Roadmap of the session:
Systems Resilience and Economic Impact

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Resilience Research

- Socio/Eco-Systems Research
  - Holling(1973) "Resilience and Stability of Ecological Systems"
    - ✓ Resilience determines the persistence of relationships within a system and is a measure of the ability of these systems to absorb changes of state variables, driving variables, and parameters, and still persist.
- Disaster research(Geography)
  - Cutter, etal (2008) "A place-based model for understanding community resilience to natural disasters" Global Env. Change
- Economic Resilience
  - Rose&Liao (2005) "Modeling Regional Economic Resilience to Disasters: A Computable General Equilibrium Analysis of Water Service Disruptions", J. Regional Science
    - ✓ economic resilience—reduced consequences of failure through the innate aspects of the economic system at all levels to cushion itself against losses in a given period.
- Engineering
  - Breneu, et.al.,(2003) "A Framework to Quantitatively Assess and Enhance the Seismic Resilience of Communities", Earthquake Spectra, 19(4)
    - ✓ Resilience can be understood as the ability of the system to reduce the chances of a shock, to absorb a shock if it occurs (abrupt reduction of performance) and to recover quickly after a shock (re-establish normal performance).

Engineering (Structural Resilience)

- Breneu, et.al.,(2003) “A Framework to Quantitatively Assess and Enhance the Seismic Resilience of Communities”, Earthquake Spectra, 19(4)

- Resilience can be understood as the ability of the system to reduce the chances of a shock, to absorb a shock if it occurs (abrupt reduction of performance) and to recover quickly after a shock (re-establish normal performance).

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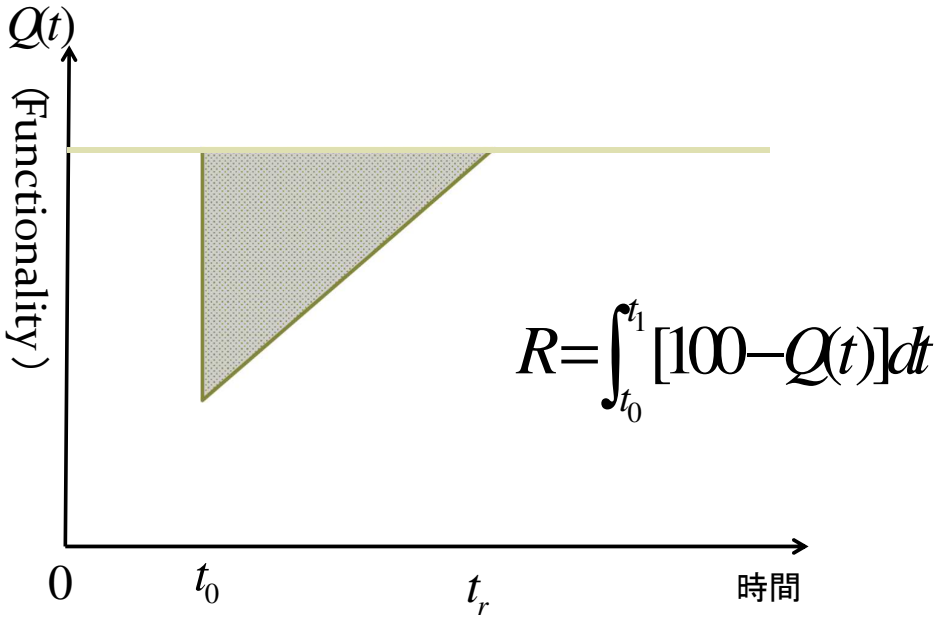
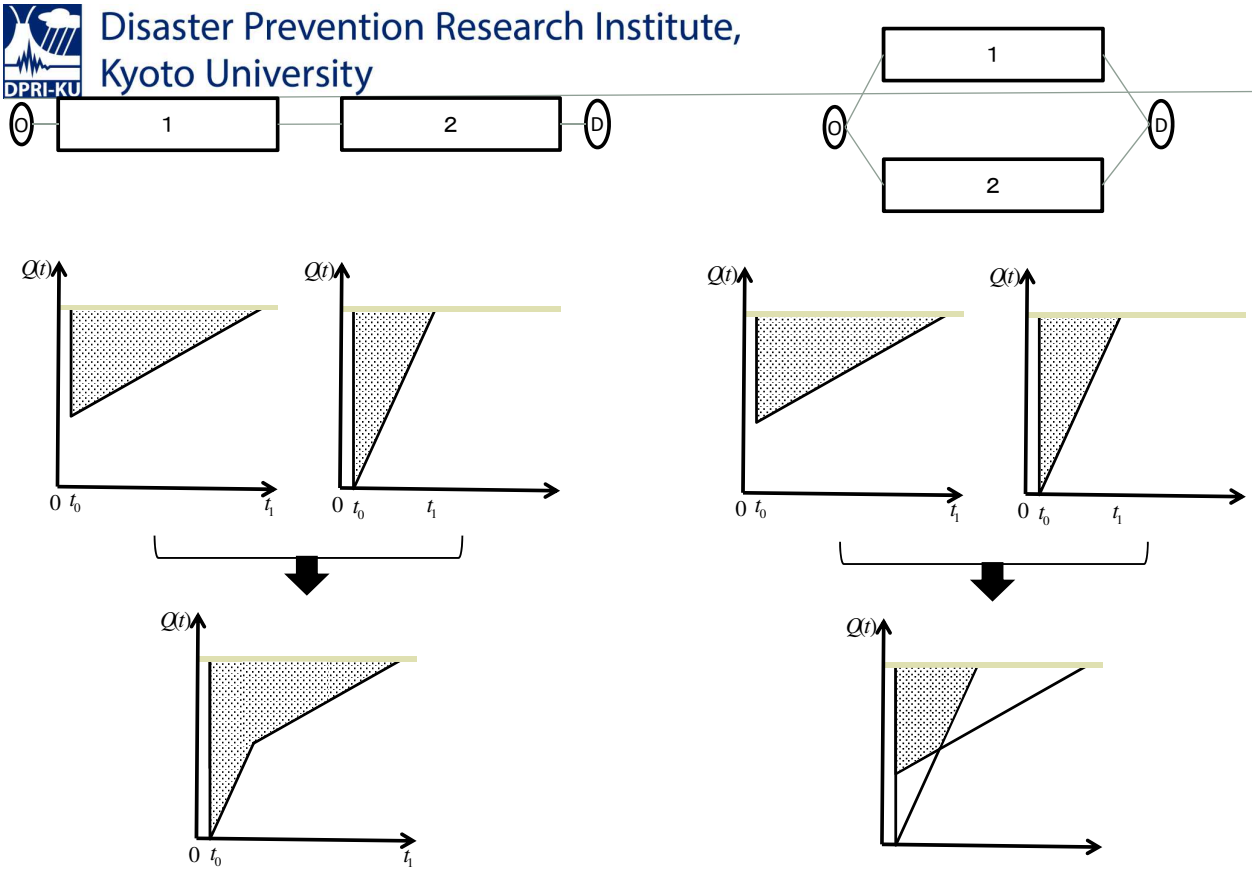


Focus on Functionality

Functionality of a system (Ststem’s Resilience) can be evaluated based on component functionality of the system.



$$Q_T(t) = \min_{i \in N}\{Q_i(t)\},\ Q_P(t) = \max_{i \in N}\{Q_i(t)\}$$

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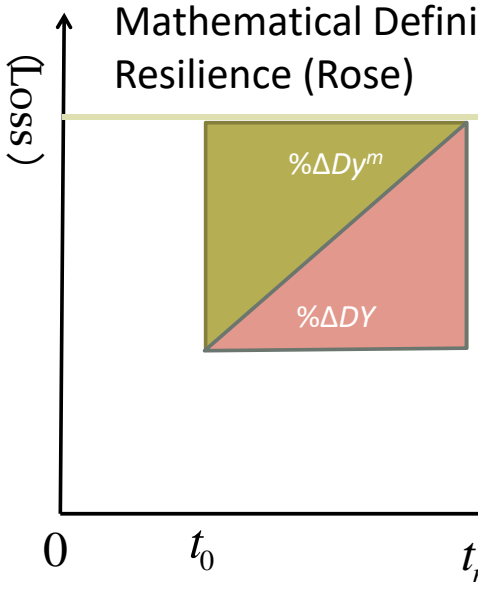
Economic Resilience(Rose 2004)

- Static:
  - General Definition: Ability of a system to *maintain function* when shocked.
  - Econ Definition: *Efficient use of remaining resources* at a given point in time to produce as much as possible.
- Dynamic
  - General: *Ability & speed* of a system to *recover.*
  - Economic: *Efficient* use of resources *over time* for investment in repair and reconstruction, including expediting the process & adapting to change
- *Metric*: *averted losses as % of potential losses*

Mathematical Definition: Direct Economic Resilience (Rose)



$$DER = \frac{\%\Delta DY^m - \%\Delta DY}{\%\Delta DY^m}$$

where

$\%\Delta DY^m$ is the maximum percent change in direct output

$\%\Delta DY$ is the estimated percent change in direct output

In essence, *DER* is the **% avoidance of a maximum disruption to a given shock**

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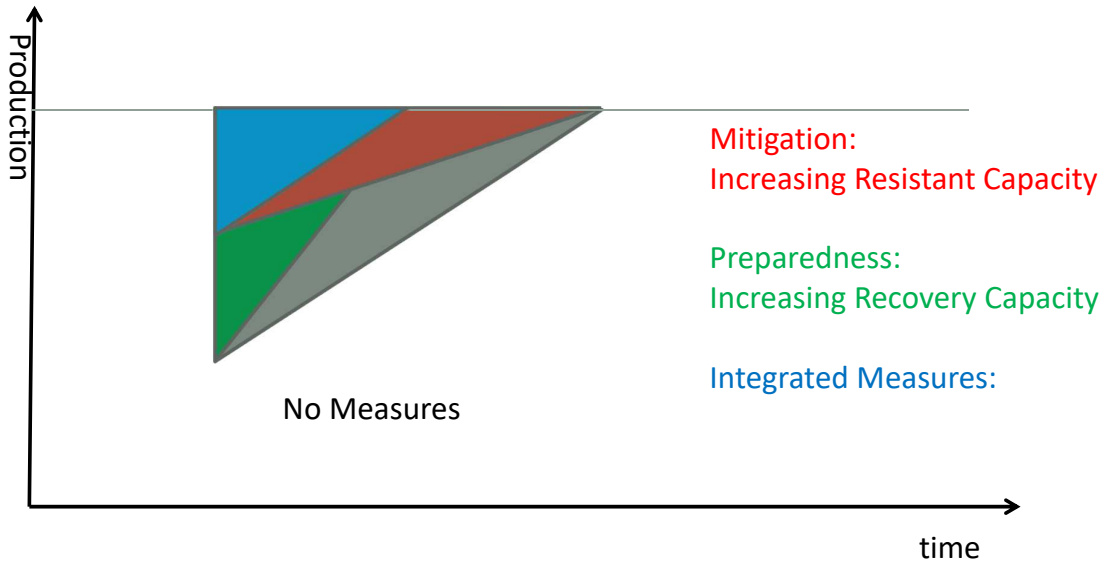
Economic Resilience

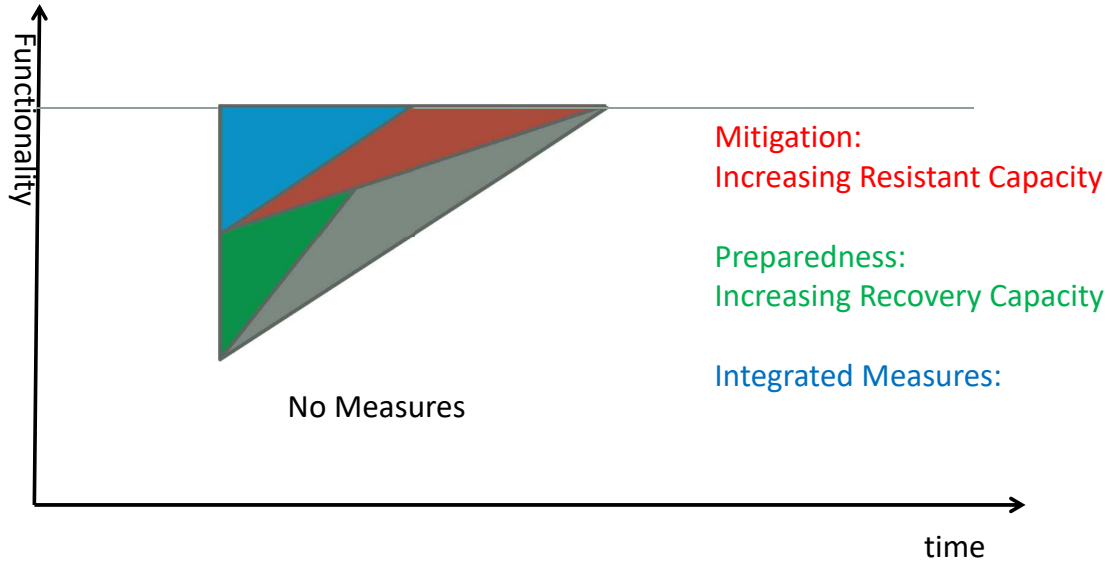
- Resilience : Bounce back

  = Resistant capacity + Recovery capacity



Resilience

- "Functionality" in stead of "production"



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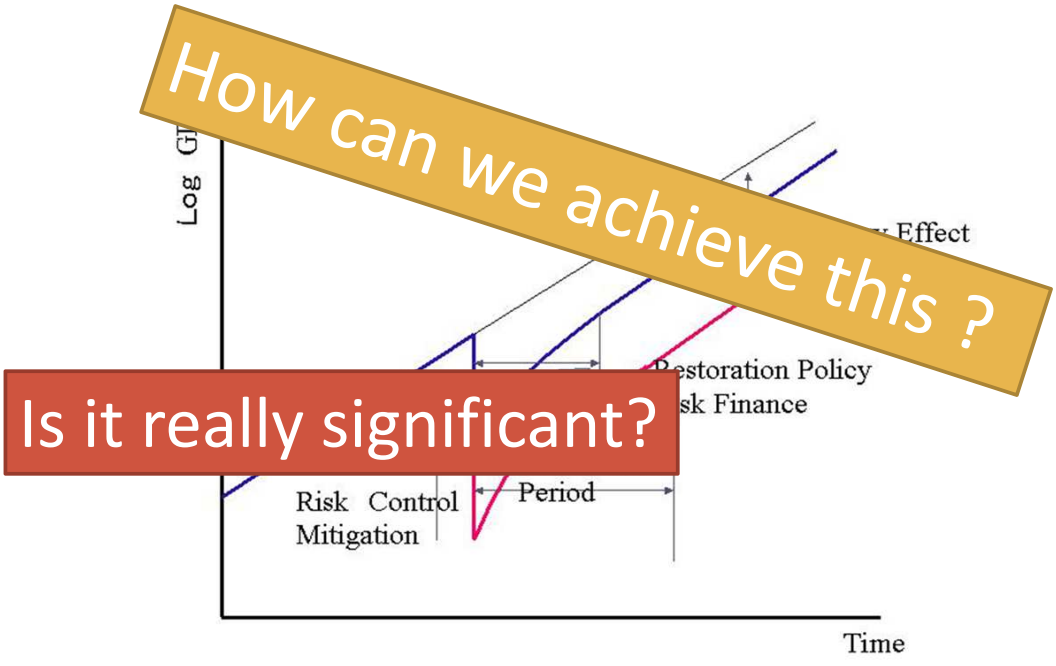
How can we measure economic resilience in the outcome bases?

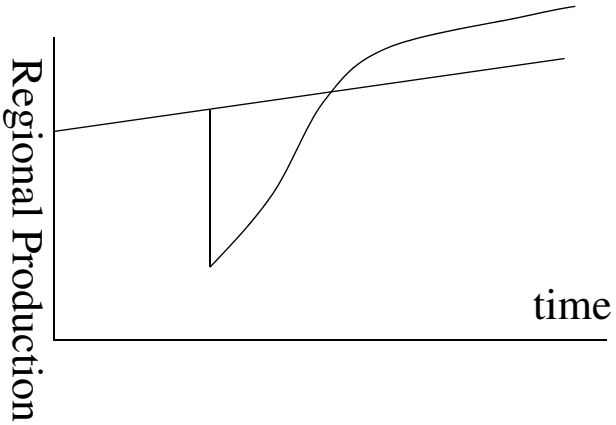


Conventional Framework of Loss Estimation

Total Loss = Direct Loss + Indirect Loss

What are the direct and indirect losses?

How can we estimate them?



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Damages in "STOCK"

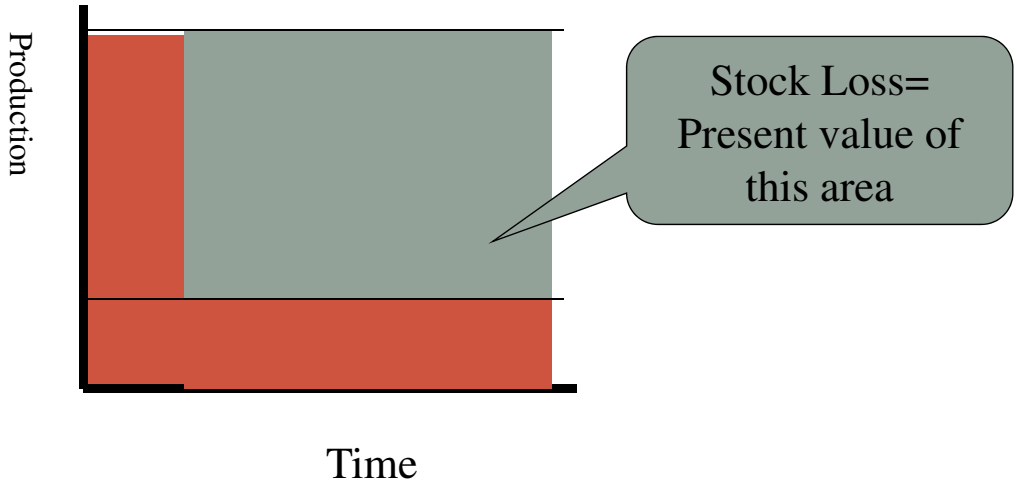
- STOCKS : infrastructure, building, production capital, etc

  - used repeatedly for producing services

- Value of STOCK :
  - Present value of a flow of services which will be produced in the future by the stock
- Economic losses in "STOCK" :
  - Lost present value of services which could be produced by the damaged / lost stock

Direct Loss＝Stock Loss

- 80% of “Stocks” are supposed to be lost by a disaster



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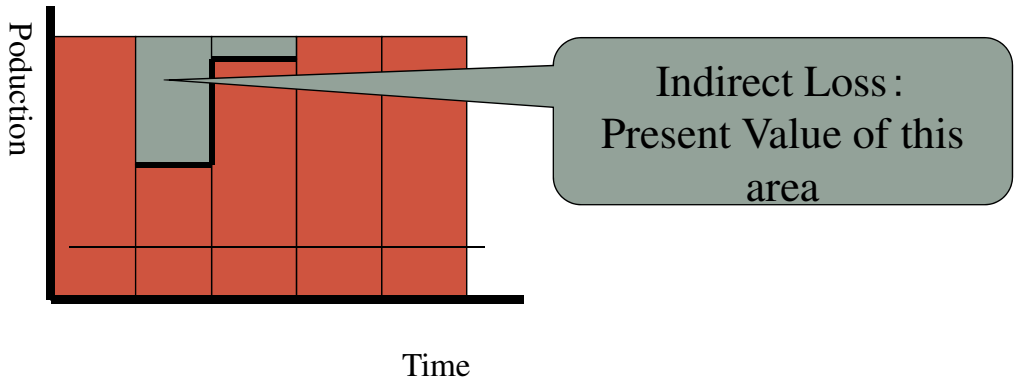
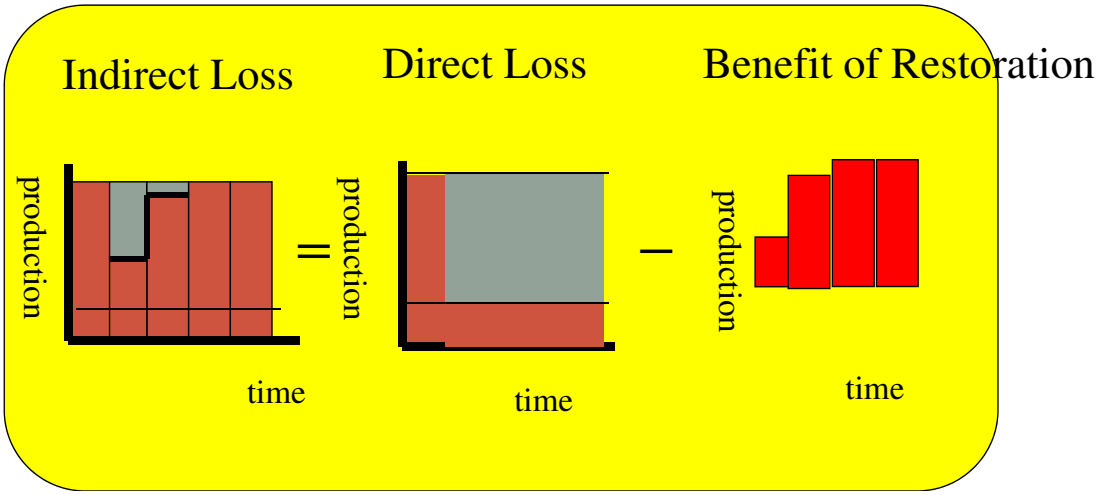
Indirect Loss

- Forgone flow of benefit (profit) which could be earned if the stock were not damaged, e.g., business interruption losses.



Indirect Loss
＝Direct loss－Benefit of Restoration

- When we often talk about total losses, effects of two different events together: Earthquake and Restoration.



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Therefore,

- Total Loss (Economic Effect of the Earthquake and Restoration actions)

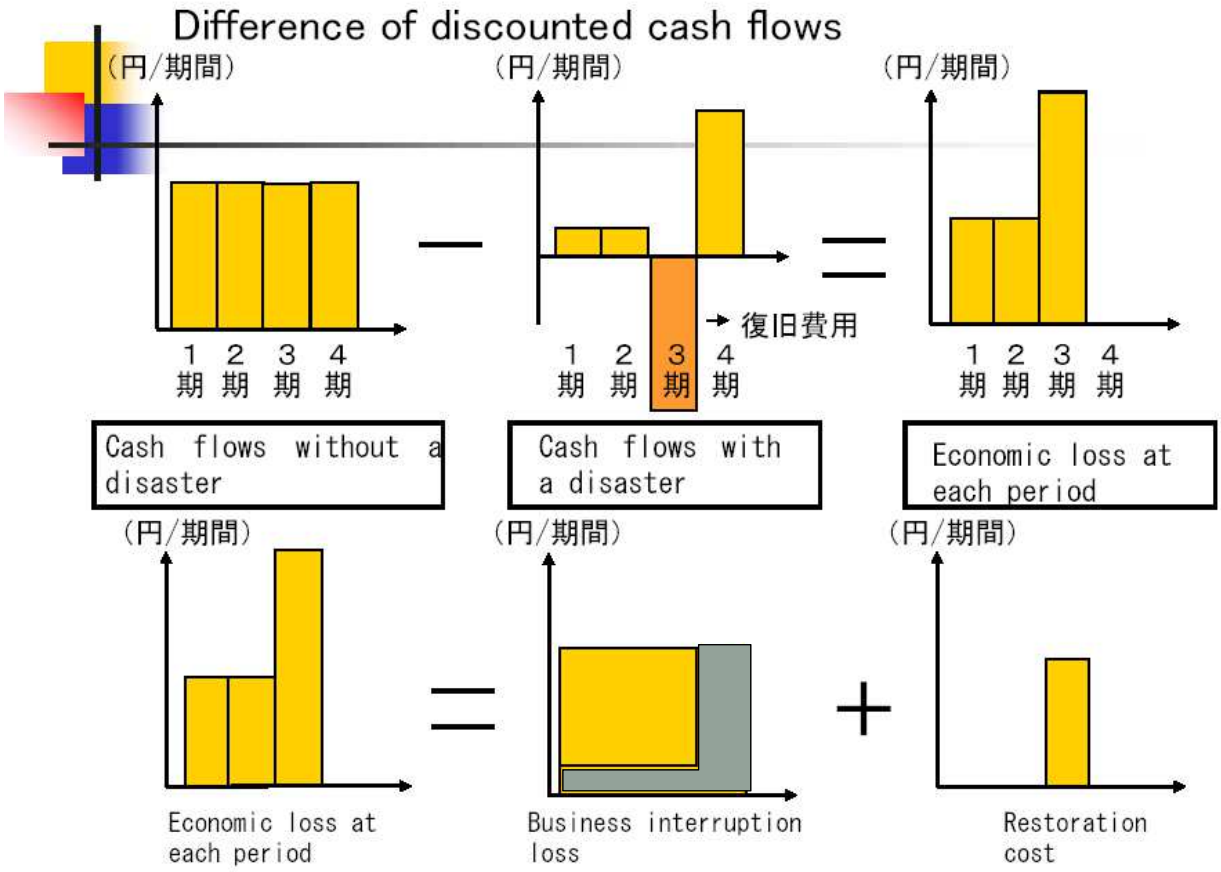
＝Direct Loss－Net Benefit of Restoration

＝Indirect Loss＋Cost of Restoration

Restoration cost should be regarded as the direct loss ！ ！

Hanshin Awaji Earthquake：
Restoration cost of highway bridges' pillars were 2-10 times larger than the construction cost.

Another consistent economic loss estimation method



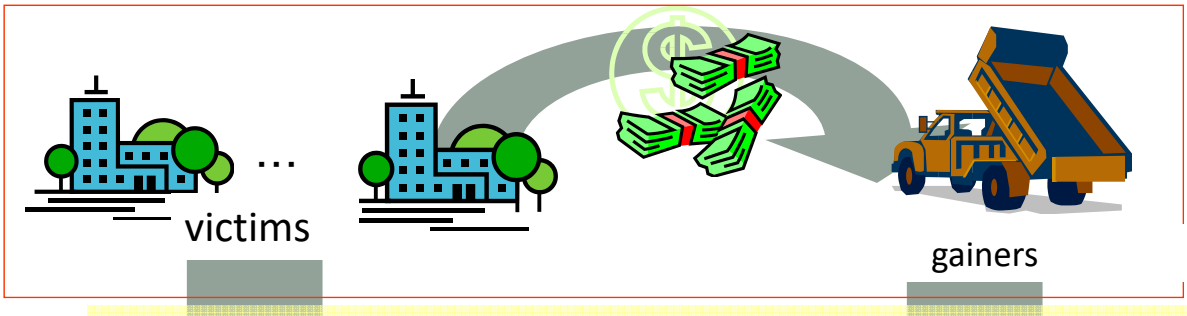
Aggregation in a region

- During some sector will increase because of restoration, e.g., construction.

Question:

- Should we add the negative economic loss (=positive benefit) in such sectors to estimate consistent total economic loss in industrial sectors?

Restoration Demand and Loss estimation



restoration cost of victims= increased revenue of gainers
cancel out in regional aggregation

Business interruption loss (foregone revenue) + Cost for Restoration (opportunity cost of labors and capitals used for restoration)

→Actual opportunity cost of a disaster

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Summing up difference of discounted cash flows

Answer : yes
Difference of discounted cash flows aggregated over a region (ADDCL)
=Regional opportunity cost of a disaster

ADDCL=foregone revenue + ~~restoration expenses~~
- ~~revenue increase by restoration demand~~
+ increase in production cost of restoration

Business interruption loss (foregone revenue) + Cost for Restoration (opportunity cost of labors and capitals used for restoration)

Avtural opportunity cost of a disaster

Outcome of resilience

- Resilience ↑

- Economic Loss (Total) ↓

- We regards the outcome based measure of resilience could be decrease of (total) economic loss (=BI loss + recovery cost).

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How significant?

- Resistance capacity vs Recovery capacity?

Post-Disaster Business Surveys in the area affected by the Great East Japan Earthquake: Summary of the regional and sectorial impacts

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(2) IRIDeS, Tohoku University

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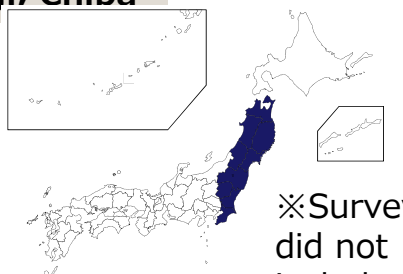
Post event surveys

	Survey ①	Survey ②
area	**Iwate, Miyagi**	**Akita, Aomori, Fukushima, Yamagata, Ibaragi, Tochigi, Chiba**
Period	Nov.-Dec. 2011	Nov.-Dec. 2012
Method	Questionnaire mail survey	Questionnaire mail survey
List (address)	Teikoku Data Bank	Telephone Book 2012
Sampling	Random Sampling	Random Sampling
Distribution	12,836	8,000
Answered	2,669	1,289
Ratio	**20.8%**	**16.1%**
Surveyors	DPRI, KU & CRIEPI	DPRI, KU & IRIDeS Tohoku U.



※Survey did not include Tsunami and nuclear accident affected areas.

Estimating “Decrease of Profit”

1. Estimating Revenue Recovery Process

- Initial drop of revenue is estimated by the functional fragility curves.
- Given initial drop of revenue, fit the recovery curves of production activities.

↓

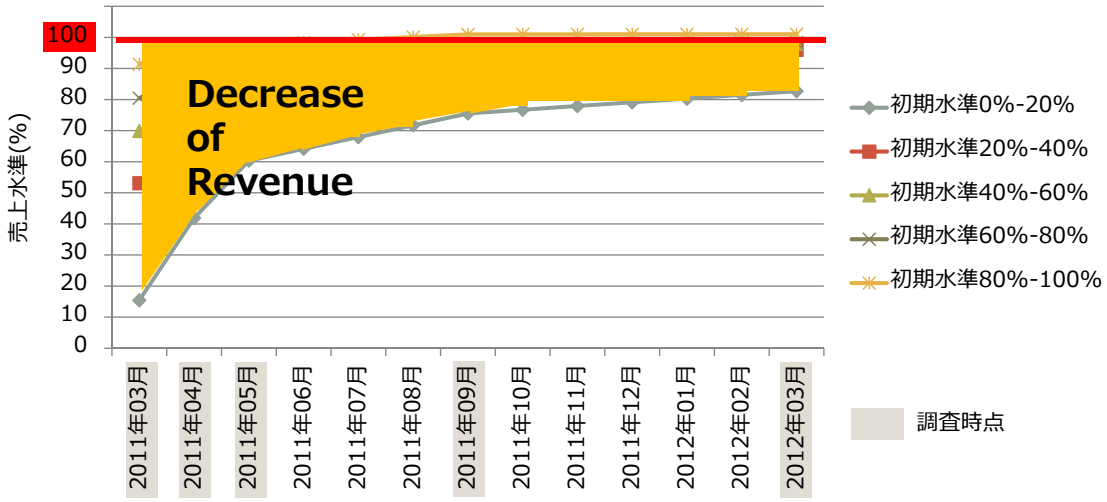
2. Transforming “revenue recovery process” into “profit recovery process”

↓

Profit decrease ratio for each levels of initial drop of revenue

1. Estimating Revenue Recovery Process

Decrease of revenue accelerated with the initial inoperability (=inverse of functionality) of the industry.

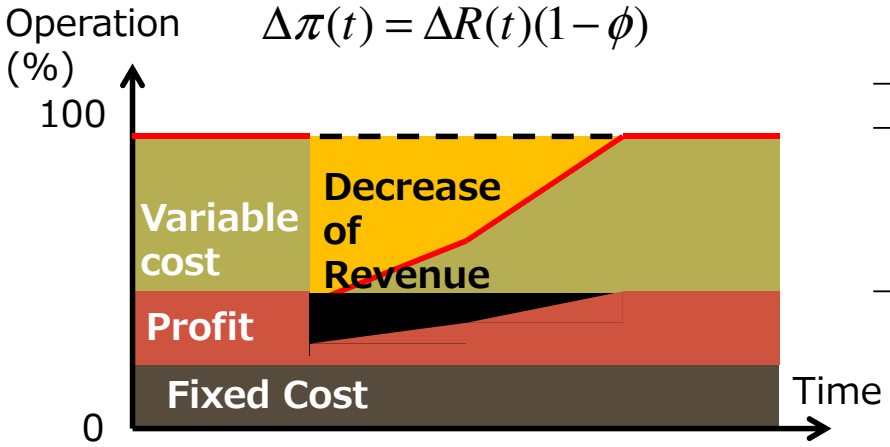


2. Profit Recovery

Transforming Revenue recovery process into profit recovery process

$$\pi(t) = R(t) - C_V(t) - C_F$$
$$= R(t)(1-\phi) - C_F$$
$$\Delta\pi(t) = \Delta R(t)(1-\phi)$$

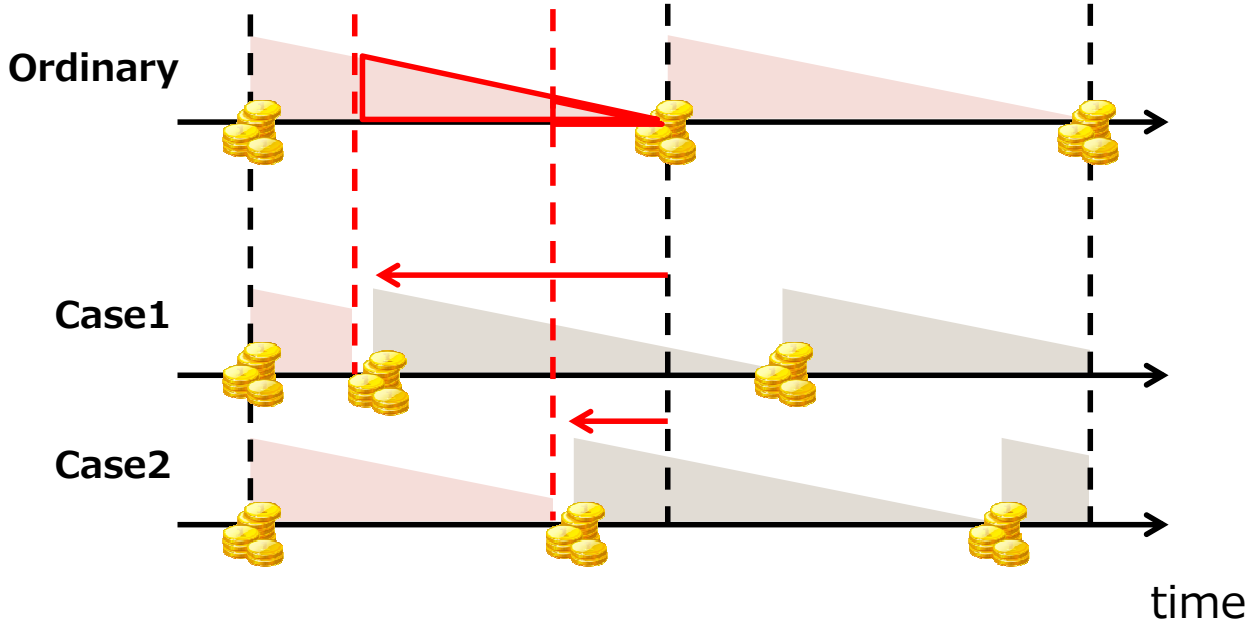
π : profit
R : revenue
C_V : variable cost $= \phi R$
C_F : fixed cost
ϕ : variable cost / revenue ratio



Industry	ϕ
Materials	0.792
Processing and assembly	0.783
Life related	0.790
Construction	0.800
Transportation	0.640
Wholesale/Retail	0.891
Finance, Insurance and Real estate	0.742
Service	0.620

2. Modification of Recovery Cost Ratio

A disaster brings about shorter replacement schedule for existing buildings and facilities.



Estimated Profit Decrease Ratio

Given initial functionality(=1-initial drop ratio of revenue), Profit Decrease Ratio for each industry is estimated.

Estimated Profit Decrease Ratio

	Industries	Initial Functionality				
		0%-20%	20%-40%	40%-60%	60%-80%	80%-100%
Manufacturing	Materials	7.06	2.81	1.99	1.08	0.187
	Processing and assembly	7.37	2.93	2.08	1.13	0.196
	Life related	7.13	2.83	2.01	1.09	0.189
Non-Manufacturing	Construction	7.14	2.79	2.41	1.15	0.0343
	Transportation	12.9	5.02	4.35	2.08	0.0618
	Wholesale/Retail	3.89	1.52	1.32	0.629	0.0187
	Finance, Insurance and Real estate	9.21	3.60	3.11	4.19	0.0443
	Service	13.6	5.30	4.59	2.19	0.0652

Estimated impact(Ground motion)

Estimated economic loss is 3.418 trillion JP Yen (Furuhashi, et.al.2013)

(Million JPYen)

	Decrease of Profit	Recovery Cost	Retirement cost	Total
Aomori	40,222	1,963	246	42,431
Iwate	154,736	16,656	2,264	174,017
Miyagi	355,694	50,089	9,703	415,186
Akita	17,581	907	97	18,585
Yamagata	65,341	5,902	763	72,006
Fukushima	449,909	45,259	7,828	502,996
Ibaragi	897,150	69,164	11,955	978,270
Tochigi	484,427	35,410	5,423	525,260
Chiba	642,059	40,475	6,414	688,949
Total	3,107,120	265,826	45,054	3,418,000

Summary and Discussion

The estimated loss is corresponding to 0.7% of Japanese GDP.

- About 5% of regional GDP in the affected area.
- At 2011, net GDP growth ration is -0.59%.

Recovery Cost is 10 times smaller than Business interruption cost by strong ground motion in the case of 2011 Great eastern Japan Earthquake.

Recover cost might be too small.

- Questionnaire survey based on random sampling leads small business intensive survey, which not including large companies.
  - By use of other sources, e.g., IR report for Tokyo Stock Exchange Market, can be used. (E.g., Furuhashi, 2012)
- Tsunami・Nuclear Accident is not included.

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Challenges in this session

- Development of methodology
  - Infrastructure as a system of systems
  - From Component resilience to Infrastructure Resilience focusing its “functionality.”
  - Integration of infrastructure resilience to “Economic Resilience”

Topics to be discussed

- セッションのねらいと進行方法
  Roadmap of the session — By Hirokazu Tatano
- 個別要素のレジリエンスから，システムのレジリエンスを構成するための方法と課題
  Understanding the infrastructure resilience framework: interactions between system functionality, operability, service provision and economic activity
  By Craig Davis
- システムのシステムとしてみたインフラシステムのレジリエンス計量化の可能性と課題
  Challenges for assessing infrastructure resilience from the System of Systems perspective
  By Nobuoto Nojima
- ライフラインシステムの機能低下に伴う経済影響の計量化の方法と課題
  Challenges in economic impact analysis to reflect lifeline resilience
  By Yoshio Kajitani
- 学術上・実務上の課題と取り組みの優先順位（総合討論）
  Discussion on academic and practical challenges and priority areas of collaboration

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Discussion on challenges and priority areas of collaboration

- What are the key challenges for us to tackle with?
  - Identify the most important challenges in each areas
- What is the goal for us to set for the ASCE-JSCE research collaboration in this field?