An Introduction to the Natural Disaster Vulnerability Evaluation Modeling (NDVE-Modeling): Theory and Application

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Abstract

The natural disasters have a potentially large impact on economic growth but measuring their economic impact is subject to a great deal of uncertainty. The central objective of our paper is to set forth a model – the natural disasters vulnerability evaluation modeling (**NDVE-Modeling**) – to evaluate the impact of natural disasters on GDP growth. The model is based on three basic indicators - (i) the natural disasters vulnerability propensity rate (**Ω**); (ii) the natural disaster devastation magnitude rate (**Π**); and (iii) economic desgrowth rate (**δ**). We apply the **NDVE-Modeling** on different countries around the world and especially on the case of the Japanese Tsunami in March 2011.

1. Introduction

The natural disasters can have a potentially large effect on economic growth but measuring their economic impact is subject to a great deal of uncertainty. They impose both direct and indirect costs, and those costs change and evolve over time. Natural disasters adversely affect economic activity in the short run through a number of channels. For example, the Northeast Japan earthquake and tsunami of March 2011 severely curtailed manufacturing output by destroying power stations, production facilities, and transportation and other infrastructure. Beyond the very short term, however, the negative economic impact of natural disasters tends to fade. For example, in the Kobe earthquake of January 1995, the government's reconstruction spending spearheaded a robust recovery in private investment and consumption. As a result, macroeconomic indicators recovered very quickly after an initial drop.

Given the potentially large effects of natural disasters on economic growth, it is important for policymakers to have reasonably accurate estimates of those effects. However, this is difficult given the high uncertainty surrounding the measurement of those effects. The motivation for this paper comes from the large numbers of natural disasters which seem to be inflicting damage on the world economy with growing frequency. Developing countries in particular are more vulnerable to natural disasters due to weaker infrastructure and lack of anticipatory measures. Developing Asia in particular accounted for 61% of global fatalities and 90% of all persons affected globally by natural disasters between 1970 and 2008. According to Table 1 shows the fatalities and estimated damages from various types of natural disasters in developing Asia between 2000 and 2010. The estimated damages imply a sizable negative economic impact on the region.

[INSERT TABLE 1]

The central objective of our paper is to set forth a model – the natural disasters vulnerability evaluation modeling (**NDVE-Modeling**) – to evaluate the impact of natural disasters on GDP growth. The model is based on three basic indicators - (i) the natural disasters vulnerability propensity rate (**Ω**); (ii) the natural disaster devastation magnitude rate (**Π**); and (iii) economic desgrowth rate (**δ**). We look at different types of natural disasters that occurred around the world between 1959 and 2011. To illustrate and illuminate the **NDVE-Modeling**, we apply it to assess the economic impact of the Northeast Japan earthquake and tsunami which devastated Japan in March 2011. For comparative purposes, we also apply the model to an earlier earthquake in Japan which affected the Kobe region in January 1995. We hope that the **NDVE-Modeling** will contribute toward a more systematic and accurate measurement of the economic impact of natural disasters.

2. The Natural Disasters Vulnerability Evaluation Modeling (NDVE-Modeling)

The natural disasters vulnerability evaluation modeling (**NDVE-Modeling**) assumes that any country is vulnerable to get a natural disaster anytime and anywhere. Hence, our world is in a state of constant chaos. When this model is referring to a natural disaster, we are referring to any event beyond human control that can generate a massive destruction anytime anywhere without any advance warning. The quantification and monitoring of natural disasters is inherently difficult, and we cannot evaluate and predict them with any degree of accuracy. In addition, this **NDVE-Modeling** is useful for demonstrating how the GDP growth rate is directly connected to natural disasters events.

In the context of the **NDVE-Modeling**, we like to propose three new indicators - the natural disasters vulnerability propensity rate (**Ω**), natural disaster devastation magnitude rate (**Π**) and the economic desgrowth rate (**δ**). These three indicators aim to simultaneously show the different levels of vulnerability and devastation levels arising from different natural disasters. The natural disasters vulnerability propensity rate (**Ω**), natural disaster devastation magnitude rate (**Π**) and the economic desgrowth rate (**δ**) are based on the collection of historical data from different natural disasters that have been suffered by any country, natural disasters are defined according to certain intervals of time and the magnitude of destruction on material resources (infrastructure) and non-material resources (human lives).

According to our model the analysis of any natural disasters from an economic point of view need to take into account the production reduction (capital) and human capital mobility (labor) simultaneously. In this part of this model we introduce a new concept is called "**Economic Desgrowth** (**δ**)**"** (Ruiz Estrada, 2011b). The economic desgrowth rate (**δ**) is defined as a leakage of economic growth due to any natural disaster. The main objective of the economic desgrowth rate (**δ**) is to observe the final impact of any natural disaster on the final GDP growth rate behavior over a certain period of time. The basic data used by the natural disasters vulnerability evaluation modeling (**NDVE-Modeling**) is based on the uses of sixteen different possible natural disasters events. These include earthquake (β_1); tsunami (β_2); floods (β_3); volcano eruption (β_4); typhoon (β_5); fire pollution (β_6); snow avalanches (β_7); landslide (β_8); blizzards (β_9); cyclonic storms (β_{10}); Tornadoes (β_{11}); epidemics (β_{12}); droughts (β_{13}); hailstorms (β_{14}); sandstorm (β_{15}); and hurricane (β_{16}) respectively. The quantification of each possible natural event is based on the uses of intervals of probability between zero and one (see Expression 1).

$$f(X_{n+1}) \text{ exist } [0,1] \ \forall \ X \in \Omega \qquad (1)$$

$$P(X_{n+1}) = \sum R_+ \in X_n$$

$$\sum R_+ \varepsilon X_{n+1} = 1$$

According to the **NDVE-Modeling**, we assume an irregular oscillation into different natural disasters events all the time. We do so by applying the simple rule of irregular series (X_n) as a function of n according to James Gleick (1988) (see Expression 2).

$$X_{n+1} = f(X_n) \quad \textbf{(2)}$$

It means that our world is going to be in permanent chaos under high risk to of a natural disasters event anytime. The **NDVE-Modeling** allows for different magnitudes of destruction. Therefore, we have a large number of irregular series (Nagashima & Baba, 1992) under expression 3 and 4:

$$X_{n+1} = T(X_n) = \begin{cases} 2X_n \\ 2 - 2X_n \end{cases} \quad \textbf{(3)}$$

$$X_{n+1} = T(X_n) = T(X_n)/B(X_n) \Rightarrow \begin{cases} 2\,X_n & (0 \leq X_n \leq 1) \\ 2 - 2X_n & (0 \leq X_n \leq 1) \end{cases} \quad \textbf{(4)}$$

The application of X_{n+1} random intervals makes it possible for the **NDVE-Modeling** to analyze unexpected results from different natural disasters events which cannot be predicted and monitored with the traditional methods of linear and non-liner mathematical modeling. This is because we assume at the very outset that our world is in a state of constant chaos. At the same time, we are looking to include the Lorenz transformation assumptions (Lorenz, 1993) to facilitate the analysis of our final result in this specific model.

a. The Natural Disaster Vulnerability Propensity Rate (Ω)

Initially, we need to assume that the construction of the natural disasters vulnerability propensity rate (**Ω**) is directly connected to the GDP growth rate behavior (see Expression 5 and Figure 1). We would also like to keep all the variables in the natural disasters vulnerability propensity rate (**Ω**) in an interval between 0 and 1 (see Expression 6).

$$\mathrm{GDP}_{n+1} = f(\Omega_n) \quad \textbf{(5)}$$

$$\Omega \in [0,1] \quad \textbf{(6)}$$

Subsequently, the construction of the natural disasters vulnerability propensity rate (Ω) is based on the application of expression 7. The final total of the natural disasters vulnerability propensity rate **(Ω)** is always equal to 100%. Therefore, we apply a constant (k) of 6.25 to normalize the final result to 100%.

$$\boldsymbol{\Omega} = \Sigma[k(\beta_1)+ k(\beta_2)+ k(\beta_3)+ k(\beta_4)+ k(\beta_5)+ k(\beta_6)+ k(\beta_7)+ k(\beta_8)+ k(\beta_9) + k(\beta_{10}) + k(\beta_{11}) + k(\beta_{12})+ k(\beta_{13}) + k(\beta_{14}) + k(\beta_{15}) + k(\beta_{16})] \quad \textbf{(7)}$$

where βi represent the probability of any possible natural disaster event in a specific period of time (**t**) according to $0 \leq \beta i_t \leq 1$. The natural disasters vulnerability propensity rate (**Ω**) includes a total of sixteen possible natural disasters events (variables) that are following by earthquake ($\boldsymbol{\beta_1}$); tsunami ($\boldsymbol{\beta_2}$); floods ($\boldsymbol{\beta_3}$); volcano eruption ($\boldsymbol{\beta_4}$); typhoon ($\boldsymbol{\beta_5}$); fire pollution ($\boldsymbol{\beta_6}$); snow avalanches ($\boldsymbol{\beta_7}$); landslide ($\boldsymbol{\beta_8}$); blizzards ($\boldsymbol{\beta_9}$); cyclonic storms ($\boldsymbol{\beta_{10}}$); Tornadoes ($\boldsymbol{\beta_{11}}$); epidemics ($\boldsymbol{\beta_{12}}$); droughts ($\boldsymbol{\beta_{13}}$); hailstorms ($\boldsymbol{\beta_{14}}$); sandstorm ($\boldsymbol{\beta_{15}}$); hurricane ($\boldsymbol{\beta_{16}}$) respectively. Hence, we can simplify expression 6 by using expression 8.

$$\boldsymbol{\Omega} = \left(\sum_{i=0}^{\infty} \beta_{i(T/\beta_i)K} \right)^t \quad \textbf{(8)}$$

Thus $\beta i = \{\text{if } \beta i \in 0 \leq \beta i_t \leq 1\}$ applies a constant of k = 6.25 (see Table 2). The evaluation of the natural disasters vulnerability propensity rate (**Ω**) is based on three different levels of vulnerability:

Level 1: High vulnerability (red color alert): 1 - 0.75

Level 2: Average vulnerability (orange color alert): 0.74 – 0.34

Level 3: Low vulnerability (green color alert): 0.33 - 0

However, in Figure 1 and Figure 2, it is possible to observe diminishing returns between the GDP growth rate and the natural disaster vulnerability propensity rate (**Ω**). We can have three possible scenarios of analysis in this relationship between GDP growth rate and the natural disaster vulnerability propensity rate (**Ω**). First scenario, if the natural disaster vulnerability propensity rate (**Ω**) is very high then the GDP growth rate became low. Second scenario, if the natural disaster vulnerability propensity rate (**Ω**) is very low then the GDP growth rate became high. Finally, the last scenario is when the natural disaster vulnerability propensity rate (**Ω**) intercepts the GDP growth rate at a certain level and reaches some kind of an equilibrium. We define this type of equilibrium as **"Equilibrium Mediation"**, The equilibrium mediation never keeps static but constantly keeps changing. Hence, we suggest the application of the Omnia Mobilis assumption (Ruiz Estrada, 2010a) to keep the equilibrium mediation in the long run. It changes according to changes in the natural disaster vulnerability propensity rate (**Ω**).

[INSERT FIGURE 1 AND FIGURE 2]

b. The Natural Disaster Devastation Magnitude (Π)

To calculate the natural disaster devastation magnitude rate (**Π**), we need to apply expression 9.

$$\Pi\,(\boldsymbol{\Phi},\boldsymbol{\Psi}) = [\Phi_{k(x+1)}] + [\Psi_{L(x+1)}] \qquad \textbf{(9)}$$

Basically, we are using two main variables to calculate the natural disaster devastation magnitude rate (**Π**). The first main variable that is capital devastation (**Φ**). We compute capital devastation (**Φ**) by dividing the area of infrastructure hit by natural disaster (km^2)by total infrastructure area (km^2). The second main variable is human capital devastation (**Ψ**). We compute human capital devastation (**Ψ**) by dividing the number of people killed by or missing due to natural disaster by the total population. After calculating both main variables, we can then sum up the results to get our natural disaster devastation magnitude rate (**Π**). In short, the natural disaster devastation magnitude rate (**Π**) is the sum of capital devastation (**Φ**) and human capital devastation (**Ψ**).

c. The Economic Desgrowth (δ)

In the first instance, the measure of the economic desgrowth **(δ)** is based on the application of partial derivatives in each possible natural disaster event probability between the present time (this year) and the past time (last year) (see Expression 10).

$$\Delta\beta i = \delta\beta i_{t+1} / \delta\beta i_t \geq n \text{ where } n = \{-\infty\ldots,-1, 0, 1,\ldots\infty+\} \qquad \textbf{(10)}$$

$$\textbf{-}\boldsymbol{\Delta\Omega}\textbf{=} \begin{pmatrix} (\beta_1)_{t+1}/(\beta_1)_t & (\beta_2)_{t+1}/(\beta_2)_t & (\beta_3)_{t+1}/(\beta_3)_t & (\beta_1)_{t+4}/(\beta_1)_t \\ (\beta_5)_{t+1}/(\beta_5)_t & (\beta_6)_{t+1}/(\beta_6)_t & (\beta_7)_{t+1}/(\beta_7)_t & (\beta_8)_{t+1}/(\beta_8)_t \\ (\beta_9)_{t+1}/(\beta_9)_t & (\beta_{10})_{t+1}/(\beta_{10})_t & (\beta_{11})_{t+1}/(\beta_{11})_t & (\beta_{12})_{t+1}/(\beta_{12})_t \\ (\beta_{13})_{t+1}/(\beta_{13})_t & (\beta_{14})_{t+1}/(\beta_{14})_t & (\beta_{15})_{t+1}/(\beta_{15})_t & (\beta_{16})_{t+1}/(\beta_{16})_t \end{pmatrix} \qquad \textbf{(11)}$$

Second, to measure the negative natural disaster vulnerability propensity matrix (**–ΔΩ**), we need to find the determinant of a four by four matrix under the sixteen different possible natural disasters events in our model (see Expression 11). Finally, the measurement of the economic desgrowth **(δ)** is on the product of multiplying the negative natural disaster vulnerability propensity matrix (**–ΔΩ**) and the present GDP growth rate (ΔGDP) (see Expression 12).

$$\boldsymbol{\delta} = \Delta GDP \text{ x } -\Delta\Omega \qquad \textbf{(12)}$$

d. The Natural Disasters Vulnerability Surface (NDV-Surface)

The construction of the **NDVE-Surface** is based on the negative natural disaster vulnerability propensity rate (**–ΔΩ**) matrix results and the mega-surface coordinate space (see Expression 13 and Figure 3). The negative natural disaster vulnerability propensity rate (**–ΔΩ**) matrix is a four by four matrix that contains the individual results of all sixteen variables (taken from Table 1). The underlying idea here is to use the results of sixteen variables in the negative natural disaster vulnerability propensity matrix (–**ΔΩ**) to build a symmetric surface. When the negative natural disaster vulnerability propensity rate (–**ΔΩ**) has strictly the same number of rows as the number of columns, then the negative natural disaster vulnerability propensity rate (–**ΔΩ**) can always be perfectly symmetric.

$$-\Delta\Omega = \begin{pmatrix} X_1 & X_5 & X_9 & X_{13} \\ X_2 & X_6 & X_{10} & X_{14} \\ X_3 & X_7 & X_{11} & X_{15} \\ X_4 & X_8 & X_{12} & X_{16} \end{pmatrix} \qquad (13)$$

The final analysis of the **NDV-Surface** depends on any changes that this surface can experience in a fixed period of time.

[INSERT FIGURE 3]

3. The Natural Disasters Vulnerability Evaluation Modeling (NDV-Modeling): Japanese case

Applying the **NDVE-Modeling** to the Japanese economy will give us a much better idea of how the model works. Before we do so, it is useful to have a look at general data about Japan such as the contribution of each region to the final GDP of Japan and the geographical distribution of Japanese industry. In terms of the geographical distribution of Japanese GDP, we find that Hokkaido contributes around 8% of GDP. Honshu and Tohoku region contributes 18% and Kanto and Chubu region contribute 39%, the highest share. The region with the second highest contribution to Japan's GDP is Kinki and Shikoku region with 28%. Therefore, the major contributors to Japanese GDP are the Kanto and Chubu region and Kinki and Shikoku region, which collectively account for 67% of Japanese output. Finally, the region of Kyushu region and Nansei region each contribute 7% to Japanese output (see Figure 4). Kanto and Chubu region and Kinki and Shikoku also account for about 70% of Japanese industrial output, with the remaining industrial output divided among the other regions. (see Figure 5)

[INSERT FIGURE 4 AND 5]

4. The Natural Disaster Vulnerability Propensity Rate (Ω)

In this section, we first examine the natural disaster vulnerability propensity rate for countries around the world and then we take a closer look at Japan's natural disaster vulnerability propensity rate.

a. The World Wide Natural Disaster Vulnerability Propensity Rate (Ω)

Table 2 shows the natural disaster vulnerability propensity rate (**Ω**) in 59 countries around the world. The 59 countries show a wide range of probability of natural disaster event based on their historical data. We use three different colors to classify countries according to their natural disaster vulnerability propensity rate (**Ω**). Firstly, the red color represents high vulnerability, the orange color represents medium vulnerability and the yellow color represents low vulnerability. We can observe in Table 2 that the ten countries with the highest risk of natural disasters are China; Japan; U.S.; Indonesia; Philippines; Australia; South Korea; Taiwan; Chile; Guatemala. Figure 9 shows the natural disaster vulnerability surface for 5 countries – Japan, US, China, Luxembourg and Guatemala. Therefore, Japan is among the top ten countries with the highest natural disaster vulnerability propensity rate (**Ω**), to be more specific second highest according to the list. On the other hand, countries such as Mongolia, Hungary, South Africa, Denmark, Belgium and Luxemburg have the lowest natural disaster vulnerability propensity rate (**Ω**). This means that according to historical data, they face lower risk of natural disaster than the other countries in our sample.

[INSERT TABLE 2 AND FIGURE 9]

b. The Japanese Natural Disaster Vulnerability Propensity Rate (Ω)

In the case of Japan, we find large differences between the maximum and minimum of natural disaster vulnerability propensity rate (**Ω**). According to historical data of natural disasters, Hokkaido has the lowest vulnerability, with a minimum of only 0.01 and maximum of 0.15. In the rest of Japan, the natural disaster vulnerability propensity rates are higher. More specifically, vulnerability rate ranges from 0.25 to 0.75) in Honshu and Tohoku, 0.30 to 0.85 in Kanto and Chubu region, from 0.25 to 0.95 in Kinki and Shikoku region, and from 0.20 to 0.85 in Kyushu and Nansei region. (see Table 6).

[INSERT FIGURE 6]

In addition, we would like to compare the natural disaster devastation magnitude rate (**Π**) between Kobe earthquake of 1995 and the Northeast Japan earthquake of 2011. We like to estimate and compare the magnitude of the impact of those natural disasters on Japan. According to our results the devastation resulting from the 1995 Kobe earthquake was quite limited at 1.7%. But the devastation caused by the 2011 Northeast Japan earthquake and tsunami was much larger at 35% according to our computations below. In Figure 7, we can observe more clearly from a graphical perspective that the Northeast Japan earthquake and tsunami caused a much larger devastation several times than the Kobe earthquake.

[INSERT FIGURE 7]

Kobe Earthquake of 1995:

$\mathbf{\Pi}_{1995}$ = 552 Km^2/378,000 Km^2 + 7,000/128.000,000

(0.0015) (0.000055) = 0.017 * 100% = -1.7%

Northeast Japan Earthquake and Tsunami of 2011:

$\mathbf{\Pi}_{2011}$ = 132,000 Km^2/378,000 Km^2 + 20,000/128.000,000

(0.35) (0.00016) = 0.35 * 100% = -35%

Natural disaster devastation magnitude rate of Kobe earthquake $\mathbf{\Pi}_{(1995)}$ = 1.70%

Natural disaster devastation magnitude rate of Northeast Japan earthquake and Tsunami in 2011 $\mathbf{\Pi}_{(2011)}$ = 35.00%

5. The Economic Desgrowth (δ)

Finally, to measure the impact of the earthquakes and tsunamis on economic growth, we use the new concept of "**Economic Desgrowth** (**δ**)" introduced by Ruiz Estrada (2011b). According to the concept of economic desgrowth, we try to discover possible leakages that can adversely affect GDP performance. Basically, this new concept assumes that in the process of the GDP formation, leakages may arise due to different factors, in our case natural disasters. According to our estimates, the economic desgrowth caused by the Kobe earthquake is an impact of -0.02% on Japan's GDP. Our estimates indicate that the economic desgrowth caused by the Northeast Japan earthquake and tsunami of 2011 has been much larger, at -2.7% in 2011. Therefore, economic growth is going to be between -1.5% and 0% in 2011 according to our final results in table 3 and Figure 8.

[INSERT TABLE 3 AND FIGURE 8]

6. Concluding Observations and Policy Implications

Natural disasters can have a significant negative impact on economic performance but measuring this impact with any degree of certainty is inherently challenging. In this paper, we propose a new model for evaluating the impact of natural disasters on economic performance. The natural disaster vulnerability evaluation modeling (**NDVE-Modeling**) is based on three indicators - (i) the natural disasters vulnerability propensity rate (**Ω**); (ii) the natural disaster devastation magnitude rate (**Π**); and (iii) economic desgrowth rate (**δ**). The underlying intuition is that the economic impact of natural disasters depend on a country's vulnerability to natural disasters and the devastation caused by natural disasters, which jointly determine the leakage from economic growth and hence the impact on growth. We hope that our model will contribute to a better understanding of measuring the economic impact of natural disasters. The application of our model to two natural disasters in Japan – the Kobe earthquake of January 1995 and the Northeast Japan earthquake and tsunami of March 2011 – indicates that Northeast Japan will have a bigger impact on the Japanese economy than Kobe. The effects of the Northeast Japan earthquake and tsunami together are still being felt – for example, in the continuing power shortages – and it is too early to make a definitive assessment. Nevertheless, the immediate implication for Japanese policymakers is that they may need to stronger measures to support growth than they did in 1995. At a broader level, our results confirm that natural disasters can have a significant economic impact even in advanced countries with good infrastructure and high level of preparedness. The inescapable policy implication for developing countries, which tend to suffer the bulk of natural disasters, is that investing in anticipatory measures such as rigorous building codes, early warning systems and emergency response plans may yield sizable benefits in the medium and long term.

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TABLES AND FIGURES

Table 1: Major Natural Disasters in Developing Asia, 2000-2010

	Earthquake		Flood		Storm		Drought		Epidemic
	Deaths	**Damages ($ bill.)**	**Deaths**	**Damages ($ bill.)**	**Deaths**	**Damages ($ bill.)**	**Deaths**	**Damages ($ bill.)**	**Deaths**
Central and West Asia	74,965	5.6	5,910	10.5	727	1.6	180	0.8	3,708
East Asia	91,003	130.9	9,302	66.6	5,582	73.4	134	10.8	769
Pacific	59	0.0	56	0.1	270	0.1	0	0.0	381
South Asia	73,221	6.9	18,668	19.7	6,856	2.9	20	1.5	2,964
Southeast Asia	183,979	12.8	7,701	5.8	147,457	9.4	0	0.7	2,034
Total	**423,227**	**156.3**	**41,637**	**102.7**	**160,892**	**87.4**	**334**	**13.8**	**9,856**

Note: East Asia excludes Japan and Macao, China.

Source: EM-DAT, The International Disaster Databases, Centre for Research on the Epidemiology of Disasters. (accessed April 2011).

Table 2: Probability of Natural Disasters Events According to Historical Data from 1959 to 2011

No.	Country	β1	β2	β3	β4	β5	β6	β7	β8	β9	β10	β11	β12	β13	β14	β15	β16	ΣβL	ΣβT	ΣβA	k	ΩL	ΩT	ΩA
1	CHINA	0.95	0.55	0.99	0.05	0.95	0.65	0.55	0.65	0.30	0.20	0.35	0.95	0.65	0.30	1.00	0.85	10	16	13	6.25	62	100	81
2	JAPAN	1.00	1.00	0.35	0.75	0.85	0.00	0.65	0.55	0.35	0.65	0.45	0.85	0.00	0.10	0.85	0.90	9	15	12	6.25	58	94	76
3	U.S.	0.65	0.25	0.85	0.25	0.75	0.65	0.50	0.20	0.65	0.65	0.70	0.50	0.35	0.4	0.25	0.65	8	16	12	6.25	51	100	76
4	INDONESIA	0.95	0.95	0.85	1.00	0.95	0.65	0.00	0.85	0.00	0.25	0.00	0.65	0.00	0.00	0.00	0.95	8	10	9	6.25	50	63	56
5	PHILIPPINESS	0.99	0.98	0.85	0.95	0.95	0.00	0.00	0.85	0.00	0.75	0.00	0.65	0.00	0.00	0.00	0.98	8	9	8	6.25	50	56	53
6	AUSTRALIA	0.35	0.35	1.00	0.00	0.50	1.00	0.00	0.00	0.00	0.55	0.65	0.90	0.65	0.00	0.65	0.75	7	11	9	6.25	46	69	57
7	SOUTH KOREA	0.80	0.75	0.70	0.00	0.85	0.00	0.25	0.35	0.25	0.55	0.85	0.65	0.00	0.00	0.35	0.89	7	12	10	6.25	45	75	60
8	TAIWAN	0.80	0.75	0.55	0.35	0.95	0.00	0.00	0.55	0.00	0.55	0.65	0.45	0.00	0.00	0.35	0.99	7	13	10	6.25	43	82	63
9	CHILE	0.85	0.75	0.65	0.55	0.35	0.35	0.85	0.75	0.25	0.25	0.20	0.25	0.30	0.3	0.20	0.10	7	13	10	6.25	43	81	62
10	GUATEMALA	0.95	0.25	0.55	1.00	0.35	0.85	0.00	0.90	0.00	0.25	0.00	0.85	0.35	0.00	0.00	0.55	7	13	10	6.25	43	80	61
11	EL SALVADOR	0.95	0.25	0.55	1.00	0.35	0.85	0.00	0.90	0.00	0.25	0.00	0.85	0.00	0.00	0.00	0.55	7	12	9	6.25	41	75	58
12	HONDURAS	0.95	0.25	0.55	1.00	0.35	0.85	0.00	0.90	0.00	0.25	0.00	0.85	0.00	0.00	0.00	0.55	7	12	9	6.25	41	75	58
13	NICARAGUA	0.95	0.25	0.55	1.00	0.35	0.85	0.00	0.90	0.00	0.25	0.00	0.85	0.00	0.00	0.00	0.55	7	12	9	6.25	41	75	58
14	COSTA RICA	0.95	0.25	0.55	1.00	0.35	0.85	0.00	0.90	0.00	0.25	0.00	0.85	0.00	0.00	0.00	0.55	7	12	9	6.25	41	75	58
15	PANAMA	0.95	0.25	0.55	1.00	0.35	0.85	0.00	0.90	0.00	0.25	0.00	0.85	0.00	0.00	0.00	0.55	7	12	9	6.25	41	75	58
16	MEXICO	0.95	0.20	0.70	0.75	0.55	0.35	0.00	0.45	0.00	0.20	0.20	0.75	0.45	0.00	0.05	0.55	6	11	9	6.25	38	71	55
17	RUSSIA	0.85	0.15	0.75	0.20	0.10	0.85	0.95	0.35	0.95	0.00	0.00	0.75	0.10	0.00	0.05	0.00	6	11	9	6.25	38	70	54
18	VIETNAM	0.65	0.90	1.00	0.00	0.95	0.00	0.00	0.55	0.00	0.00	0.00	0.95	0.00	0.00	0.00	0.95	6	11	9	6.25	37	70	54
19	CARIBBEAN	0.95	0.85	0.45	0.00	0.99	0.00	0.00	0.20	0.00	0.95	0.00	0.55	0.00	0.00	0.00	0.99	6	11	8	6.25	37	68	53
20	INDIA	0.65	0.55	1.00	0.00	0.85	0.75	0.00	0.10	0.00	0.00	0.00	0.85	0.45	0.00	0.15	0.55	6	11	9	6.25	37	70	53
21	CAMBODIA	0.70	0.85	1.00	0.00	0.95	0.00	0.00	0.65	0.00	0.00	0.00	0.98	0.00	0.00	0.00	0.75	6	11	8	6.25	37	69	53
22	THAILAND	0.35	0.85	0.85	0.00	0.90	0.00	0.00	0.65	0.00	0.00	0.00	0.98	0.00	0.00	0.00	0.90	5	11	8	6.25	34	66	50
23	BANGLADESH	0.10	0.90	1.00	0.00	0.99	0.00	0.00	0.55	0.00	0.00	0.00	0.90	0.03	0.00	0.00	0.85	5	11	8	6.25	33	66	50
24	COLOMBIA	0.95	0.10	1.00	0.00	0.55	0.20	0.00	0.85	0.00	0.00	0.00	0.65	0.00	0.00	0.00	0.55	5	9	7	6.25	30	55	43
25	EGIPT	0.85	0.15	0.90	0.00	0.00	0.10	0.00	0.25	0.00	0.00	0.00	0.85	0.65	0.00	1.00	0.00	5	9	7	6.25	30	54	42
26	VENEZUELA	0.95	0.20	1.00	0.00	0.65	0.25	0.00	0.75	0.00	0.00	0.00	0.45	0.00	0.00	0.00	0.45	5	8	7	6.25	29	53	41
27	SINGAPORE	0.03	0.95	0.95	0.00	0.90	0.00	0.00	0.00	0.00	0.00	0.00	0.95	0.00	0.00	0.00	0.90	5	9	7	6.25	29	58	44
28	ECUADOR	0.95	0.10	1.00	0.00	0.35	0.15	0.00	0.90	0.00	0.00	0.00	0.55	0.00	0.00	0.00	0.65	5	8	7	6.25	29	52	41
29	ITALY	0.98	0.20	0.95	0.95	0.00	0.00	0.65	0.25	0.15	0.00	0.00	0.30	0.00	0.00	0.05	0.15	5	8	6	6.25	29	52	40
30	MALAYSIA	0.03	0.75	0.75	0.00	0.85	0.00	0.00	0.35	0.00	0.00	0.00	0.85	0.00	0.00	0.05	0.75	4	9	7	6.25	27	55	41
31	PAKISTAN	0.95	0.05	0.85	0.00	0.00	0.55	0.10	0.65	0.00	0.00	0.00	0.55	0.15	0.45	0.00	0.00	4	8	6	6.25	27	48	37
32	BRAZIL	0.35	0.85	0.85	0.00	0.00	0.35	0.00	0.00	0.00	0.25	0.00	0.65	0.25	0.00	0.00	0.65	4	8	6	6.25	26	50	38
33	NEW ZEALAND	0.95	0.35	0.35	0.55	0.25	0.00	0.20	0.00	0.00	0.35	0.00	0.30	0.00	0.00	0.00	0.85	4	7	6	6.25	26	46	36
34	GREECE	0.95	0.90	0.25	0.05	0.20	0.00	0.00	0.55	0.00	0.00	0.00	0.85	0.00	0.00	0.00	0.35	4	7	6	6.25	26	45	35
35	ICELAND	0.65	0.20	0.01	0.35	0.00	0.00	0.75	0.00	0.95	0.00	0.00	0.03	0.00	0.85	0.00	0.00	4	7	5	6.25	24	43	34
36	HOLLAND	0.15	0.85	1.00	0.00	0.55	0.00	0.00	0.00	0.00	0.00	0.00	0.85	0.00	0.00	0.00	0.25	4	7	5	6.25	23	45	34
37	MOROCCO	0.90	0.85	0.25	0.00	0.00	0.00	0.00	0.25	0.00	0.00	0.00	0.35	0.60	0.00	0.00	0.10	3	6	5	6.25	21	36	28
38	BOLIVIA	0.95	0.00	0.55	0.35	0.00	0.00	0.00	0.65	0.00	0.00	0.00	0.55	0.15	0.10	0.00	0.00	3	6	4	6.25	21	35	28
39	CYPRUS	0.25	0.85	0.45	0.00	0.00	0.00	0.00	0.50	0.00	0.00	0.00	0.45	0.00	0.00	0.00	0.55	3	6	4	6.25	19	37	28
40	CANADA	0.10	0.10	0.10	0.00	0.00	0.00	0.65	0.35	0.55	0.00	0.00	0.25	0.00	0.75	0.05	0.00	3	6	4	6.25	18	36	27
41	KENYA	0.55	0.00	0.10	0.15	0.00	0.15	0.00	0.00	0.00	0.00	0.00	0.90	0.65	0.00	0.15	0.00	3	5	4	6.25	17	30	23
42	SWEDEN	0.00	0.15	0.05	0.00	0.00	0.00	0.45	0.00	0.55	0.30	0.00	0.05	0.00	0.75	0.00	0.00	2	5	3	6.25	14	29	22
43	NORWAY	0.00	0.15	0.05	0.00	0.00	0.00	0.45	0.00	0.55	0.30	0.00	0.05	0.00	0.75	0.00	0.00	2	5	3	6.25	14	29	22
44	ISRAEL	0.85	0.05	0.01	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.60	0.55	0.00	0.00	0.10	2	4	3	6.25	14	22	18
45	SPAIN	0.75	0.10	0.35	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.10	0.40	0.35	0.00	0.00	0.00	2	4	3	6.25	13	22	18
46	LAOS	0.35	0.00	0.55	0.00	0.00	0.00	0.00	0.65	0.00	0.00	0.00	0.55	0.00	0.00	0.05	0.00	2	4	3	6.25	13	24	18
43	PARAGUAY	0.95	0.00	0.45	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.35	0.10	0.00	0.00	0.00	2	3	2	6.25	12	18	15
48	ARGENTINA	0.35	0.10	0.35	0.10	0.00	0.00	0.15	0.15	0.10	0.00	0.00	0.25	0.05	0.10	0.00	0.15	2	3	3	6.25	12	21	16
49	FRANCE	0.05	0.10	0.10	0.00	0.00	0.00	0.35	0.00	0.35	0.00	0.00	0.55	0.00	0.25	0.00	0.00	2	3	3	6.25	11	22	16
50	URUGUAY	0.55	0.35	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.15	0.00	0.25	0.00	0.00	0.00	0.00	2	3	2	6.25	10	16	13
51	ENGLAND	0.25	0.35	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.00	0.35	0.00	0.05	0.00	0.00	2	3	2	6.25	9	17	13
52	GERMANY	0.10	0.05	0.05	0.00	0.00	0.00	0.35	0.00	0.25	0.00	0.00	0.20	0.00	0.25	0.00	0.00	1	2	2	6.25	8	15	11
53	CZECH REPUBLIC	0.10	0.00	0.15	0.00	0.00	0.00	0.25	0.00	0.00	0.00	0.00	0.45	0.00	0.25	0.00	0.00	1	2	2	6.25	8	14	11
54	MONGOLIA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.03	0.00	0.00	1.00	0.00	1	2	2	6.25	7	14	11
55	HUNGARY	0.00	0.00	0.15	0.00	0.00	0.00	0.20	0.00	0.25	0.00	0.00	0.05	0.00	0.25	0.00	0.00	1	2	1	6.25	6	11	8
53	SOUTH AFRICA	0.00	0.25	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.35	0.00	0.15	0.00	0.00	0.00	0.00	1	2	1	6.25	5	11	8
57	DENMARK	0.00	0.15	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.35	0.00	0.00	1	1	1	6.25	4	8	6
58	BELGIUM	0.10	0.05	0.15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.15	0.00	0.03	0.00	0.00	0	1	1	6.25	3	5	4
59	LUXEMBURG	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.05	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0	1	1	6.25	2	4	3
	TOTAL	[illegible]	22.38	[illegible]	13.35	19.83	12.1	8.55	20.8	6.45	9.15	4.25	[illegible]	6.83	6.2	6.25	22.4	0	0	0	0	0	0	0

High level of risk

1 **Earthquake**
2 **Floods**
3 **Epidemics**

Ω = Probability to have any natural disaster anytime
L = Minimum
A= Average
T = Maximum

NATURAL DISASTERS EVENTS

β1 Earthquake
β2 Tsunami
β3 Floods
β4 Volcano eruption
β5 Typhoon
β6 Fire pollution
β7 Snow avalanche
β8 Landslide
β9 Blizzards
β10 Cyclonic storms
β11 Tornadoes
β12 Epidemics
β13 Droughts
β14 Hailstorms
β15 Nuclear pollution
β16 Hurricane

Source: EM-DAT, the International Disaster Databases, Centre for Research on the Epidemiology of Disasters. (accessed April 2011).

Note: We applied probabilities according to the record of all natural disasters events are mentioned in this table. Hence, we are taking 59 countries with different levels of natural disasters levels in the past 52 years from 1959 to 2011.

Table 3: Japanese GDP Growth rates from 1971-2011*

1	1971	4.4				
2	1972	8.4				
3	1973	8.0				
4	1974	-1.2				
5	1975	3.1				
6	1976	4.0				
7	1977	4.4				
8	1978	5.3				
9	1979	5.5				
10	1980	3.2				
11	1981	4.2				
12	1982	3.4				
13	1983	3.1				
14	1984	3.1				
15	1985	4.5				
16	1986	2.8				
17	1987	4.1				
18	1988	7.1				
19	1989	5.4				
20	1990	5.6				
21	1991	3.3				
22	1992	0.8				
23	1993	0.2				
24	1994	0.9				
25	1995	1.9	δ = -0.02	θ = [0.5 & 2]	Ω = 7	Π = 0.07
26	1996	1.7				
27	1997	1.6				
28	1998	-2.0				
29	1999	-0.1				
30	2000	2.9				
31	2001	0.2				
32	2002	0.3				
33	2003	1.4				
34	2004	2.7				
35	2005	1.9				
36	2006	2.0				
37	2007	2.4				
38	2008	-1.2				
39	2009	-5.2				
40	2010	1.2				
41	2011	**-1.5**	δ = -2.7	θ = [0.1 & 3.0]	Ω = 9	Π = 35
			δ = -1	θ = [0 & -2.0]		
			δ = -0.5	θ = [0 & -1]		
			δ = 1.5	θ = [0 & 1]		
			δ = 2	θ = [0 & 2.5]		

Variables:
δ = GDP desgrowth rate
θ = GDP growth rates intervals
Ω = The natural disasters vulnerability propensity rate
Π = The natural disaster devastation magnitude rate

Source: International Monetary Found (IMF)

http://www.econstats.com/weo/V002.htm

Figure 1: The Relationship between the Natural Disasters Vulnerability Propensity Rate (**Ω**) and the GDP Growth Rates

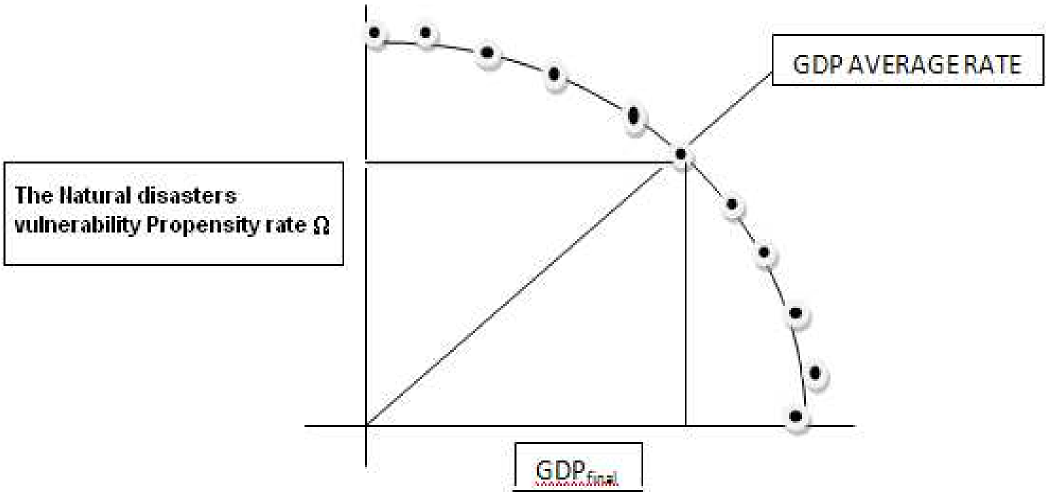


Figure 2: How Natural Disasters Vulnerability Propensity Rate can affect on the Final GDP Growth Rate

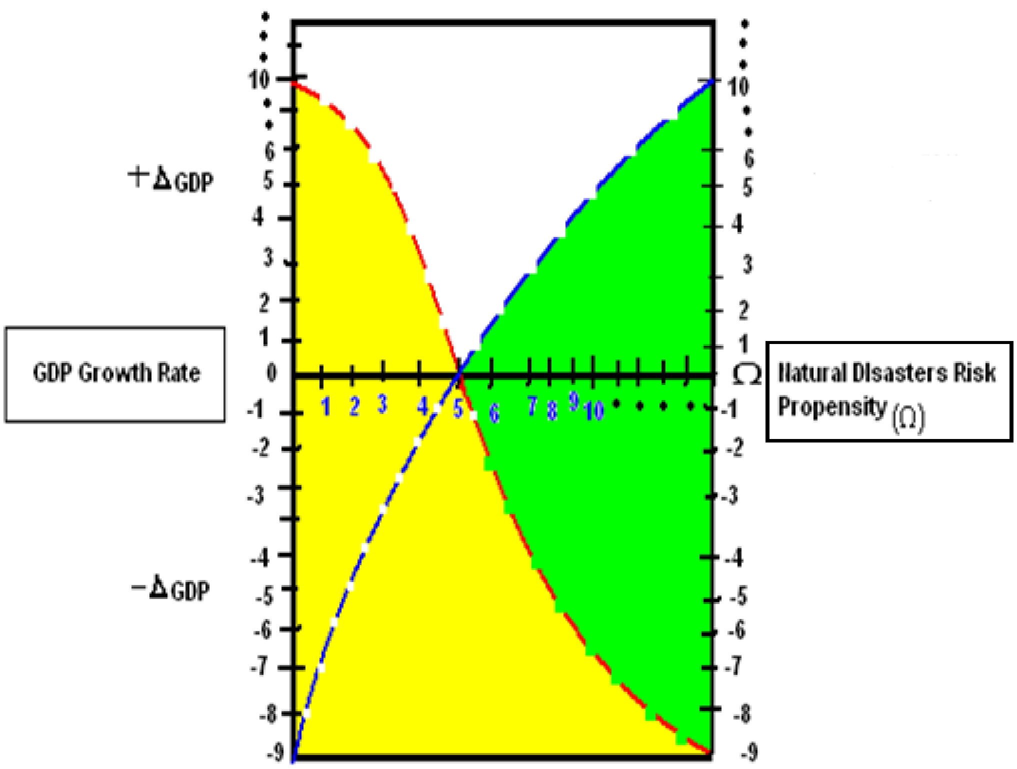


Figure 3: The Mega-Surface Coordinate Space

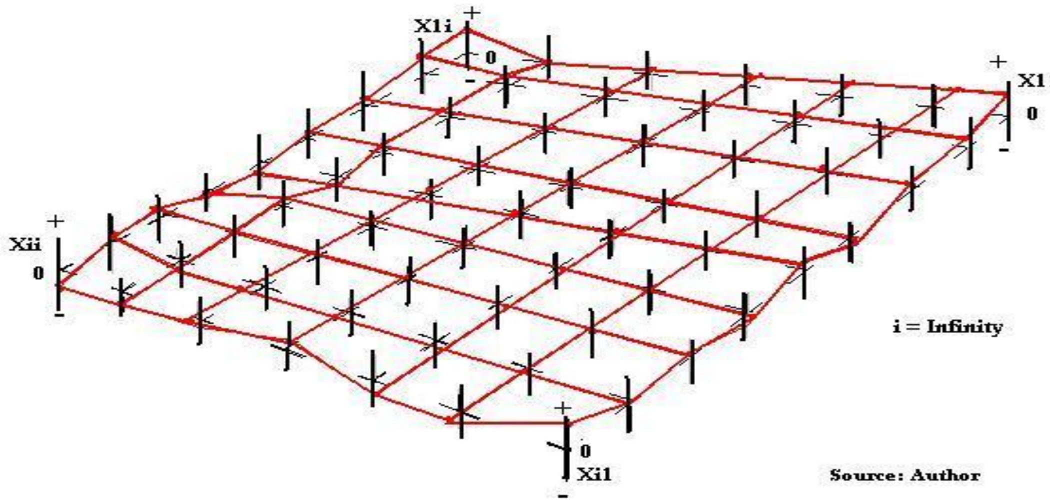
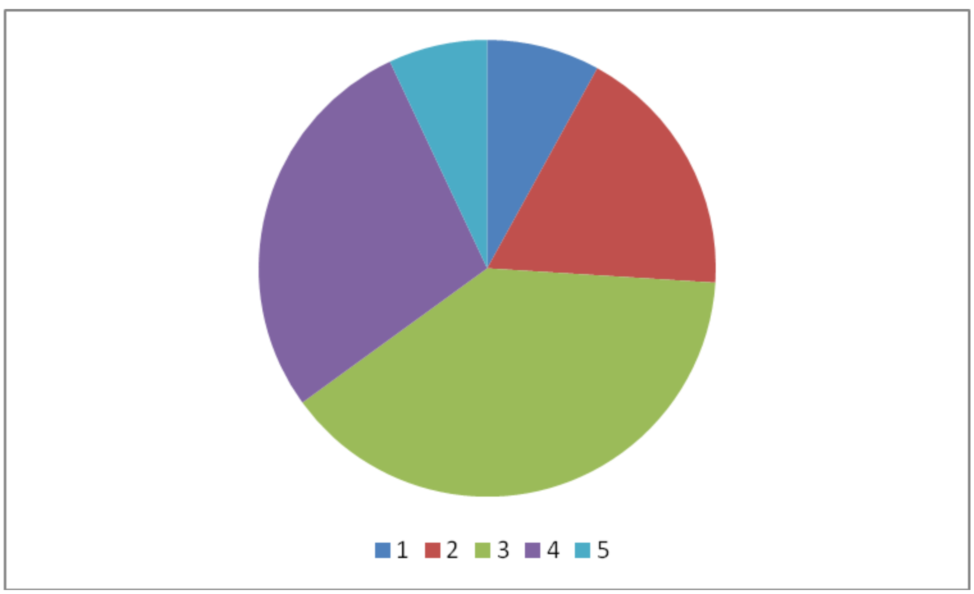


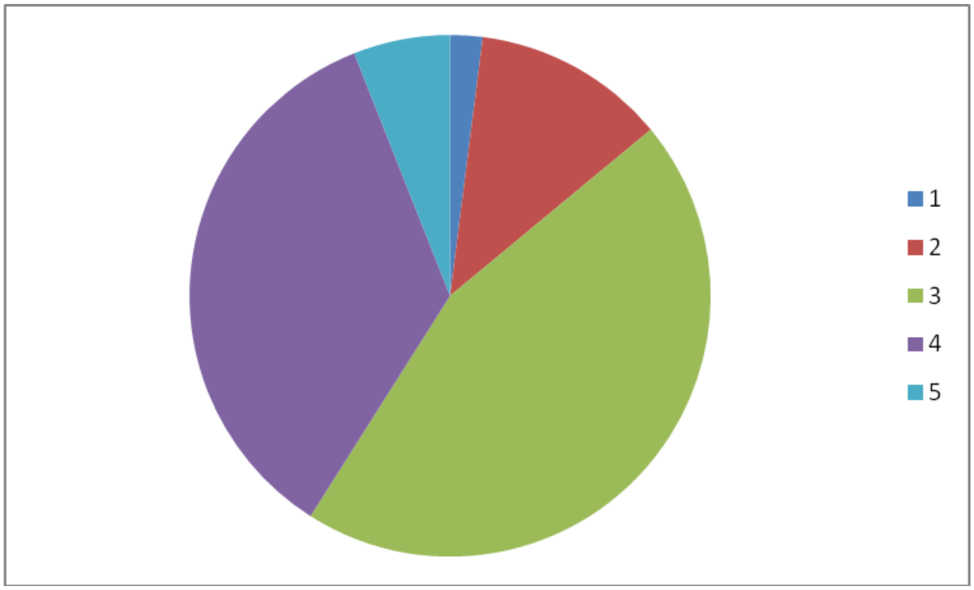
Figure 4: Contribution of each Japanese Region on the Final GDP (1999-2010)



Region		
1	Hokkaido region	8%
2	Honshu region and Tohoku region	18%
3	Kanto region and Chubu region	39%
4	Kinki region and Shikoku region	28%
5	Kyushu region and Nansei region	7%
	Total	100%

Source: JETRO and METI (accessed April 2011).

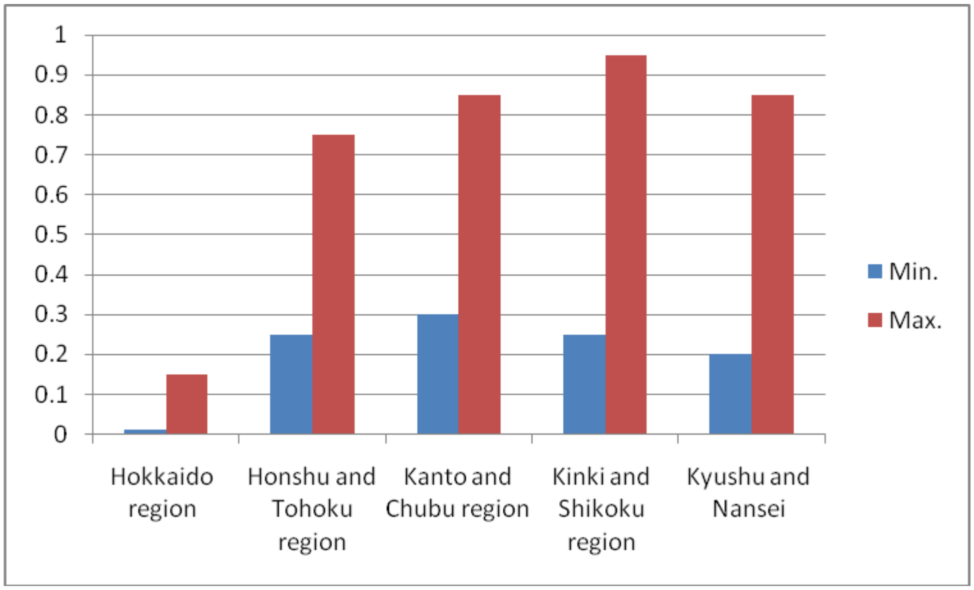
Figure 5: Concentration of Japanese Industrial Input-Output (1999-2011)



Region		
1	Hokkaido region	2%
2	Honshu region and Tohoku region	12%
3	Kanto region and Chubu region	45%
4	Kinki region and Shikoku region	35%
5	Kyushu region and Nansei region	6%
	Total	100%

Source: JETRO (accessed April 2011) and METI (accessed April 2011).

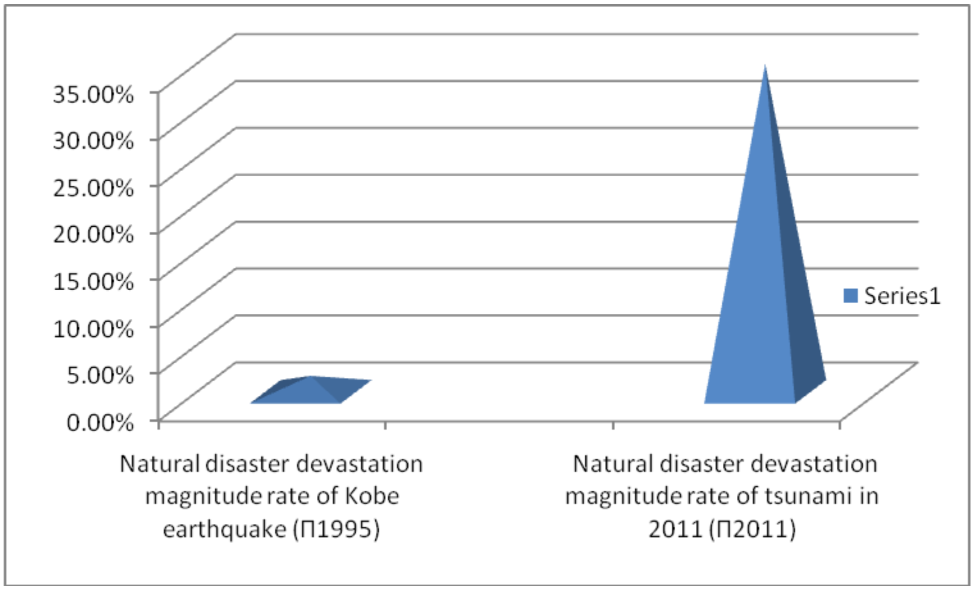
Figure 6: The Natural Disaster Vulnerability Propensity Rate by Region (Japan) 1959-2011



Region	Min.	Max.
Hokkaido region	0.01	0.15
Honshu and Tohoku region	0.25	0.75
Kanto and Chubu region	0.30	0.85
Kinki and Shikoku region	0.25	0.95
Kyushu and Nansei	0.20	0.85

Source: EM-DAT, the International Disaster Databases, Centre for Research on the Epidemiology of Disasters. (accessed April 2011).
The Fire and Disasters Management Agency (FDMA) – Japan. (accessed April 2011).

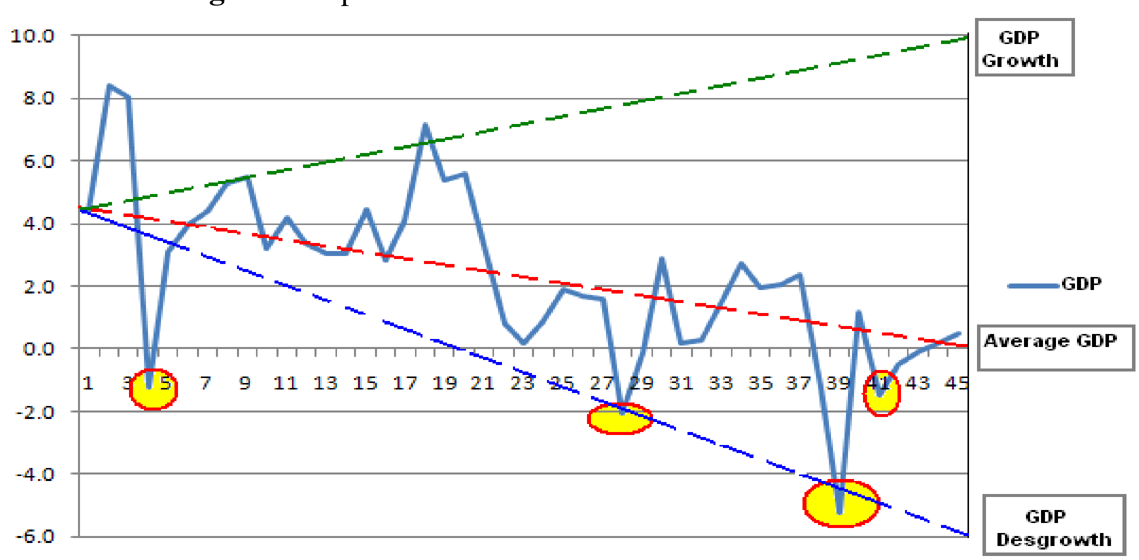
Figure 7: Natural Disaster Devastation Magnitude Rate between Kobe earthquake (1995) and Tsunami (2011)



Natural disaster devastation magnitude rate of Kobe earthquake (Π_{1995})	1.70%
Natural disaster devastation magnitude rate of tsunami in 2011 (Π_{2011})	35.00%

Note: Final results from authors model

Figure 8: Japanese GDP Growth Rate from 1971-2011*

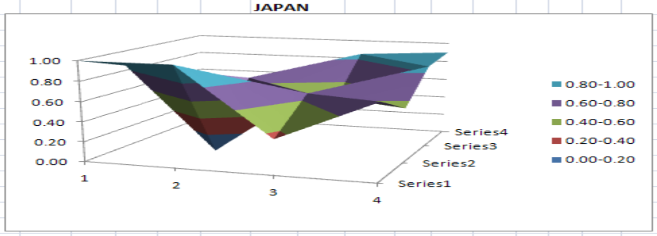


Source: International Monetary Fund (IMF) (accessed April 2011).

Table 9: The Natural Disasters Vulnerability Surface (NDV-Surface) for Japan, U.S., China, Luxemburg, Guatemala and South Korea

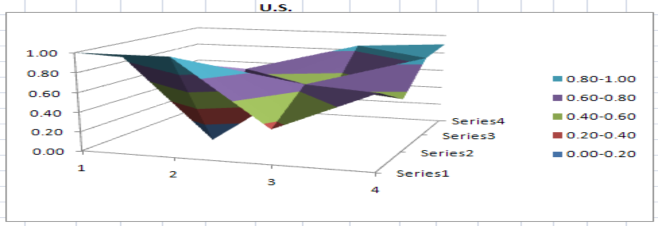
1.00	1.00	0.35	0.75
0.85	0.00	0.65	0.55
0.35	0.65	0.45	0.85
0.00	0.10	0.85	0.90

JAPAN



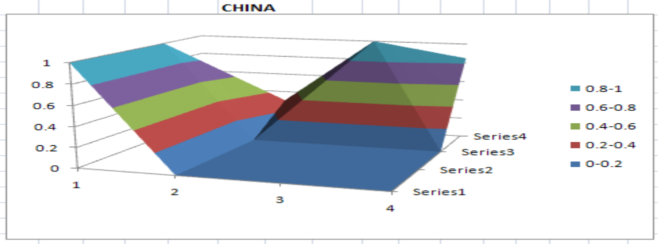
U.S.

1.00	1.00	0.35	0.75
0.85	0.00	0.65	0.55
0.35	0.65	0.45	0.85
0.00	0.10	0.85	0.90



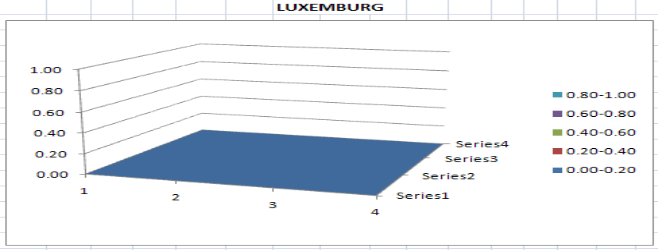
0.95	0.55	0.99	0.05
0.95	0.65	0.55	0.65
0.30	0.20	0.35	0.95
0.65	0.30	1.00	0.85

CHINA



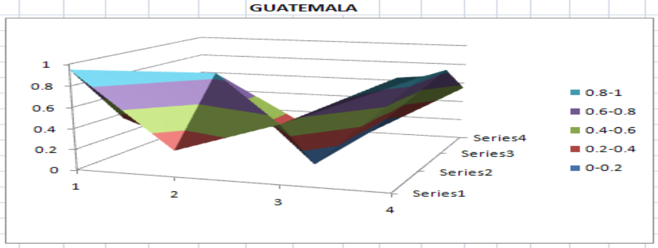
LUXEMBURG

0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00



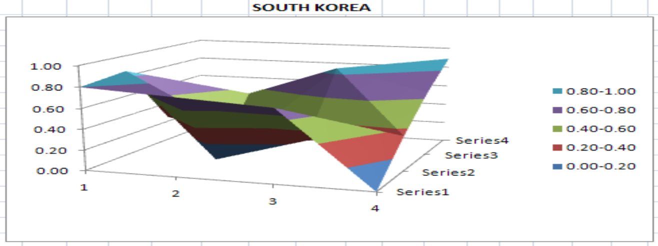
0.95	0.25	0.55	1.00
0.35	0.85	0.00	0.90
0.00	0.25	0.00	0.85
0.35	0.00	0.00	0.55

GUATEMALA



0.80	0.75	0.70	0.00
0.85	0.00	0.25	0.35
0.25	0.55	0.85	0.65
0.00	0.00	0.35	0.89

SOUTH KOREA



Source: EM-DAT, the International Disaster Databases, Centre for Research on the Epidemiology of Disasters. (accessed April 2011).