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# Risk Analysis for Interdependent Security Problems

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Presentation at  
CREATE Symposium  
on  
Terrorism Risk Analysis  
University of Southern California  
January 14-15, 2005



## 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 Frankfurt 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



# Class 2: Complete Protection

## **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 Security Scenario Illustrating Class 1 IDS Problem

**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  $A_i$  :  $c_i$

# Payoffs & Contamination

Investing (S) & Not Investing (N) in Security System

AIRLINE 2

|   |                                       | S  | N |
|---|---------------------------------------|--|---|
|   |                                       | AIRLINE 1  |   |
| S | $Y - c_1$ : $Y - c_2$                 | $Y - c_1 - p_{21} L$ : $Y - p_{22} L$  |   |
| N | $Y - p_{11} L$ : $Y - c_2 - p_{12} L$ | $Y - p_{11} L - (1 - p_{11}) p_{21} L$<br>$Y - p_{22} L - (1 - p_{22}) p_{12} L$ |   |

**Consider Airline 1**

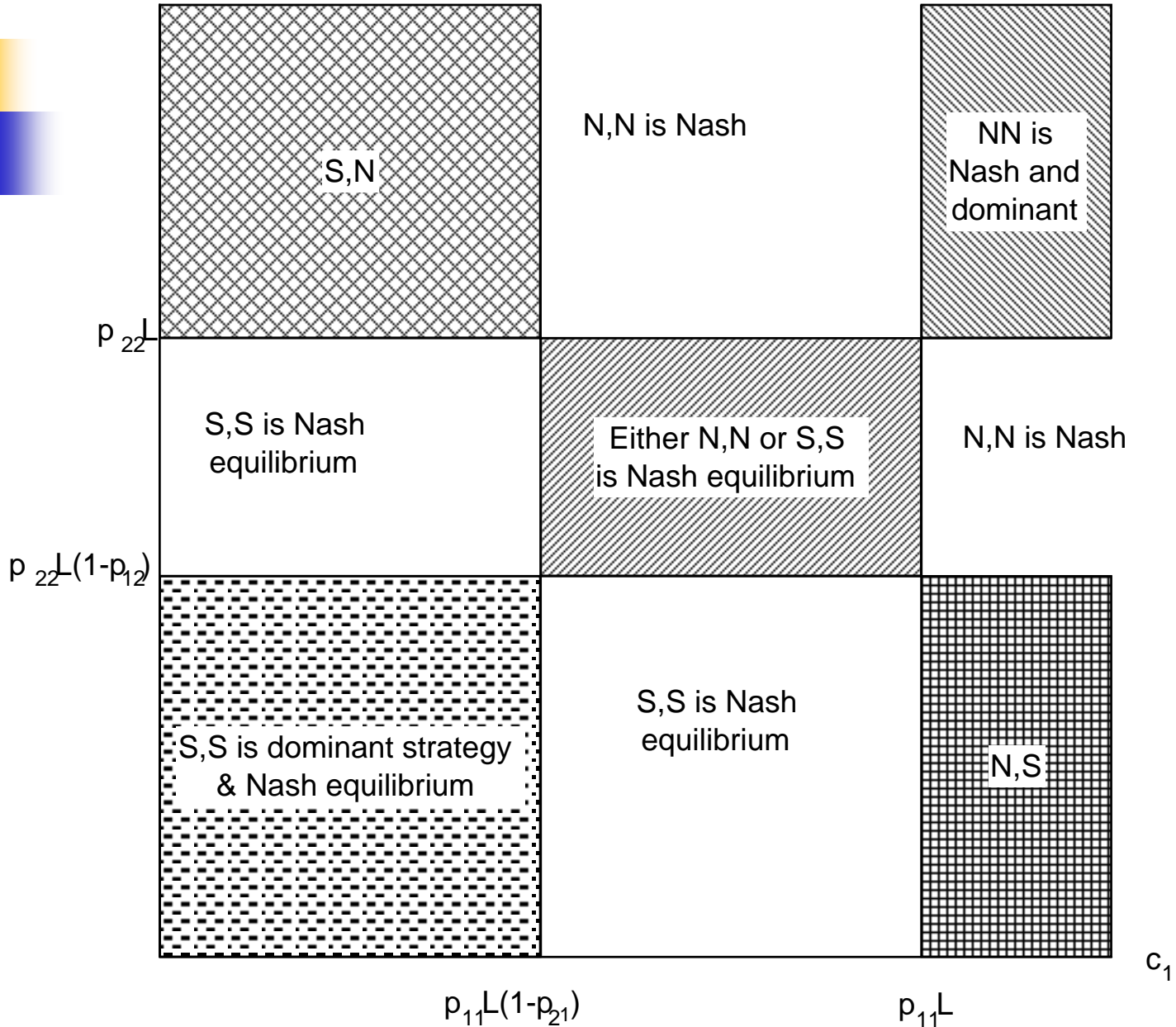
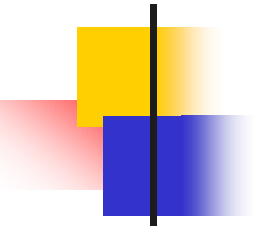
If  $c_1 < p_{11} L(1 - p_{21})$  then airline 1 will invest.

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**

$c_2$





## 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)



# Illustrative Example of Tipping

Consider 3 airlines

Airlines 1 and 2 are identical

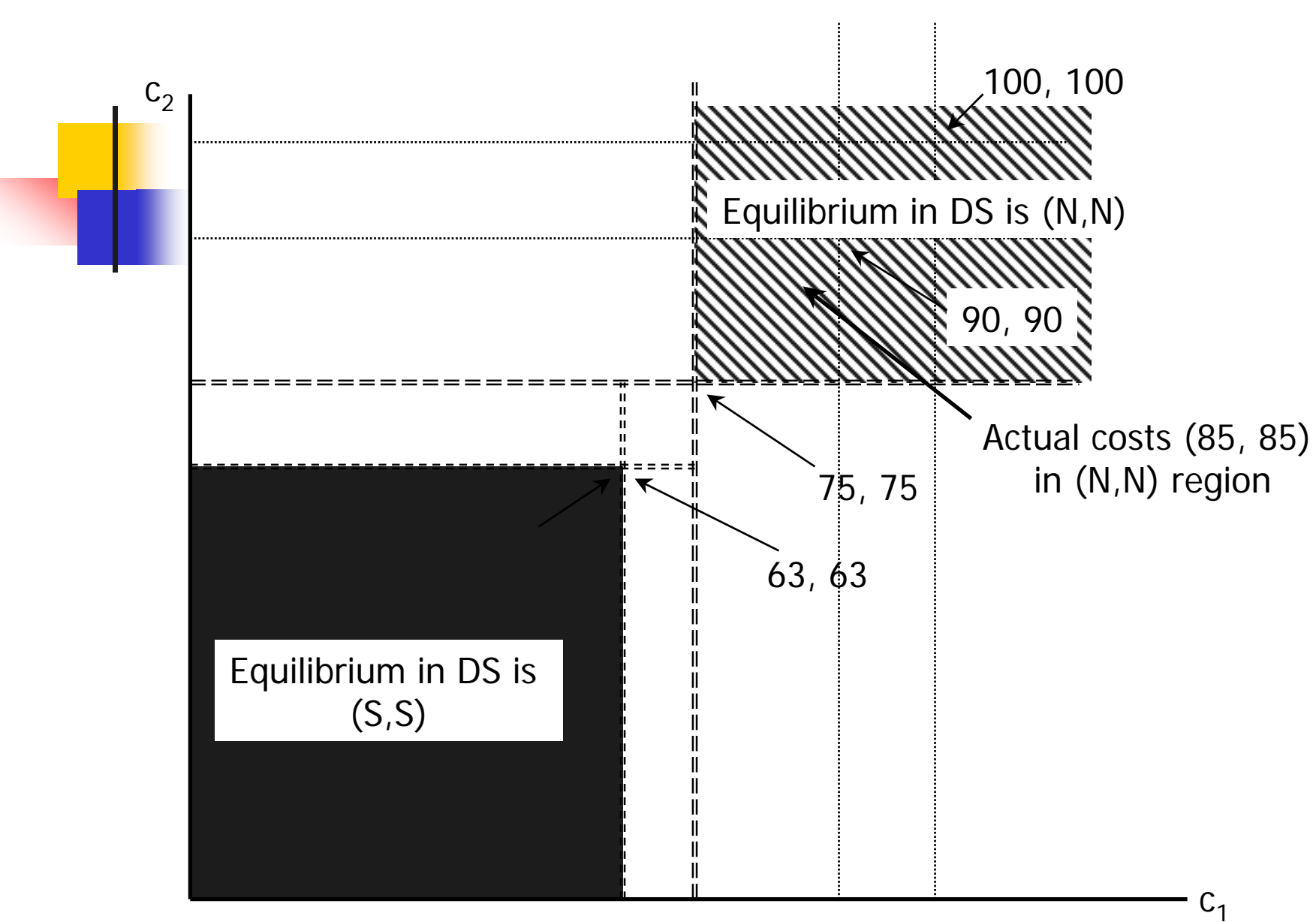
$$p_{11} = p_{12} = p_{21} = p_{22} = 0.1;$$

$$L = 1000 \quad c_1 = c_2 = 85$$

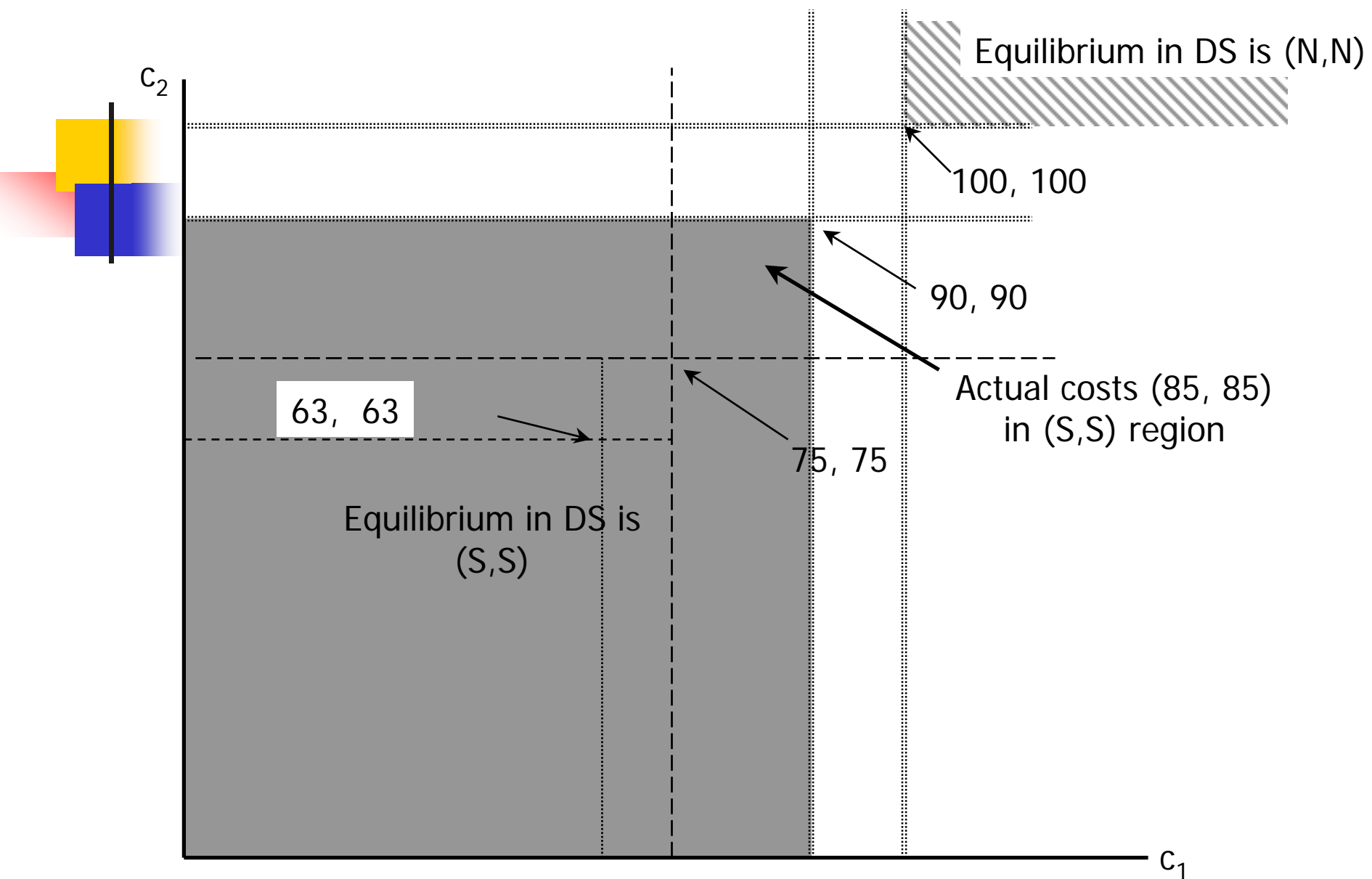
Airline 3 has risks and costs so that the Nash Equilibrium is where no airline invests in security

$$p_{31} = p_{32} = 0.3 \quad p_{33} = 0.2 \quad c_3 = 200$$

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



Firm 3 does not invest



Firm 3 invests: phase diagram is now different & investing is dominant for 1 and 2



# Private and Social Welfare

## Comparing Firm and Industry Firm Profitability

### **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 =  $Y-200$



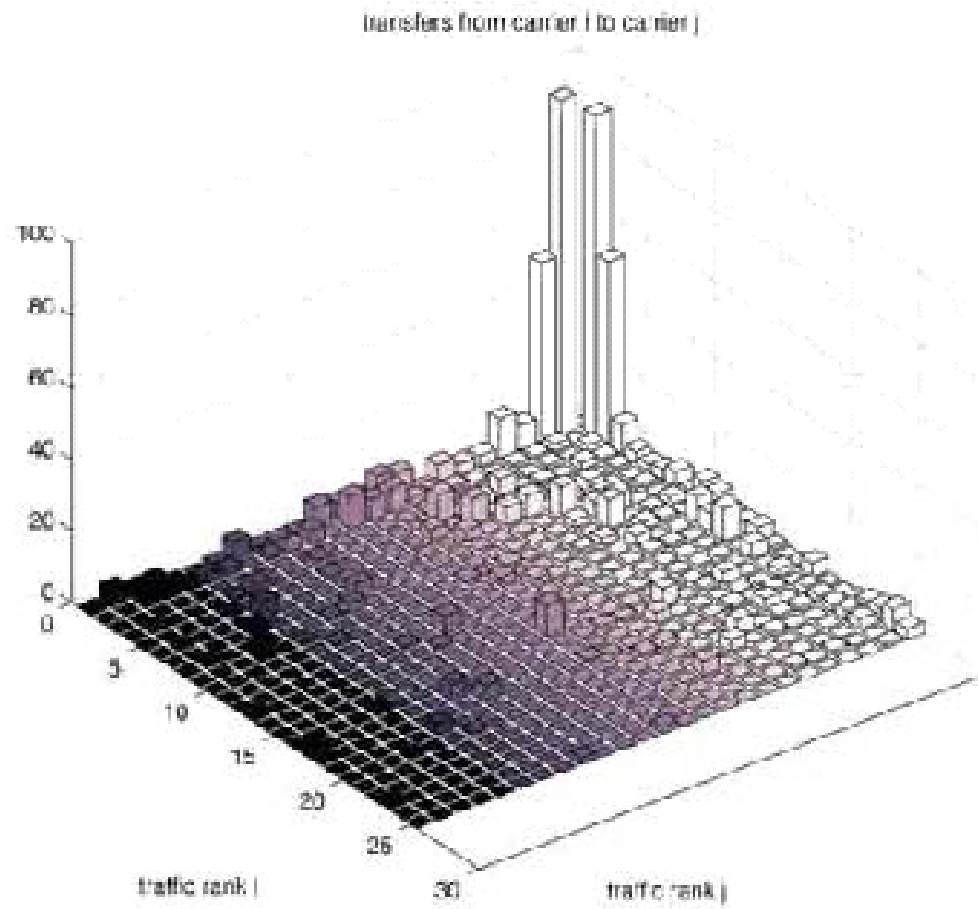
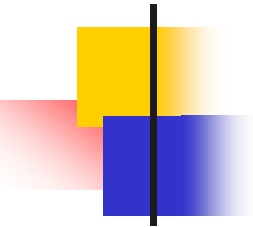
## Application to PNR Data

All reservations made in 1 day in the U.S. on a GDS

Totally cleared data (anonymous)

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

Identify patterns of interdependence





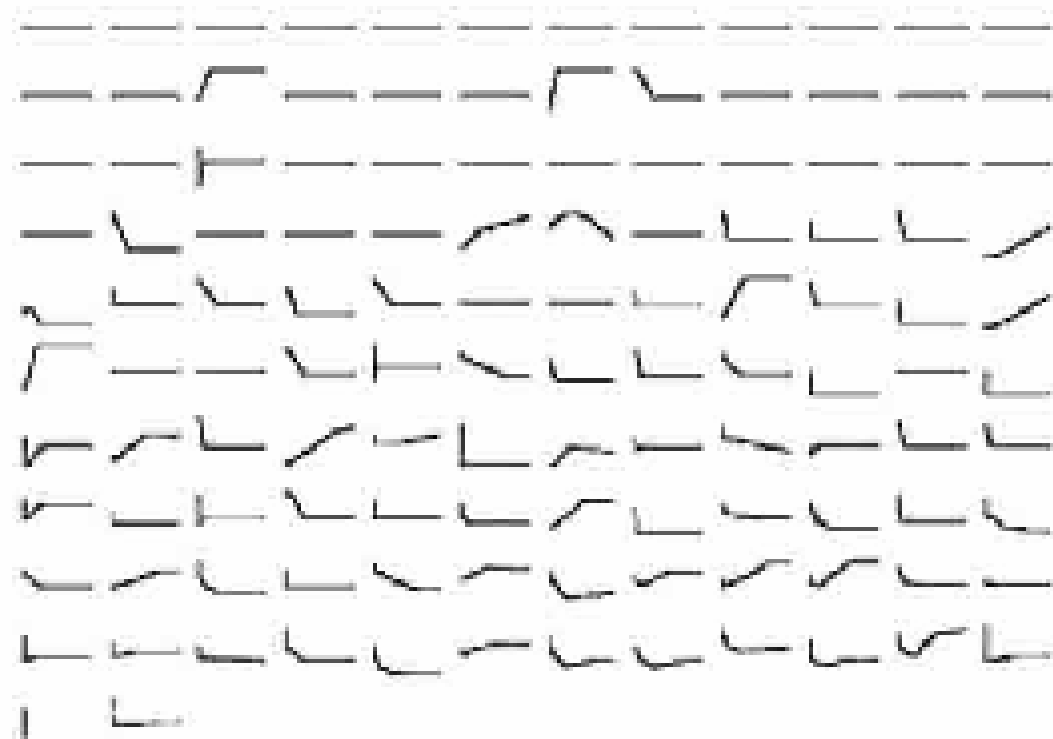
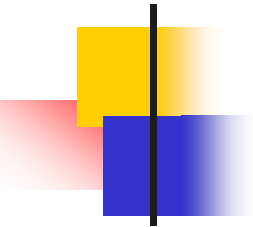
## Simulating equilibria

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



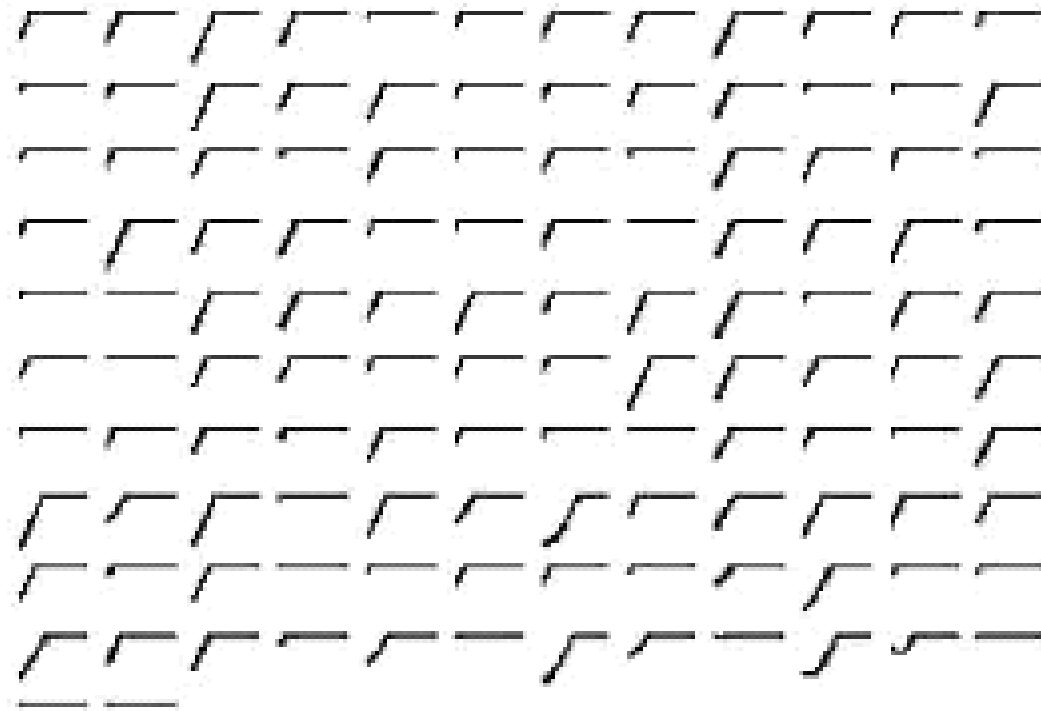
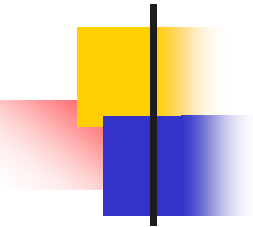


# Tipping

Fix three largest at full investment.

All others now converge to this

Three largest are a critical coalition





# Policy Options

## (Internalizing Negative Externalities)

### Insurance

Not feasible under current system because insurer of firm  $i$  does not pay for damage to agent  $j$   $j \neq i$

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



# Challenges for Empirical Studies on IDS

IDS empirical studies provide promising results based on a limited data set

Access to large set of micro-data in specific critical sectors facilitates quantification of interdependent risk analysis between organizations in these sectors

Data on operation of interconnected networks provide a more realistic framework of risks associated with growing globalization

- Electric power network
- Computer systems
- Banking & Finance
- Global supply chains



# Challenges for Empirical Studies on IDS

Firms are reluctant to share information about their operation and/or clients because data sets are viewed as strategic assets (competition issues) or because of fear of lawsuits (privacy issues)

Federal agencies (DHS, DOD) are concerned with releasing information on threats (national security issues)

Open question: *How can we facilitate information sharing on security issues with the research community?*



# Challenges for Empirical Studies on IDS: Information Sharing

## **Data available for IDS on airline security**

Micro-data: passenger transfer

Macro-data: major incidents in civil aviation that occur worldwide  
(*sources: FAA*)

- Nature of the incident (bombing/shooting on aircraft, hijackings, attacks at airports)
- Location (North America, Europe, Asia, Middle East, etc)
- Time
- Physical destruction and injuries



# Challenges for Empirical Studies on IDS: Information Sharing (Cont'.)

*Passenger is a terrorist/ A bag or a cargo  
container contains a weapon*

|                                       |     | Yes           | No           |
|---------------------------------------|-----|---------------|--------------|
| <i>Inspection<br/>raises<br/>Flag</i> | Yes | Success       | Type I Error |
|                                       | No  | Type II Error | Success      |

More micro-data needed to refine the IDS results:

- What level of investment do airline/airport support for security?
- How many bag/passenger are checked per day, per year for a specific airline? A specific airport?
- Likelihood of Type I/Type Two Errors?
- Cost of Type I and Type II Errors?



# Challenges for Empirical Studies on IDS: Next Steps in Data collection: Airline Security

Discussion with Transportation Security Administration (DHS) and Lockheed Martin to provide access to extended GDS dataset (US market, passenger transfer)

Discussions with IATA (currently working on new international security standards) to facilitate access to large database on passenger and cargo traffic internationally

Idea: focus on a few major airlines and/or major hubs in the US, Europe and Asia to better quantify global interdependencies and develop global strategies



# Challenges for Empirical Studies on IDS

## Cargo Marine Containers

Quantify the weakest link in the supply chain.

What are the sources of interdependencies?

What would be the impact on global supply chain of a terrorist threat that requires to order shutting down a major port?

Wharton-George Washington Univ. joint workshop in October 2004 in DC with major US retailers (Home Depot, Target)



# 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?



# 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.

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# 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 to undertake empirical studies