Chagas Disease: the Silent Killer

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History of Chagas disease

- Discovery by Carlos Chagas in 1909, Brazil
- Considered a neglected tropical disease
  - WHO and CDC
- Chagas disease is
  - caused by the parasite *Trypanasoma cruzi*
  - transmitted to humans and animals (reservoir) by insect vectors, mainly *Triatoma sp.* insects.

Triatoma sp. Insect

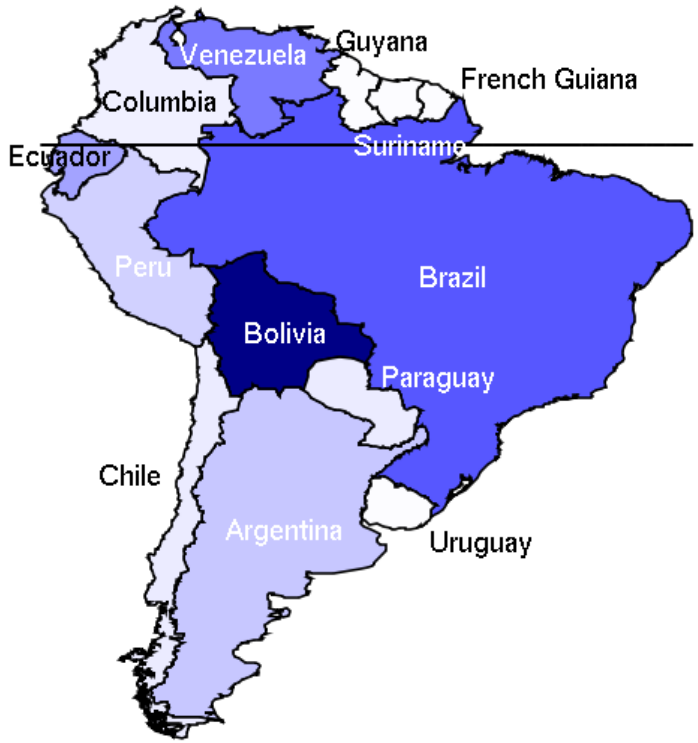
0.75 to 1.25 inches in length

- Carrier of *Trypanasoma cruzi* parasite.
- Blood sucking insect
- Ingests the parasite from the blood of person or animal(reservoir) already infected
- When feeding, secretes feces containing the parasite near the bite site
- Lives in mud, thatch or adobe houses
- Feeds on faces (“kissing bugs”)

Location of disease

South America 2004

South America 2008



Location of disease

Central America 2004

Central America 2008

Stages and Symptoms

Stage	Symptoms
Acute	Swelling at infection site, fever, fatigue, rash, aches, nausea, Romana's sign
Latent	Asymptomatic, test positive with blood tests
Chronic	Irregular heartbeat, congestive heart failure, cardiac arrest, enlarged esophagus, colon, and heart.

Reservoir

- Animals that the T. cruzi parasite might affect
  - Are bitten by the kissing bugs and then can either
    - carry the parasite
    - become infected by it
    - transfer it to other kissing bugs
  - opossums, armadillos, raccoons, monkeys, rats, coyotes, dogs, cats, birds, reptiles, livestock, and many others.



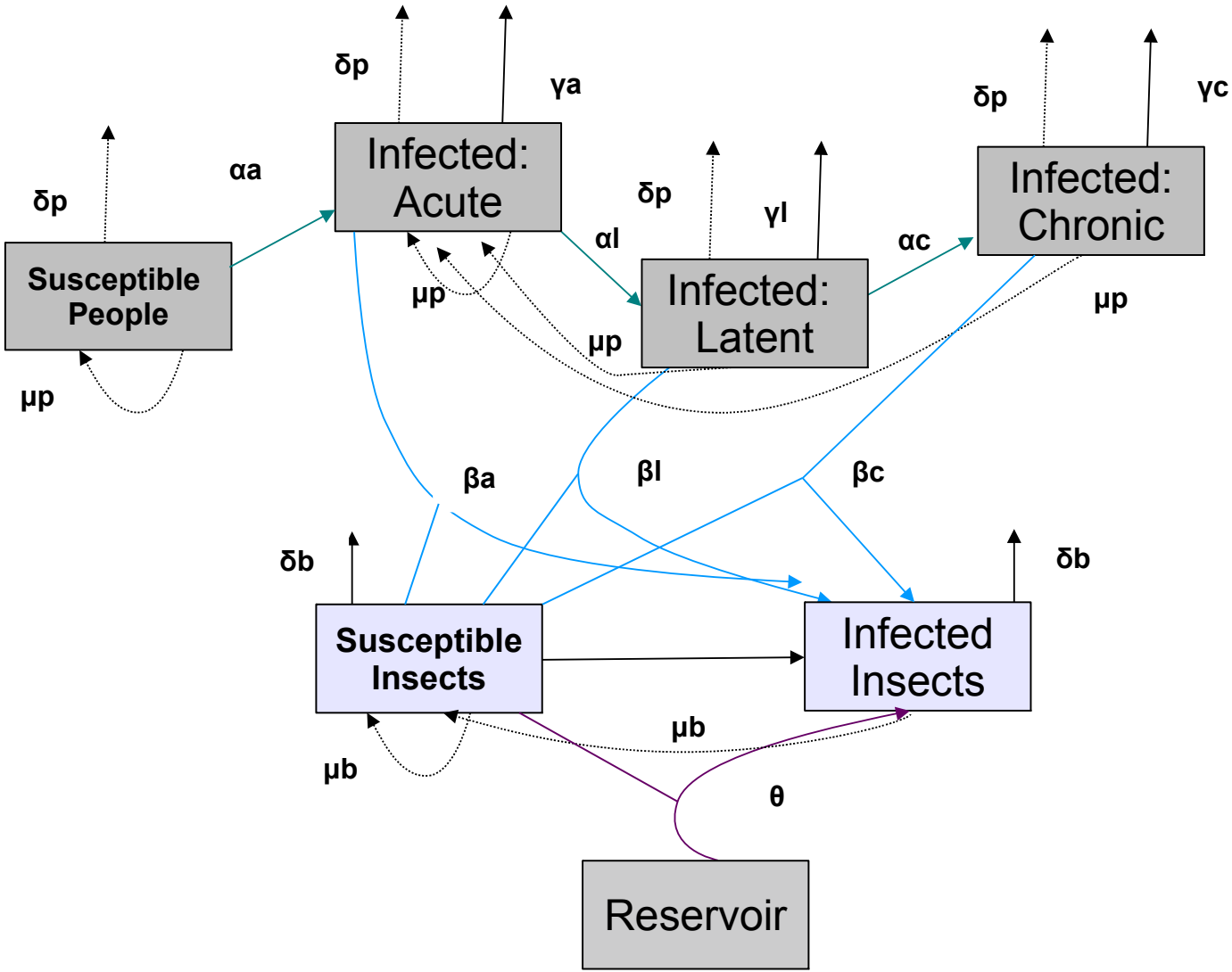

Prevention and Treatment

- Antibiotics available for those who are in the acute stage only, other treatments are not available
- Prevention:
  - Nets and insecticides are the most efficient
  - Avoid living in mud, thatch, and adobe houses

The Problem

- “Neglected” status repercussions
- Lack of information
- Combining Treatments, prevention strategies, general form of the spread of the disease, etc.
- Death rates
- Devillers Model (2008)

Map of Disease



Populations

- Susceptible Insects (Sb)
- Susceptible People (Sp)
- Infected People in the Acute stage (Ipa)
- Infected People in the Latent stage (Ipl)
- Infected People in the Chronic stage (Ipc)
- Infected Insects (Ib)

* These values vary but typically set at 30% for Ib and 40-44% distributed for Ipa, Ipl, and Ipc

Parameters

Table 1: Parameters

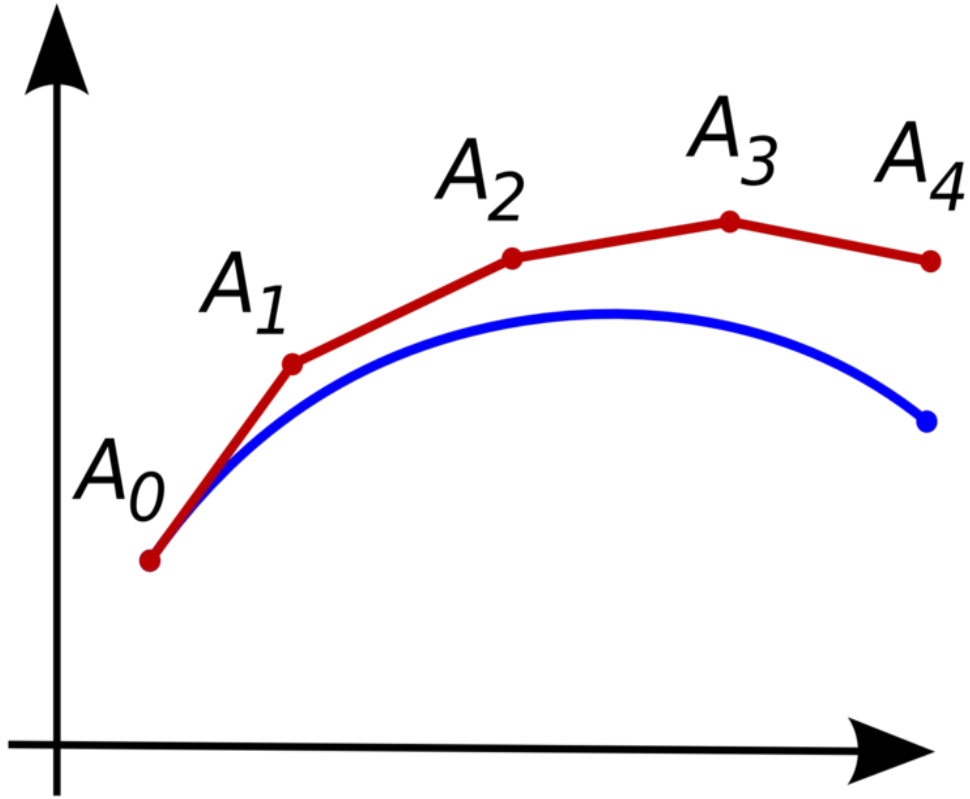
Parameter	Description	Value	Source
α_a	Transmission rate from insect to human	?	This study
α_l	Rate from acute to latent stage	0.125	Prata (2001)
α_c	Rate from latent to chronic stage	0.0001	Prata (2001)
β_a	Transmission rate human to insect in acute stage	$\beta_c/4$	This study
β_l	Transmission rate human to insect in latent stage	$\beta_c/2$	This study
β_c	Transmission rate human to insect in chronic stage	?	This study
γ_a	Human mortality from the acute stage	0.00003	Sanchez-Guillen et al. (2006)
γ_l	Human mortality from the latent stage	0.00001	Devillers (2008)
γ_c	Human mortality from the chronic stage	0.0005	Prata (2001)
δ_p	Human death rate from other causes	0.0003	Devillers (2008)
δ_b	Insect death rate	0.05	Canals et al. (1991)
μ_p	Human birth rate	0.000323	This study
μ_b	Insect birth rate	0.05	This study
θ	Transmission rate from reservoir to insect	?	This study

ODE Model

$$
\begin{aligned}
\frac{dS_p}{dt} &= -\alpha_a S_p I_b + \mu_p S_p - \delta_p S_p, \\
\frac{dI_{pa}}{dt} &= \alpha_a S_p I_b - \alpha_l I_{pa} - \delta_p I_{pa} + \mu_p (I_{pa} + I_{pl} + I_{pc}) - \gamma_a I_{pa}, \\
\frac{dI_{pl}}{dt} &= \alpha_l I_{pa} - \alpha_c I_{pl} - \delta_p I_{pl} - \gamma_l I_{pl}, \\
\frac{dI_{pc}}{dt} &= \alpha_c I_{pl} - \delta_p I_{pc} - \gamma_c I_{pc}, \\
\frac{dS_b}{dt} &= -\beta_a S_b I_{pa} - \beta_l S_b I_{pl} - \beta_c S_b I_{pc} + \mu_b (S_b + I_b) - \delta_b S_b - \theta S_b, \\
\frac{dI_b}{dt} &= \beta_a S_b I_{pa} + \beta_l S_b I_{pl} + \beta_c S_b I_{pc} - \delta_b I_b + \theta S_b.
\end{aligned}
$$

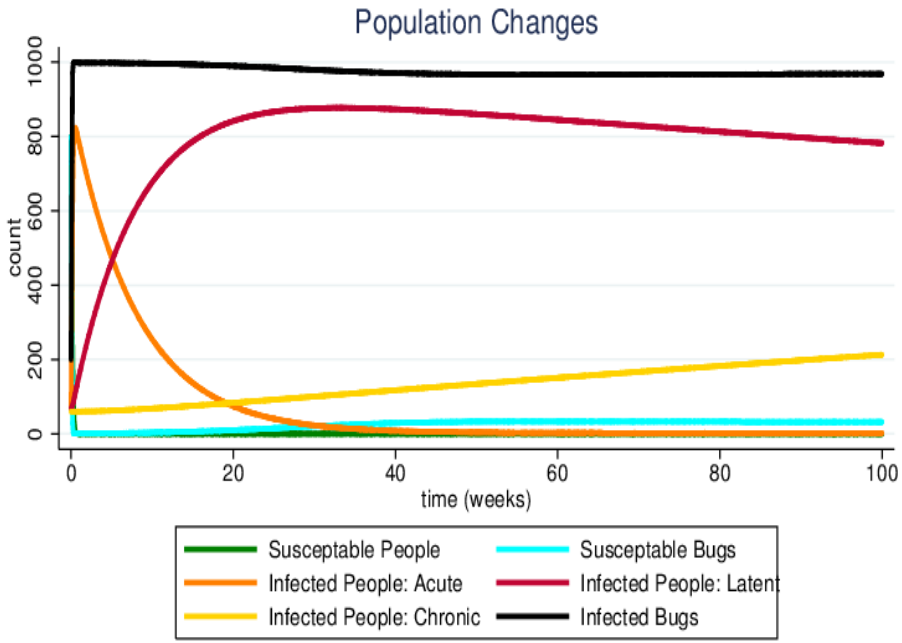
Approximate Numerical Solutions

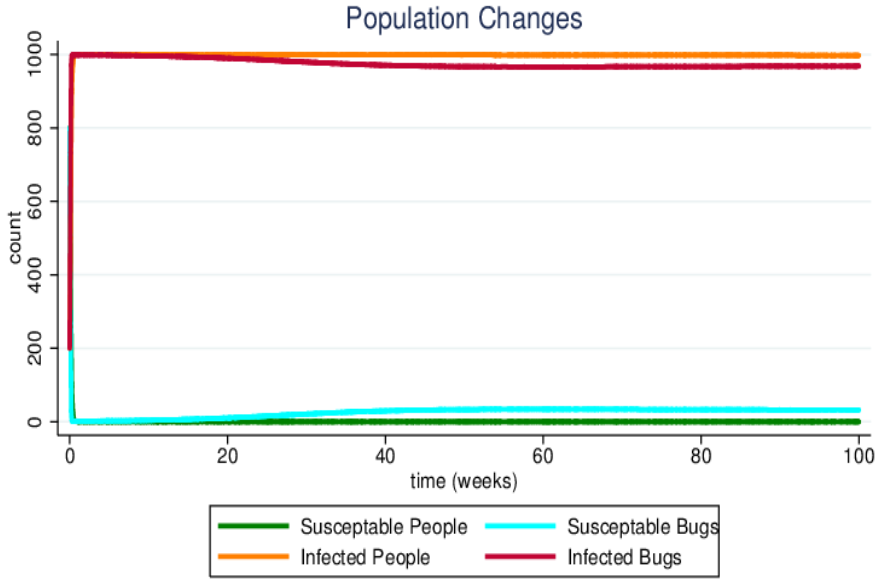
- Euler's Method



Devillers' Parameters

- Problems with Devillers model
  - Unrealistic parameters





alphaa=0.01 alphal=0.125 alphac=0.001
betaa=0.05 betal=0.001 betac=0.003
gammaa=0.00003 gammal=0.00001
gammac=0.0001 deltap=0.0003
deltab=0.05 mup=0.003 mub=0.05

Table 2: Stochastic Model Equations

Equation	Description
a1=$\mu_p S_p$	Birth for S_p
a2=$\delta_p S_p$	Death for S_p
a3=$\alpha_a S_p I_b$	Transition from S_p to I_{pa}
a4=$\mu_p(I_{pa} + I_{pl} + I_{pc})$	Birth for I_p
a5=$\delta_p I_{pa}+\gamma_a I_{pa}$	Death for I_{pa}
a6=$\alpha_l I_{pa}$	Transition from I_{pa} to I_{pl}
a7=$\delta_p I_{pl} + \gamma_l I_{pl}$	Death for I_{pl}
a8=$\alpha_c I_{pl}$	Transition from I_{pl} to I_{pc}
a9=$\delta_p I_{pc} + \gamma_c I_{pc}$	Death for I_{pc}
a10=$\mu_b(S_b + I_b)$	Birth for S_b
a11=$\delta_b S_b$	Death for S_b
a12=$\beta_a S_b I_{pa} + \beta_l S_b I_{pl} + \beta_c S_b I_{pc} + \theta S_b$	Transition from S_b to I_b
a13=$\delta_b I_b$	Death for I_b

Approximate Solution

- Gillespie Algorithm,1977

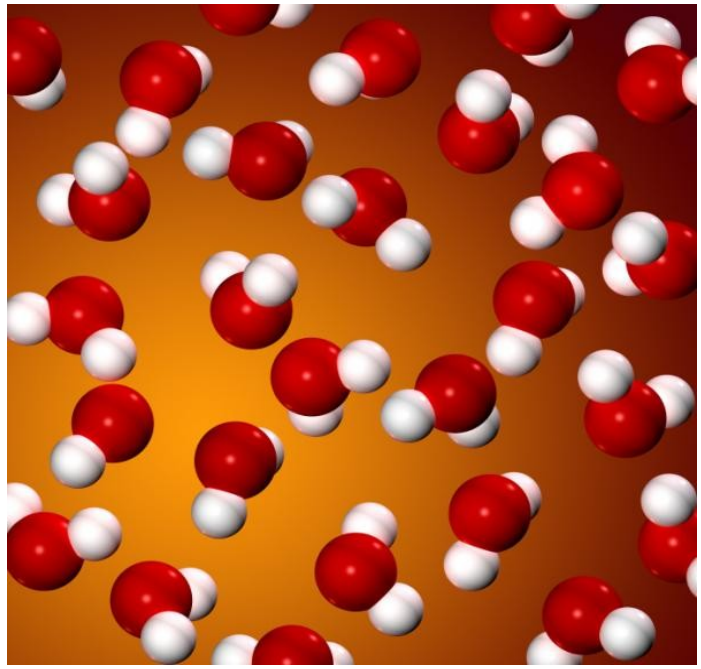
- Probabilities

  b1=a1/a0

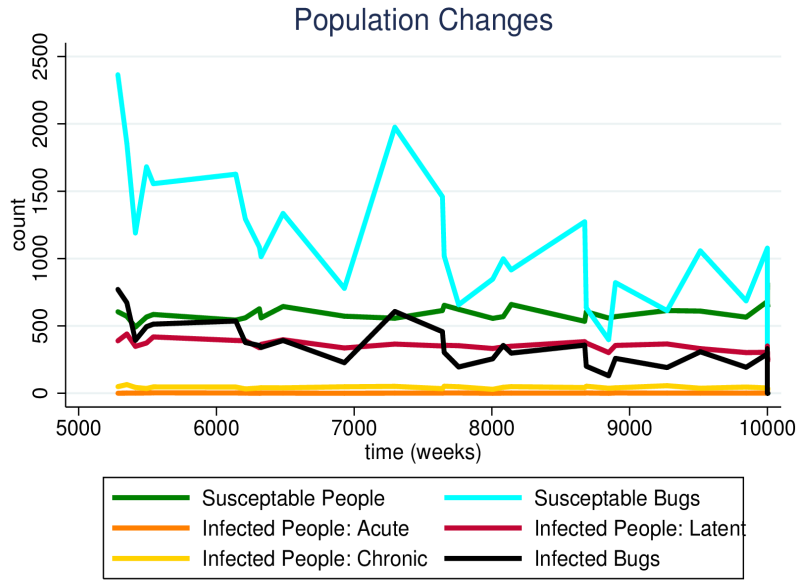
  b2=(a1+a2)/a0

  b3=(a1+a2+a3)/a0....

- a0 is the sum of all a's



Results of Continuous Time Model

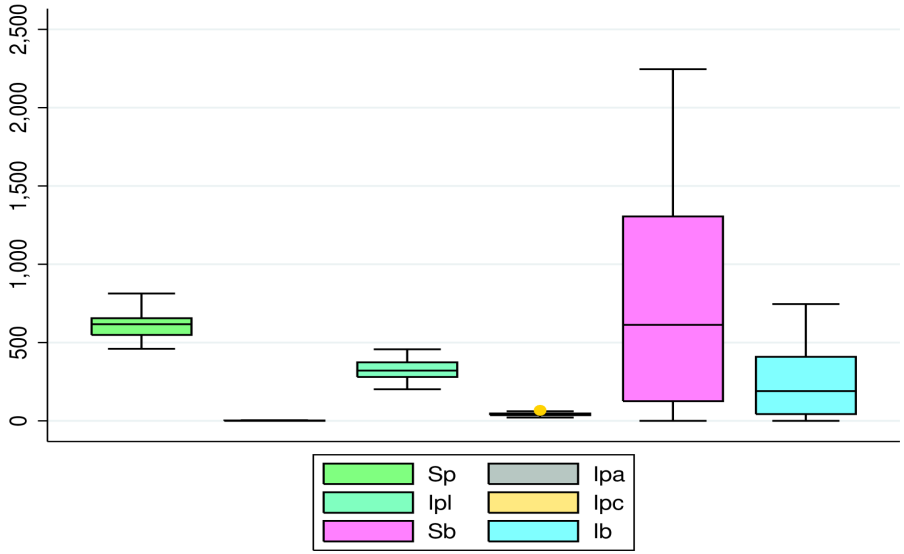


One Simulation

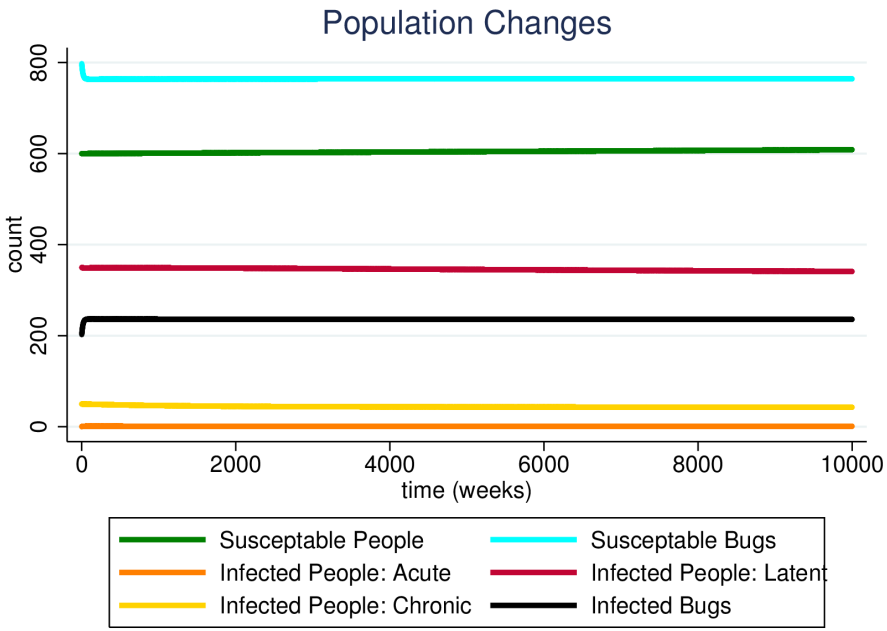
Mean Prevalence

Insect: approx. 25%
Human: approx. 40%

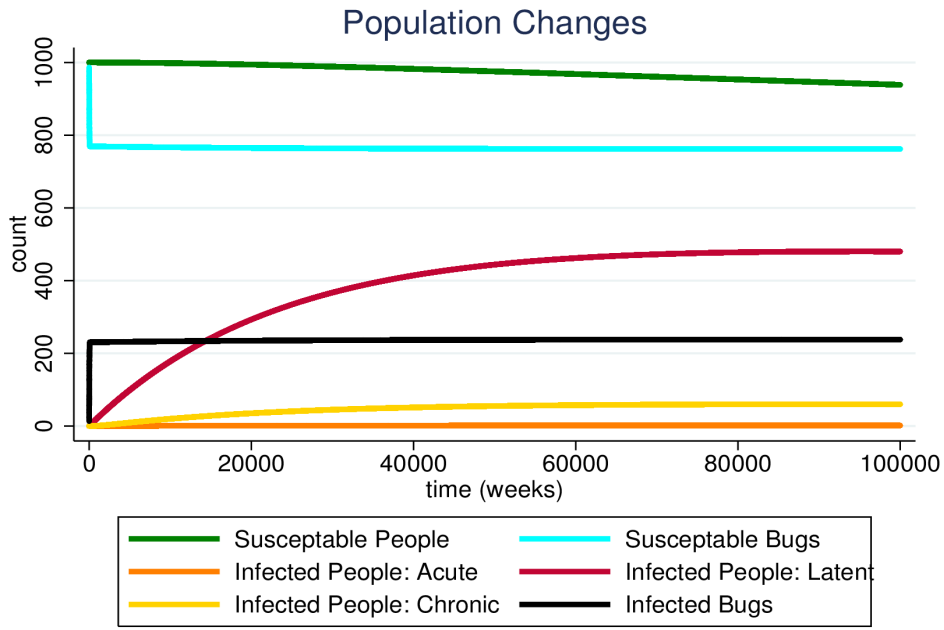
50 Simulations



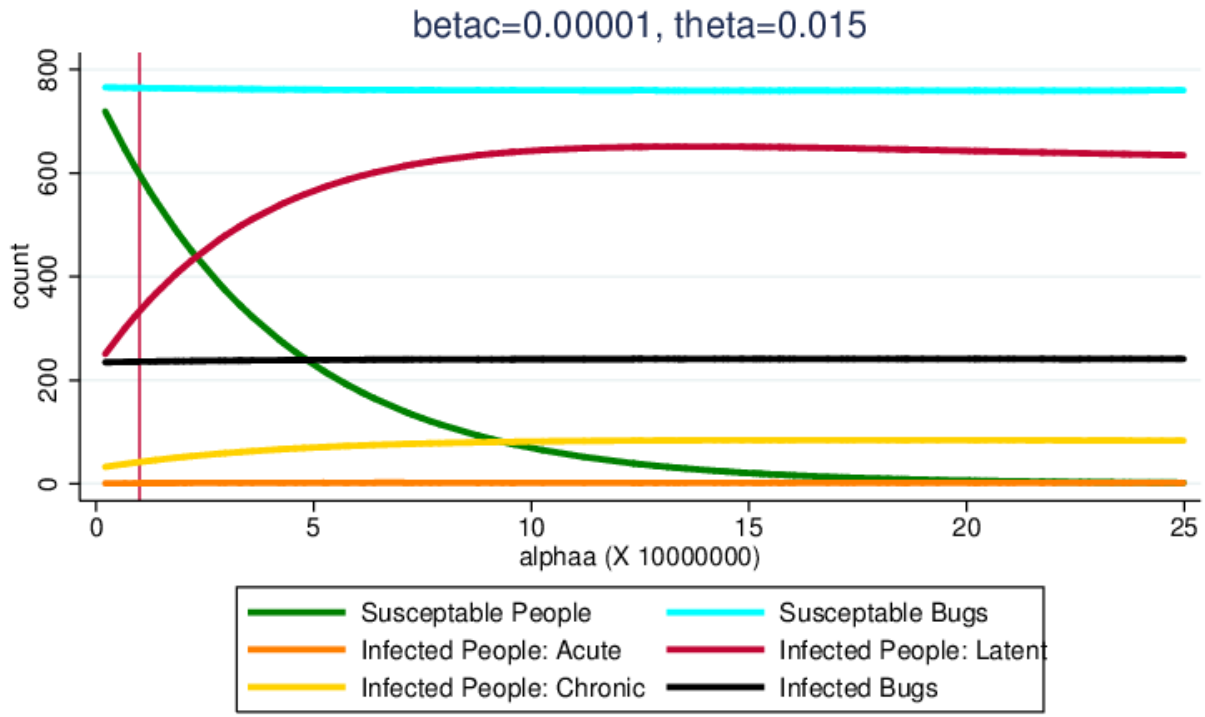
Results of ODE Model



Alphaa= 0.0000001
Betac= 0.00001
Theta= 0.015



Sensitivity Analysis for ODE Model



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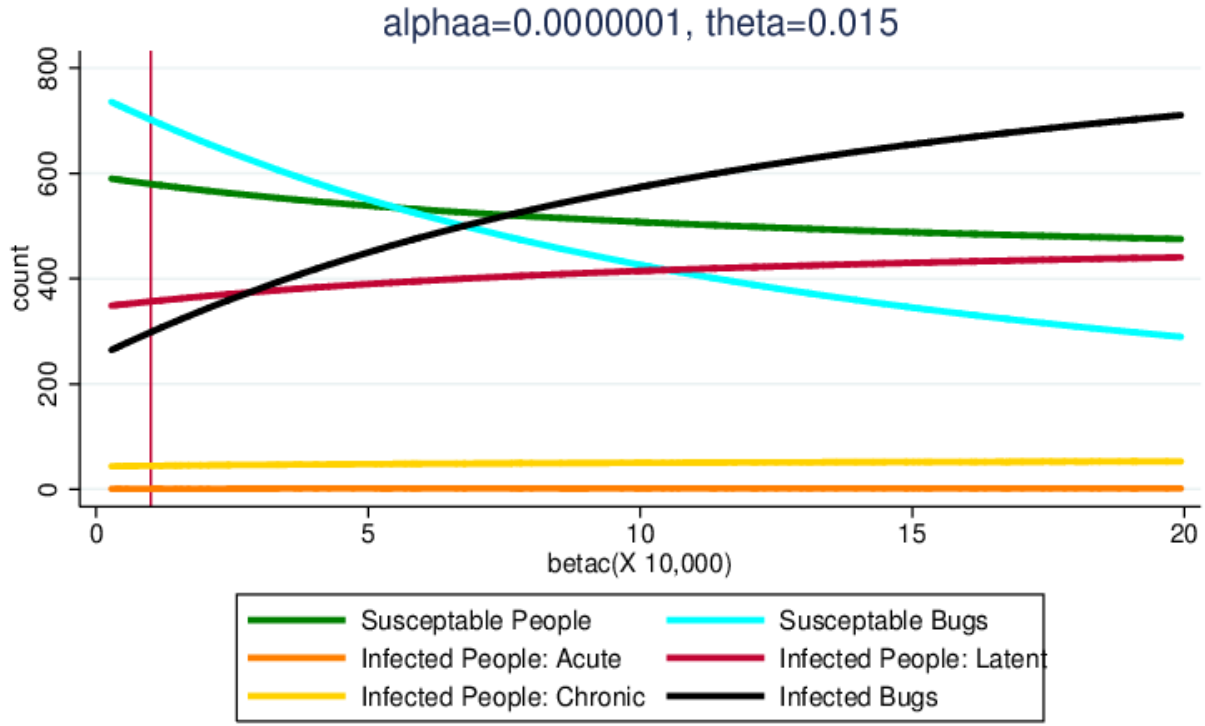
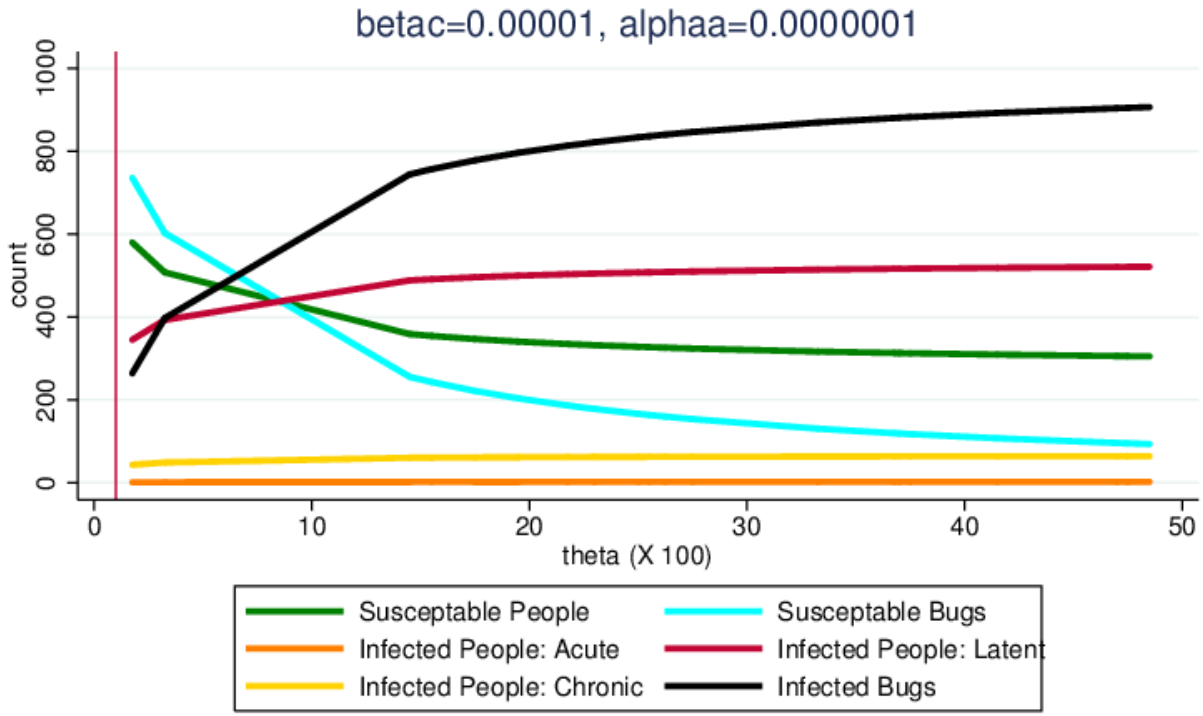


Sensitivity Analysis for ODE Model



Further Research

With this model we can include the effects of

- Making medicines available
- Available nets
- Spraying techniques

Sources

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