Risk Transfer Mechanism to Promote Mitigations in Interdependent Security Problems

Mamoru Yoshida

Assistant Prof.(GCOE " Global Center for Education and Research on Human Security Engineering for Asian Megacities)

Eisuke Imai

Master's Course of Department of Social Informatics, Kyoto University

Hirokazu Tatano

Prof., DPRI, Kyoto University

Background

- Critical Infrastructure (e.g., international ports and harbors) brings about significant negative impacts to a society when its function stops
- Hanshin-Awaji Quake brought about significant impact to Kobe economy and made downward shift for the share of port of Kobe in the world.

→Importance of Global Critical Infrastructure Protection.

Focus of the paper

- Interdependent Security Problem (Heal,Kunreuther,2003) :
  - Do firms have adequate incentives to invest in protection against a risk whose magnitude depends on the actions of others?
- International seaports
  - Malfunction of the other nations' seaport affects the own nation's benefit from international trade, and vice versa.

Research Question

- What are the social optimal mitigations under interdependent risks

- How do interdependent risks bring about inefficiency in mitigations

- Are there any policies to solve the problem related with risk interdependency?

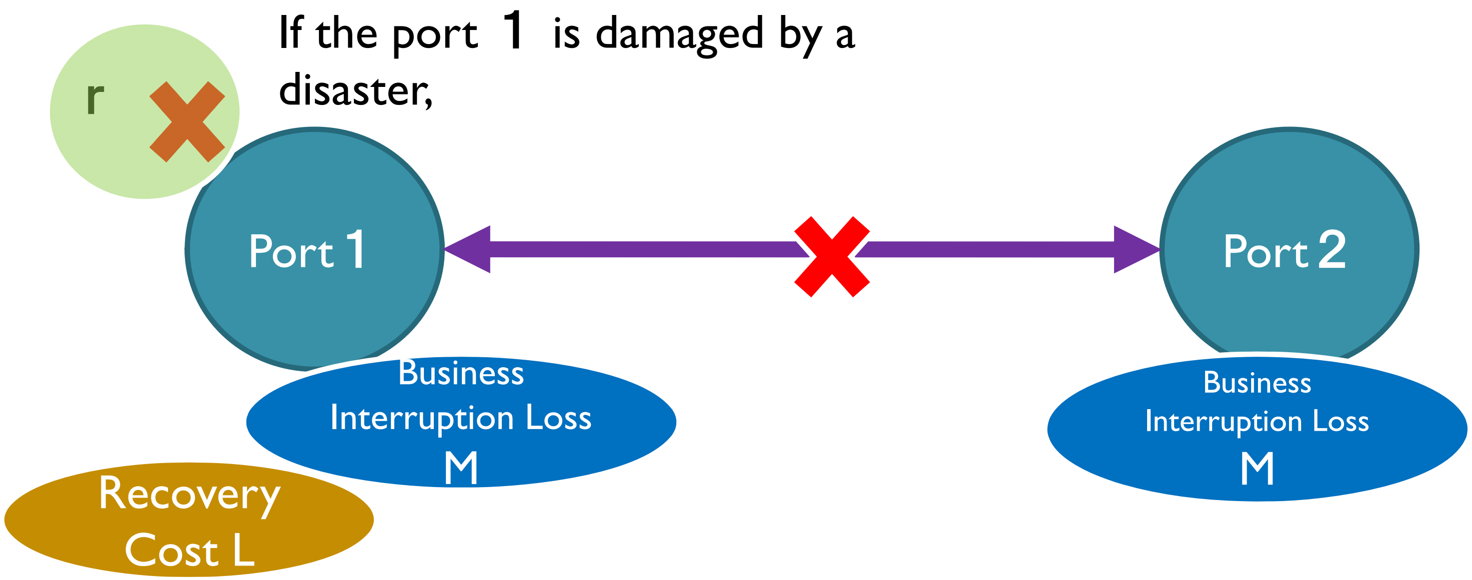
Contents

- Private Interests and Social Optimum
  - Equilibrium model based on its own private interest
  - Social Optimal Investment Decisions
- Risk pooling arrangement
  - Trigger: malfunction of its own or the other ports.

Assumption of the model

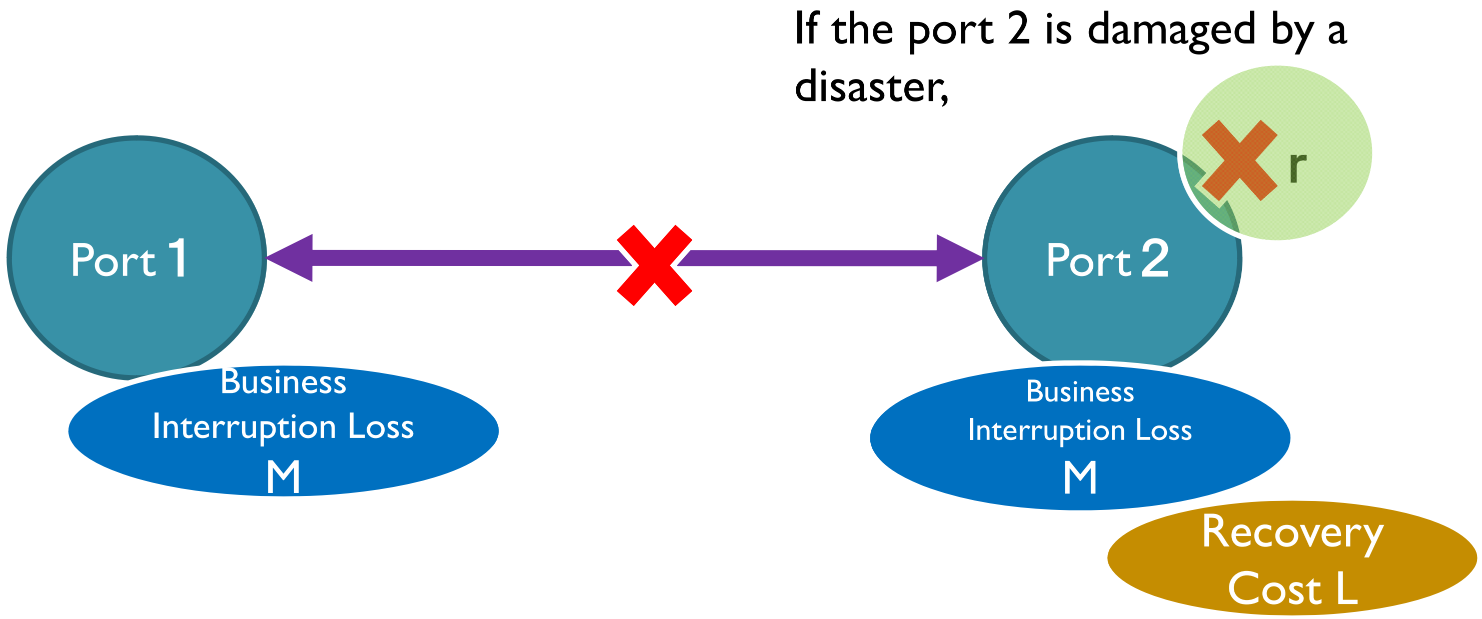
- $k_i \in [0,1]$: possible actions of the port i
- $C(k_i) = ck_i^2$:investment cost of port i
- If the port invests k_i , no damage occurs with probability $1-k_i$ when an earthquake happens

Assumptions



- r:Probability of occurrence of a disaster
- L: Recovery cost
- M:Business interruption cost
  - L and M are assumed to be symmetric between two ports

Assumptions



- r:Probability of occurrence of a disaster
- L: Recovery cost
- M:Business interruption cost
  - L and M are assumed to be symmetric between the two ports

Investment for the mitigation with private interest

Risk Cost for port 1: $B_1(k_1, k_2) = C_1(k_1) + (1-k_1)r(L+M)$
$$+(1-(1-k_2)r)(1-k_1)rM$$

Risk Cost for port 2: $B_2(k_1, k_2) = C_2(k_2) + (1-k_2)r(L+M)$
$$+(1-(1-k_1)r)(1-k_2)rM$$

Investment level (Nash Equilibrium): (k_1^*, k_2^*)

$$\underset{k_1 \in [0,1]}{Min}\, B_1(k_1, k_2^*)$$

$$\underset{k_2 \in [0,1]}{Min}\, B_2(k_1^*, k_2)$$

Optimal investment level with individual interest

First order condition $C_1'(k_{1\,1}^*) - r(L+M) + (1-k_2^*)r^2M = 0$

$$C_2'(k_2^*) - r(L+M) + (1-k_1^*)r^2M = 0$$

Nash Equilibrium Investment level: (k_1^*, k_2^*)

$$k_1^* = k_2^* = \frac{rL + r(1-r)M}{2c - r^2M} \qquad \left(\frac{\partial k_1^*}{\partial M} = \frac{\partial k_2^*}{\partial M} > 0 \right)$$

Social Optimal Investment Level

- The sum of the expected risk cost is

$$B_1(k_1, k_2) + B_2(k_1, k_2)$$

$$\underset{k_1, k_2 \in [0,1]}{Min}\ B_1(k_1, k_2) + B_2(k_1, k_2)$$

Social Optimal Investment level: (k_1^{so}, k_2^{so})

First Order Conditions:

$$C_1'(k_1^{so}) - r(L+M) + (1-k_2^{so})r^2M - (1-(1-k_2^{so})r)rM = 0$$
$$C_2'(k_2^{so}) - r(L+M) + (1-k_1^{so})r^2M - (1-(1-k_1^{so})r)rM = 0$$

Social Optimal Investment Level

Social Optimal Investment level:

$$k_1^{so} = k_2^{so} = \frac{rL + 2r(1-r)M}{2c - 2r^2 M}$$

Comparison between Nash equilibrium and Social Optimum:

$$\frac{rL + r(1-r)M}{2c - r^2 M} = k_1^{*} = k_2^{*} \le k_1^{so} = k_2^{so} = \frac{rL + 2r(1-r)M}{2c - 2r^2 M}$$

Nash equilibrium investment level $\le$ Social Optimal Investment level

The existence of business interruption loss causes the ports to underinvest for the mitigations

How to fill the gap?

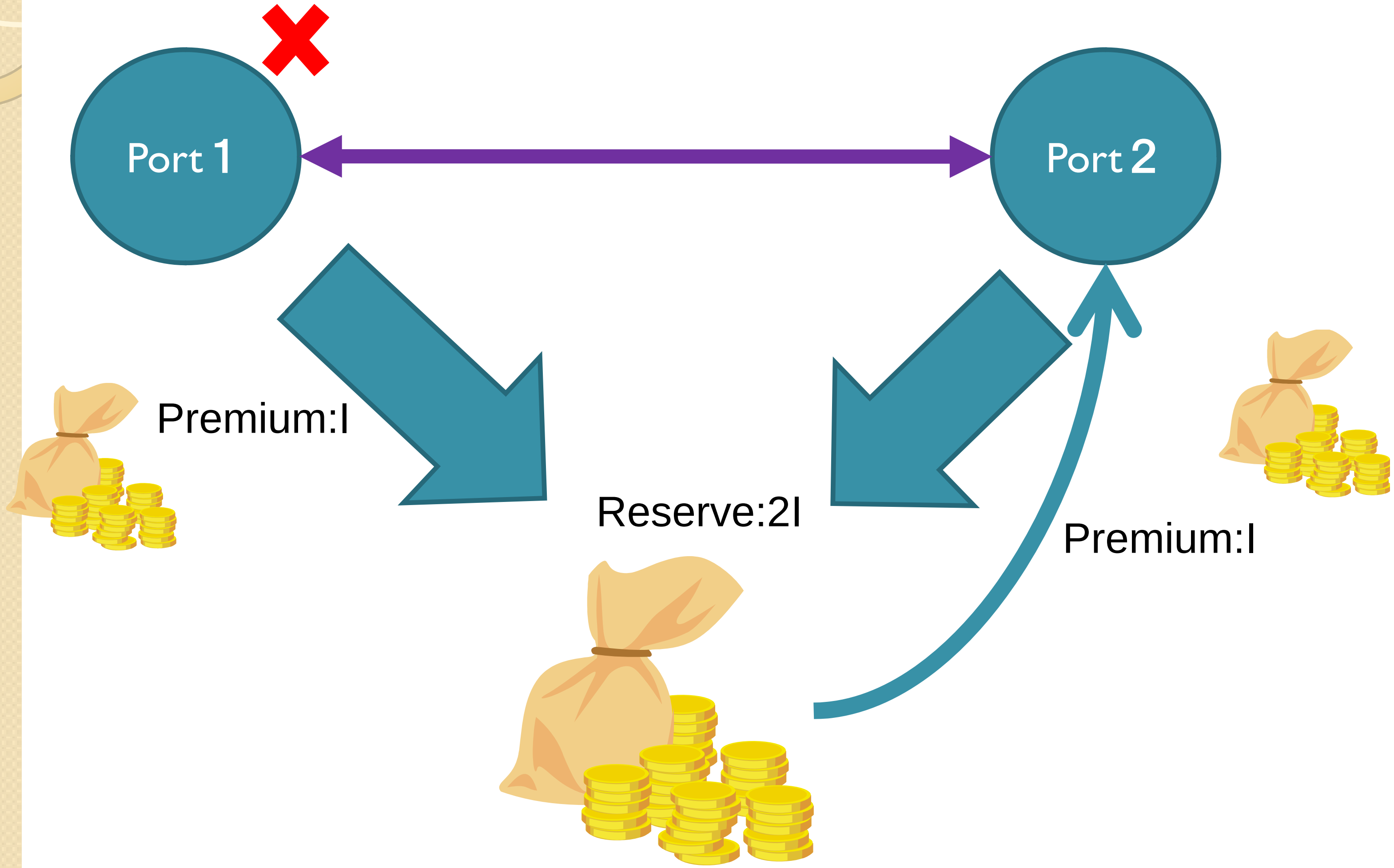
- Subsidy
- Penalty

- There are no authority to control the levels of the security

→Needs for incentive compatible mechanism between different nations to reduce interdependent security problem.

- We focus the way to internalize the externality of the port malfunctioning.
- Risk pooling mechanism to offset the externality!

Risk pooling mechanism to promote social optimal investment



Fist stage

Premium setting(underwriting) and closing a risk financing contract

Second Stage

Security Investment Decisions by Individual Ports

Third Stage

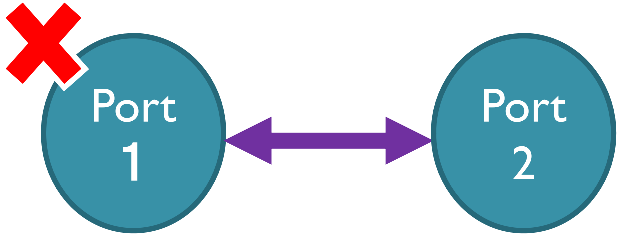
Disaster happens with probability of *r.*

Forth Stage

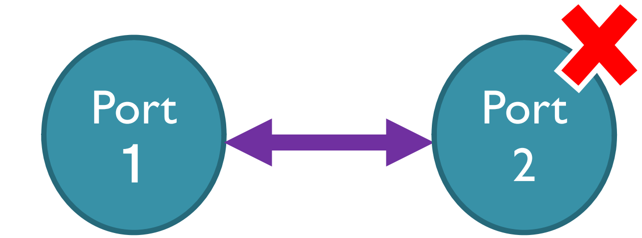
Execution of Ex post Payout

Risk cost under the risk pooling arrangement

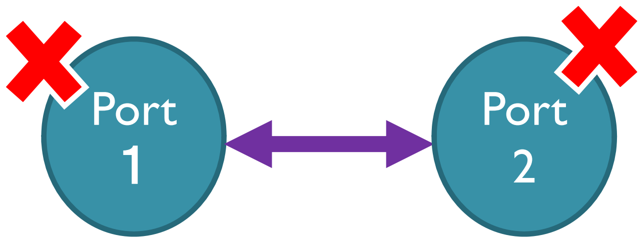
Third Stage and Forth Stage



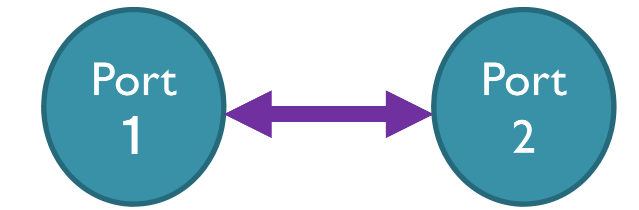
$$B_1(k_1,k_2)=C_1(k_1)+L+M-I$$
$$B_2(k_1,k_2)=C_2(k_2)+L+M-I+2I$$



$$B_1(k_1,k_2)=C_1(k_1)+L+M-I+2I$$
$$B_2(k_1,k_2)=C_2(k_2)+L+M-I$$



$$B_1(k_1,k_2)=C_1(k_1)+L+M$$
$$B_2(k_1,k_2)=C_2(k_2)+L+M$$



$$B_1(k_1,k_2)=C_1(k_1)+L+M$$
$$B_2(k_1,k_2)=C_2(k_2)+L+M$$

Investment level of mitigations under risk pooling arrangement

Second Stage

$$B_1(I,k_1,k_2)=C(k_1)+r^2(1-k_1)(1-k_2)(L+M)$$
$$+(1-(1-k_2)r)(1-k_1)r(L+M+I)$$
$$B_2(I,k_1,k_2)=C(k_2)+r^2(1-k_1)(1-k_2)(L+M)$$
$$+(1-(1-k_1)r)(1-k_2)r(L+M+I)$$

Nash Equilibrium Investment Level with premium I: $\left(k_1^{**}(I),k_2^{**}(I)\right)$

$$\begin{cases} \underset{k_1\in[0,1]}{Min}\ B_1(I,k_1,k_2^{**}) \\ \underset{k_2\in[0,1]}{Min}\ B_2(I,k_1^{**},k_2) \end{cases}$$

$$k_1^{**}(I)=k_2^{**}(I)=\frac{rL+r(1-r)M+rI}{2C-r^2M}$$

Provision for the Cover for Business Interruption from the other ports' malfunctions

First Stage

$$\underset{I}{Min}\, B_1(I, k_1^{**}, k_2^{**}) + B_2(I, k_1^{**}, k_2^{**})$$

$$s.t. \qquad I \geq 0$$

$$B_1(I, k_1^{**}, k_2^{**}) \leq B_1(k_1^{*}, k_2^{*})$$

$$B_2(I, k_1^{**}, k_2^{**}) \leq B_2(k_1^{*}, k_2^{*})$$

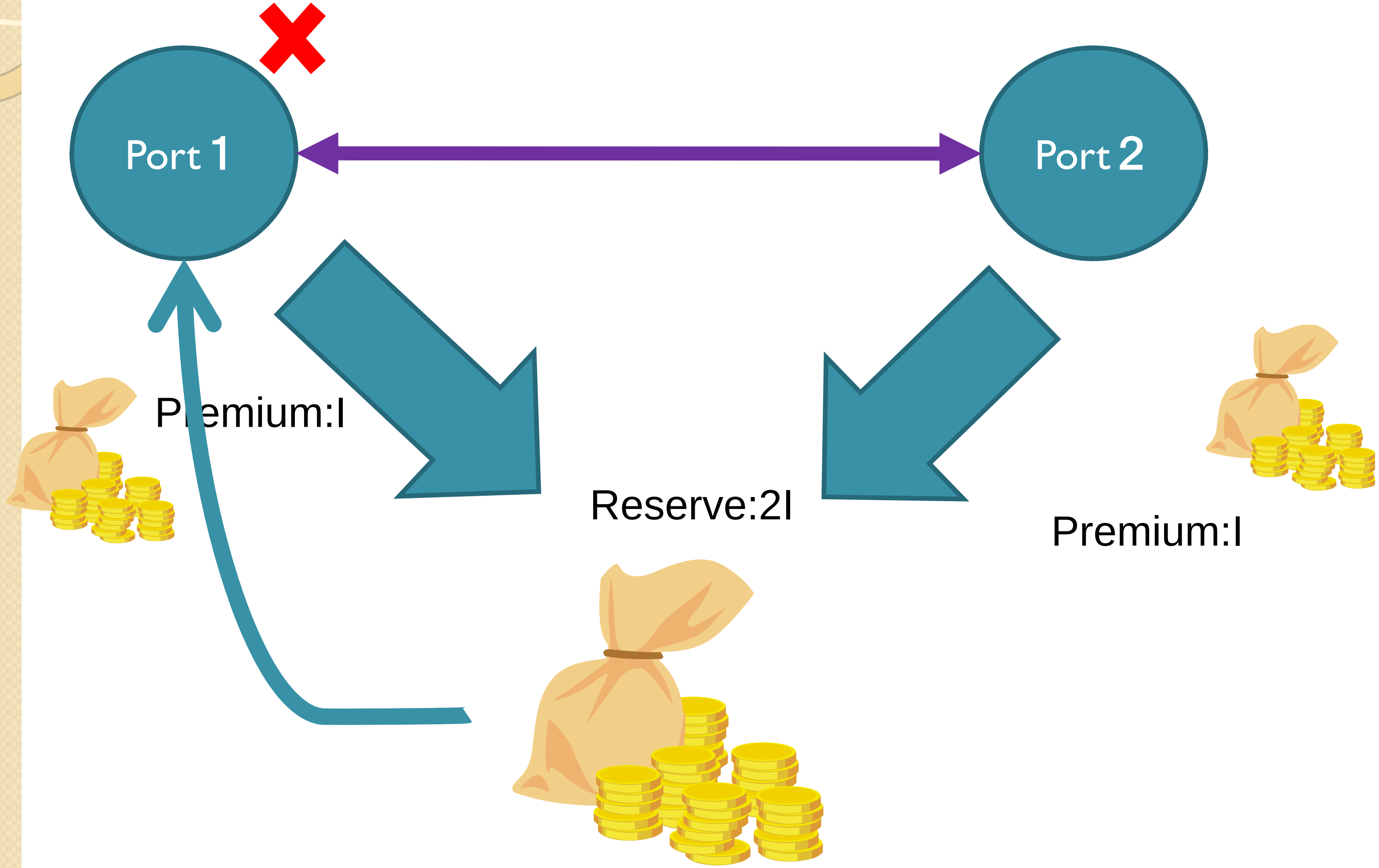
Incentive Compatible Condition

$$k_1^{**}(I^{**}) = k_2^{**}(I^{**}) = k_1^{so} = k_2^{so}$$

$$I^{**} = \frac{r^2 LM + 2cM(1-r)}{2(c - r^2 M)}$$

Social Optimal Investment can be induced through the proper premium setting

The failure of risk pooling arrangement



The failure of risk pooling arrangement

First Stage $$\underset{I}{Min}\, B_1(I, k_1^{***}, k_2^{***})$$

$$s.t. \qquad I \geq 0$$

$$B_1(I, k_1^{***}, k_2^{***}) \leq B_1(k_1^{*}, k_2^{*})$$

$$B_2(I, k_1^{***}, k_2^{***}) \leq B_2(k_1^{*}, k_2^{*})$$

Incentive Compatible Condition

$$\Rightarrow \quad I^{***} = 0$$

Social Optimal Investment can not be induced.

Risk pooling mechanism for the risk that the port cannot directly control can internalize the externality of interdependent risk, and promote social optimal investment for mitigation of the ports under the proper premium setting.

Summary

- We have interdependent security problems in security investment decisions among international harbors.
- The interdependent security problem brings about inefficiency without coordination of the security investment among ports.
- The gaps between social optimum and Nash equilibrium investment can be resolved by introducing proper risk pooling mechanism

Further Research

- How to design a risk financing in international ports
  - Asymmetric business interruption loss
  - Network reformation
  - Stakeholders: port authority, shippers, mega-terminal operators, etc.
  - Incomplete information
  - Donation – developing countries –

Thank you for your attention!!