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An application of Mean Escape Time and metapopulation on forestry catastrophe insurance☆

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HIGHLIGHTS

- We investigate a forestry catastrophe insurance model via metapopulation and Escape Time.
- Parameters are estimated with real data set of China.
- Probability of loss and its payment time are respectively investigated.
- An optimal payment time of insurance can be found.

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ABSTRACT

A forestry catastrophe insurance model due to forestry pest infestations and disease epidemics is developed by employing metapopulation dynamics and statistics properties of Mean Escape Time (MET). The probability of outbreak of forestry catastrophe loss and the catastrophe loss payment time with MET are respectively investigated. Forestry loss data in China is used for model simulation. Experimental results are concluded as: (1) The model with analytical results is shown to be a better fit; (2) Within the condition of big area of patches and structure of patches, high system factor, low extinction rate, high multiplicative noises, and additive noises with a high cross-correlated strength range, an outbreak of forestry catastrophe loss or catastrophe loss payment due to forestry pest infestations and disease epidemics could occur; (3) An optimal catastrophe loss payment time MET due to forestry pest infestations and disease epidemics can be identified by taking proper value of multiplicative noises and limits the additive noises on a low range of value, and cross-correlated strength at a high range of value.

1. Introduction

Insurance is designed to secure the relatively infrequent loss events in many spheres of life. Compared to other insurance products, forestry catastrophe insurance is among the most difficult to develop. Miranda [1] built a crop yield insurance model based on Johnson's [2] hedging model and applied it to Kentucky soybean farms. She assumed that the crop insurance coverage levels was the only selective choice for farmers. And farmer's utility could be maximized by minimizing his revenue

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variance. After that, Smith, Chouinard and Baquet [3] improved Miranda's insurance model and implemented it to wheat farmers in Montana and France. Skees, et al. [4] used an empirical model based on the coefficient of variation of a portfolio of several crops, and the results showed that nearly 29% of the aggregated regional revenue risk could be reduced. The aggregated data was used by Skees, Hazell and Miranda [5] in insurance discussion. Raushan and Gunnar combined the mean–variance(MV) approach with Second Degree Stochastic Dominance(SSD) [6] criterion for an expected utility consistent empirical procedure. Areas that are affected by forestry infestations and disease epidemics are typically huge. This raises the issue of systemic risk, or, put differently, spatial correlation of yield losses. Roberts [7] puts forth the painted apple moth Teia (an insect)would pose a threat to New Zealand's forest industry and forest reserves, so the need for forestry infestations and disease epidemics mechanisms has increased dramatically. Vado Sequeira, Ligia [8] believed that forestry products are vulnerable to random changes in weather, pest infestations and disease epidemics. The interaction between various kinds of agricultural technologies, extreme weather risks and agricultural insurance were explored. However, the crop yield losses are generally difficult to determine, Multi-peril Crop Insurance (MPCI) is used to protect against different causes of yield losses [9]. MPCI calculates insured yield as a percentage of the historical average yield for insured plot. When realized yield is under the insured yield, the difference between realized yield and insured yield is paid as an indemnity [10]. A stochastic model with endogenous and exogenous periodicities is also to model the crop yield losses due to pests and diseases [11].

As a significant sector of Chinese economy, forestry industry and forestry reserves are seriously affected by forestry pest infestations and disease epidemics. Pest infestations and disease epidemics were recognized as two of the most important threats to exotic plantation forestry [12]. Su et al. [13] showed that the annual losses approximated to 88 billion Yuan, in which the direct economic losses were about 14.5 billion Yuan and the ecological losses were about 73.5 billion Yuan, resulting from some main forest pests infestations and disease epidemics from 1996 to 2001. Yan and Cai [14] analyzed Chinese forestry pest infestations incidence data, and concluded that over 14.67 billion dollars losses were caused by forestry pest infestations and disease epidemics. JIN M-T [15] believed that forest insurance is an effective method for Chinese forestry industry development and forestry reserves. Under the consideration of China's economic and ecological benefits, to apply forestry catastrophe insurance in impacts of forestry pest infestations and disease epidemics should be addressed. By using cluster analysis method Zhao and Wang [14] quantified the risk of forestry pest infestations with an index. And an insurance product for forest pest infestations was proposed on the ground of the index. Carlson [16] suggested that the increasing availability of crop damage insurance reduced the use of pesticide in crop.

Some research convinced evident that standard finance models are for short of covering the complicities of empirical research in the area of forests insurance, therefore new ideas and models from Physics are called for [17]. As an interdisciplinary field, Econophysics [18] applies statistical physics theories, methods and models to analyze economic and financial problems. Various econophysicists have introduced models for price fluctuations in financial markets or proposed original points of view on established models. What is more, several scaling laws was found in various economic data. Exerting the strength of quantitative analysis, Econophysics is also applied in solving insurance problems, in which uncertainty or stochastic processes and nonlinear dynamics are used. In areas of metastable systems [19,20], bistable system [21,22], Malthus–Verhulst stochastic model [23,24], randomly switching piece-wise metastable linear potential [25], the growth of tumor influenced by external fluctuations and periodic treatment [26], a self-propelled Janus particle [27], a ecological system [28–32], an energy depot model [33] and a synthetic gene circuit [34], the effects of noise on the stability of the system with the escape time and stochastic resonance were vastly used. MET is a terminology used in Physics to describe the interval of a particle in certain region, portrays the statistics properties of transit issues in nonlinearly system. The statistics properties of MET were studied in market system with stochastic volatility, especially in analysis the stability of stock price, representing the time of the stock price staying in a price range [35–37].

We employed the statistics properties of MET in catastrophe risk due to forestry pest infestations and disease epidemics. This study analyzes the appraisal of loss and method for catastrophe risk characterization due to forestry pest infestations and disease epidemics. Section 2 defines the loss model due to forestry pest infestations and disease epidemics and estimates the corresponding parameters according to an empirical study on pest incidence data of 15 cities in China. The expected value of loss payment is analyzed based on the proposed loss model in Section 3. Meanwhile, the correlation between expected value of loss payment and deductible is estimated, in addition, the probability density function (PDF) obtained from the sample data and the PDF based on proposed model are compared, and the full deductible and full indemnity are quantified respectively. In Section 4, the MET of catastrophe loss payment occurring is gained lay by the mean escape time defined as above. Conclusions and future works are presented in Section 5.

2. The loss model due to forestry pest infestations and disease epidemics

The loss caused by forestry pest infestations and disease epidemics is given based the metapopulation model proposed by Hanski, Wahlberg and Ovaskainen [38,39]. Then the simplified model can be obtained after assuming theoretically that: (i) the spatial structures of patches satisfy the coupled map lattice, and (ii) these patches are possessed of identical structural characteristics and qualities, their probabilities occupied at any time are equal to each other [38]. The loss can be defined as:

$$\frac{dl}{dt} = \frac{l^2(1-l)}{l^2 + y^2/A^2} - \frac{e}{A^b} l - l\xi(t) + \eta(t), \quad l \in [0, 1], \tag{1}$$

where $l(t)$ is the rate that patch is occupied by forestry pest infestations and disease epidemics at time t; $y = 1/(fc^{1/2})$, and f is the structure factor of patches, $f = \sum_{j\neq i} ea^{d_{ij}}$, $1/a$ gives the average migration distance and d_{ij} is the distance between