Planning horizon affects prophylactic decision-making and epidemic dynamics

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Motivation

- **Infectious diseases** remain a major **threat to human health**. For example, the recent outbreaks of SARS, H1N1 flu, and Ebola.

- **Human behavior** has been recognized to play a significant role in the spread of infectious diseases.
Aspects of human behavior incorporated in infectious disease models:

- Individual responses to different types of public health interventions

- Influence of risk of infection and social cost on individual behavioral changes

- Effect of awareness or fear spreading on individual behavioral decisions
Objective

Understand how individuals’ planning horizons influences behavioral changes (i.e., adopt or not prophylaxis) and how this in turn influences epidemic dynamics.
Objective

Definition

Planning horizon is the time in the future over which individuals consider to make a behavioral decision to adopt prophylaxis.
The **SPIR** model (Susceptible, Prophylactic, Infectious, Recovered) is an **epidemiological agent-based model** that couples individual behavioral decisions with a disease dynamics model.
SPIR Model

Agent States

- Susceptible
- Prophylactic
- Infectious
- Recovery
Event 1: Interaction and Infection

Transmission Probability ($b_s$)
Disease Dynamics Model

Event 1: Interaction and Infection
Event 1: Interaction and Infection

Transmission Probability ($\rho b_s$)
Disease Dynamics Model

Event 2: Recovery

Recovery Probability (g)
Disease Dynamics Model

Event 2: Recovery
Event 3: Behavioral Decision

Should I continue Susceptible or adopt Prophylactic behavior?
Behavioral Decision Model

- Agents use a **rational choice model** to decide whether to adopt Susceptible or Prophylactic behavior

- Agents adopt the behavior that has the **largest utility** over the **planning horizon** $H$

- Agents have **identical** and **complete knowledge** of the disease and its prevalence

- Agents assume the disease prevalence **remains at its current value** during the next $H$ time steps
Behavioral Decision Model

1. Expected Time

- **Susceptible**
  - Planning Horizon (H)
  - Expected % of H
    - 0%: 0
    - 25%: 100
    - 50%: 75
    - 75%: 50
    - 100%: 25

- **Prophylactic**
  - Planning Horizon (H)
  - Expected % of H
    - 0%: 100
    - 25%: 75
    - 50%: 50
    - 75%: 25
    - 100%: 0

\[ T_S = 52, \quad T_I = 30, \quad T_R = 18 \]
\[ T_P = 70, \quad T_I = 19, \quad T_R = 11 \]
Behavioral Decision Model

1. Expected Time

- **Susceptible**
  - Planning Horizon (H) vs. Expected % of H
  - $T_S = 52$, $T_I = 30$, $T_R = 18$

- **Prophylactic**
  - Planning Horizon (H) vs. Expected % of H
  - $T_P = 70$, $T_I = 19$, $T_R = 11$

2. Payoff

- **State**
  - Payoff graph
  - Ex: $u_S = 1.0$, $u_P = 0.9$, $u_I = 0.1$, $u_R = 0.95$
Behavioral Decision Model

1. Expected Time

- **Susceptible**
  - Planning Horizon (H)
  - Expected % of H
  - S
  - I
  - R
- **Prophylactic**
  - Planning Horizon (H)
  - Expected % of H
  - P
  - I
  - R

$T_S = 52, \ T_I = 30, \ T_R = 18 \quad T_P = 70, \ T_I = 19, \ T_R = 11$

2. Payoff

- Ex: $u_S = 1.0, \ u_P = 0.9, \ u_I = 0.1, \ u_R = 0.95$

3. Utility Calculation

$U_S = u_S T_S + u_I T_I + u_R T_R$
$U_P = u_P T_P + u_I T_I + u_R T_R$

Ex:
$U_S = 1.0 \times 52 + 0.1 \times 30 + 0.95 \times 18 = 72.1$
$U_P = 0.9 \times 70 + 0.1 \times 19 + 0.95 \times 11 = 75.35$
Behavioral Decision Model

1. Expected Time

![Graph showing Expected Time](image)

\[ T_S = 52, \ T_I = 30, \ T_R = 18 \]
\[ T_P = 70, \ T_I = 19, \ T_R = 11 \]

2. Payoff

![Graph showing Payoff](image)

Ex: \( u_S = 1.0, \ u_P = 0.9, \ u_I = 0.1, \ u_R = 0.95 \)

3. Utility Calculation

\[
\begin{align*}
U_S &= u_S T_S + u_I T_I + u_R T_R \\
U_P &= u_P T_P + u_I T_I + u_R T_R
\end{align*}
\]

Ex:
\[
\begin{align*}
U_S &= 1.0 \times 52 + 0.1 \times 30 + 0.95 \times 18 = 72.1 \\
U_P &= 0.9 \times 70 + 0.1 \times 19 + 0.95 \times 11 = 75.35
\end{align*}
\]

4. Decision Making

\[
\text{Decision} = \begin{cases} 
\text{Prophylactic} & \text{for } U_S < U_P \\
\text{Susceptible} & \text{otherwise}
\end{cases}
\]

Ex: \((U_S = 72.1) \leq (U_P = 75.35)\)

Decision = Prophylactic
Behavioral Decision Analysis

Switching Point

What is the proportion of infectious agents beyond which it would be advantageous for an agent to switch from Susceptible (i.e. non-prophylactic) to Prophylactic behavior or vice-versa?
Behavioral Decision Analysis

Switching Point

What is the proportion of infectious agents beyond which it would be advantageous for an agent to switch from Susceptible (i.e. non-prophylactic) to Prophylactic behavior or vice-versa?

[Diagrams showing graphs with axes labeled as follows:
- For graph A: Utility vs. % Infectious (i) with lines indicating Susceptible and Prophylactic behavior.
- For graph B: % Protection vs. % Infectious (i) with lines and color gradient showing Planning Horizon (H).
- For graph C: Utility vs. % Infectious (i) with lines indicating Susceptible and Prophylactic behavior.]
Influence on Epidemic Dynamics

Research Question

How does planning horizon affect prophylactic decision-making and epidemic dynamics?
Influence on Epidemic Dynamics

Research Question

How does planning horizon affect prophylactic decision-making and epidemic dynamics?

Table: Experiment simulation input parameters

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<thead>
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<th>Type</th>
<th>Name</th>
<th>Value</th>
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<tr>
<td>General</td>
<td>Number of Agents</td>
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<td>Behavioral</td>
<td>${u_S, u_P, u_I, u_R}$</td>
<td>${1, 0.95, 0.1, 0.95}$</td>
</tr>
</tbody>
</table>
Influence of the Planning Horizon

Baseline
- Never consider adopting prophylactic behavior
- No impact on the epidemic dynamic
Influence of the Planning Horizon

**Planning Horizon (H)**

- **1**
- **30**

**Switch Point**

- **0%**
- **5%**
- **10%**
- **15%**

**Time**

- 0
- 500
- 1000
- 1500
- 2000

**% Infected (i)**

**Short**

- Consider adopting prophylactic behavior
- Never adopt prophylactic behavior
- No impact on the epidemic dynamic
Influence of the Planning Horizon

Intermediate
- Adopt prophylactic behavior
- Impact on the epidemic dynamic
Influence of the Planning Horizon

**Long**
- Never consider adopting prophylactic behavior
- No impact on the epidemic dynamic
- “Get it over with”
Influence of the Decision Frequency

- Reduces the peak size
- Prolongs the epidemic
- Generates secondary infection waves

Increasing $d$
Conclusions

- Agents do not engage in prophylactic behavior for short and long planning horizons; for intermediate planning horizon agents adopt prophylactic behavior depending on the disease parameters.

- The adoption of prophylactic behavior is not always monotonically associated with the prevalence of the disease.

- Adoption of prophylactic behavior reduces the epidemic peak size while prolonging the epidemic and potentially generates secondary waves of infection.

- Increasing decision frequency makes the effects of adopting prophylactic behavior stronger.
Future Work

- Evaluate scenarios composed of heterogeneous agents (e.g., different risk perception, payoff structure, etc.) and different topological structures (e.g., scale-free network).

- Perform comparative studies with different behavioral decision models. For example, relax some of the assumptions of rationality.

- Incorporate social influence aspects into the behavioral decision model.
Thank you

Questions?

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