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Aspects of the Theory of Financial Risk Management for Natural Disasters

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Abstract—We analyze two aspects of the theory of financial risk management for natural disasters such as earthquakes. First, we use the theory of Poisson processes to construct a model of an earthquake. We then use this model to provide an index of the monetary damage from an earthquake with aftershocks. Second, we study the question of business failure, i.e., the likelihood that an insurance provider will become insolvent in the event that earthquake insurance is provided and a major earthquake does in fact occur.

Keywords—Financial risk management, Insurance, Natural disaster.

1. INTRODUCTION

One cannot completely insulate oneself from the deleterious effects of natural disasters. However, by carefully planning for such disasters, one certainly can lessen the effects of the losses that inevitably do arise when a natural disaster occurs. Recognition of this fact has given rise to much literature in the field of financial risk management.[1] Specifically, researchers in this field have pointed out that natural disasters are costly in terms of human life and property, and that the consequences of such disasters can often be managed to reduce the losses greatly. This is exactly what the field of financial risk management seeks to do. In particular, by stressing preparedness, this field seeks to save lives, mitigate the monetary damages from disasters, and reduce the vulnerability of humankind to natural hazards.

In this paper, we explore two issues in financial risk management for natural disasters. We focus on the provision of insurance in the context of earthquakes. As Kleffner and Doherty [4] and others have noted, due to the vulnerability of large parts of the U.S.A. to earthquakes, the question of optimal financial management for earthquakes has become an important public

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[1]For more on this literature, see [1–4].

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policy issue. From a risk management perspective, insuring for earthquakes is difficult for at least two reasons. First, because the correlation of losses between the insured parties is *not* low for earthquakes, the provision of earthquake insurance "cannot be considered under normal actuarial methods..." [5, p. 19]. Second, "the decision to provide earthquake insurance involves the assumption of very large-scale liabilities with relatively little information about necessary reserves or rates" [5, p. 18]. Because of these and other difficulties involved in the provision of earthquake insurance, there has been much discussion of the need for federal involvement in the provision of earthquake insurance. Indeed, as Kunreuther *et al.* [6] and others have noted, a major earthquake may leave many insurance companies vulnerable to business failure. For their part, the insurance industry (see [7]) has concluded that earthquakes are an "uninsurable hazard" and that the federal government should be the provider of earthquake insurance.

Given this situation, two of the most relevant questions regarding the provision of earthquake insurance relate to

(i) the determination of the financial damage from an earthquake, and
(ii) a determination of the likelihood of business failure in the event of a major earthquake.

An answer to the first question will provide insurers with a theoretical tool for assessing the magnitude of the monetary liabilities that they are likely to face in the aftermath of an earthquake. An answer to the second question will be helpful to insurers in analyzing the effects of alternate reserve levels on the likelihood of becoming insolvent. Although researchers have studied a variety of questions related to financial risk management for natural disasters,[2] to the best of our knowledge, a dynamic and stochastic analysis of these two specific questions has not been conducted in the literature previously. Consequently, in this paper, we provide a theoretical analysis of these two questions.

The rest of this paper is arranged as follows. In Section 2, we use the theory of Poisson processes to provide a method which insurers can use to measure the financial damage from an earthquake with aftershocks. In Section 3, given that a major earthquake has occurred, we address the possibility of business failure when earthquake insurance has been provided. Section 4 concludes and offers suggestions for future research.

2. THE MEASUREMENT OF FINANCIAL DAMAGE

Consider a regional economy in which an earthquake and subsequent aftershocks occur according to a Poisson process with rate δ.[3] Let the earthquake damage (in dollars) be D_1, and let the subsequent aftershock damages be denoted by D_i, $i \geq 2$. In general, one expects the aftershock damages to be less severe than the initial earthquake damage. Consequently, we suppose that these damages decline exponentially over time. Mathematically, this means that if the initial damage of a shock is D, then at some later time t, the damage is $De^{-\pi t}$, where π is the parameter (rate) of the exponential distribution. Let $N(t)$ denote the total number of shocks that occur by time t. We suppose that the monetary damages D_i, $i \geq 1$, are independent and identically distributed (i.i.d.), and that they are independent of $N(t)$.

Suppose that the earthquake occurs at time 0 and that the subsequent aftershocks end at time t. Then, the total monetary damage in the time interval $[0, t]$ is

$$D(t) = \sum_{i=1}^{N(t)} D_i e^{-\pi(t-A_i)}, \tag{1}$$

where A_i is the arrival time of the i^{th} shock. From equation (1), it is clear that $D(t)$ is a random variable. Hence, for the purpose of financial risk management, a reasonable objective for an

[2]See footnote 1 and the references cited in these papers.
[3]The Poisson process has been used in the past in hazard management studies. For further details, see [8,9].