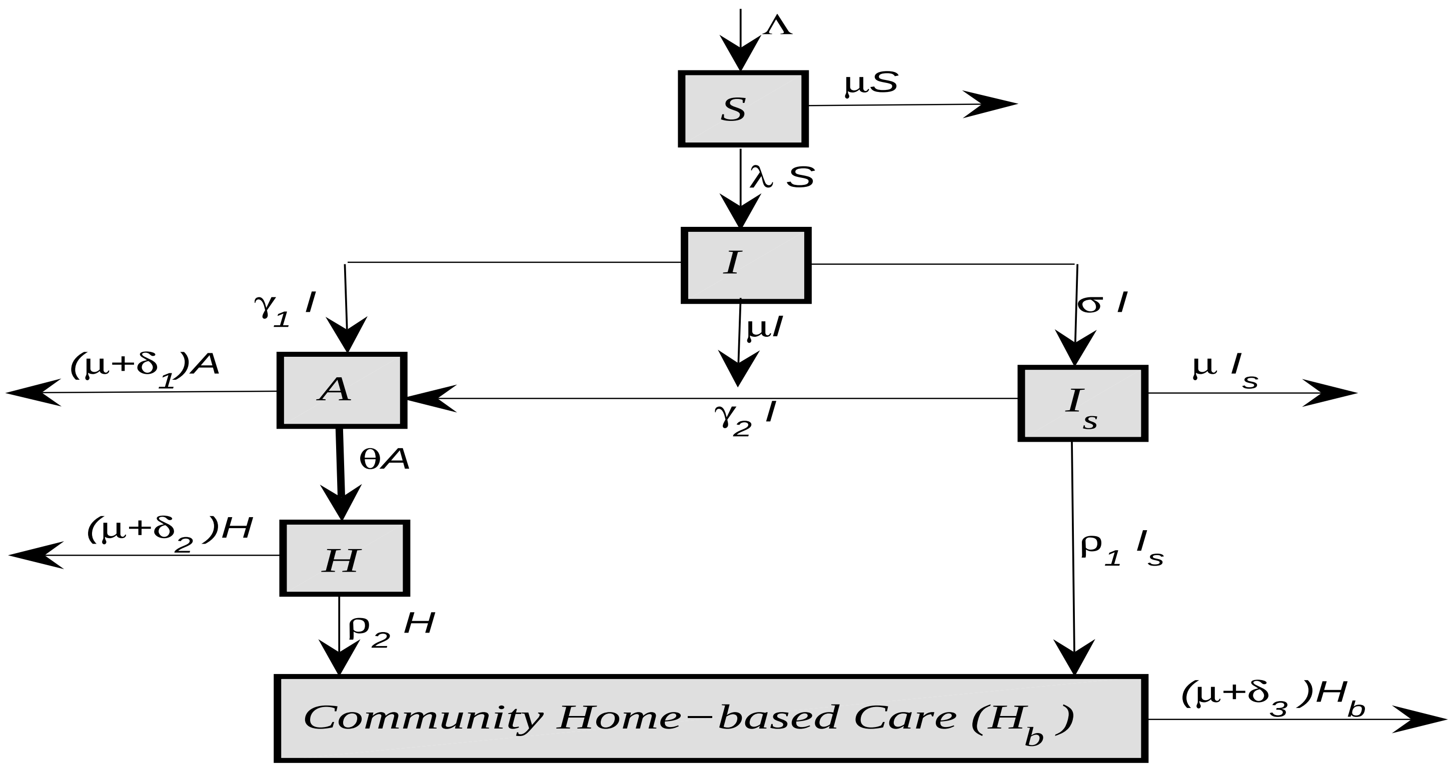
Contributions of infectious classes

where

$$R_I = \frac{\beta c}{\gamma_1 + \sigma + \mu}, \quad R_{I_s} = \frac{\eta_1 \beta c}{\gamma_2 + \rho_1 + \mu}$$

$$R_A = \frac{\eta_2 \beta c}{\theta + \delta_1 + \mu}, \quad R_{H_b} = \frac{\eta_3 \beta c(1 - \phi)}{(\delta_3 + \mu)}$$

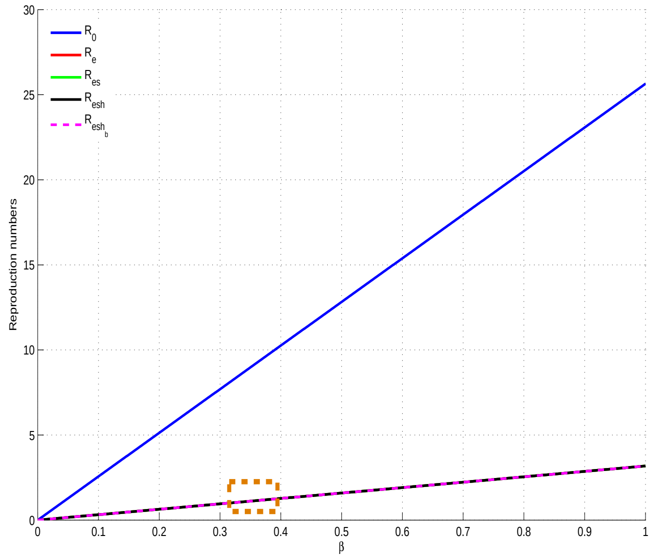
Contributions of infectious classes



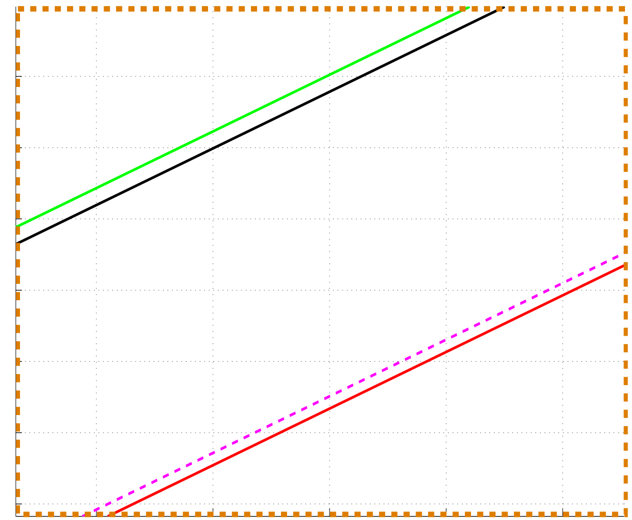
Analysis of R_e

- No intervention - R_0
- Screening and counselling - $R_{es} :-$ This is a situation which is common in Zimbabwe especially among the poor.
- Hospitalization, Screening and counselling - R_{esh}
- Home-based care, Screening and counselling - R_{eshb}
- All the strategies - R_e.

Numerical simulations of R_e



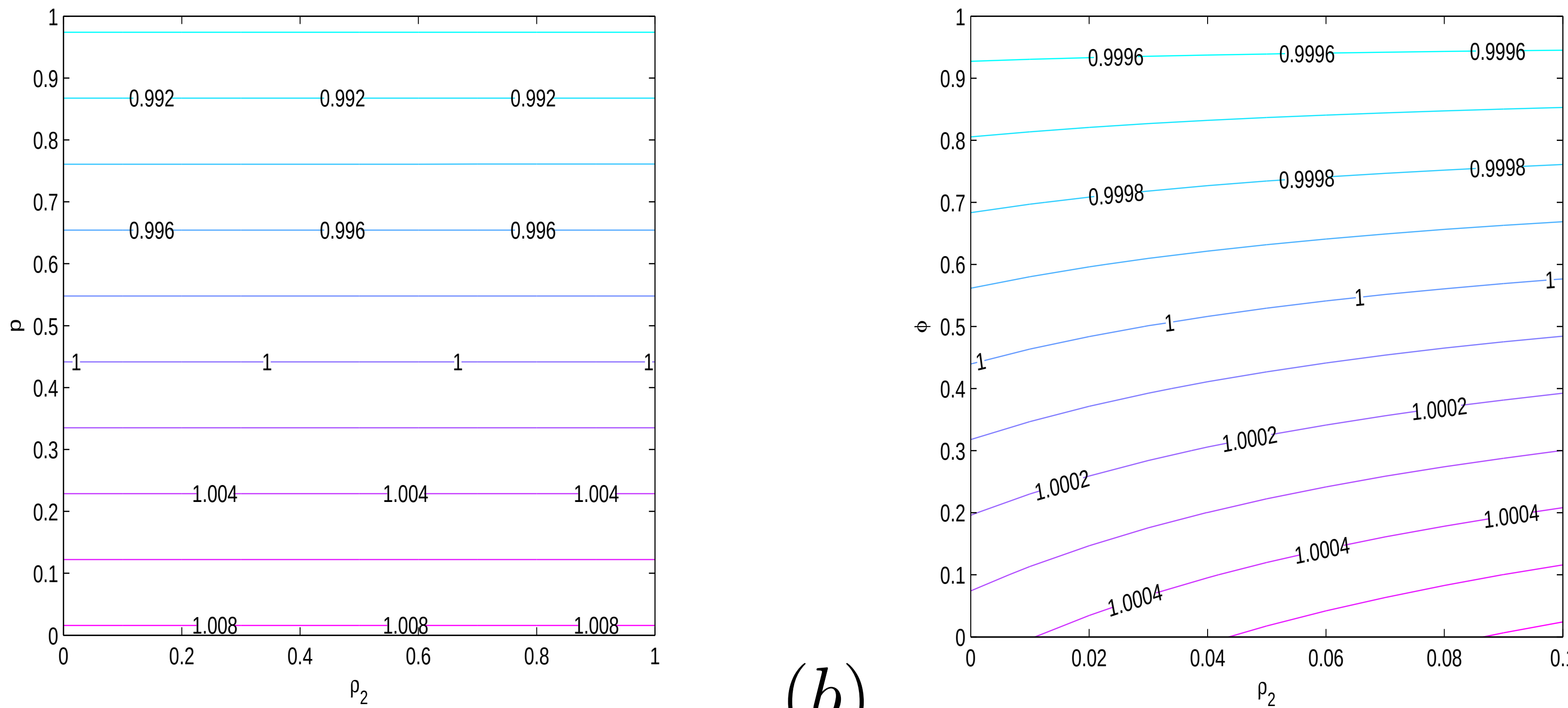
(a)



(b)

Figure 2: shows the relationship between the reproduction numbers as β changes.

Effect of parameters on R_e



(a) (b)

Figure 3: shows the effect of the parameters on the reproduction number as (a) p and ρ_2 change (b)ϕ and ρ_2 change. p > 45% and $\phi > 44\%$ contain the epidemic

Effect of withdrawal, p

Differentiating partially R_e with respect to p we obtain,

$$
\begin{aligned}
\frac{\partial R_e}{\partial p} &= \frac{-\beta}{\mu+\gamma_1+\sigma}\Bigg[\Bigg\{\frac{\eta_1\sigma}{\gamma_2+\rho_1+\mu} \\
&\quad +\frac{\eta_2}{\theta+\delta_1+\mu}\Bigg(\gamma_1+\frac{\sigma\gamma_2}{\gamma_2+\rho_1+\mu}\Bigg) \\
&\quad +\frac{\eta_3(1-\phi)}{(\mu+\delta_3)}\Bigg(\frac{\sigma\rho_1}{(\rho_1+\gamma_2+\mu)}+\ldots\ldots+\ldots\Bigg\}\Bigg] < 0,
\end{aligned}
$$

- R_e is a decreasing function of p.

Effect of CHBC, ϕ

Differentiating R_e partially with respect to ϕ we obtain,

$$\frac{\partial R_e}{\partial \phi} = \frac{-\beta}{\mu+\gamma_1+\sigma}\Big[\frac{\eta_3}{(\mu+\delta_3)}\Big(\frac{\sigma\rho_1}{(\rho_1+\gamma_2+\mu)} + \frac{\gamma_1\theta\rho_2}{(\theta+\delta_1+\mu)(\rho_2+\delta_2+\mu)} + ... + ..\Big)\Big] < 0, \forall\phi.$$

- R_e is a decreasing function of ϕ.

Stability analysis of the equilibria

Theorem 1 *If* $R_e > 1$*, the system (1) has a unique endemic equilibrium given* E_1 *in* $\mathring{\Omega}$*.*

Theorem 2 *If* $R_e < 1$*, the disease-free equilibrium is globally asymptotically stable and unstable if* $R_e > 1$*.*

A Lyapunovv function of the form

$$L = aI + bI_s + cA + dH + eH_b \tag{2}$$

where $a,\ b,\ c,\ d,\ e$ are constant to be determined, was used.

Stability analysis of the equilibria

Theorem 3 *If $R_e > 1$, the endemic equilibrium is locally asymptotically stable and unstable if $R_e < 1$.*

Employed the centre manifold theory as described in the works of Castillo-Chavez and Song, 2004 (Theorem 4.1).

Numerical simulations:Parameters

- Integrate (1) by RK-4 in Matlab to determine the effects of various parameters on the dynamics of the disease rates vary.
- First cases of HIV were recorded in 1985 in Zimbabwe (Zungu-Dirwayi et al, 2004) but take the initial time for our simulations - 1990 - data available from 1990.
- Zimbabwe's population $\approx$ 10.156 million in 1990, with a life expectancy of 59 years (US Census Bureau,).

Numerical simulations:Parameters

- In 2007, the population $\approx$ 13.349 million and 51.8% of the population was aged 15-49 ($\approx$ 6.915m) (UNAIDS/WHO).
- In 1990, crude estimate of the initial population of adults aged 15 - 49, $\approx$ 5.26 m, $\approx 52\%$ of the adult population.
- One condition: prevalence of infection in 1990 must approximate the data in UNAID/WHO report.

Numerical simulations:Parameters

- Life expectancy dropped to 43 years in 2006 (UNAID/WHO) and average life expectancy of 50 years over the past decade,
- 17 years the average age of first sexual intercourse globally (American Sexual Bahavior)
- $\Rightarrow$ consider $\mu = 0.029$, corresponding to an average of 33 years of sexual activity (see also Blower et al ,2002 for Botswana).

Numerical simulations:Parameters

- Λ- recruitment rate os S is chosen and calculated such that it is related to the growth rate of the country's population varying from 0.6% between 2005 and 2009 (UNAIDS), 2.28% in 1990, 2% between 2002 and 2005 (Zimbabwe), -0.8% in 2007 (USB).
- Here we consider an average growth rate of 1% so that $\Lambda = 52600$.
- No treatment - the average time from infection to death due to the disease $\approx$ 10.5 years (Hallet et al, 2009) $\rightarrow$ to between 18 and 20 years in the presence of treatment (Hallet et al, 2009)

Numerical simulations:Parameters

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- Progression rates are generally difficult to measure as they vary between individuals.
- Give ranges between which these progression rates vary
- Infection and progression rates between compartments are estimated from published data
- The uptake rates into treatment are from 2% in 2004 to 18% in 2007, representing a mean rate of 0.053 per year (UNAIDS2). For Botswana, a value of 0.05 per year was chosen in similar way.

Numerical simulations:Parameters

- Treatment is offered to individuals in the AIDS classes on national ART programs, we take $\rho_2 = 0.053$ and estimate a much lower value for ρ_1.
- HIV-related bed occupancy vary from 5%-80% in many African countries (Guinness *et al*, 2000).
- An average value of 12 years is chosen for the progression of individuals who have been screened for HIV, to the symptomatic AIDS stage giving $\gamma_2 = 1/12$.
- Model parameters based on the progression and transmission rates given in (Hallet et al ,2009) for the HIV epidemic in Zimbabwe.

Numerical simulations:Parameters

Table 1: Parameter values used in the simulations

Parameter	Range	Source
β	(0,1)	[**?**, **?**]
c	(1,5)	(Nyabadza,2006)
μ	0.029	(Bloer et al)
ϕ	(0,1)	fitted
p	(0,1)	fitted
η_1, η_2	(0,1)	fitted
η_3	(1,3)	fitted
ρ_1	(0.01,0.053)	fitted
ρ_2	0.053	(UNAIDS)

Numerical simulations:

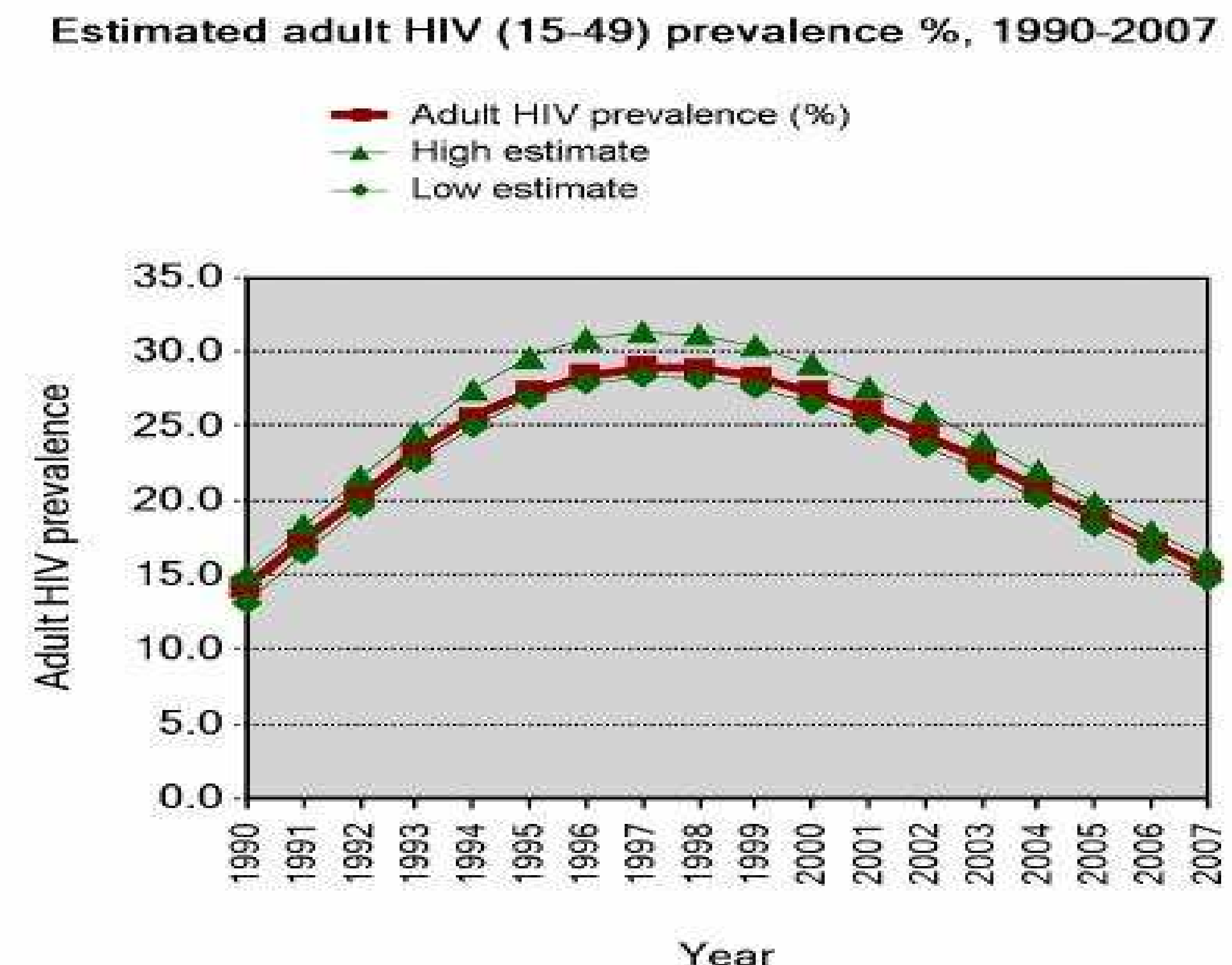
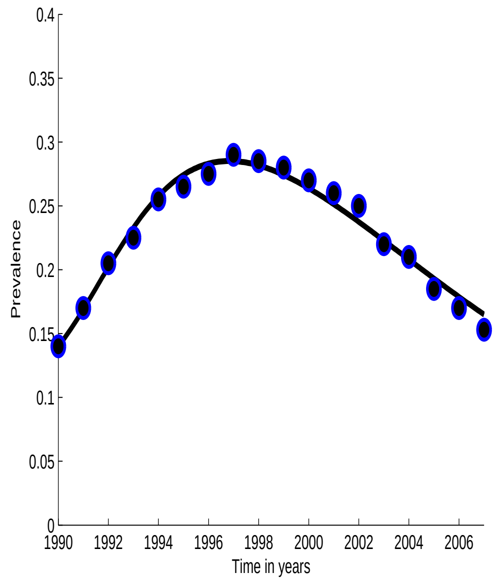
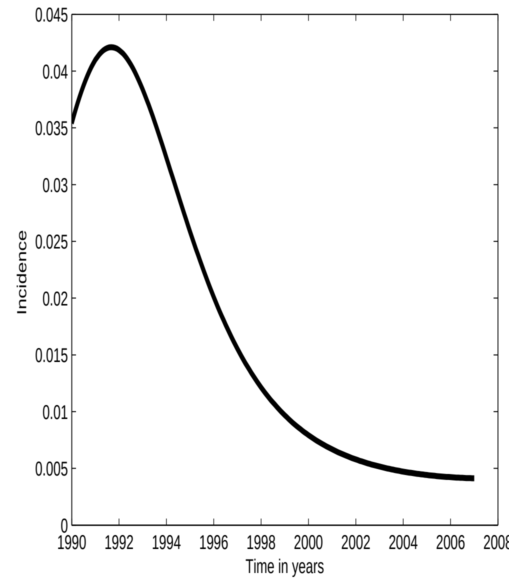


Figure 4: Prevalence data for Zimbabwe. Source (UNAIDS2)

Prevalence/Incidence:



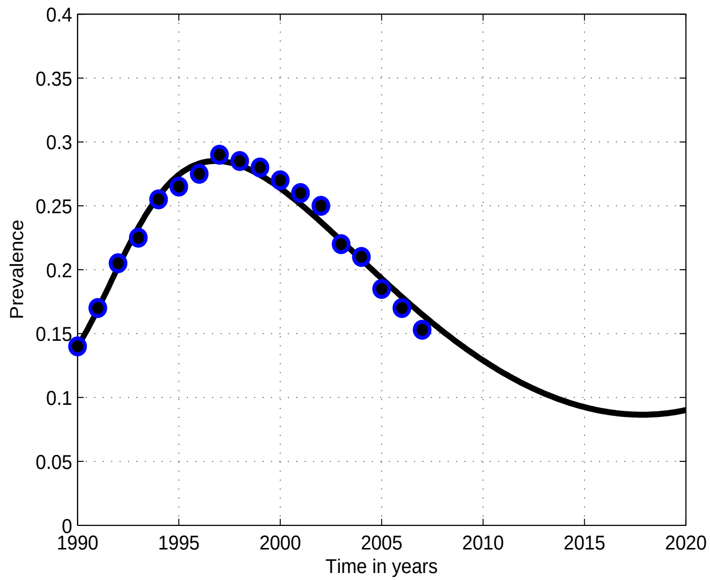
(a)



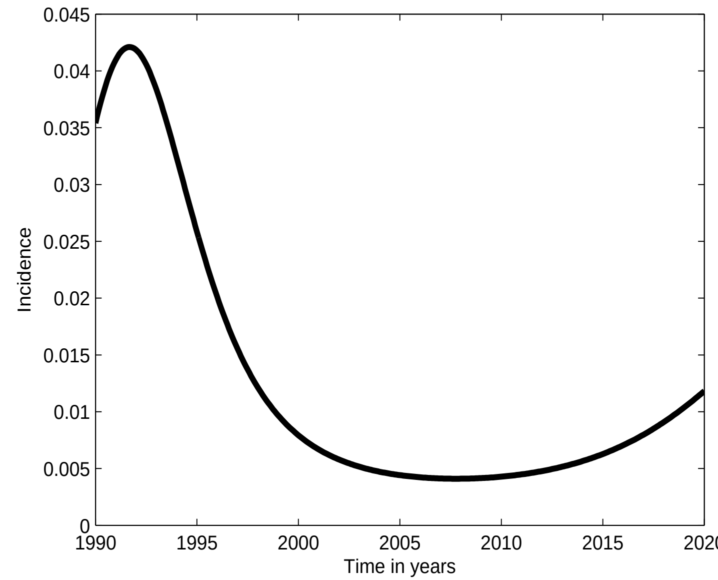
(b)

Figure 5: (a) shows the prevalence fit to the UN-AIDS data for Zimbabwe. (b) show the incidence curve corresponding the prevalence curve of the model fit.

Prevalence/Incidence:



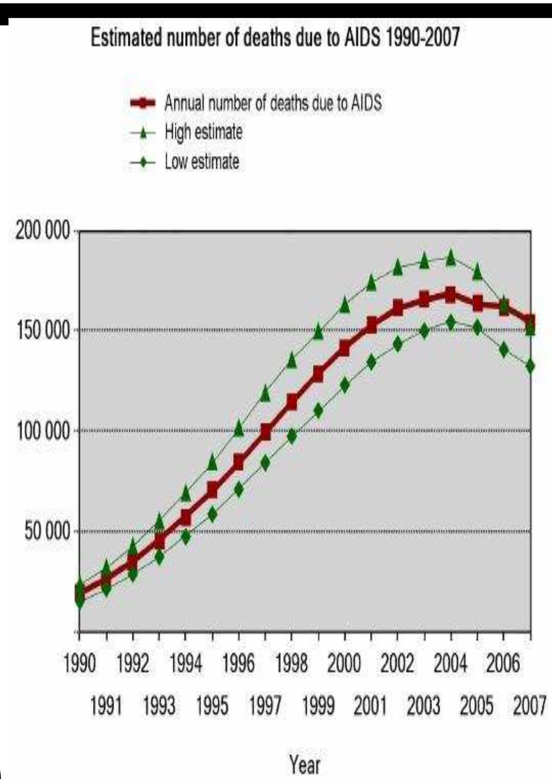
(b)



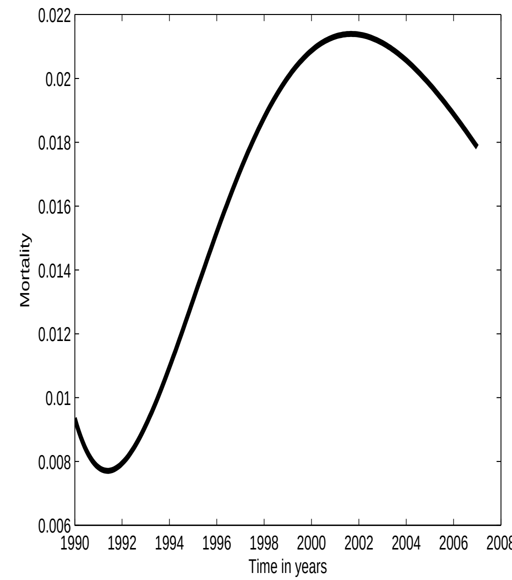
(b)

Figure 6: (a) shows projection of prevalence up to 2020. and (b) show the projected incidence up to 2020.

Mortality:



(a)



(b)

Figure 7: (a) show the mortality curve taken from UNAIDS, 2008 and (b) shows the mortality curve corresponding to the prevalence curve of the model fit.

Population Dynamics:

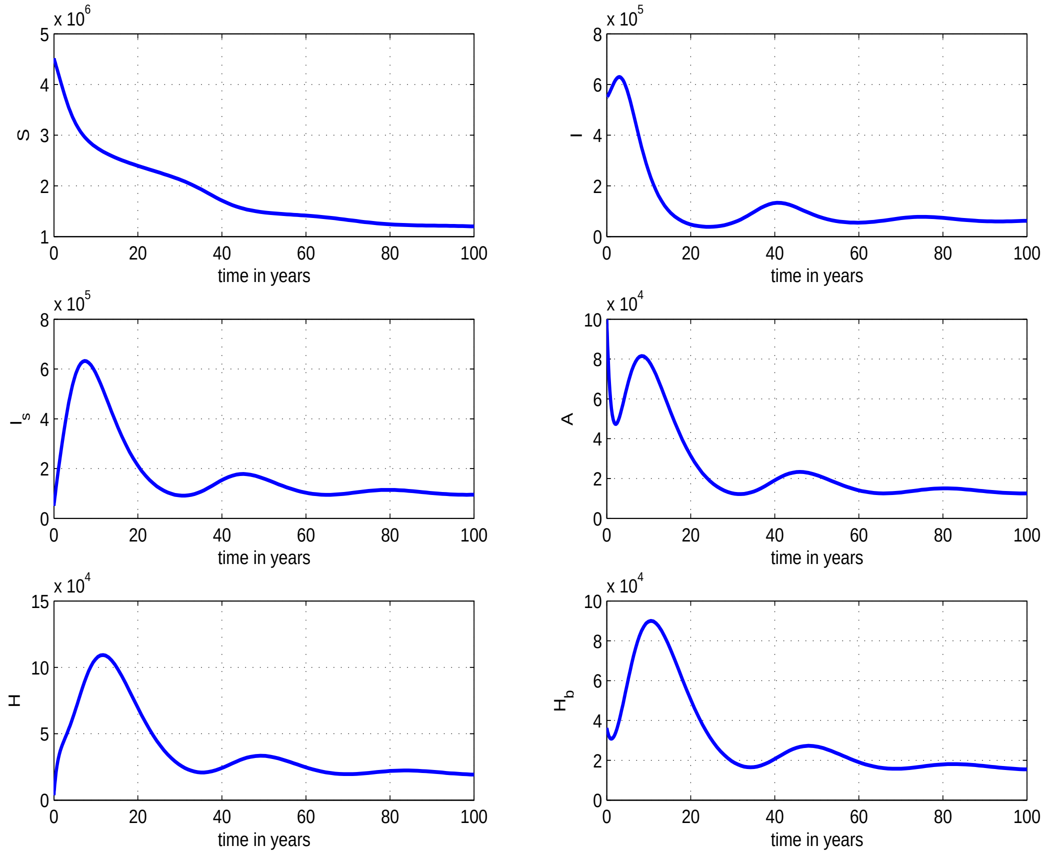


Figure 8: shows the changes in the population trends over 100 years for the parameter values that fit to the curve. $R_e = 2.4815$

Screening into CHBC:

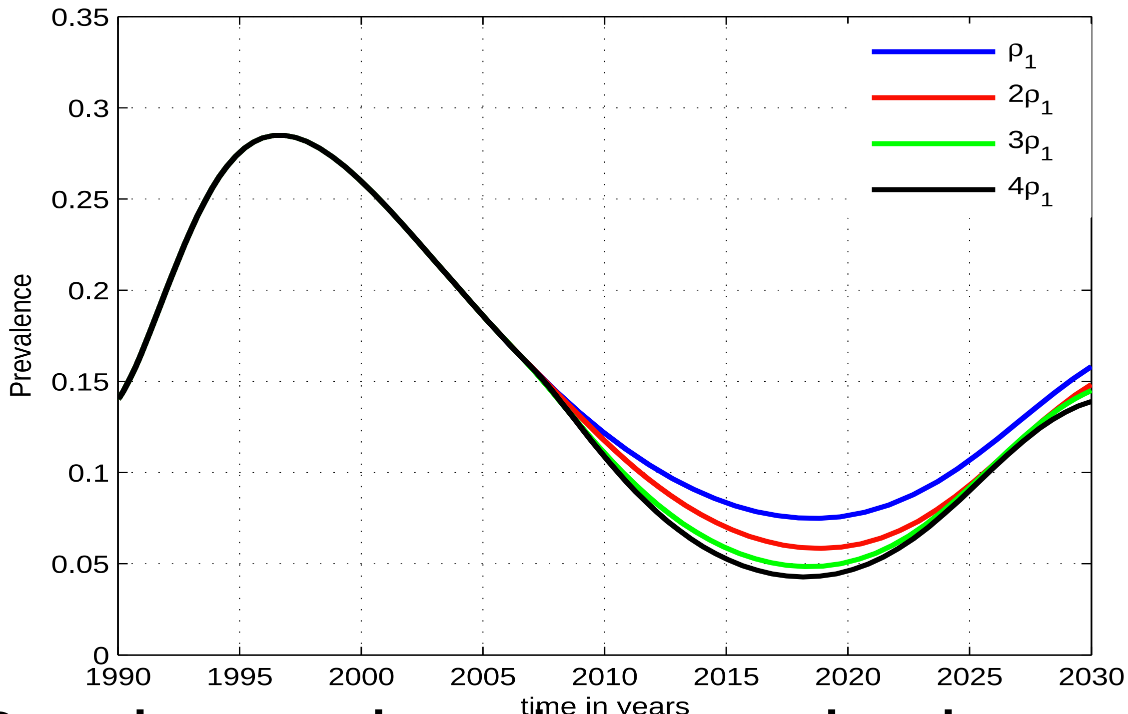


Figure 9: shows the changes in the prevalence with increasing recruitment of the screened into the CHBC.

Changes in population trends

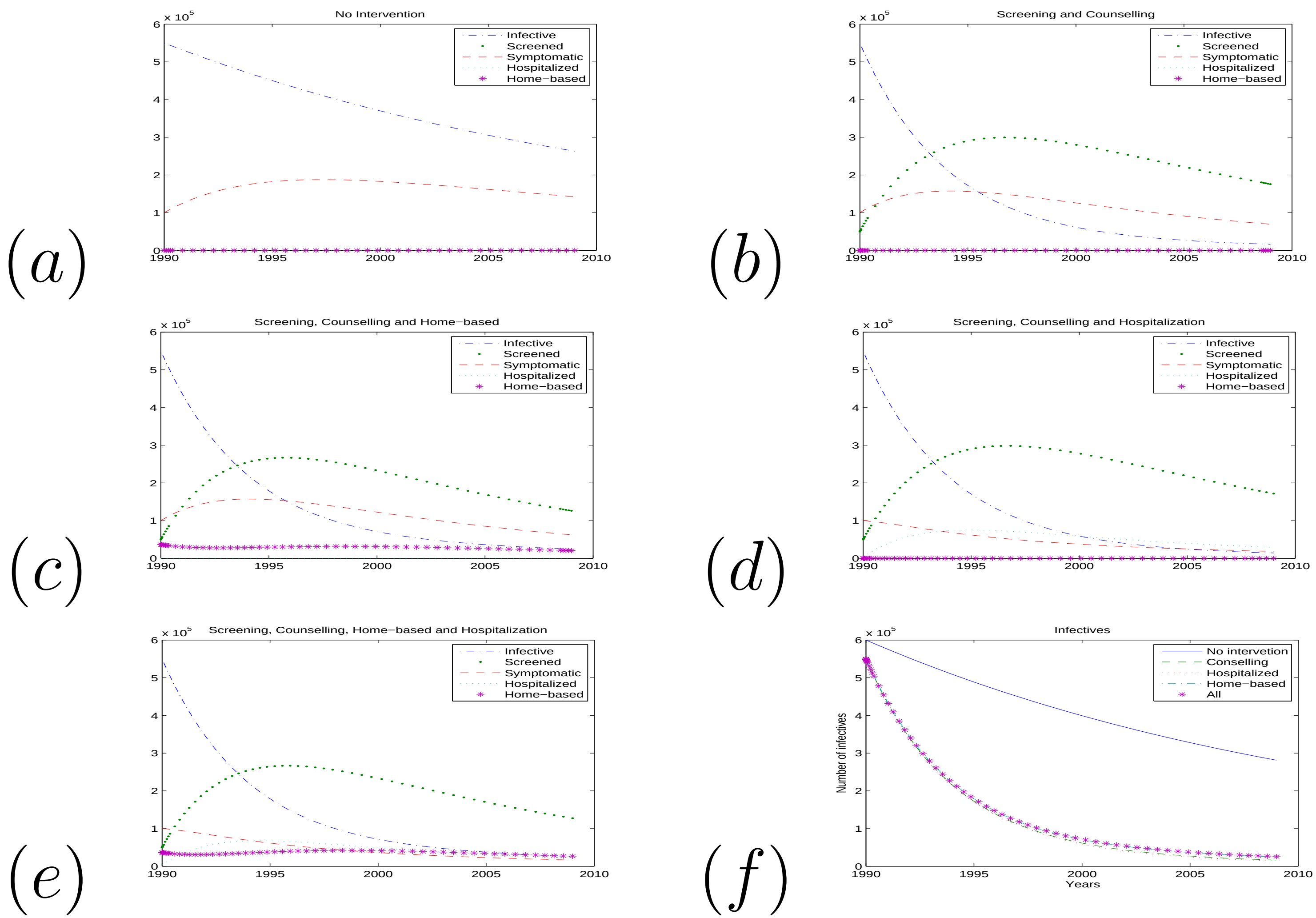


Figure 10: shows the changes in the population trends from 1990 to 2009 with (a) no inter-

Infections and death Averted:

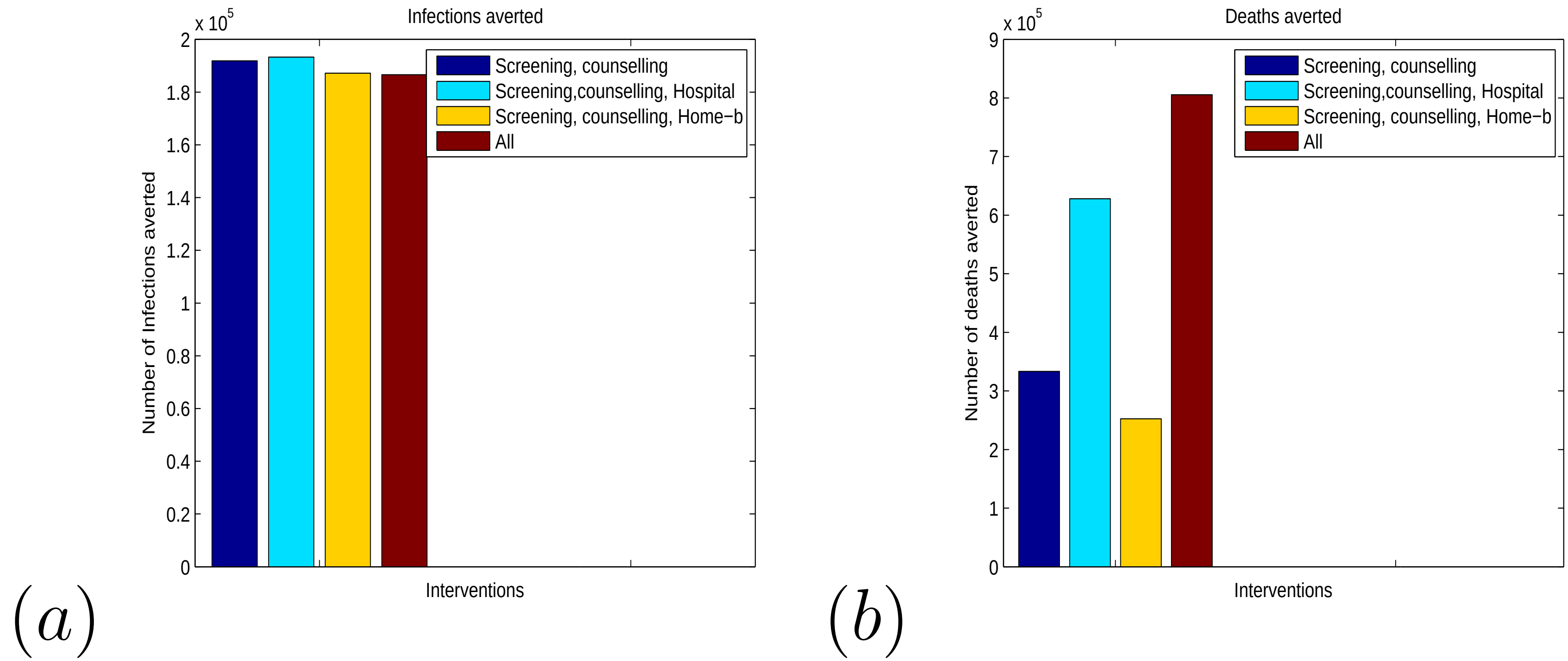


Figure 11: (a) shows the number of infections averted and (b) show the number of deaths averted.

Results-Conclusion

- The paper highlights **four** major challenges associated with the HIV/AIDS epidemic in Zimbabwe.
  - Hospitalization of AIDS suffers,
  - CHBC,
  - Screening
  - Behavior change driven by mortality.
- CHBC class is likely to grow as it acts as the destination of many HIV infected individuals as a result of HAART- $\phi > 45\%$
- At least 45% to withdrawal from risky sexual activities.

Results-Conclusion

- Latest data shows that Zimbabwe HIV rate continue to drop rapidly.
- Overall HIV prevalence among pregnant women who attended antenatal clinics decreased from 23% in 2001 to 11 % at the end of 2008.
- Our projections predict a value around 12%.
- The projections also reveal a scenario depicting prevention fatigue - mirrors complacency .

Results-Conclusion:

- A positive response to an intervention program, leading to a fast decline in the contact rate.
- This is then followed by a sustained slow decline of the contact rate.
- Leads to a relapse of risky sexual behavior and this has been observed recently
- An individual's behavior depends on prevalence.

Results-Conclusion:

- Treatment of AIDS, especially in CHBC, has reduced stigma and encouraged testing [**?**].
- In CHBC, the fight against HIV/AIDS is led by victims of the disease and they have made a significant impact in reducing stigma and caring for their fellow sufferers.
- The success of HIV treatment programs, depends on **identification and screening** of asymptomatic HIV infectives and an effective monitoring of the hospitalized cases.

Work in progress:

- We are in the progress of evaluating the benefits of CHBC and the cost effectiveness of HIV/AIDS interventions discussed in this paper.
- This is being necessitated by the need to strike the right balance between prevention, treatment and care, all of which are essential components of a comprehensive fight against HIV/AIDS.
- Policy makers need to know the benefits and costs of the intervention.

TO GOD BE THE GLORY

THANK YOU