Interdependent Security: A General Model

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Characteristics of the Problem

Risk faced by one person/firm depends on both its own security investments as well as on the actions of others (stochastic externalities)

Agent can suffer direct and indirect losses

Indirect losses may be conditioned on the direct loss not occurring
Examples of Interdependent Security Problems

Investing in airline security
Vaccination against infectious diseases
Investing in Research and Development (R&D)
Mitigation against damage from fires and natural disasters
Protecting a utility against power failures
Securing computer systems against attacks.
Product contamination via multiple suppliers
Avoiding divisional gambles that could bankrupt entire firm

Baring’s Bank (Singapore branch)
Arthur Andersen (Houston office)
Real-World Example: Pan Am 103 Crash in 1988

Terrorist loaded bomb at Gozo Airport, Malta that was set to explode above 28,000 feet

Transferred to Pan Am feeder at Frankfort airport

Transferred to Pan Am 103 at Heathrow

Nothing Pan Am could do to prevent crash unless it inspected all transferred bags
Classes of IDS Problems

Class 1: Partial Protection

Class 2: Complete Protection

Class 3: Positive Externalities
Class 1: Partial Protection

Type of Externalities
There is a chance that others will still subject a firm to risks even if it invests in protection.
The more firms invest in preventive measures, the lower are the negative externalities in the system.

Nash Equilibria
Multiple equilibria
Possibilities of tipping and cascading

Illustrative Example: Investing in airline security
Type of Externalities
If an individual invests in prevention it cannot be harmed by the actions of others nor can it harm others.
The more individuals invest in preventive measures, the lower are the negative externalities in the system.

Nash Equilibria
Only one Nash equilibrium
Cannot have tipping and cascading
May be inefficient --- two few individuals investing in prevention

Illustrative Example: Deciding whether to be vaccinated
Class 3: Positive Externalities

Type of Externalities
Investment by one firm creates positive externalities, substituting for the same investment by others & making it less attractive for others to follow suit

The more firms invest, the greater are the positive externalities in the system.

Nash Equilibria
Only one Nash equilibrium
Cannot have tipping and cascading
May be inefficient---too few firms investing

Illustrative Example: Investing in research and development (R&D)
Airline considering installing baggage checking system for added protection.
Needs to balance the cost of this system with reduction in risk of explosion of luggage not only checked in with itself but also from bags of passengers checked in on other airlines and transferred.
Game Theory Framework

**Airlines** $A_1$ and $A_2$.

$Y =$ income of airline before expenditure on security

$p_{ij} =$ probability on any trip a bag containing a bomb is loaded onto airline $i$, is then transferred to airline $j$ and explodes on $j$

$p_{ii} =$ probability on any trip a bag containing a bomb is loaded onto airline $i$ and explodes on $i$

Loss if a bag explodes : $L$

Cost of Baggage Security System for $A_i$ : $c_i$
Consider Airline 1
If $c_1 < p_{11} L (1-p_{21})$ then airline 1 will invest.

Alone would invest if $c_1 < p_{11} L$.

Tighter inequality reflects reduced incentive to invest because of interdependence & risk of contamination.

**Investment no longer buys complete security**
S, S is dominant strategy & Nash equilibrium

Either N, N or S, S is Nash equilibrium

S, S is Nash equilibrium

N, N is Nash and dominant

S, S is Nash equilibrium
More is worse - much!

Bottom line – one unprotected firm/individual imposes a risk on others

Link many of them so that security of each depends on what others do and problem gets exponentially worse as number of unprotected agents increases. (e.g. weakest-link problem is an example)

Some individuals/firms offer vast policy leverage because of their linkages & positions in the network (Have tipping power: Can lead everyone to protect)
Consider 3 airlines
Airlines 1 and 2 are identical
\[ p_{11} = p_{12} = p_{21} = p_{22} = 0.1; \]
\[ L = 1000 \quad c_1 = c_2 = 85 \]
Airline 3 has risks and costs so that the Nash Equilibrium is where no airline invests in security
\[ p_{31} = p_{32} = 0.3 \quad p_{33} = 0.2 \quad c_3 = 200 \]

If \( A_3 \) is taxed so it decides to invest in security it will tip the equilibrium so both \( A_1 \) and \( A_2 \) will also want to invest in security
Equilibrium in DS is \((N,N)\)

Actual costs \((85, 85)\) in \((N,N)\) region

Equilibrium in DS is \((S,S)\)

Firm 3 does not invest
Equilibrium in DS is (S,S)

Firm 3 invests: phase diagram is now different & investing is dominant for 1 and 2
Optimal industry profits depends on three factors

- cost of investing in security,
- probability of a bomb being loaded directly onto an airplane and exploding
- likelihood of bomb being transferred from another plane and then exploding

Situations where all firms may not want to invest in security but it will be optimal for all of them to invest

Example

If airline 3 doesn’t invest then 1 and 2 will also not invest

- Expected Profits of 1 and 2 = Y-433; 3 = Y-352

If airline 3 invests then 1 and 2 will also invest

- Expected Profits of 1 and 2 = Y-85; 3 = Y-200
Application to PNR Data

All reservations made in 1 day on a GDS

Show transfers from airline i to j for i, j the 25 most busy

Identify patterns of interdependence
Simulating equilibria

Security a continuous variable in $[0,1]$  

Apply gradient algorithm or fictitious play algorithm to find Nash equilibria  

Small airlines all invest  

Large ones don’t
Fix three largest at full investment.

All others now converge to this

Three largest are a critical coalition
Vaccination Against Diseases
Class 2 IDS Problem

Individual can protect against a disease by being vaccinated

Reasons for getting vaccine:
   Can get disease from an external source
   Can get disease from others who are infected

Reasons for not getting vaccine:
   Cost in money and time
   Negative side effects
Two Individuals.

\[ Y = \text{income of individual before expenditure on vaccine} \]

\[ p = \text{probability of catching disease even if no one else has it} \]

\[ q = \text{probability of catching disease and infecting another person:} \]

\[ L = \text{loss (possibly death) from catching the disease.} \]

\[ c = \text{cost (in time and money) of being vaccinated} \]

Assume that vaccine provides total protection against the disease (e.g. smallpox)
## Payoffs & Nash Equilibria for Two-Person Vaccination Problem

### Vaccinating (V) and Not Vaccinating (N)

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<th>INDIV. 2</th>
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<td>$Y - p L - (1-p)q L$, $Y - p L - (1-p)q L$</td>
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### Nash Equilibria

If $c < pL$ then $(V,V)$ is an equilibrium

When $pL < c < pL + (1-p)qL$ then both $(N,V)$ or $(V,N)$ are equilibria

When $c > pL + (1-p)qL$ then $(N, N)$ is an equilibrium.
Investing in R&D

Class 3 IDS Problem

Resembles airline security problem with key differences

*Airline security*---investment by one encourages others to invest and can lead to *tipping* behavior

*R&D*—investment by one firm discourages others from following suit and can lead to *free riding*
Investing in R&D

Notation for firm i

c_i = cost of investing in R&D
p_i = probability of success and G is payoff in event of success
q_j = probability that other firm j invests, succeeds and firm i has access to the results through spillover (free-rider effect)
I = invest in R&D
N = not invest in R&D
Insurance
Not feasible under current system because insurer of firm $i$ does not pay for damage to agent $j$.
Social insurance addresses problems of internalizing negative externalities as government provides coverage to all facing a risk. Firm that adopts protective measures given premium reductions for reduced losses to themselves and others.

Financial Institutions
Can require investment in security as a condition for a loan
Need a coalition of banks to require this to change industry equilibrium
Policy Options (continued)

Taxation/Subsidization

Can levy a tax of $t$ dollars on any firm that does not invest in protection
May selectively apply these measures to key firms and tip others

Coordinating mechanisms

International Air Transport Association (IATA)---require baggage security on all bags to be transferred to other airlines

Coops in NYC—Require that all buyers of apartments invest in sprinkler system as a condition for purchase

Regulations and Standards

Baggage security measures mandated by the government
Well enforced building codes
Open Questions and Future Research

Similarities and Differences Between IDS Problems
- Airline security--- reduced incentive to invest in protection if others don’t
- Vaccination---increase incentive to invest in if others are not taking action

Endogenous Probabilities
- If some airlines are known to be more security-conscious than they are less likely to be terrorist targets. (Displacement or substitution)
- Similar to problem of theft protection: burglar chooses unprotected home

Multi-Period and Dynamic Models
- How does nature of interdependence change from static to dynamic context?
- How does the process of coordination and cooperation start in a dynamic setting?
- What are the ways in which individuals learn over time?
- What are impacts of special features of social networks on system interdependencies?
### Open Questions and Future Research

**Controlled Laboratory Experiments**

### Investing (Yes) or Not Investing (No) in Protection

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### Preliminary Results: Context Matters

Financial decision: Most people say **No** and expect other person to say **No**

Fire protection: Most people say **Yes** and expect other person to say **Yes**
Future Research: Risk Management Strategies

Collecting better information on risk and costs

Designing incentive systems (e.g. loans, subsidies or taxes)

Role of coordinating mechanisms
  Require that all buyers of apartment units invest in fire prevention measures (e.g. smoke alarms) as a condition for purchase

  Social norms—desire to invest in protection because it is the right thing to do. It may also increase property values.

Carefully designed standards (e.g. building codes for high-rises to withstand future disasters) that are well-enforced using third-party inspections.

Developing insurance programs for encouraging investment in protective measures when firms are faced with contamination.
Conclusions

IDS structure – non-additive damages and interdependencies between agents characterizes wide range of problems (E.g. Airlines, computers, bankruptcy of firms, vaccination)

Need creative private-public partnerships for improving firm and industry performance as well as social welfare

Future research requires more realistic characterization of behavior, multi-period models, and close interaction with industry and government