Modeling Intervention Strategies for United States TB Control

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Introduction

Epidemiological models offer insight into the structure of disease outbreaks and the merits of various interventions. Compartmental differential equation models are a common model in which populations move between various health states, or compartments, according to predetermined rates. This work is an extension of the Hill Model, a complex compartmental model of tuberculosis (TB) in the United States.

The Basic Hill Model

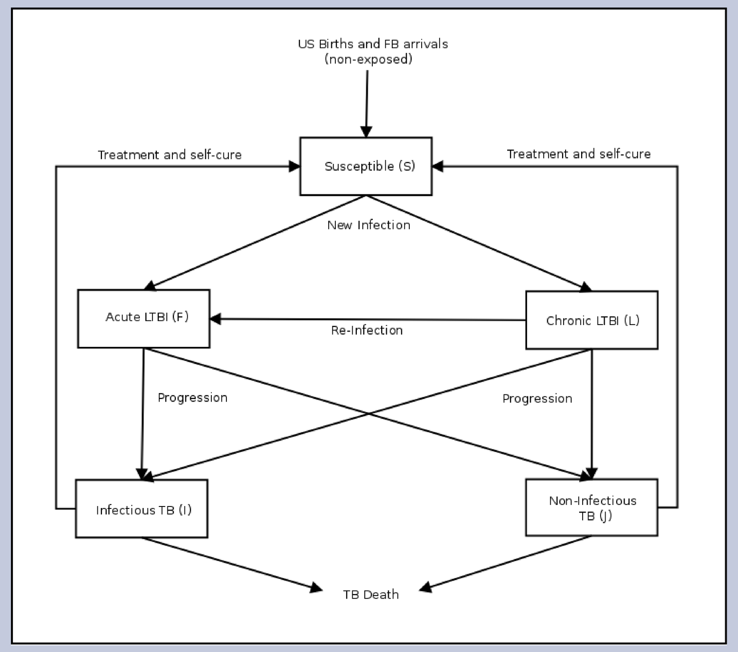

Figure: A flow chart representing the compartments of the Hill Model.

Populations:

- US Born (USB)
- Foreign Born (FB)

Individuals also leave the model due to natural death.

- USB TB levels are declining
- FB LTBI arrivals remain high
- TB elimination in total US population not projected by 2100

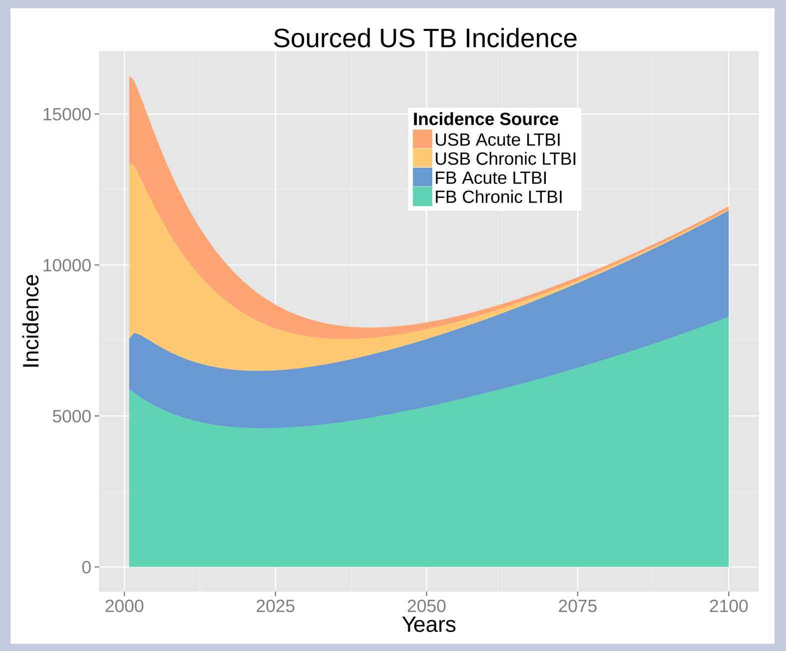

Figure: The source population of US TB incidence

Analyzing US TB Reduction Strategies

- Implemented in R, with various numerical DE solvers
- Tracks US Health Care System (HCS) cost
- Tracks statistics about various health states

Intervention Analysis

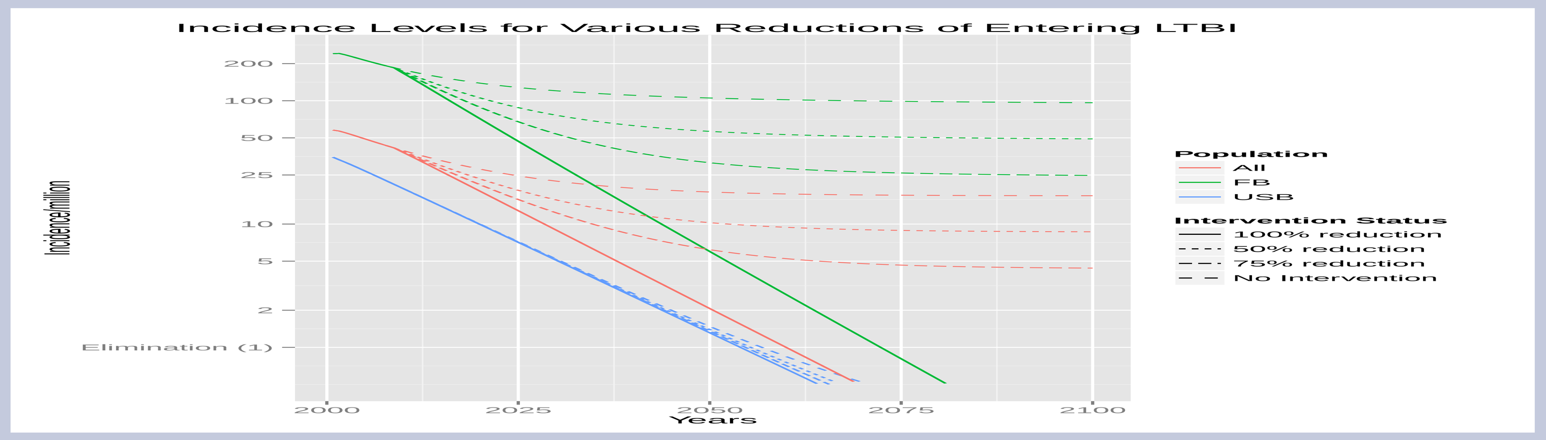

Figure: Incidence/million in USB, FB, and total populations, given 0%, 50%, 75%, or 100% treatment of incoming LTBI.

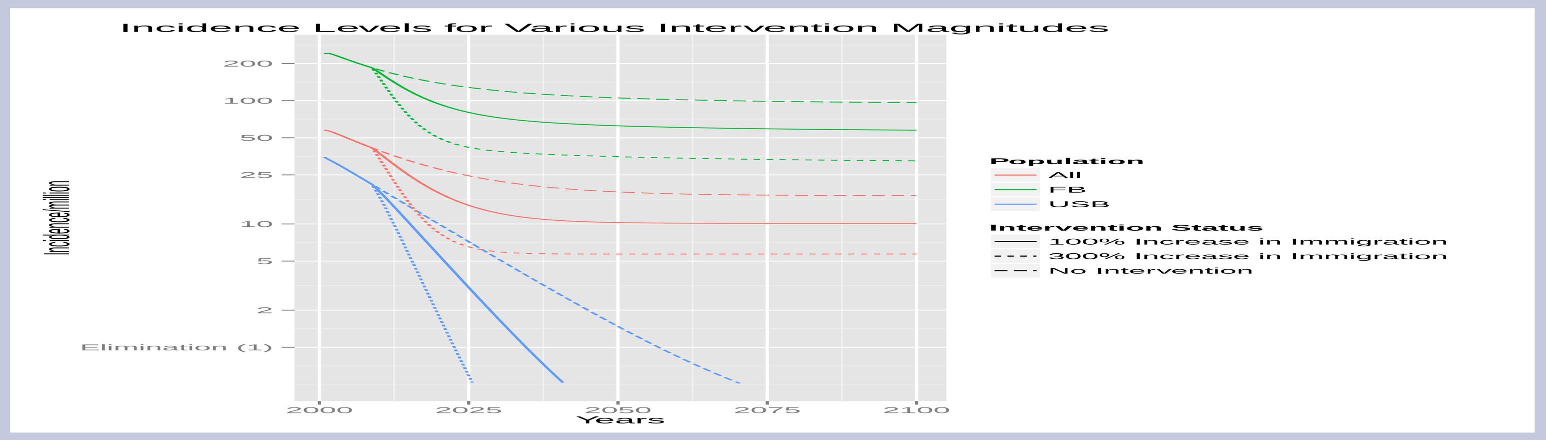

Figure: Incidence/million in USB, FB, and total populations, given 0%, 100%, or 300% LTBI treatment increase.

Economic Modeling

- Tracks treatment costs for various disease states
- Estimates implementation cost of intervention

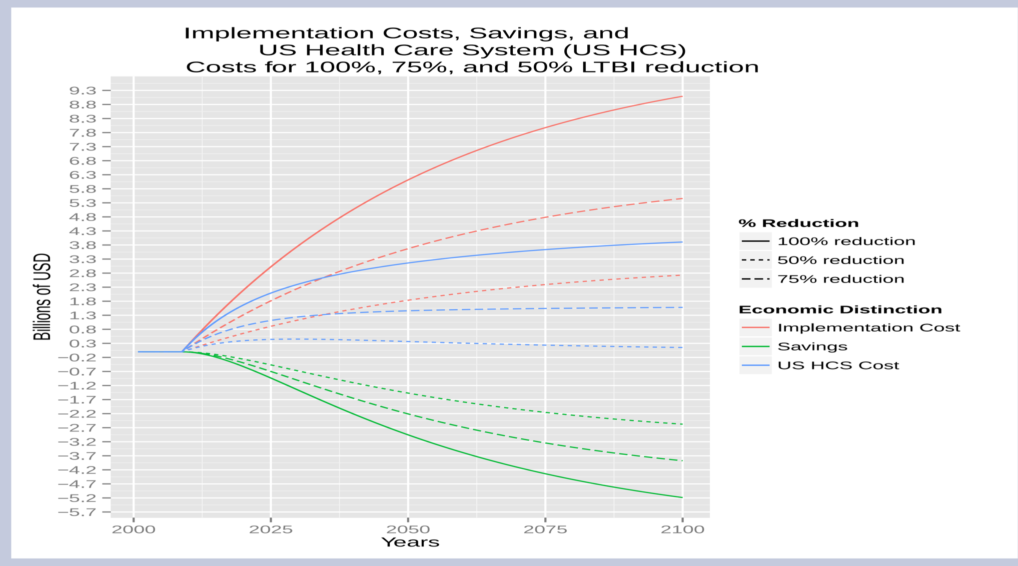

Figure: Cumulative implementation costs, US HCS savings, and net US costs of LTBI arrival cure rates. Cost/case cured was $600, $800, and $1000 for 50%, 75%, and 100% cured.

Base HCS Costs:

Active TB: $14,014.90

LTBI: $403.45

An Agent-Based Implementation

Agent-based models capture disease dynamics on the individual level, and reflect stochasticity and granularity lost in compartmental models. Agent-based counterparts to the Hill model were implemented in Netlogo and C++.

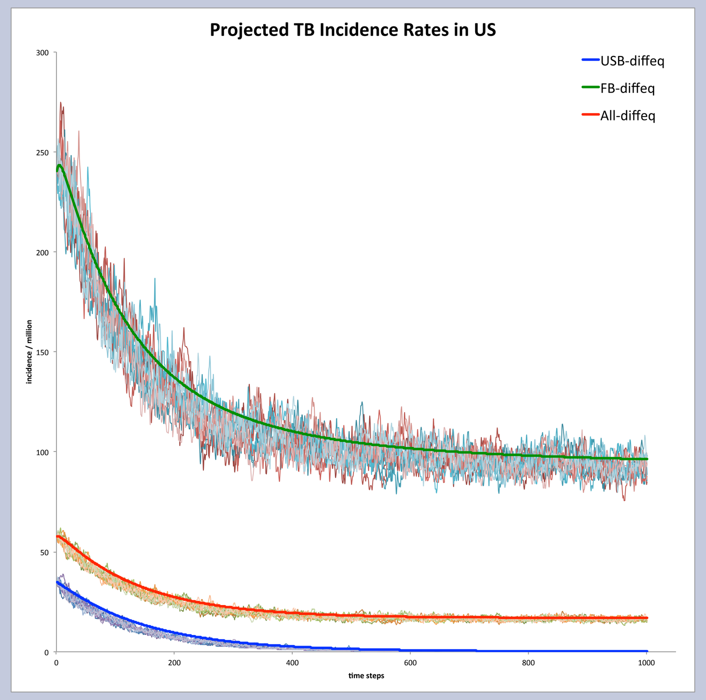

Figure: Incidence/million for R and NetLogo models (12 runs, $\Delta t = 0.1$, popConst $= 100$)

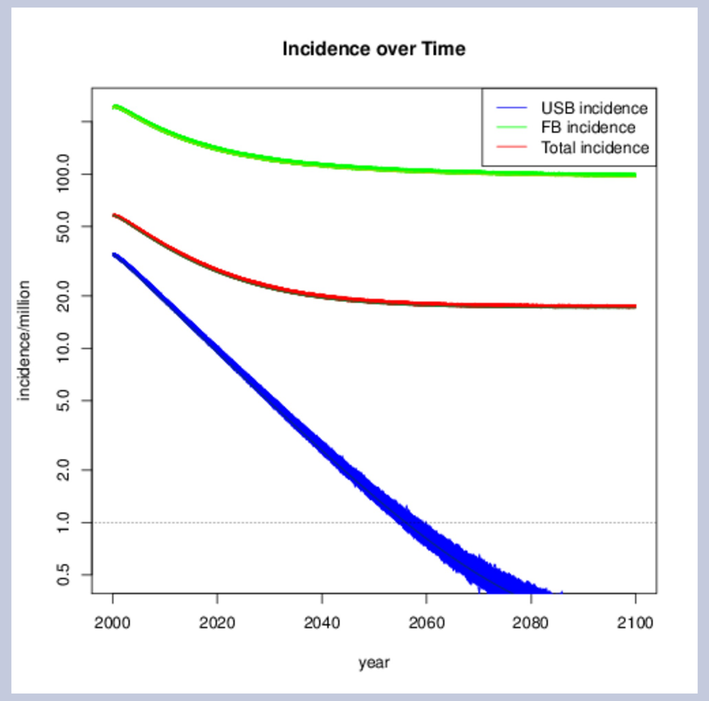

Figure: Incidence/million for R and C++ models (2100 runs, $\Delta t = 0.01$, popConst $= 1$)

Stochastic Models as a Measure of Variability

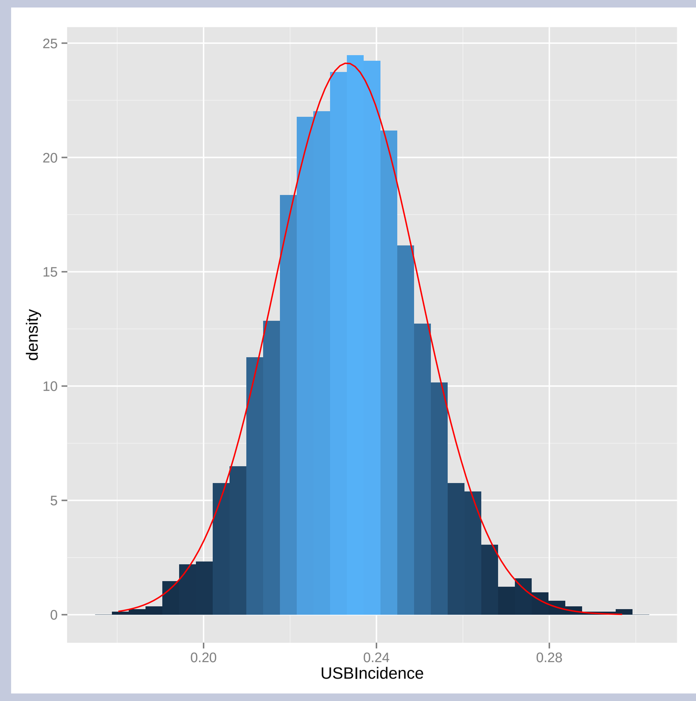

Figure: Distribution of USB Incidence (C++) with fitted Normal curve

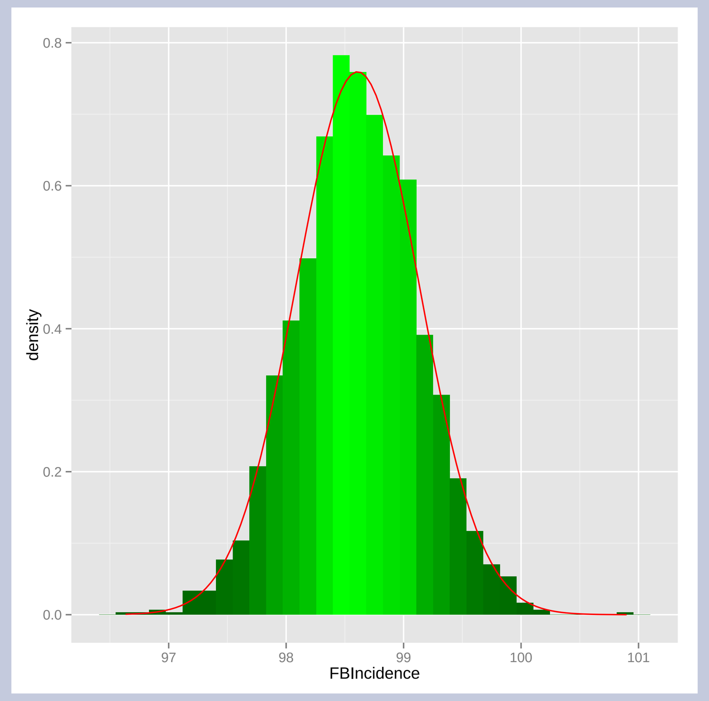

Figure: Distribution of FB Incidence (C++) with fitted Normal curve

References

Hill, A. N., Becerra, J. E., & Castro, K. G. (2012). Modelling tuberculosis trends in the USA. Epidemiology and infection, 140(10), 1862.

https://www.github.com/mmcdermott/disease-modeling