Voluntary Participation in Cyber-insurance Markets

Parinaz Naghizadeh, Mingyan Liu

Department of Electrical Engineering and Computer Science
University of Michigan, Ann Arbor, MI

13th Workshop on the Economics of Information Security (WEIS)
June 24, 2014
The cyber-insurance market ¹

- Over 30 companies offering insurance in the US.
- Growth of 10-25% in premiums reported.
- Total amount of premiums estimated between $500M and $1bn.
- Premiums $10k - $50M, coverage limits $16M - $300M.
- Cyber-insurance proposed for both risk transfer and shaping incentives.

¹Romanosky, *Comments to the Department of Commerce on Incentives to Adopt Improved Cybersecurity Practices*, 2013.

Interdependent security risks

- Security investments of a user have *positive externalities* on other users.
- Users’ preferences are in general heterogeneous:
  - Heterogeneous costs.
  - Different valuations of security risks.
- Heterogeneity leads to under-investment.
Cyber-insurance literature

Competitive markets
[Shetty 10, Pal 13]

- Perfect competition with free entry.
- Insurance contracts optimized from individual users’ viewpoint.
- Decreases incentive to invest in security, but individually rational.

Monopolistic markets
[Hoffman 07, Lelarge 09]

- A single profit neutral insurer (social planner).
- Socially optimal investments in model with binary decisions.
- Assumes compulsory insurance, participation incentives not studied.
Introduction

Model and Contract Design

Voluntary Participation

Discussion and Conclusion
Interdependent security (IDS) investment game

- A set of N users.
- User $i$’s action: invest $x_i \geq 0$ in security.
- User $i$ chooses $x_i$ to maximize its utility:

$$u_i(x) := - L_i f_i(x) - h_i(x_i).$$

$L_i$: assets subject to loss
$f_i(x)$: security risk of $i$, $x$ vector of investments
$h_i(\cdot)$: cost of investment
Interdependent security (IDS) investment game

- A set of $N$ users.
- User $i$’s action: invest $x_i \geq 0$ in security.
- User $i$ chooses $x_i$ to maximize its utility:

$$u_i(x) := -L_i f_i(x) - h_i(x_i).$$

$L_i$: assets subject to loss

$f_i(x)$: security risk of $i$, $x$ vector of investments

$h_i(\cdot)$: cost of investment
Interdependent security (IDS) investment game

- A set of $N$ users.
- User $i$’s action: invest $x_i \geq 0$ in security.
- User $i$ chooses $x_i$ to maximize its utility:

$$u_i(x) := -L_i f_i(x) - h_i(x_i).$$

$L_i$: assets subject to loss

$f_i(x)$: security risk of $i$, $x$ vector of investments

$h_i(\cdot)$: cost of investment
Interdependent security (IDS) investment game

- A set of $N$ users.
- User $i$’s action: invest $x_i \geq 0$ in security.
- User $i$ chooses $x_i$ to maximize its utility:

$$u_i(x) := -L_i f_i(x) - h_i(x_i).$$

$L_i$: assets subject to loss

$f_i(x)$: security risk of $i$, $x$ vector of investments

$h_i(\cdot)$: cost of investment
Interdependent security (IDS) investment game

- A set of $N$ users.
- User $i$’s action: invest $x_i \geq 0$ in security.
- User $i$ chooses $x_i$ to maximize its utility:

  $$u_i(x) := -L_if_i(x) - h_i(x_i).$$

$L_i$: assets subject to loss
$f_i(x)$: security risk of $i$, $x$ vector of investments
$h_i(\cdot)$: cost of investment
Cyber-insurance implementation

- A monopolist profit-neutral insurer, determines \( \{(\rho_i, I_i)\}_{i=1}^N \): premium and indemnification payment (coverage).

- Utility of user \( i \) when purchasing insurance:

\[
 u_i(x, \rho_i, I_i) = -(L_i - I_i)f_i(x) - h_i(x_i) - \rho_i .
\]

- The positive externality investment mechanism [Hurwicz 79]
  Each participant \( i \) inputs message \( m_i := (\chi_i, \pi_i) \), consisting of an investment profile and a price profile.
Cyber-insurance implementation

• A monopolist profit-neutral insurer, determines \( \{(\rho_i, l_i)\}_{i=1}^{N} \): premium and indemnification payment (coverage).

• Utility of user \( i \) when purchasing insurance:

\[
    u_i(x, \rho_i, l_i) = -(L_i - l_i)f_i(x) - h_i(x_i) - \rho_i .
\]

• The positive externality investment mechanism [Hurwicz 79]
Each participant \( i \) inputs message \( m_i := (\chi_i, \pi_i) \), consisting of an investment profile and a price profile.
Outline

Introduction

Model and Contract Design

Voluntary Participation

Discussion and Conclusion
On incentives to participate

- User participation depends on:
  1. game form
  2. options when staying out

- Most public good problems assume a zero share of resources for those staying out.

- Security is a non-excludable public good: users can stay out and still free-ride on (possibly lower) levels of security.

- Loner: stays out and best responds to the remaining $N - 1$ users.
On incentives to participate

- User participation depends on:
  1. game form
  2. options when staying out

- Most public good problems assume a zero share of resources for those staying out.

- Security is a non-excludable public good: users can stay out and still free-ride on (possibly lower) levels of security.

- Loner: stays out and best responds to the remaining $N - 1$ users.
On incentives to participate

• User participation depends on:
  1. game form
  2. options when staying out

• Most public good problems assume a zero share of resources for those staying out.

• Security is a non-excludable public good: users can stay out and still free-ride on (possibly lower) levels of security.

• Loner: stays out and best responds to the remaining $N - 1$ users.
On incentives to participate

- User participation depends on:
  1. game form
  2. options when staying out

- Most public good problems assume a **zero share** of resources for those staying out.

- Security is a **non-excludable** public good: users can stay out and still free-ride on (possibly lower) levels of security.

- **Loner**: stays out and best responds to the remaining $N - 1$ users.
On incentives to participate

- User participation depends on:
  1. game form
  2. options when staying out

- Most public good problems assume a zero share of resources for those staying out.

- Security is a non-excludable public good: users can stay out and still free-ride on (possibly lower) levels of security.

- Loner: stays out and best responds to the remaining $N - 1$ users.
Reasons for opting out (I)

Free riders paying for security; can enjoy spill-overs without paying. Free-rider 4 is happy; free-rider 1 would rather stay out.

Figure: Expenditure in security

Figure: Participation Incentive
Reasons for opting out (II)

Main investor not receiving high enough compensation.
Investor 2 is happy; investors 3 and 5 would rather stay out.

**Figure**: Expenditure in security

**Figure**: Participation Incentive
An impossibility result

There are instances in which no mechanism can satisfy both types.

- Free-riders are only willing to pay so much (esp. given spillovers).
- Main investors demand compensation.
- Mechanism designer does not inject resources into the system.

Positive examples
Problem families in which users voluntarily participate in the positive externality mechanism.
An impossibility result

There are instances in which no mechanism can satisfy both types.

- Free-riders are only willing to pay so much (esp. given spillovers).
- Main investors demand compensation.
- Mechanism designer does not inject resources into the system.

Positive examples

Problem families in which users voluntarily participate in the positive externality mechanism.
An impossibility result

There are instances in which no mechanism can satisfy both types.

- Free-riders are only willing to pay so much (esp. given spillovers).
- Main investors demand compensation.
- Mechanism designer does not inject resources into the system.

Positive examples
Problem families in which users voluntarily participate in the positive externality mechanism.
Discussion

Tradeoffs

- Profit-neutrality, socially optimal outcome, participation

Alternative mechanisms?

- Capital injection, e.g., cyber-insurance with catastrophe coverage
- $\epsilon$-optimal solution
- Partial coverage

Combined with secondary incentives?

- Business opportunities
Discussion

Tradeoffs

- Profit-neutrality, socially optimal outcome, participation

Alternative mechanisms?

- Capital injection, e.g., cyber-insurance with catastrophe coverage
- $\epsilon$-optimal solution
- Partial coverage

Combined with secondary incentives?

- Business opportunities
Discussion

Tradeoffs

- Profit-neutrality, socially optimal outcome, participation

Alternative mechanisms?

- Capital injection, e.g., cyber-insurance with catastrophe coverage
- $\epsilon$-optimal solution
- Partial coverage

Combined with secondary incentives?

- Business opportunities
Conclusion

- Sub-optimality of an unregulated interdependent security games
- A positive externality mechanism to induce socially optimal security investment
- The challenge of ensuring voluntary participation