Security investment (failures) in five economic environments: A comparison of homogeneous and heterogeneous user agents

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Presented By Qi Xie
Outline

- Introduction
- Three security games
- Nash with homogeneous and heterogeneous agents
- Social optima with homogeneous agents
- Conclusion & Discussion
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Introduction

- Security game
  - A game-theoretic model
- Two key components
  - Self-protection
  - Self-insurance
Assumptions

- All entities in the network share a single purely public protection output
- A single individual decides on protection efforts for each entity
Generic utility function

\[ U_i = M_i - p_i L_i (1 - s_i) (1 - H(e_i, e_{-i})) - b_i e_i - c_i s_i \]
Generic utility function

\[ U_i = M_i - \frac{p_i L_i (1-s_i) (1-H(e_i, e_{-i})) - b_i e_i - c_i s_i}{1} \]
Generic utility function

\[ U_i = M_i - p_i L_i (1 - s_i)(1 - H(e_i, e_{-i})) - b_i e_i - c_i s_i \]
Generic utility function

\[ U_i = M_i - p_i L_i (1 - s_i)(1 - H(e_i, e_{-i})) - b_i e_i - c_i s_i \]
Generic utility function

\[ U_i = (M_i - p_i L_i (1 - s_i)(1 - H(e_i, e_{-i}))) - b_i e_i - c_i s_i \]
Generic utility function

\[ U_i = \left( M_i - p_i L_i (1 - s_i) (1 - H(e_i, e_{-i})) - b_i e_i \right) - c_i s_i \]
Generic utility function

\[ U_i = M_i - p_i L_i (1 - s_i)(1 - H(e_i, e_{-i})) - b_i e_i - c_i s_i \]
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Three canonical security games

- Total effort security game
- Weakest-link security game
- Best shot security game
- Weakest target security game (without mitigation)
- Weakest target security game (with mitigation)
Total effort security game

- The overall protection level
  - Normalized sum of contributions

\[ H(e_i, e_{-i}) = \frac{1}{N} \sum_i e_i \]

\[ U_i = M_i - p_i L_i (1 - s_i) \left(1 - \frac{1}{N} \sum_k e_k \right) - b_i e_i - c_i s_i \]
Total effort security game

Example:

- In the BitTorrent p2p service, an attacker wants to slow down transfer of a given piece of information.
Weakest-link security game

The overall protection level
- The minimum contribution offered over all entities

\[ H(e_i, e_{-i}) = \min(e_i, e_{-i}) \]

\[ U_i = M_i - p_i L_i (1 - s_i) (1 - \min(e_i, e_{-i})) - b_i e_i - c_i s_i \]
Weakest-link security game

Example:
- A two-way communication, where the security of the communication is determined by the least secure communication parties.
Best shot security game

The overall protection level
- Maximum contribution offered over all entities

\[ H(e_i, e_{-i}) = \max(e_i, e_{-i}) \]

\[ U_i = M_i - p_i L_i (1 - s_i)(1 - \max(e_i, e_{-i})) - b_i e_i - c_i s_i \]
Best shot security game

Example:

- A piece of information will remain available as long as a single node serving that piece of information can remain unharmed.
Summary of three security games

- Practical scenarios may involve social composition functions combining two or more of these games
- Example: Protecting a communication flow between two hosts
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Homogeneous agents VS Heterogeneous agents

Homogeneous agents
- Share the same values for cost of protection and self-insurance
- Individual faces the same threats with identical consequence if compromised

Heterogeneous agents
- Protection and self-insurance costs per unit are NOT necessary identical
- The threats individual faces are NOT necessary the same
- If compromised, consequences are NOT necessary identical
Homogeneous agents VS
Heterogeneous agents (cont.)

Recall the generic function

\[ U_i = M_i - p_i L_i (1 - s_i) H(e_i, e_{-i}) - b_i e_i - c_i s_i \]

Simplified generic function with homogeneous agents

\[ U_i = M - p L (1 - s_i) H(e_i, e_{-i}) - b e_i - c s_i \]
Nash Equilibrium analysis

Total effort

Homogeneous agents

- Full protection eq: \((e_i, s_i) = (1, 0)\) if \((pL > bN \&\& c > b + pL(N-1)/N)\)
- Full self-insurance eq: \((e_i, s_i) = (0, 1)\) if \(((pL > bN \&\& c <= b + pL(N-1)/N) \mid\mid c < pL < bN)\)
- Passive eq: \((e_i, s_i) = (0, 0)\) if \((pL < bN \&\& pL < c)\)
Nash Equilibrium analysis

Total effort

Heterogeneous agents

- Condition to select a protection-only strategy

\[
\frac{1}{N - 1} \sum_{j \neq i} e_j > 1 - \frac{N}{N - 1} \frac{c_i - b_i}{p_i L_i}
\]
Nash Equilibrium analysis
Weakest-link

Homogeneous agents

- Multiple protection eq. \((e_i, s_i) = (e_0, 0)\) if \((p_L > b \&\& (p_L < c || (p_L \geq c \&\& e_0 > (p_L - c)/(p_L - b))))\)
- Full self-insurance eq. \((e_i, s_i) = (0, 1)\) if \((p_L > c \&\& (p_L < b || (p_L = b \&\& e_0 < (p_L - c)/(p_L - b))))\)
- Passive eq. \((e_i, s_i) = (0, 0)\) if \((p_L < b \&\& p_L < c)\)
Nash Equilibrium analysis
Weakest-link

Heterogeneous agents

- Full protection eq. \((e_i, s_i) = (e_0, 0)\) if
  \((p_i L_i > b_i \land (p_i L_i < c_i \lor (p_i L_i >= c_i \land e_0 > \max_i ((p_i L_i - c_i)/ (p_i L_i - b_i))))\)

- Multiple eq. without protection (above condition not hold)
Nash Equilibrium analysis

Best shot

Homogeneous agents

- Full self-insurance eq. \((e_i, s_i) = (0, 1)\) if \((b<c)\)
  - Should the condition be \(c<b \&\& pL>c\)?
- Passive eq. \((e_i, s_i) = (0, 0)\) if \((pL<b \&\& pL<c)\)
- No protection eq.
Nash Equilibrium analysis
Best shot

Heterogeneous agents

- Possible protection eq. \((e, s) = (1, 0)\) (Only one player faces disproportional losses || her protection costs are small)
- Protection eq. are increasingly unlikely to happen as \(N\) grows
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Social optima with homogeneous agents

Total effort game
- Protection \((e_i, s_i) = (1, 0)\) if \((b < pL \&\& b < c)\)
- Self-insurance \((e_i, s_i) = (0, 1)\) if \((c < pL \&\& c < b)\)
- Passive \((e_i, s_i) = (0, 0)\) if \((c > pL \&\& b > pL)\)

Nash eq. of total effort game
- Full protection eq: \((e_i, s_i) = (1, 0)\) \((pL > bN \&\& c > b + pL(N-1)/N)\)
- Full self-insurance eq: \((e_i, s_i) = (0, 1)\) \((pL > bN \&\& c <= b + pL(N-1)/N) \&\& c < pL < bN)\)
- Passive eq: \((e_i, s_i) = (0, 0)\) \((pL < bN \&\& pL < c)\)
Social optima with homogeneous agents

Total effort game
- Protection \((e_i, s_i) = (1, 0)\) if \((b < pL \&\& b < c)\)
- Self-insurance \((e_i, s_i) = (0, 1)\) if \((c < pL \&\& c < b)\)
- Passive \((e_i, s_i) = (0, 0)\) if \((c > pL \&\& b > pL)\)

Nash eq. of total effort game
- Full protection eq: \((e_i, s_i) = (1, 0)\) if \((pL > bN \&\& c > b + pL(N-1)/N)\)
- Full self-insurance eq: \((e_i, s_i) = (0, 1)\) if \(((pL > bN \&\& c <= b + pL(N-1)/N)) || c < pL < bN)\)
- Passive eq : \((e_i, s_i) = (0, 0)\) if \((pL < bN \&\& pL < c)\)
Social optima with homogeneous agents

**Weakest-link game**
- Protection \((e_i, s_i) = (1, 0)\) if \((b<p_L \land b<c)\)
- Self-insurance \((e_i, s_i) = (0, 1)\) if \((c<p_L \land c<b)\)
- Passive \((e_i, s_i) = (0, 0)\) if \((c>p_L \land b>p_L)\)

**Nash eq. of weakest-link game**
- Multiple protection eq. \((e_i, s_i) = (e_0, 0)\) if \((p_L>b \land (p_L<c \lor (p_L=c \land e_0>(p_L-c)/(p_L-b))))\)
- Full self-insurance eq. \((e_i, s_i) = (0, 1)\) if \((p_L>c \land (p_L<b \lor (p_L=b \land e_0<(p_L-c)/(p_L-b))))\)
- Passive eq. \((e_i, s_i) = (0, 0)\) if \((p_L<b \land p_L<c)\)
Social optima with homogeneous agents

Weakest-link game

- Protection \((e_i, s_i) = (1, 0)\) if \((b<p_L \&\& b<c)\)
- Self-insurance \((e_i, s_i) = (0, 1)\) if \((c<p_L \&\& c<b)\)
- Passive \((e_i, s_i) = (0, 0)\) if \((c>p_L \&\& b>p_L)\)

Nash eq. of weakest-link game

- Multiple protection eq. \((e_i, s_i) = (e_0, 0)\) if \((p_L>b \&\& (p_L<c || (p_L=c \&\& e_0>(p_L-c)/(p_L-b))))\)
- Full self-insurance eq. \((e_i, s_i) = (0, 1)\) if \((p_L>c \&\& (p_L<b || (p_L=b \&\& e_0<(p_L-c)/(p_L-b))))\)
- Passive eq. \((e_i, s_i) = (0, 0)\) if \((p_L<b \&\& p_L<c)\)
Social optima with homogeneous agents

- **Best shot game**
  - Protection \((e, s) = (1, 0)\) if \((b/c < N)\)
  - Insurance \((e_i, s_i) = (0, 1)\) if \((b/c > N)\)

- **Nash eq. of best shot game**
  - Full self-insurance eq. \((e_i, s_i) = (0, 1)\) if \((c < b \&\& pL > c)\)
  - Passive eq. \((e_i, s_i) = (0, 0)\) if \((pL < b \&\& pL < c)\)
  - No protection eq.
Social optima with homogeneous agents

Best shot game
- Protection \((e, s) = (1, 0)\) if \((b/c < N)\)
- Insurance \((e_i, s_i) = (0, 1)\) if \((b/c > N)\)

Nash eq. of best shot game
- Full self-insurance eq. \((e_i, s_i) = (0, 1)\) if \((c < b \&\& pL > c)\)
- Passive eq. \((e_i, s_i) = (0, 0)\) if \((pL < b \&\& pL < c)\)
- No protection eq.
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Conclusions

- Model security decision-making by homogeneous and heterogeneous agents in selection of five games
- Find Nash Equilibria for homogeneous and heterogeneous agents in selection of five games
- Compare the Nash and social optima for homogeneous agents
Future research directions

- Extend the analysis to more formally explain the impact of limited information on agents strategies
- Develop a set of laboratory experiments to conduct user studies and attempt to measure the differences between rational behavior and actual strategies played
Discussions

Strength

- Plenty of examples
- Well done proofs and computations
- Good conclusion

Weakness

- Does not provide the simplified generic function
- The condition of the protection Nash eq. is incorrect for the Best shot game with homogeneous agents