The 1st Interuniversity Symposium on Field Based Design

Hong Kong Baptist University - Kyoto University

Ph.D Student Forum

Infectious Disease Control:

Voluntary Vaccination and Human Decision Making

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Contents

1. A real-world epidemic

- The 2009 Hong Kong H1N1 influenza
- Human Swine Influenza (HSI) vaccination program

2. Public vaccination acceptance

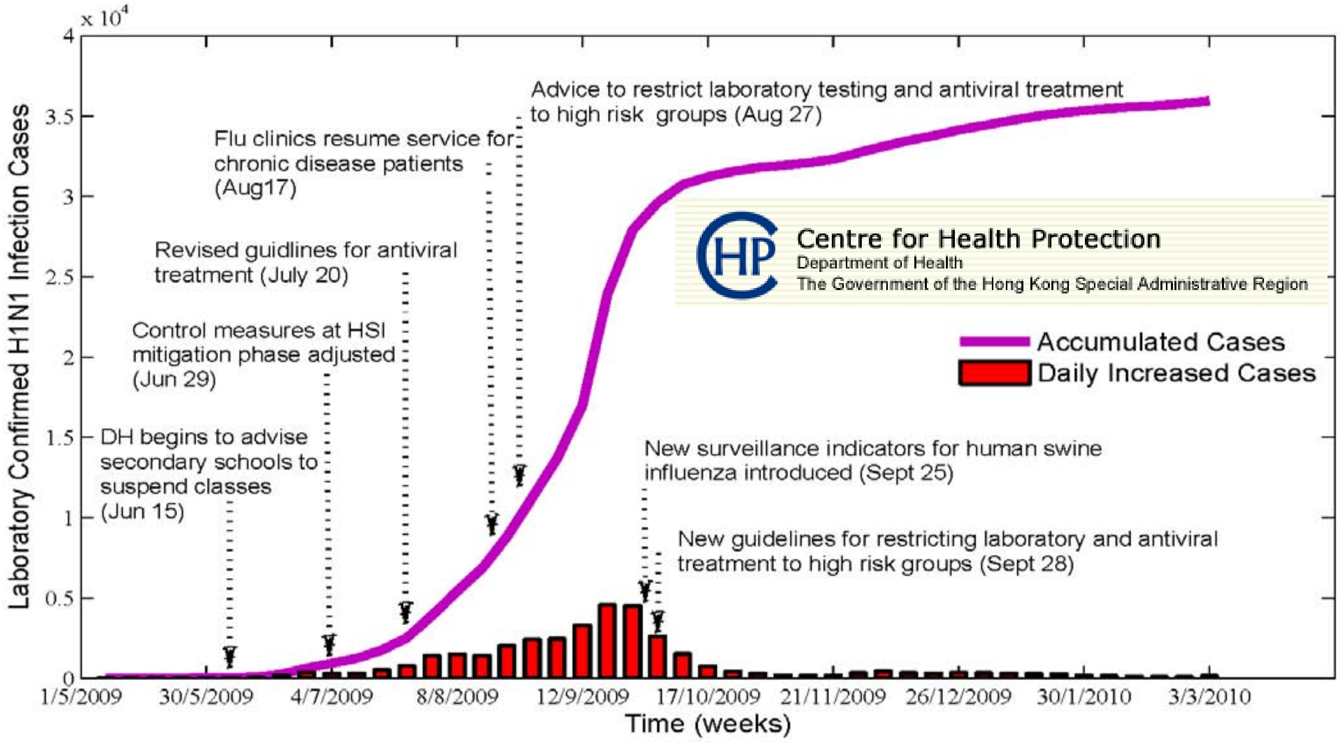
- Impact factors of individuals’ vaccination decisions

3. Understanding vaccination decision making

- Risk-benefit analysis (game-theory)
- Impact of social influence (social impact theory)

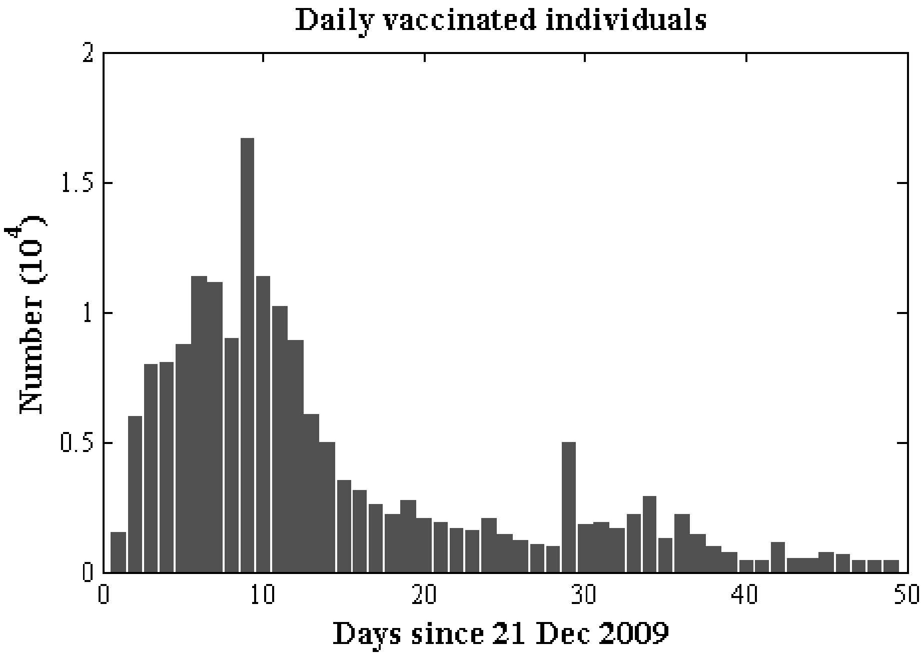
A Real-World Case: Influenza Epidemic

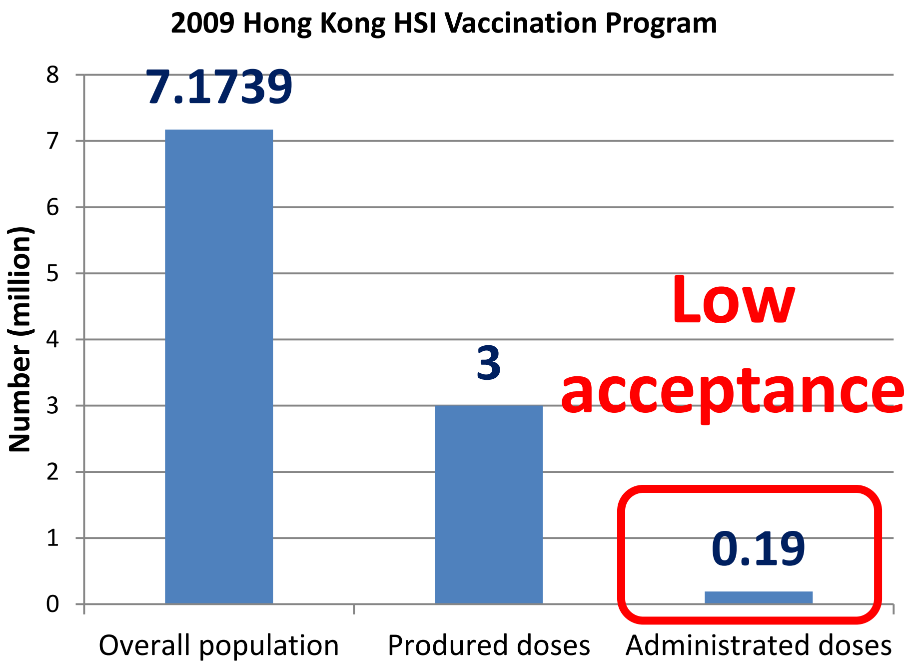
- **The 2009 Hong Kong H1N1 Influenza Epidemic**
  1. 1st imported case confirmed on 1 May 2009
  2. Pandemic ***ALERT LEVEL 6*** (announced by WHO on 11 June 2009)
  3. Over ***36,000*** confirmed cases as of September 2010
  4. ***290*** severe cases and over ***80*** death



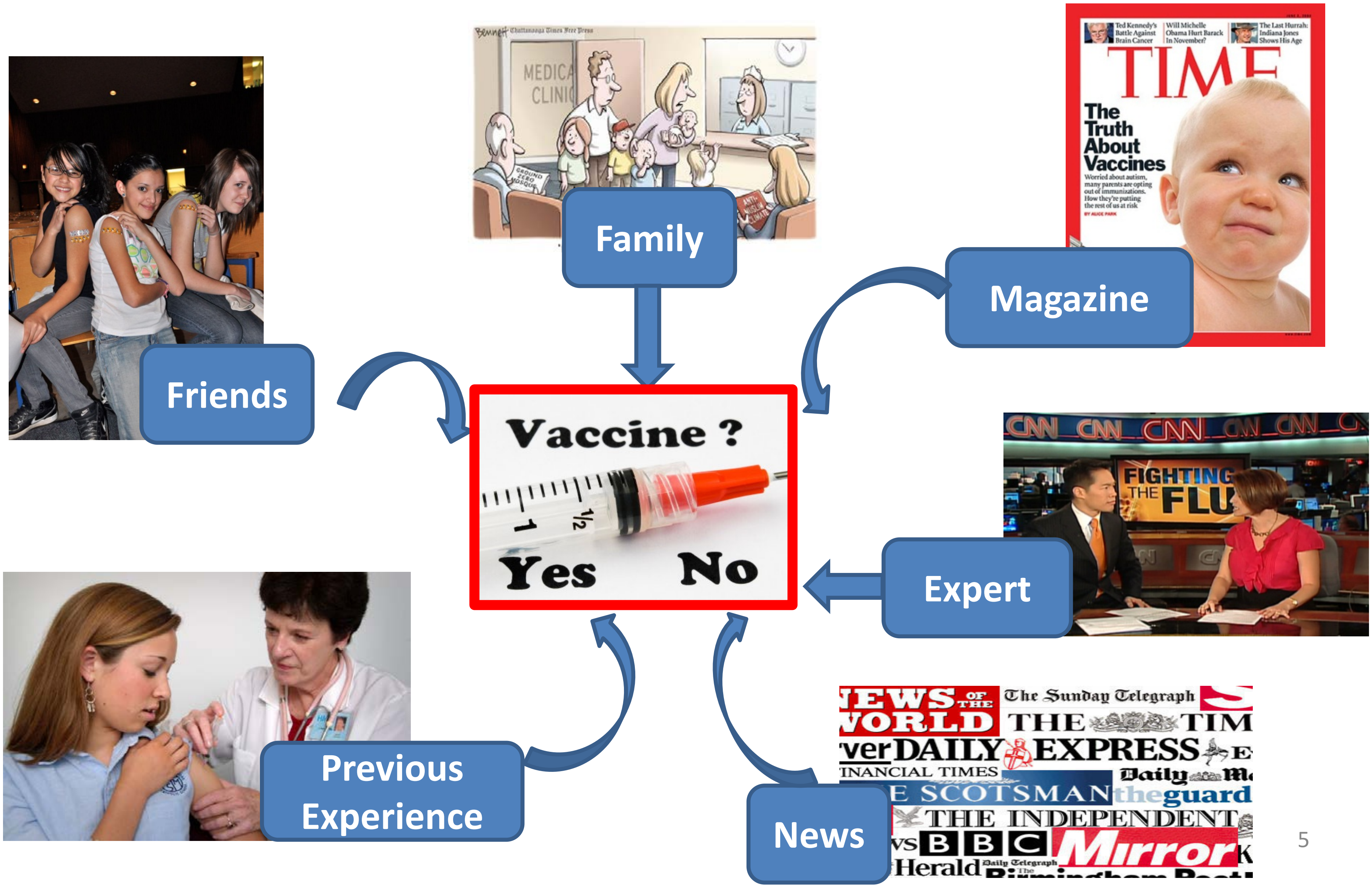
A Real-World Case: Vaccination Program

- **Human Swine Influenza (HSI) Vaccination Program**
  1. Program started on 21 December 2009
  2. ***Three million*** doses of HSI vaccine procured
  3. Over ***191,508*** doses administrated until 13 September 2010
  4. Total ***34*** cases of adverse effects were reported





Public Vaccination Acceptance



Individuals' Vaccination Decisions

- **Impact factors** [Bish,2011]

  - **Personal background:**
    1. Past history of seasonal influenza vaccination
  - **Risk-benefit awareness/perceptions:**
    1. Perceived infection severity
    2. Perceived vaccine efficacy and safety
  - **Social influence:**
    1. Recommendations from family members
    2. Friends taken up vaccine

Bish A, Yardley L, Nicoll A, Michie S. Factors associated with uptake of vaccination against pandemic influenza: A systematic review. Vaccine. 2011;29(38):6472–6484. (doi: 10.1016/j.vaccine.2011.06.107).

Understanding Individuals' Vaccination Decisions

- **Research issues**

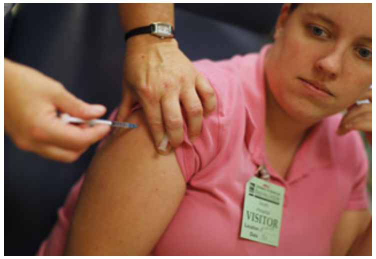
1. Modeling individuals' vaccination decision making

- Risk-benefit analysis (game-theory)
- Impact of social influence (social impact theory)

2. Evaluating its impacts on infectious disease control

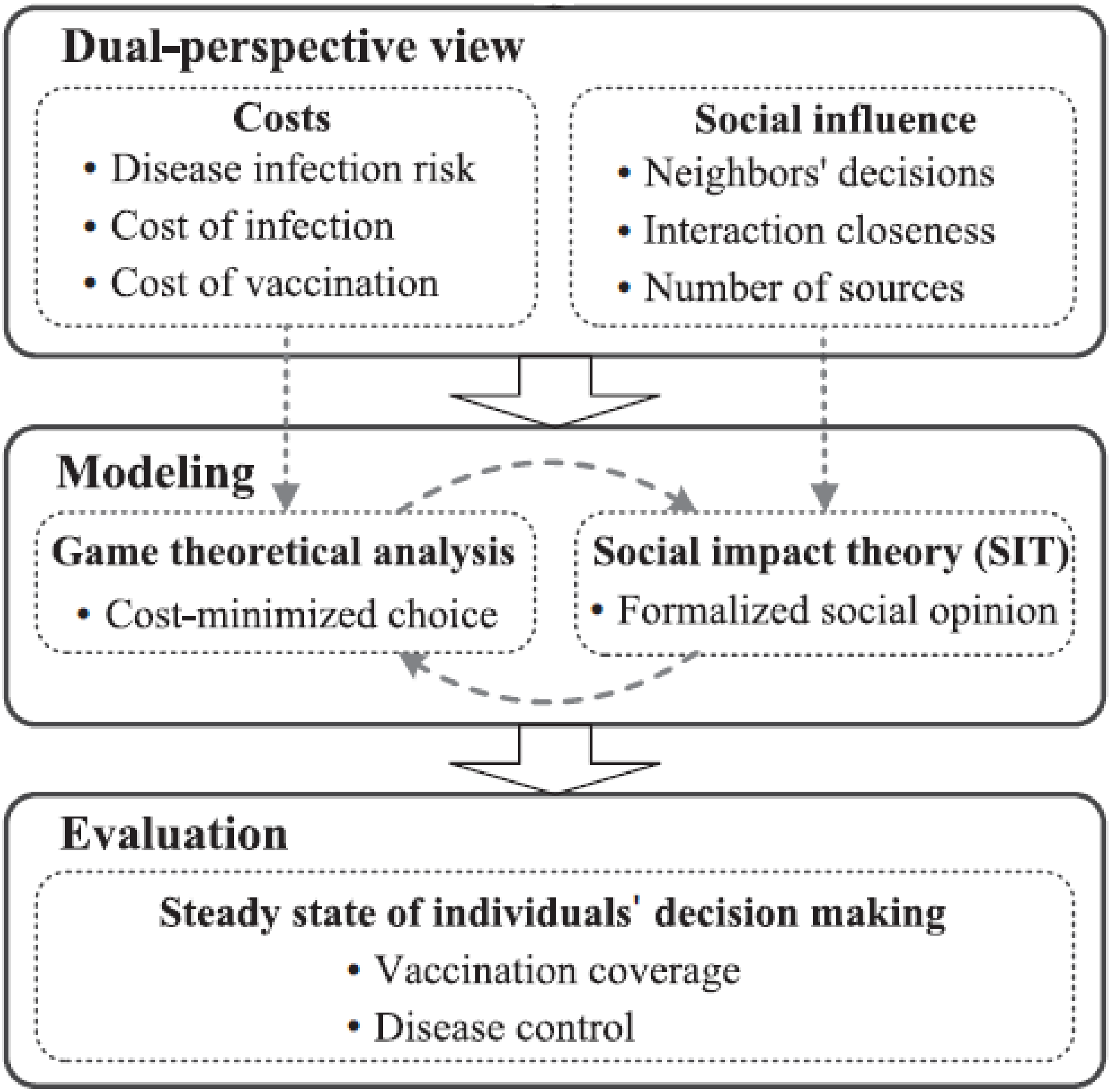
- Vaccination coverage
- Disease attack rate

Disease Spreading



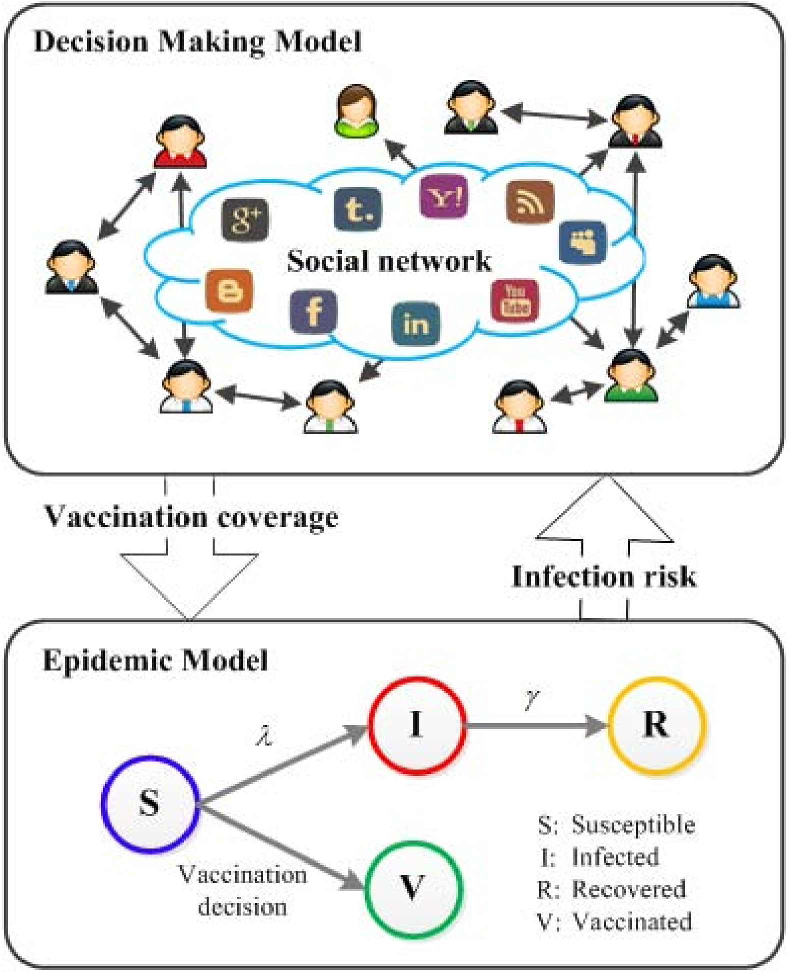
Vaccination Control

A Duel-Perspective of Vaccination Decision Making



Modeling Individuals' Vaccination Decision Making

- **Schema**



1. **Vaccination decision**: σ_i
   - σ_i=1, vaccination
   - σ_i=-1, non-vaccination
2. **Social network**: $NW = < V, E >$
   - *Node V: individuals*
   - *Edge E: closeness*
3. **SIR epidemic model**

$$\frac{dS}{dt} = -\lambda \cdot S$$
$$\frac{dI}{dt} = \lambda \cdot S - \gamma \cdot I$$
$$\frac{dR}{dt} = \gamma \cdot I$$

4. **Disease infection risk**: λ

$$\lambda = \beta \cdot \frac{I}{N}$$

Risk-Benefit Analysis

- **Cost analysis (game theoretical analysis** [Bauch,2003]**)**
  1. Cost of vaccination: C_{vac}
  2. Cost of infection: C_{inf}
  3. Relative cost ratio: $r = C_{vac}/C_{inf}$
- **Cost function**

$$C_i\,(\sigma_i) = (1+\sigma_i)\cdot r + (1-\sigma_i)\cdot \lambda_i$$

- **Cost minimized choice**

$$\hat{\sigma}_i = \begin{cases} +1,\ \ if\ r < \lambda_i \\ -1,\ \ if\ r > \lambda_i \\ \text{unchanged},\ \ if\ r = \lambda_i \end{cases}$$

Bauch CT, Earn DJD. Vaccination and the theory of games. Proc Natl Acad Sci. 2004;101(36):13391–13394. (doi: 10.1073/pnas.0403823101).

Impact of Social Influence

- **Social influence (social impact theory** [Nowak,1990]**)**

$$\iota_i^{vac} = (N_i^{vac})^{1/2} \cdot \sum_{j \in N_i^{vac}} w_{ij}^2$$

$$\iota_i^{non} = (N_i^{non})^{1/2} \cdot \sum_{j \in N_i^{non}} w_{ij}^2$$

$$\Delta \iota_i = \frac{\iota_i^{vac} - \iota_i^{non}}{\iota_i^{vac} + \iota_i^{non}}$$

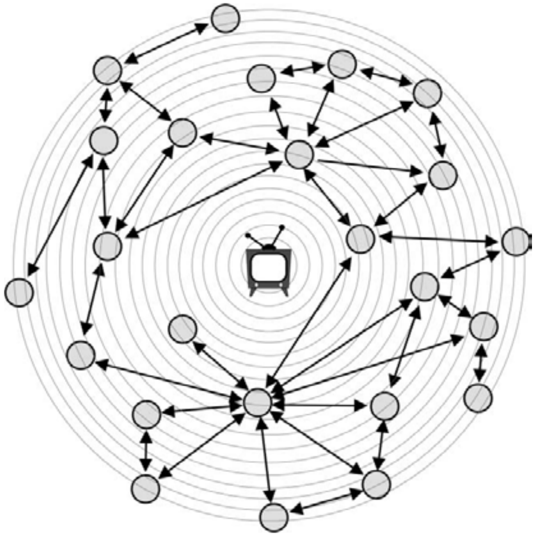
Bibb Latané (1937) is a United State social psychologist.

- **Opinion of social neighbors**

$$\tilde{\sigma}_i = \begin{cases} +1, \; with\ probability\ P(\Delta \iota_i) \\ -1, \; with\ probability\ 1 - P(\Delta \iota_i) \end{cases}$$

Fermi function

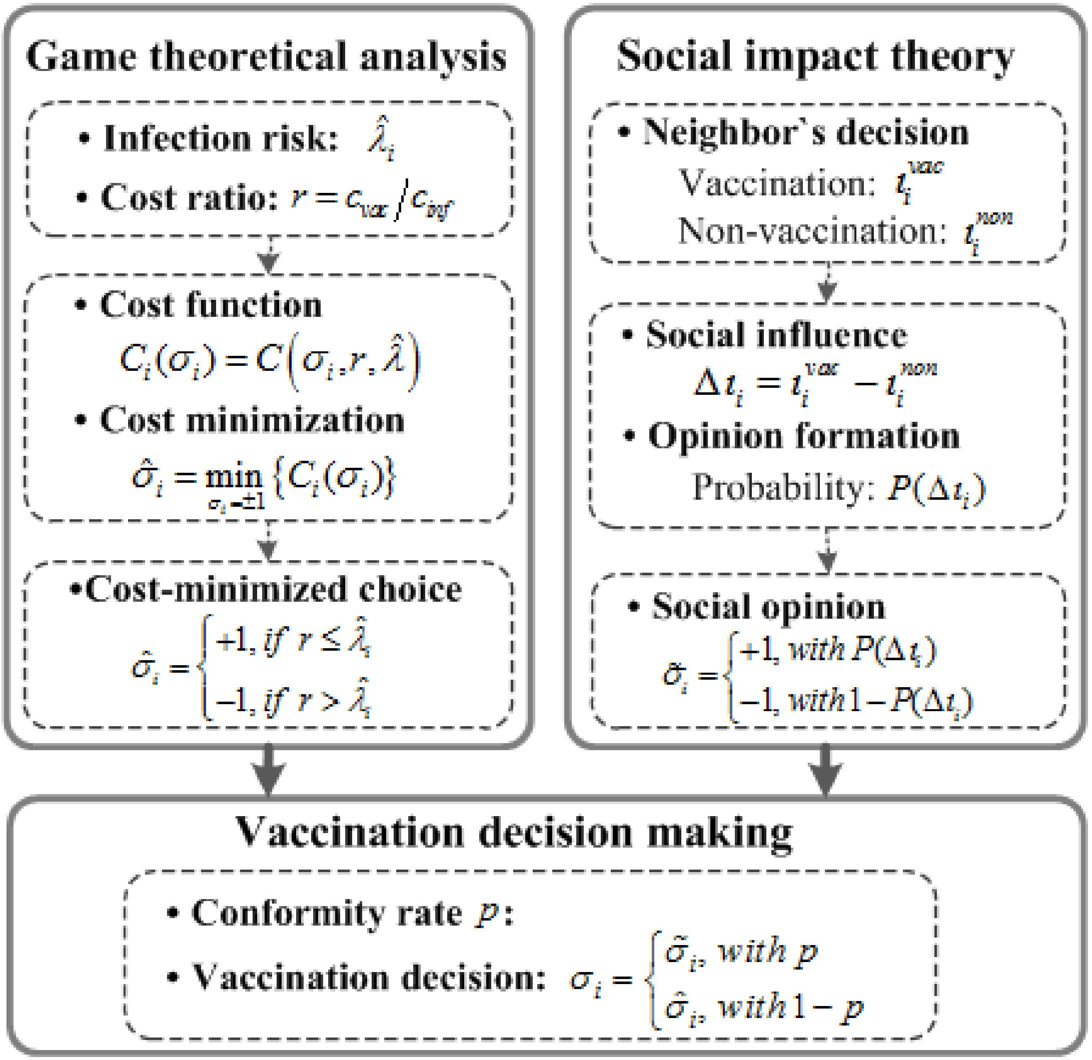
$$P(\Delta \iota_i) = \frac{1}{1 + \exp\left(-\alpha \cdot \Delta \iota_i\right)}$$



The social influence based the communication interaction among individuals.

Nowak A, Szamrej J, Latane B. From private attitude to public opinion: A dynamic theory of social impact. Psychol Rev. 1990;97(3):362–376. (doi: 10.1037/0033-295X.97.3.362).

Vaccination Decision Making



- **Conformity rate p**

The degree of individuals' tendency towards adopting the social opinion of his/her connected neighbors, instead of the cost minimized choice

Simulation-Based Experiments

- **Parameterization**
    1. The 2009 Hong Kong H1N1 Epidemic [Cowling,2010]
    2. Social interaction network at an American high school [Salathe,2010]
- **Control variables**
    1. Initial vaccination willingness
    2. **Cost ratio r**: the relative costs of vaccination and infection
    3. **Conformity rate ρ**: the impact of social influence
- **Measurement**
    1. Vaccination coverage, i.e., the size of vaccinated population
    2. Disease attack rate, i.e., the size of infected population

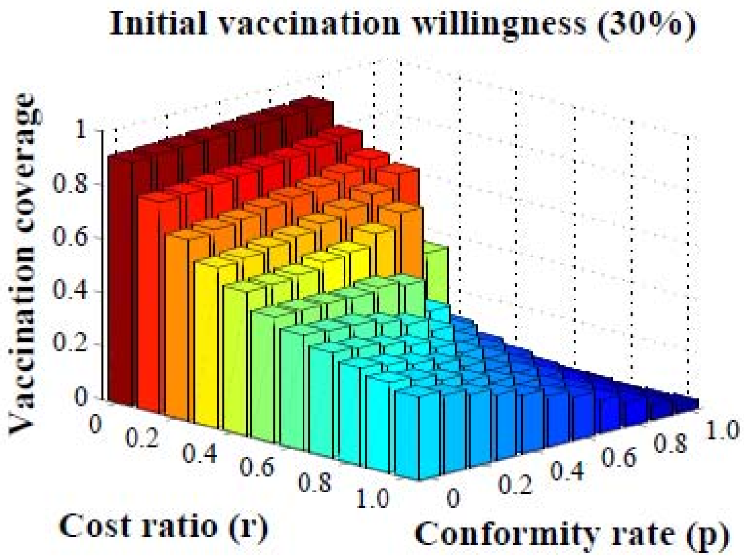
Cowling BJ, et al. The effective reproduction number of pandemic influenza: prospective estimation. Epidemiology. 2010;21(6):842–846. (doi: 10.1097/EDE.0b013e3181f20977).

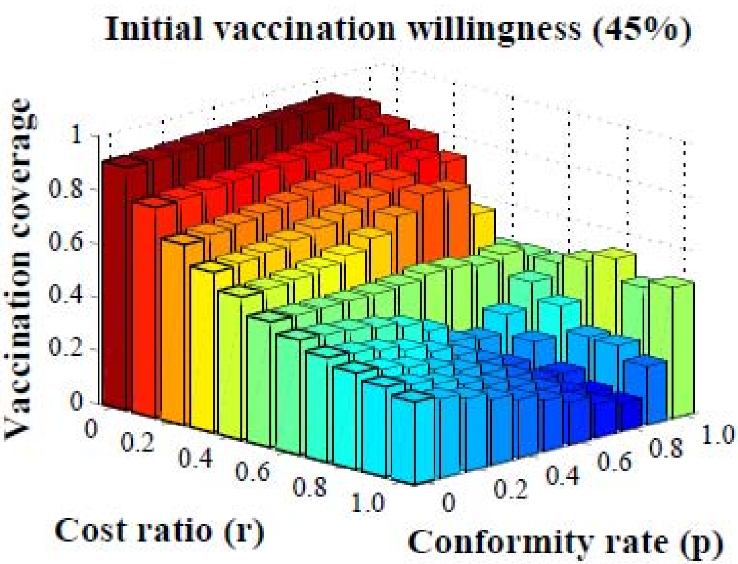
Salathe M, et al. Jones JH. A high resolution human contact network for infectious disease transmission. PNAS. 2010;107(51):22020–22025. (doi: 10.1073/pnas.1009094108).

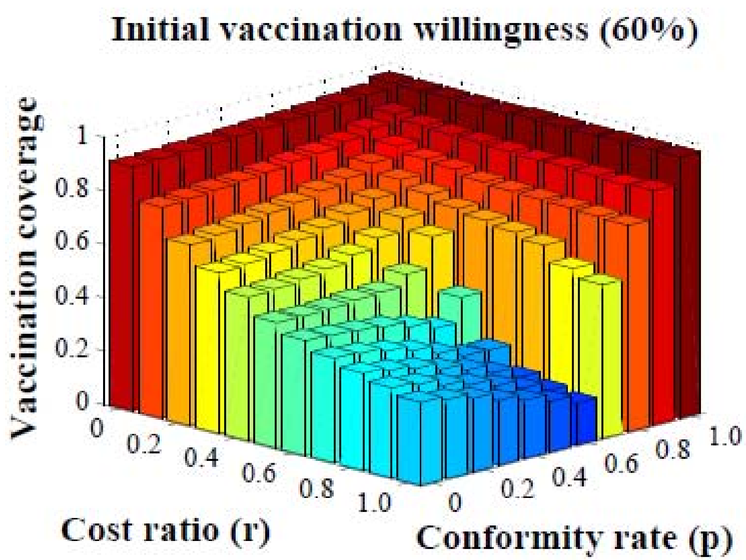
Simulation Results: Vaccination Coverage

- **Simulation setting**

1. Cost ratio $r \in [0,1]$
2. Conformity rate $\rho \in [0,1]$
3. Initial vaccination willingness: 30%, 45%, 60%



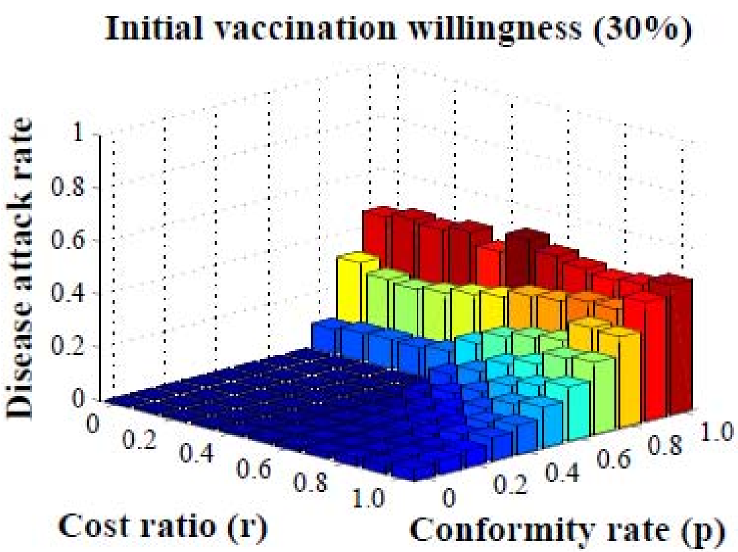


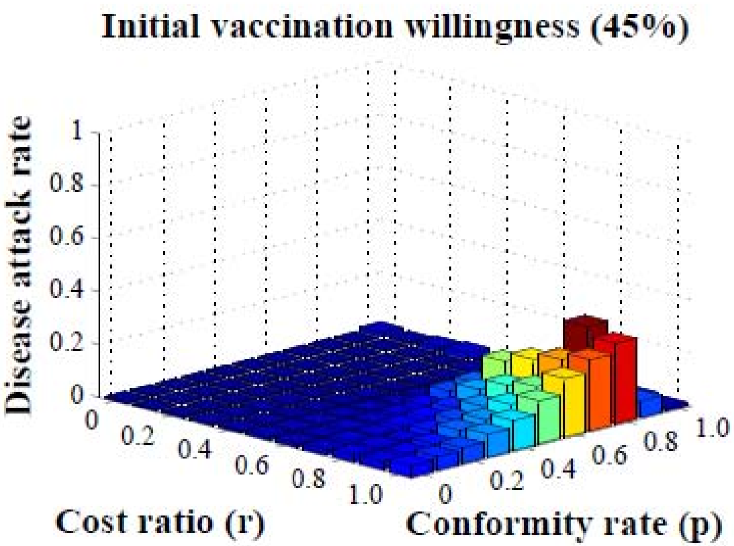


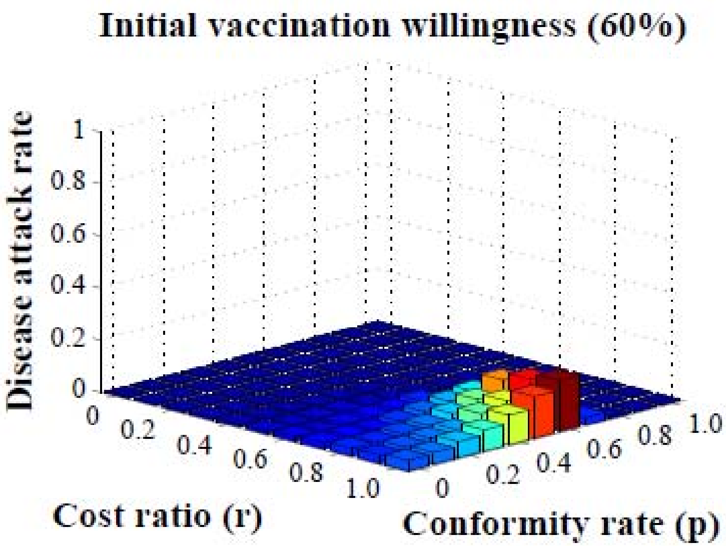
Simulation Results: Disease Attack Rate

- **Simulation setting**

1. Cost ratio $r \in [0,1]$
2. Conformity rate $\rho \in [0,1]$
3. Initial vaccination willingness: 30%, 45%, 60%







Summary

1. **Understanding individual's vaccination decisions**
    - Impact factors
2. **A duel perspective for modeling vaccination decision making**
    - Cost-benefit analysis (game theoretical analysis)
    - The impact of social influence (social impact theory)
3. **Evaluating its impacts on infectious disease control**
    - Simulation-based experiments
    - Vaccination coverage
    - Disease attack rate

Publication

Xia S, Liu J. A Computational Approach to Characterizing the Impact of Social Influence on Individuals' Vaccination Decision Making. *PLoS ON*E. 2013; accepted for production.

THANK YOU