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Full length research paper

Random uncertain model for natural disaster risk management

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This paper introduces the general natural disaster mechanism, defines the disaster factors, object at exposure, disaster environment and conditions. And then disaster factor model is developed to calculate the occurrence probability of the natural disaster, this model is a binary choice model, therefore coefficients estimation approach is logistic regression. The loss rate model is given to assess the exposure of the disaster; this model is a linear model. A case about snow & ice disaster appeared in four provinces of south china is studied; empirical distribution function of random variable is shown in this paper.

Keywords: Disaster factor model; disaster loss rate model; random uncertain variable; logistic regression; binary choice model

INTRODUCTION

Natural disasters, including snow, flood, rainstorm, typhoon, landslide and so on, occurs more and more frequently, this phenomena is likely linked to climate change (Neumayer and Barthel 2011). There is a growing recognition that natural disasters is one of the most dangerous threaten to human system, and natural disaster risk management has became one of the globe issue(Irasema 2002); many scholars devoted themselves into this field. Generally speaking, management of disaster risks involves pre-, co-, and post-disaster phases (Erdik, Şeşetyan et al. 2011).

(Guzzetti, Reichenbach et al. 2005) indicated that the probability that a landslide will occur in an area is $P_{AL}=P\{AL\geq a_L\}$, in which AL is the area of a landslide greater or equal than a minimum size, a_L, and a specific equation about P_{AL} is given as

$$P_{A_L}=\int_{a_L}^{\infty}\frac{1}{a\Gamma(\rho)}\left[\frac{a}{A_L-s}\right]^{\rho+1}\exp\left[-\frac{a}{A_L-s}\right]dA_L$$

(Su, Zhang et al. 2011) believed that frequency of snow disaster is increasing in China recently; and they studied the flood/snow disaster outbreaks and the important disaster-forming environmental factors, using by spatial auto-correlation model and canonical correlation model. Disaster factors in logistic are analyzed by (Zhang, Chen et al. 2011), these factors are transportation factors, handling and loading and unloading factors. (Castellarin, Vogel et al. 2007) introduce multivariate regional envelopes (MVEs) of extreme floods, based on probabilistic regional envelope curves of extreme floods (RECs). (Christian 1999) introduced the risk sources of major industrial accidents, nuclear accidents, major accidents at sea and disasters due to natural hazards. Taiwan scholars (Chang, Chiang et al. 2007) built a logistic regression model to solve landslide disaster problem, the key factors are elevation, slope, sin of aspect, cos of aspect, plane curvature, profile curvature, distance to fault line, distance to channel, distance to ridge line and wetness index. (Coles and Casson 1998) modeling the hurricane wind speed by extreme value theory, the key model is

$$\Pr\{X<x\}=1-\lambda\left[1+\xi^*\frac{x}{\sigma^*}\right]^{-1/\xi^*}\quad(x>u)$$

where, X is the factor, σ^* and ξ^* are parameters, u is a threshold value. (Batabyal and Beladi 2001) used the theory of Poisson processes to construct a model of earthquake; also studied the question of business failure problem. (Nakai, Sato et al. 2012) introduced a snow disaster forecasting system.

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Disaster loss estimation immediately after an disaster should consider direct physical damage (building stock, high potential loss facilities, transportation system and utility system), direct economic social loss (casualties, shelter), and induced physical damage (inundation, fire, hazmat, debris) (Erdik, Şeşetyan et al. 2011); and the relationship between GDP and seismic loss is

$$L = \sum P(I)F(I, GDP)GDP$$

Where L is the economic loss, $P(I)$ is the probability of earthquake intensity I, $F(I, GDP)$ is measurement of the area's vulnerability to earthquake damage for given GDP value and earthquake intensity I. (Dutta, Herath et al. 2003) introduced an integrated model for flood loss estimation, combining a physically based distributed hydrologic model and a distributed flood loss estimation model.

(Lumbroso and Gaume 2012) analyzed how the uncertainty in indirect discharge estimates can be reduced during post-event surveys and through consistency checks; and provided a serials of guidelines, for reducing uncertainty in estimates of extreme flash flood discharges.

Some researchers have gain many achievements in specific natural disaster, such as (Bommer, Scott et al. 2000; Fäh, Kind et al. 2001; Meletti, Galadini et al. 2008; Erdik, Şeşetyan et al. 2011; Shieh, Wu et al. 2011) have researched the earthquake mechanism and seismic risk management; (I.R 2003; Peacock, Brody et al. 2005) have studied the hurricanes risk; (Ercanoglu and Gokceoglu 2004; Chang, Chiang et al. 2007; Corominas and Moya 2008; Harp, Keefer et al. 2011; Tang, Zhu et al. 2011) have published their research in landslide risk field; (Bimal Kanti 1997; Dutta, Herath et al. 2003; Kelman and Spence 2004; Castellarin, Vogel et al. 2007; Lumbroso and Gaume 2012) introduce the floods risk management approaches.

METHODOLOGY

There is no generally accepted risk definition, (Christian 1999) printout that risk is a function of the hazards connected with a certain technological or environmental system, the "likelihood" that a hazard results in an undesired event ("accident", "disaster") and the vulnerability of the environment. Many planners and policy makers often employ expert risk model to justify hazard policies (Peacock, Brody et al. 2005). Many scholars believe that disaster risk is always decomposed into the probability of the event (P) and potential exposures (E). Risk could be illustrated by the following equation

$$\text{Risk(R)}=\text{Probability(P)}\times\text{Exposures(E)}$$

The probability of occurrence is one of the key components (Corominas and Moya 2008), there are two different approaches have been used to assess probability of disaster: (1)occurrence of disaster is obtained by computing the probability of failure of the object at risk; (2)the probability is obtained by means of the statistical analysis of past disaster events, specifically by the assessment of the past disaster frequency. In this research, factor disaster model is built to estimate the probability.

Estimation of economic loss is very important for disaster risk management (Dutta, Herath et al. 2003), especially for real-time disaster mitigation decision. Disaster loss rate model is developed in this research to solve exposure assessment problem.

Uncertain Random Theory

Uncertain theory is introduced by (Liu 2007). Based on the uncertain theory, (Liu 2011) built uncertain random theory.

Define 1: An uncertain random variable is a function ξ from a probabilities space (Ω, F, Pr) to a collection of uncertain variables such that $M\{\xi(\omega)\in B\}$ is a measurable function of ω for any *Borel* set B.

Define 2: let ξ be an uncertain random variable, and let B be a *Borel* set of real numbers. Then the chance measure of uncertain random event $\xi\in B$ is defined by

$$Ch\{\xi \in B\} = \int_0^1 \Pr\{\omega \in \Omega \mid M\{\xi(\omega) \in B\} \ge r\} dr.$$

Define 3: let ξ be an uncertain random variable. Then its chance distribution is defined by

$$\Phi(x) = \text{Ch}\{\xi \le x\}. \text{ for any } x\in R.$$

The chance measure has characters: (1) $\text{Ch}\{\xi\in \Phi\}=0$, $\text{Ch}\{\xi\in R\}=1$; (2) $\text{Ch}\{\xi\in B\}$ is a monotone increasing set function; (3) $\text{Ch}\{\xi\in B\}+\text{Ch}\{\xi\in B^c\}=1$. Hence $\Phi(x)$ is a monotone increasing function except $\Phi(x)\equiv0$ and $\Phi(x)\equiv1$.there holds $\text{Ch}\{\xi\ge x\}=1-\Phi(x)$.

Disaster Factor Model

The disaster system contains four sections: disaster environment, disaster factors, objects at exposure and condition elements. In the disaster environment, and affected by certain condition elements, disaster factors endangered the objects at exposure, when the shock power of factors is bigger that the threshold levels that object at exposure resist, then disaster event burst out; else, disaster event doesn't appear. This theory is similar to the argument "that signal a serious breakdown in sustainability" (Peacock, Brody et al. 2005).

Disaster factors are the drivers that may cause catastrophic event, such as huge casualties, property

Table 1: Disastrous factors and its measurement

Source	Factors	Key measurement
Atmosphere	snow	Sleet, freeze, Low temperature
	hurricane	Duration of typhoon and rainstorm, wind velocity
	rainstorm	Rainfall in 72 hours, Rainfall in 24 hours
	hailstone	Duration of hail, precipitation
Hydrosphere	flood	Maximum flow, surface runoff
	water logging	Depth of flood, duration
Lithosphere	earthquake	Magnitude, seismic intensity, aftershock
	landslide	Volume
	debris	Volume of flow, area

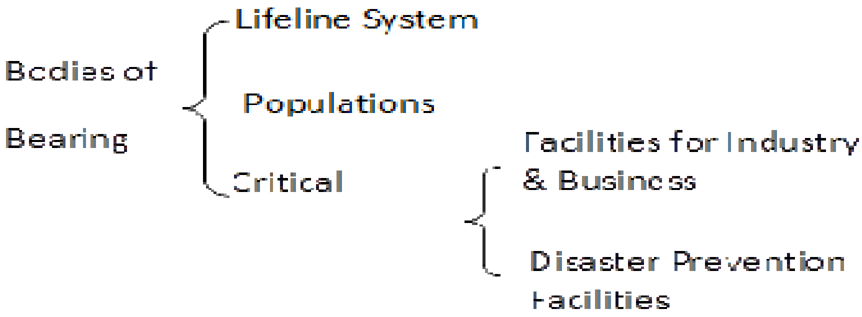

Figure 1 Types of hazard bearing body

damage, and destruction of infrastructures and so on. Simply speaking, disaster factors are the disaster sources or any things leading to disasters. There are natural disastrous factors and man-made disastrous factors. The natural disaster factors are shown in table 1.
Natural disaster is low frequency and catastrophic event, there are litter or on notice. It is difficult to predict the natural disaster event before it appears exactly, so this paper trades these unknown elements as random variables. What's more, some factors in the disaster source is invariant, which can't be exactly detected and measured, these factor should be taken as uncertain variable. Hence, Disastrous factor is an uncertain random variable, that is

$$\varepsilon(\omega)= w(\zeta_1(\omega), \zeta_2(\omega), \cdots, \zeta_n(\omega), \sigma) \qquad (1)$$

where $\zeta_1(\omega)$, $\zeta_2(\omega)$, ···, $\zeta_n(\omega)$ are a random variables with distribution function $F_1(x)$, $F_2(x)$, ···, $F_n(x)$; representing the disaster factors that can be measured; uncertain variable σ is the disaster factors that can't be exactly observed; $\varepsilon(\omega)$ belongs to a collection of uncertain variables, it is assumed that the chance distribution of factor $\varepsilon(\omega)$ is $\Phi(x)$.

Disaster environment is the system in the planet, in which disaster event may appear or the disaster factor may arise. Atmosphere, hydrosphere, lithosphere and so on are disaster environment. Condition elements are the factors that can foster the disaster or make it more serious; Such as, the wind in a fire disaster is the condition elements.
Objects at exposure are the human system or social system that has been destroyed or has the likelihoods to been destroyed by potential disasters. This paper divides the objects at exposure into three categories: populations, lifeline system, and critical infrastructures, as shown in figure 1.

Vulnerability of objects at exposure is the requirement condition of the disaster. One of the most important missions in emergency preparedness is to reduce vulnerability of objects at exposure. It is represented by the threshold value

$$\delta=g(\eta, y) \qquad (2)$$

in which, η is the vector or variable that represent the essential attribute of the object at exposure; y is the condition vector or variable. When $\varepsilon(\omega)\geq\delta$, the disaster event outbreak (it is denoted as z=1); while $\varepsilon(\omega)<\delta$, disaster is under latent (it is denoted as z=0).

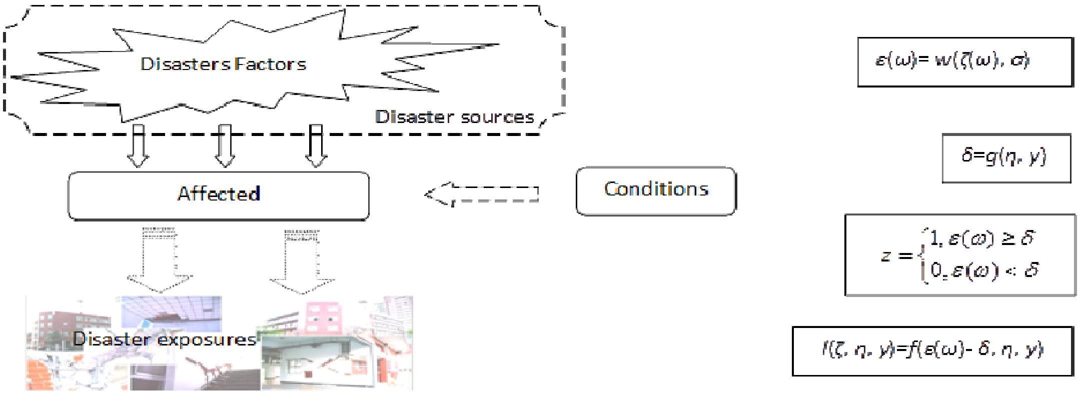

Figure 2 frame of the factor disaster model

Table 2: Statistical characteristics of low temperature data

	Jiangxi	Anhui	Hubei	Hunan
Obs.	120	120	120	120
Aver.	9.9	7.6	9.3	9.5
Std.	9.3	10.0	9.2	8.9
Min	-6.2	-11.2	-5.2	-4.7
Max	24.4	23.9	24.4	25.0
Mid.	10.1	7.3	9.2	9.1

The disaster outbreak model is

$$z=\begin{cases}1, \varepsilon(\omega)\geq\delta\\ 0, \varepsilon(\omega)<\delta\end{cases} \qquad (3)$$

Obviously, the frequency of disaster event is p=Ch{z =1}=Ch{$\varepsilon(\omega)$- $\delta\geq 0$}.

Disaster Loss Rate Model

Disaster exposure analysis is to assess loss cause by the disaster; the key index is loss rate, (Neumayer and Barthel 2011) proposed the loss calculation method is

$$Normalized\ damage=\frac{Damage}{Wealth}$$

Generally, loss rate is calculated as follow

$$loss\ rate=\frac{loss\ caused\ by\ diaster}{total\ value}$$

or

$$loss\ rate=\frac{volume\ be\ destroyed}{total\ volume}.$$

Loss rate is increasing by the disaster factors, decreasing by threshold value of object at exposure; is related to disaster condition variables. Disastrous loss rate function is

$$l(\zeta, \eta, y)=f(\varepsilon(\omega), \delta, \eta, y) \qquad (4)$$

The disaster risk model is combined by equation (1), (2), (3) and (4); this paper defines it as factor disaster model, its main frame is illustrated in figure 2.

Case Study

In this section, the snow & ice disaster in four provinces (jiangxi, anhui, hubei and hunan) in south china will be studied, this paper chooses the lowest temperatures in one month (denoted as ζ_1) and the amount of precipitation in one month (denoted as ζ_2) as factors. Data about lowest temperatures and precipitation in one month is collected from <Yearbook of China Meteorological (2001~2010)>, the statistical characteristics of ζ_1 and ζ_2 are illustrated in table 2 and table 3.

This paper tries to give the empirical distribution function of ζ_1 and ζ_2; although this process may be not

Table 3: Statistical characteristics of precipitation data

	Jiangxi	Anhui	Hubei	Hunan
Obs.	120	120	120	120
Aver.	123.3	89.7	105.4	121.6
Std.	100.9	98.2	114.9	97.0
Min	0.8	3.3	0.0	2.5
Max	522.2	898.0	758.0	799.9
Mid.	98.8	68.3	68.7	103.8

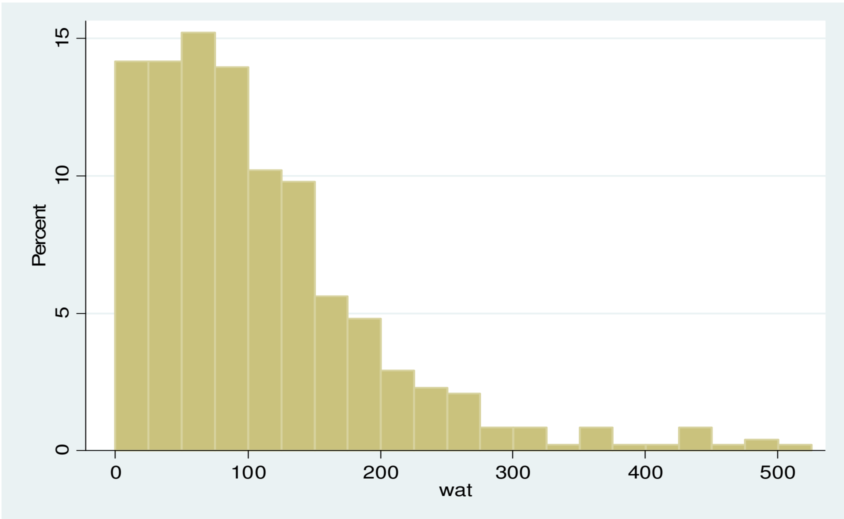

Figure 3 The histogram of random variable ζ_1

rigorous, it is meaningful to attempt. As is shown in figure 3, distribution function of random variable ζ_1 is approximately Chi-square distribution; the author using one-sample Kolmogorov-Smirnov test against chi-squared distribution with 87 degrees of freedom, the *D*-statistics is 0.3432, hence, $\zeta_1 \sim \chi(87)$. Thus, the distribution function of ζ_1 is,

$$F_{87}(x) = \frac{\gamma(87/2, x/2)}{4.78}$$

Where 4.78 is the Gamma function at 87, Γ(87). And the probability density function is of ζ_1

$$f_{87}(x) = 1.68\times10^{-14}\times x^{87/2-1}e^{-x/2}$$

Where 1.68×10^{-14} is calculated by the following fractional

$$\frac{(1/2)^{87/2}}{\Gamma(87)}.$$

Judging by figure 4, ζ_2 is a random variable with bimodal distribution. For simplicity, it is assume that the distribution function of ζ_2 is normal distribution. When testing using one-sample Kolmogorov-Smirnov test against *N*(9.07, 9.35), the *D*-statistics is 0.1002, hence $\zeta_2 \sim N(9.07, 9.35)$. Thus, the distribution function of ζ_2 is

$$F(x) = \frac{1}{\sqrt{2}\times9.35}\int_{-\infty}^{x}\exp\left(-\frac{(x-9.07)^2}{2\times9.35^2}\right)dx$$

And the probability density function is

$$f(x) = \frac{1}{\sqrt{2}\times9.35}\exp\left[-\frac{(x-9.07)^2}{2\times9.35^2}\right].$$

There are 25 disaster event records in <Yearbook of China Meteorological Disaster (2005~2010)> and <China Disaster Events (2001~2007)>, which is shown in table 4. It is clearly that disasters in Hubei province and Hunan province are more than Anhui province and Jiangxi province. In the term of outbreak time, disasters mainly appear at the beginning of one year, such as January, February and March.

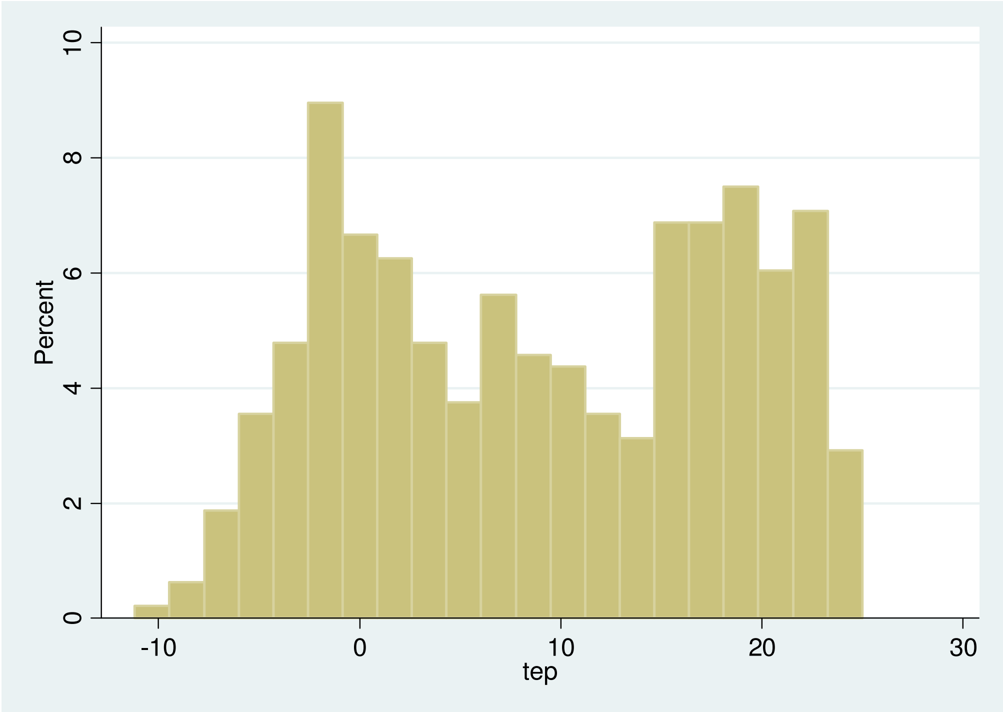

Figure 4 The histogram of random variable ζ_2

Table 4: Distribution of disasters during 2000 and 2009

	Jun	Feb	Mar	Apr	Dec	Total
Anhui	2	1	2			5
Hubei	2	5	2			9
Hunan	2	1		1	2	6
Jiangxi	2		2		1	5
Total	8	7	6	1	3	25

Disaster Factor Model

It is supposed that the factor model is a linear model. The disaster factors is

$$\varepsilon = c + b_1 \times \zeta_1 + b_2 \times \zeta_2 + \sigma$$

in which, c is the constant; b_1, b_2 are the efficient of ζ_1 and ζ_2, respectively; ζ_1 is the lowest temperatures in one month, while ζ_2 is the amount of precipitation in one month. ζ_1 and ζ_2 are random variables; σ is the uncertain variable; ε is uncertain random variables.
It is assumed that η is constant; condition variable y is a 3-dimensions vector, representing by geographical environment (location); y_i (i=1, 2, 3) are dummy variables, defined as follows

$$y_1 = \begin{cases} 1, Jiangxi\ provence \\ 0, otherwise \end{cases} \qquad y_2 = \begin{cases} 1, Hubei\ provence \\ 0, otherwise \end{cases}$$

$$y_3 = \begin{cases} 1, Hunan\ provence \\ 0, otherwise \end{cases}$$

The threshold value is determined by the following equation

$$\delta = d - b_3 \times y_1 - b_4 \times y_2 - b_5 \times y_3 - b_6 \times \eta$$

in which, d is the constant; d_3, d_4 and d_5 are the efficient of y_1, y_2 and y_3, respectively. d_6 is the efficient of η.

Table 5: Coefficient of factor model

	Coef.	[95% Conf. Interval]	P>|z|
b_1	0.1515	[-0.2205, 0.0825]	0.0000
a	-2.3461	[-2.7711, -1.9211]	0.0000

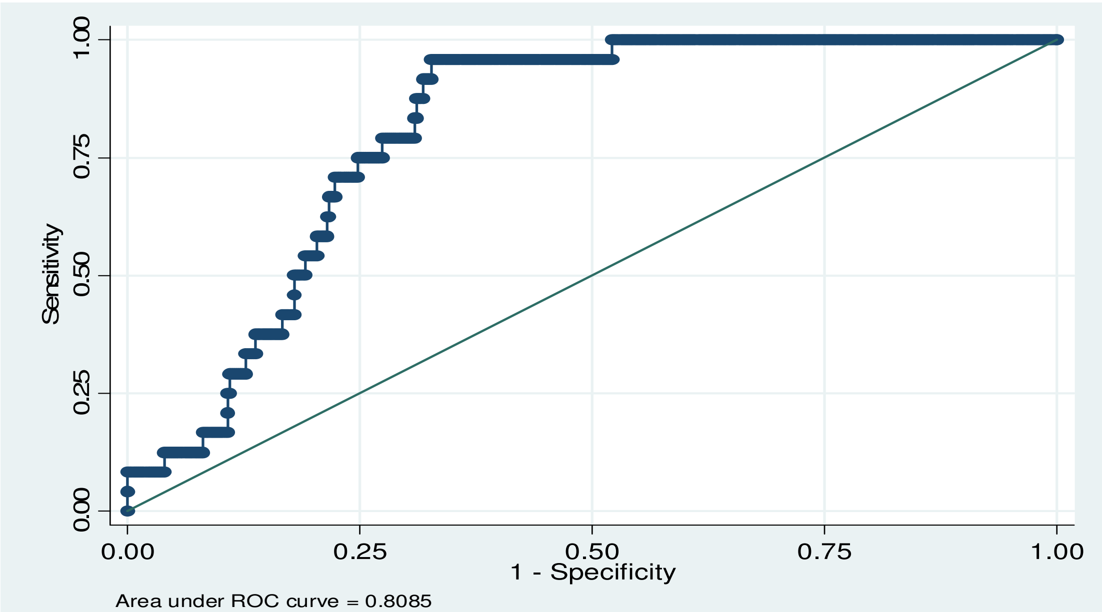

Figure 5. ROC curve of disaster factor model

Therefore, model (3) is transformed to the following model

$$z=\begin{cases}1, c+b_1\varsigma_1+b_2\varsigma_2+\sigma\geq d-b_3y_1-b_4y_2-b_5y_3-b_6\eta\\0, otherwise\end{cases} \quad (3')$$

Let $a=c-d+b_6\eta$, the model (3′) is shown as

$$z=\begin{cases}1, a+b_1\varsigma_1+b_2\varsigma_2+b_3y_1+b_4y_2+b_5y_3+\sigma\geq 0\\0, otherwise\end{cases} \quad (3'')$$

Obviously, model (3″) is a binary choice model; one of the most famous methods to solve it is logistic regression.

Disaster Loss Rate Model

Because the data about wealth and the total value of destroyed objects can't be obtained, and there holds a general law that more wealth or production materials, more GDP will be produced, that is to say, GDP is in direct proportion to the wealth possessed by people or value of the production materials. Then the loss rate is substitute by the ratio of economic loss caused by disasters to GDP in the month when disaster arises. It is assumed that the loss model is a linear model too, that is

$$l=\alpha+\beta_1\zeta_1+\beta_2\zeta_2+\beta_3y_1+\beta_4y_2+\beta_5y_3+\mu \quad (4')$$

in which, a and β_i (i=1,2, ···,5) are coefficients.

RESULTS

Disaster Factor Model

Running Stata 10.0 and using logistic regression, the coefficients are estimated, which is shown in table 5.
That is to say, only ζ_2 (the lowest temperature in a month) has significant effect to the snow & ice disaster. The performance of model (3″) is great, the Pseudo R^2 is 0.1516; the Brier score is 0.0455; ROC curve is shown in figure 5, AUC is 0.8085.
Hence, the disaster factor model is

$$\varepsilon-\delta=-2.3461+0.1515\times\zeta_1+\sigma$$

Table 6: Coefficient of loss rate model

	Coef.	[95% Conf. Inter val]	P>|t|
***β*₂**	-0.0004	[-0.0000, 0.0007]	0.0290
a	-0.0365	[-0.0266,0.0995]	0.2430

in which σ is the uncertain variable. The binary choice model is

$$z = \begin{cases} 1, \varsigma_1 \le 0.0646 \\ 0, \varsigma_1 > 0.0646 \end{cases}$$

Disaster Loss Rate Model

Using the least-squares method, coefficient of loss rate model is outputted by software Stata 10.0, which is shown in table 6.

Only ζ_2 (he amount of precipitation in one month) is significance in the loss rate model. The performance ofmodel is good, *R*-squared is 0.1994 and Adjusted *R*-squared is 0.1630. Hence, the loss rate model is

$$l=-0.0365-0.0004\times\zeta_2$$

CONCLUSION

This paper analyzes the general natural disaster mechanism. The natural disaster system could be decomposed into four sections: disaster factors, objects at exposure, disaster environment and condition elements; the shock power of the disaster factors exceed the levels that objects at exposure can resist, then disaster appears; this process is affected by environment and condition variables.

Disaster risk assessment procession is divided into probability analysis and disaster loss calculation, disaster factor model is developed to compute the frequency of disaster; and disaster loss rate model is given to determine the loss caused by disaster.

Because of data shortage, the case study in this paper is only acceptable, instead of perfect. The authors hope that other scholars give impetus to this research.

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