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

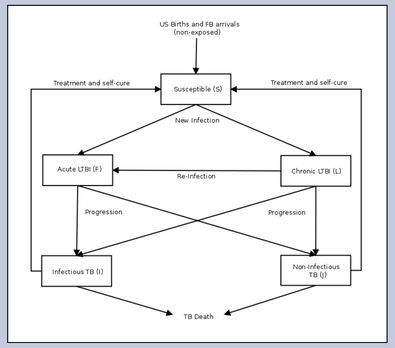

Figure: The Hill Model schematic

Populations:

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

Individuals also leave the model due to natural death.

- USB TB incidence rates are declining
- FB latent TB infection (LTBI) arrivals remain high
- TB elimination in total population not projected by 2100
- TB cases and costs dominated by FB LTBI individuals

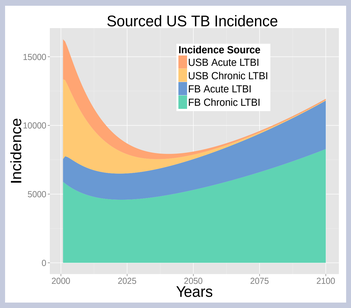

Figure: Source population of US TB incidence

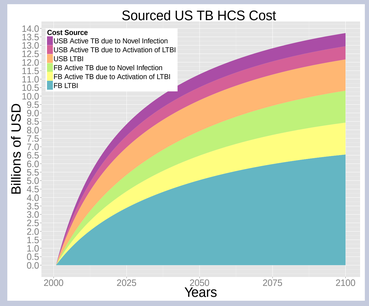

Figure: Source population of US HCS TB cost

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

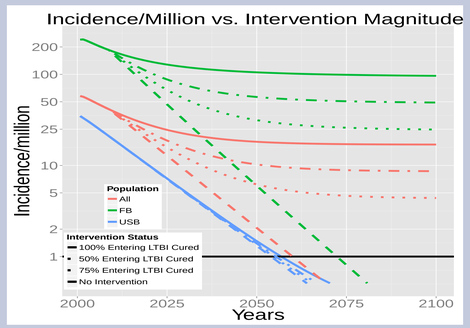

Figure: Incidence/million in USB, FB, and total populations, given 0%, 50%, 75%, or 100% treatment of incoming LTBI

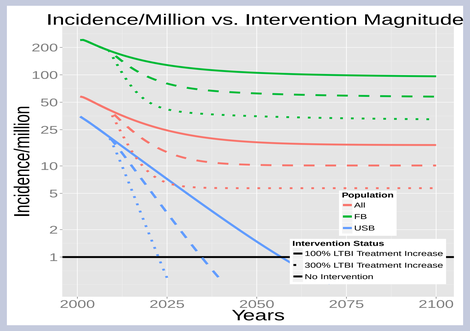

Figure: Incidence/million in USB, FB, and total populations, given 0%, 100%, or 300% LTBI treatment increase

Economic Modeling

- Tracks treatment costs for various disease states
- Estimates implementation cost of intervention
- Mean Active TB Treatment Cost: $14,014.90

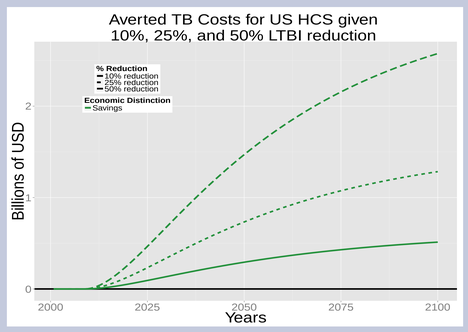

Figure: Cumulative US HCS savings from averted Active TB treatment costs given intervention magnitude. Does not include savings from averted LTBI treatment costs.

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++.

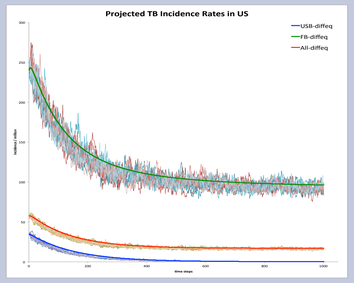

Figure: Incidence/million for R and NetLogo models (12 runs, $\Delta t = 0.1$, popConst $= 100$)

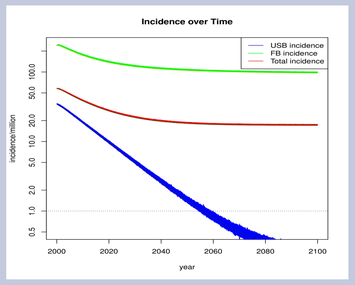

Figure: Incidence/million for R and C++ models (2100 runs, $\Delta t = 0.01$, popConst $= 1$)

Stochastic Models as a Measure of Variability

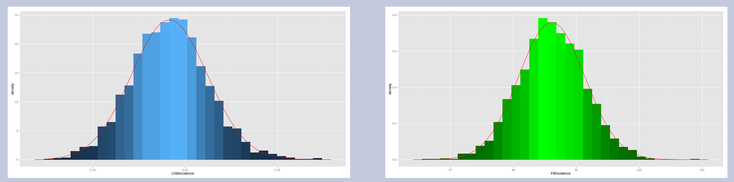

Figure: USB and FB Incidence (c++) with fitted Normal curves (USB: $\mu = 0.233, \sigma = 0.016534$, FB: $\mu = 98.6, \sigma = 0.525294$)

Summary

- LTBI dominates US TB dynamics
- Reducing FB LTBI most cost effective
- Agent-based models effective for evaluating robustness

References & Acknowledgments

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[1] 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