# Toward a Containment Strategy for Smallpox Bioterror: An Individual-Based Computational Approach

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# SUMMARY

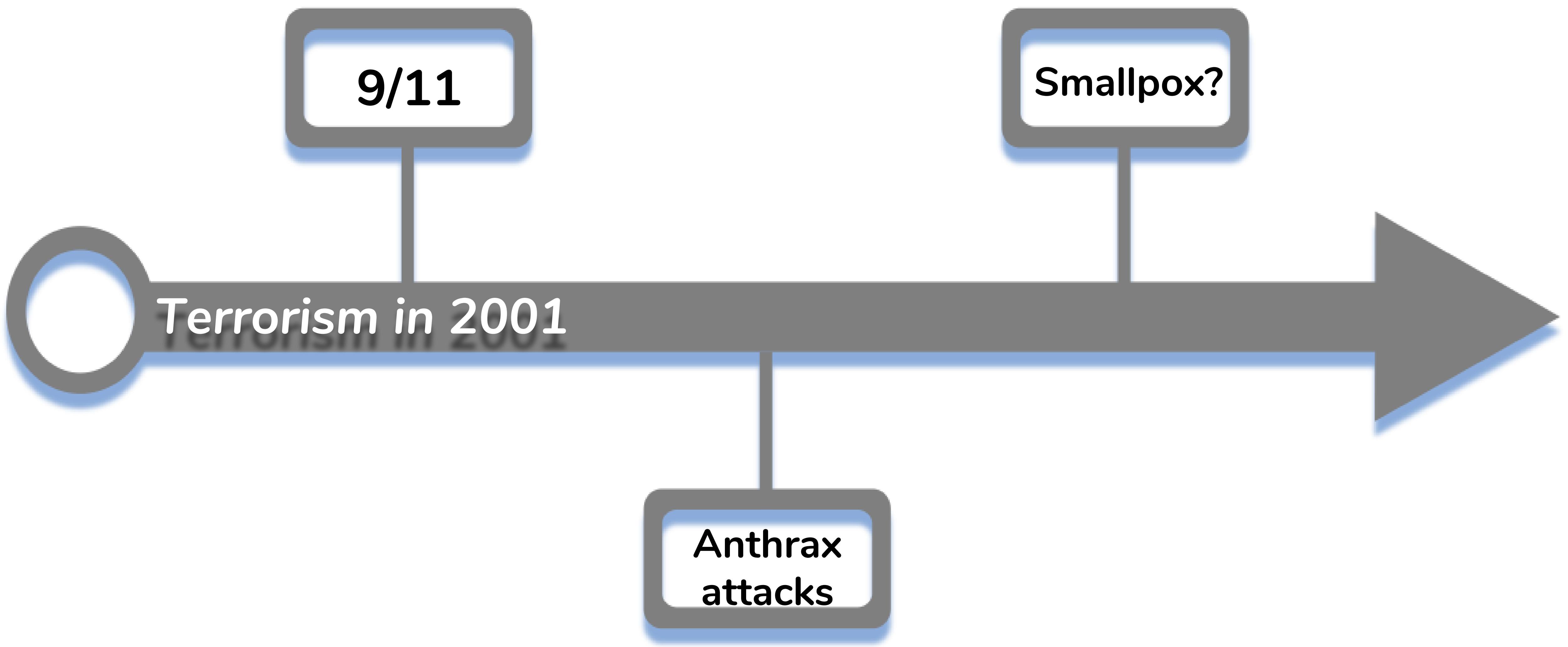
Motivation, related work, model and simulation, conclusion

# MOTIVATION

## Bioterror & the Smallpox Threat

Terrorism through the spread of a viral infection with potentially devastating effects. Risk of epidemic is heightened by a lack of population immunity in the United States.

- ★ Highly contagious
- ★ 30% fatality rate
- ★ Permanent disfigurement



# MOTIVATION

"What is the appropriate policy response?"

(Epstein et al., 2002; p.10)

# PAST WORK: COMPARTMENTAL MODELS

- Transmission of smallpox
  - Urban center in Kaplan et al. (2002) and structured community in Halloran et al. (2002)
- **Assumption 1. Homogeneous mixing**
  - Infection outbreak rate is based on number of susceptibles, infectives, and immunes
    - No differences in age, social/cultural factors, location, and “genetic heterogeneity” (Anderson & May, 1991; p. 65)
  - Everyone is equally likely to interact and everyone responds to the infection in the same way (Becker, 1989)
- **Assumption 2. Mass action kinetics**
  - “ ...the net rate of spread of infections is assumed to be proportional to the product of the density of susceptible people times the density of infectious individuals.” (Anderson & May, 1991; p. 7)

# PAST WORK: EPIDEMICS

## Outcomes

- ★ Bifurcation phenomenon
  - ○ Start with some level of immunity
  - ○ Results in either small or large outbreaks, no in between
- ★ Epidemic quenching
  - ○ Limit spread of disease to a discrete social unit
  - ○ Can a strategy be used to improve likelihood of quenching?

## Intervention Strategies

- ★ Preemptive measure
  - ○ Mass vaccination: population is vaccinated before a confirmed case
- ★ Reactive measures
  - ○ Trace vaccination: individuals who have been in contact with infected person are vaccinated
  - ○ Quarantine of infectives

# PRESENT STUDY: EPIDEMIC MODEL

## Structure

- ★ 2 towns in a county (circletown & squaretown)
- ★ 100 families in a town (400 individuals/town)
  - ○ 2 working adults + 2 school-age children
  - ○ 10% of adults commute to other town

## Social Units

These are the focus for intervention strategies.

- ★ 1 workplace + 1 school in each town
- ★ 1 hospital in the county
  - ○ 5 adults from each town work here
- ★ 1 morgue in the county

## Time

- ★ Models 2 phases: daytime and nighttime
- ★ 10 interaction rounds per phase
- ★ Each individual active once in a round

## Agents

For each individual, model tracks contacts with others and progression of disease.

- ★ Adults go to work during the day
- ★ Children go to school during the day
- ★ Adults and children interact at night

# PRESENT STUDY: EPIDEMIC SIMULATION

At time zero, the model is set at day 10, every individual is at home, and only one individual - a commuter - is infected. Parameter values are based on a European dataset. The population immunity is set to nil.

## No Intervention

★ Smallpox spreads and becomes epidemic
  ○ Everyone is infected at some point (30% die)

## 1st Intervention

★ Preemptive vaccination of hospital workers, reactive vaccination of family, and infectives quarantined

★ **Effect on epidemic quenching**

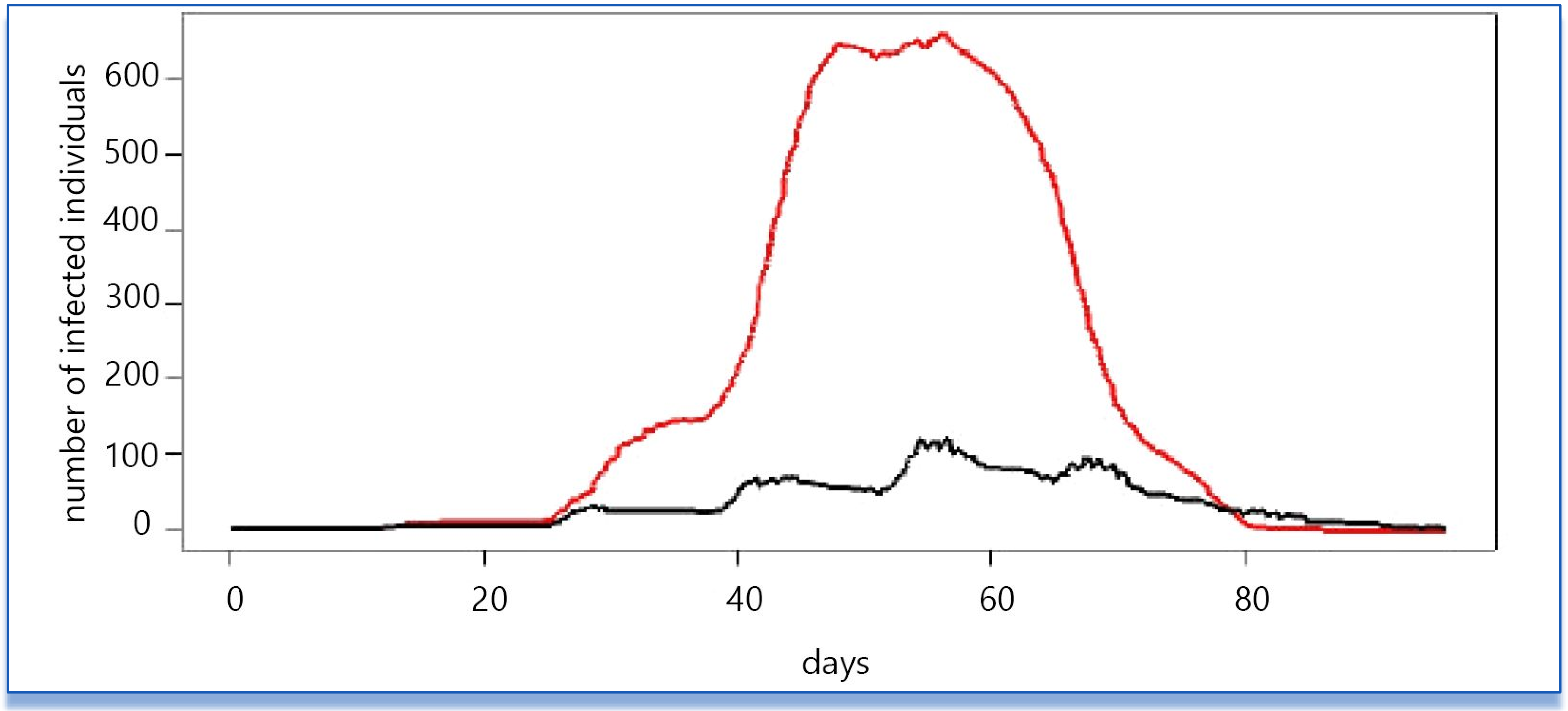



**Figure 1.** Results presented as time series data by Epstein et al. 2002. The red line represents a 'typical' run with no intervention and the black line represents a run with their first intervention strategy.

# PRESENT STUDY: EPIDEMIC SIMULATION

At time zero, the model is set at day 10, every individual is at home, and only one individual - a commuter - is infected. Parameter values are based on a European dataset. The population immunity is set to nil.

## 2nd Intervention

- ★ Preemptive mass vaccination (including hospital workers), reactive vaccination of family, and infectives quarantined
- ★ Varied level of mass vaccination
- ★ Varied extent of family trace vaccination
  - ○ 75% produced bifurcations
  - ○ 100% produced best results
- ★ **Strong effect on epidemic quenching**

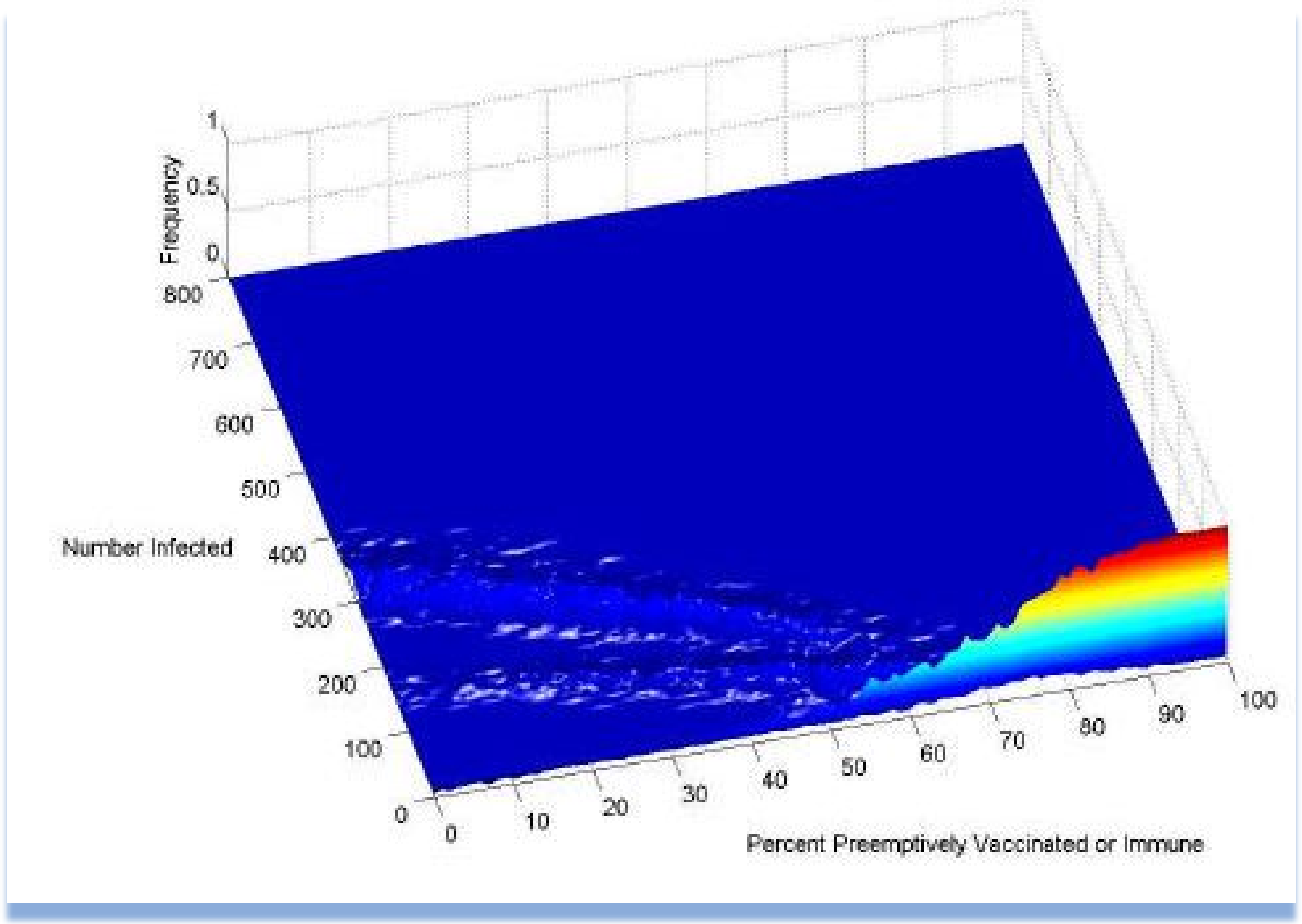



**Figure 2.** “Probability surface of the 75% family contact tracing case” (Epstein et al., 2002; p. 14)

# CONCLUSION: RECOMMENDATIONS

**Based on their results, the authors argue for a balanced policy approach.**

- ★ A solution to the problem of determining which preemptive policy measures to implement
- ★ Simulations show how mix of policy measures can help contain epidemic
- ★ These results, in combination with known risks of vaccination, are the basis for the proposed policy approach:
  - 100% family trace vaccination
  - 60% mass vaccination (portion of population unlikely to experience negative side effects)
    - 100% of hospital workers
  - Quarantine of infected individuals

# CONCLUSION: EXTENSIONS

**Authors describe several planned extensions for their model.**

★ Scale

★ Vaccinating contacts of contacts

★ Seasonality

★ Family isolation

# REVIEW

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Strengths, weaknesses, and extensions

# STRENGTH 1: BIFURCATION

**Authors successfully produced the bifurcation phenomena with their model.**

- By pinpointing the parameters which produced this phenomenon, can better understand how intervention strategies interact and result in epidemic quenching
  - Strong effect of family trace vaccination on total number of infected individuals
- Serves as a basis for proposed containment strategy
  - 100% family trace vaccination can minimize potential for large outbreak whereas 75% trace vaccination could lead to large outbreak

# STRENGTH 2: SIMULATIONS

**Authors report results from simulation runs with two intervention strategies.**

★ Base case, first intervention, and second intervention
  - Base case simulation runs produce expected results (e.g., ~30% fatality rate)
  - Observed differences are due to intervention

★ Shows the effect of various intervention combinations
  - Crucial to the development of a balanced policy approach

# STRENGTH 3: PLANNED EXTENSIONS

**Authors recognize the role of other factors in epidemic dynamics of smallpox.**

- ★ Their suggested policy approach may or may not be the most effective strategy all of the time
- ★ Could provide greater insight to what factors lead to small or large outbreak in bifurcation phenomena
  - e.g., strong effect of family isolation

# WEAKNESS 1: HOMOGENEOUS MIXING

Infection outbreak rate is based on number of susceptibles, infectives, and immunes

(Anderson & May, 1991)

Everyone is equally likely to interact and everyone responds to the infection in the same way

(Becker, 1989)

- ★ "...populations become highly heterogeneous by health status during simulations" (Epstein et al., 2002; p. 2)
  - This is true but individuals 1) are still responding to the infection in the same way and 2) have the same general types of interactions with every else (work, school, home, hospital)
- ★ No individual is more susceptible to infection
- ★ No individual is more likely to die due to infection
- ★ Neglects effects of infection based on 1) sub-populations' genetic makeup and 2) socio-cultural factors influencing interaction

# WEAKNESS 2: EPIDEMIC QUENCHING

**The authors state that their suggested policy approach can result in epidemic quenching with little evidence.**

- ★ While their suggested policy approach is based on their results, they do not provide strong evidence that it is more or less effective containment strategy compared to other intervention strategies
- ★ In reference to the outcomes observed with their proposed approach:
  - ○ “This certainly qualifies as containment, <u>compared to the no intervention base case</u> in which the entire population of 800 individuals became infected and roughly 240 die in virtually all runs.” (Epstein et al., 2002; p. 16)

# WEAKNESS 3: SOCIAL STRUCTURE

**Related to the previous weakness, authors consistently emphasize role of social units but it's unclear how this influenced their results.**

- ★ Authors do not provide results showing containment to a discrete social unit
  - ○ Presumably hospital or family home?
- ★ Paper could benefit from observations of where individuals were initially exposed to infection
  - ○ Relates their findings back to original European dataset
- ★ How did workplace (other than the hospital) and school affect transmission and containment?

# EXTENSION 1: HETEROGENOUS AGENTS

## Increasing heterogeneity of population

- ★ Although interactions and health status are heterogenous across model population, there are other differences in individuals that could produce interesting results
  - ○ Related to weakness # 1
- ★ Add sub-population with greater susceptibility to infection or death
  - ○ Increase transmission rate when interacting with these individuals
- ★ Add sub-population of single individuals and couples without children
- ★ Is it more or less important for certain individuals to receive preemptive mass vaccination?

# EXTENSION 2: SOCIAL UNITS

**Socio-cultural factors can be explored through the addition of social units other than home, school, and hospital.**

★ Socio-cultural differences may lead to different interaction patterns that influence spread of infection
★ Add other social units with regular visitors, like a place of worship
★ Allow individuals and families to visit each other's homes
  ○ Neighbors (spatial) and friends, colleagues, and family (network)
★ Does transmission differ in subpopulations that interact more frequently relative to other subpopulations?
  ○ e.g., churchgoers, multi-family homes/apartments, etc.
★ How does effectiveness of family trace vaccination differ when individuals have different levels of interaction?

# REFERENCES


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# Thanks!

Any questions?