The Cost-Effectiveness of Contact Tracing for Endemic Diseases

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Abstract

Contact tracing is an important intervention for diseases such as TB, HIV, and other STDs (for which it is often called partner notification). However, its cost-effectiveness has not been modeled much. Using a stylized compartmental model of an endemic disease we show that contact tracing is a cost-effective alternative to screening when the disease prevalence is below some threshold. Using a more detailed simulation model of disease spread on a network, we show how to determine the optimal level of investment in contact tracing.

Introduction

What is contact tracing?

- **goal:** find additional infected persons
- **method:** given an infected case, find its contacts and test them for the disease
- also known *partner notification* for HIV and other STDs

What diseases is it used for? TB, HIV, other STDs. In the US it is required that health departments contact trace TB. The CDC recommends it for HIV. It is also practiced for other STDs.

What are the alternatives? Screening, vaccination, behavior change.

What are the tradeoffs? Contact tracing is labor intensive but is likely to find infected people.

What has been done so far? Small empirical studies and models of effectiveness but not of costs.

Related work: Contact tracing is also done for epidemics such as SARS and the avian flu. It is related to ring vaccination.

Conclusions

- Contact tracing is part of the optimal strategy when the disease prevalence is below a threshold.
- This threshold depends on the relative cost per case found by screening versus contact tracing.
- Investment in contact tracing has diminishing returns to scale.
- These models (appropriately tailored) provide a useful policy tool.
- Little is known about the actual network structure for a particular disease and more research is needed.

References

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- *Optimal mix of screening and contact tracing for endemic diseases*. Mathematical Biosciences. In press.
- *Contact Tracing to Control Infectious Disease: When Enough is Enough*. Health Care Management Science. In press.

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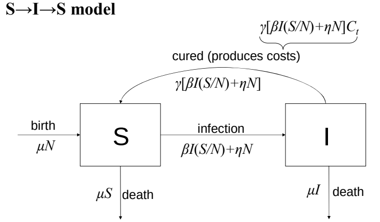
When is Contact Tracing Cost-Effective?

We build an SIS compartmental disease-transmission model and compare the costs and effectiveness of varying levels of random screening with and without contact tracing. Contact tracing will increase the number of cases found by a factor of K.

S→I→S model



μ per capita death rate
η per capita rate of outside infection
β sufficient contact rate

$p=I/N$ disease prevalence
$N=S+I$ total population
$\omega(p)=\gamma(1-p)[\beta p+\eta]$ get help because of symptoms; cured

$p'(t) = [\beta p(1-p)+\eta] - \mu p - \omega(p)$
$N'(t)=0$

Intervention 1: random screening at rate λ

- reduces prevalence at rate λp
- cost per capita is $\lambda(C_S+C_t p)$

C_t cost of testing 1 person
C_S cost of screening 1 person
C_T contact tracing cost per index case

Intervention 2: contact tracing

- $\delta=1$ if program exists, 0 if it does not
- K_T number of infected contacts per index case $\delta K_T(\lambda p+\omega(p))$ total
- C_T cost per index case, $\delta C_T(\lambda p+\omega(p))$

prevalence $p(t)' = f(p(t),\lambda(t),\delta(t)) = [\beta p(1-p)+\eta] - \mu p - (1+\delta K_T)(\lambda p+\omega(p))$

cost per capita $C(\lambda,\delta;p) = \omega(p)C_t + \lambda(C_S+C_t p) + \delta C_T(\lambda p+\omega(p))$

Minimizing Cost per Capita

1. Cost of finding n infected persons prevalence given and fixed (n small)

$$Cost = \min_{\lambda,\delta} C(\lambda,\delta;p) \quad s.t.\ N(1+\delta K_T)(\lambda p+\omega(p))=n,\ \lambda\geq 0,\ \delta=0,1$$

2. Long-term (steady-state) cost prevalence given and fixed

$$Cost = \min_{\lambda(t),\delta(t)} C(\lambda,\delta;p) \quad s.t.\ p(t)=P \text{ for all } t,\ \lambda(t)\geq 0,\ \delta(t)=0,1$$

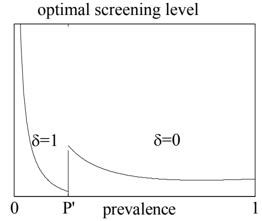
3. Total cost includes cost of untreated disease initial prevalence given $\lambda(t)$ and $\delta(t)$ vary with time α = cost of 1 case of untreated disease per year

$$\min_{p(t),\delta(t),\lambda(t)} \int_0^\infty e^{-rt}[C(\lambda(t),\delta(t);p(t))+\alpha p(t)]\,dt$$
$$s.t.\ p(0)=p_0,\ \dot{p}(t)=f(p(t),\lambda(t),\delta(t))\ \forall t$$
$$\dot{p}(t)\leq 0,\ \lambda(t)\leq\bar{\lambda}\ \forall t$$
$$\lambda(t)\geq 0,\quad \delta(t)=0,1$$

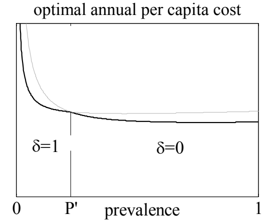
Results

In all 3 formulations, contact tracing optimal if and only if $p < P'$, $P'=C_S/(C_T/K_T - C_t)$.

optimal screening level



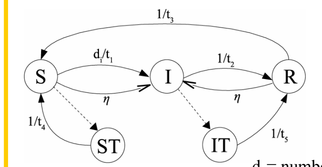
optimal annual per capita cost



How Much Contact Tracing is Cost-Effective?

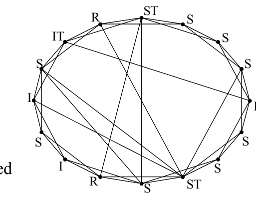
We use a simulation model of contact tracing and disease spread on a network to compare the costs and effectiveness of varying levels of contact tracing.

extended S→I→R model + **small-world network of contacts**



d_i = number of infected neighbors of node i

SIR + 2 additional states
•ST susceptible and currently being traced sought by the health department for testing
•IT infected and currently being traced



nodes in various states

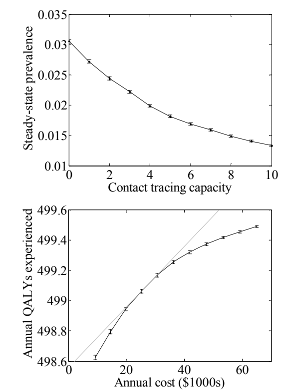
Budget: the size of the investment in contact tracing, i.e., the number of people we can trace (have in states ST and IT) at a time

n	500 individuals	size of network
t_1	90 days	
t_2	30 days	
t_3	90 days	
t_4,t_5	5 days	time needed to find a contact
η	1/9000 new cases/day/person	per capita rate of outside infections
C_T	\$6000	cost of tracing one person
C_t	\$50	cost of treating one person
q	0.9	quality multiplier of disease on a scale of 0 (death) to 1 (perfect health)

Simulation

- 1600 runs per point
- 95% confidence interval
- each simulation is over 5 years (first 180 days ignored)

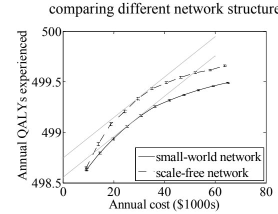
Results



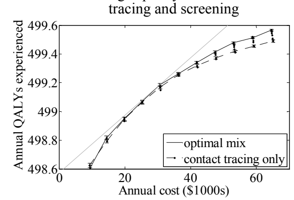
The points correspond to capacities from 0 to 10. At the optimal budget this curve has a slope of 1/α. Here α=\$50,000/QALY.

Extensions

comparing different network structures



allocating capacity between contact tracing and screening



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