Interplay of Insurance and Financial Risks in a Discrete-time Risk Model \[1\]

Qihe Tang

Department of Statistics and Actuarial Science
The University of Iowa
Email: qihe-tang@uiowa.edu

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\[1\] Based on a joint work with Jinzhu Li to appear in *Bernoulli*
Outline

1. A Stochastic Economic Environment
2. Motivations
3. Main Result
4. Future Research
Consider an insurer who invests its wealth in a financial market consisting of riskless and risky assets.

This company is exposed to the following two kinds of risk:

- **Insurance risk**: the traditional liability risk, namely insurance claims, related to the insurance portfolio.
- **Financial risk**: the asset risk related to the investment portfolio, including inflation of economy and stock market crashes.

Both insurance risk and financial risk may impair the solvency of the insurer. A well-known question is which one of them plays a dominating role.
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The Bivariate Lévy-diven Risk Model

Paulsen (1993, *SPA*) proposed a continuous-time bivariate Lévy-diven risk model in which:

- the cash flow of claims less premiums is described as a Lévy process \( \{P_t\} \)
- the log price process of the investment portfolio as another independent Lévy process \( \{R_t\} \)
- hence, the wealth process is described as

\[
W_t = e^{R_t} \left( x - \int_0^t e^{-R_s} dP_s \right) = e^{R_t} \left( x - \tilde{S}_t \right)
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References

- Norberg (1999, *SPA*)
- Kalashnikov and Norberg (2002, *SPA*)
- Frolova, Kabanov and Pergamenshchikov (2002, *FS*)
- Yuen, Wang and Ng (2004, *SPA*)
- Pergamenshchikov and Zeitouny (2006, *SPA*)
- Gerber and Yang (2007, *NAAJ*)
- Klüppelberg and Kostadinova (2008, *IME*)
- Asmussen and Albrecher (2010, *Ruin Probabilities*)
- Hult and Lindskog (2011, *FS*)
- …
A Stochastic Economic Environment

Motivations

Main Result

Future Research

Insurance Risk and Financial Risk

The Bivariate Lévy-driven Risk Model

A Discrete-time Risk Model

Denote by $X_n$ the insurer's net loss within period $n$:

$$X_n = \text{claims - premiums}$$

Denote by $Y_n$ the stochastic discount factor over period $n$:

$$Y_n = (1 + R_n)^{-1}$$

with $R_n$ the stochastic return rate.
A Discrete-time Risk Model

- Denote by $X_n$ the insurer’s net loss within period $n$:
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- Then the random variables $X_1, X_2, \ldots$ correspond to the insurance risk.

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  \[ Y_n = (1 + R_n)^{-1} \]
  with $R_n$ the stochastic return rate.

- Then the random variables $Y_1, Y_2, \ldots$ correspond to the financial risk.
A Sum–Product Structure as a Risk Management Tool

The wealth of the insurer accumulated till time $n$ is

$$W_n = x \prod_{j=1}^{n} (1 + R_j) + \sum_{i=1}^{n} \text{(Premiums} - \text{Claims)} \cdot \prod_{j=i+1}^{n} (1 + R_j)$$

$$= \left( \prod_{j=1}^{n} (1 + R_j) \right) \left( x - \sum_{i=1}^{n} X_i \prod_{j=1}^{i} Y_j \right).$$

Define

$$M_n = \max_{0 \leq k \leq n} \sum_{i=1}^{k} X_i \prod_{j=1}^{i} Y_j = \max_{0 \leq k \leq n} S_k. \tag{1}$$

Comments on this sum–product structure

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Comments on this sum–product structure
The Complete Independence Assumptions

Assume the following:

- $X_1, X_2, \ldots$ form a sequence of i.i.d. random variables with generic random variable $X$ and common distribution $F$ on $(-\infty, \infty)$
- $Y_1, Y_2, \ldots$ form another sequence of i.i.d. random variables with generic random variable $Y$ and common distribution $G$ on $(0, \infty)$
- the two sequences are mutually independent

These standard assumptions are not practical relevant. However, ...
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A Criticism on the Current Study

The mainstream of this study focuses on the case where:

- the insurance risk $X$ has a Pareto-type tail
- the financial risk $Y$ is dominated by the insurance risk $X$, that is, $G = o(F)$

This dominating relationship truly holds if we consider the classical Black–Scholes model.

However, empirical data often reveal that the lognormal model significantly underestimates the financial risk. It shows particularly poor performance in reflecting financial catastrophes such as the most recent one.
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Need to Investigate the Opposite Case

Such financial catastrophes intensify the need to investigate the **opposite case** where

- the financial risk $Y$ has a Pareto-type tail
- the insurance risk $X$ is dominated by the financial risk $Y$

For this case, the stochastic quantities $S_n$ and $M_n$ in (1) become much more intractable, due to the **asymmetric** roles of $X$ and $Y$. The main difficulty exists in dealing with the product of many Pareto-type random variables.
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Our Goal

We shall give a unified treatment in the sense that no dominating relationship between the two kinds of risk is required.

That is to say, we aim at an asymptotic result that holds simultaneously for the cases where:

- $X$ is more heavy-tailed than $Y$
- $X$ is less heavy-tailed than $Y$
- $X$ is the same heavy-tailed as $Y$
A distribution $U$ on $(-\infty, \infty)$ is said to be of regular variation if

$$\lim_{x \to \infty} \frac{U(xy)}{U(x)} = y^{-\alpha}, \quad y > 0,$$

for some $0 \leq \alpha < \infty$. We write $U \in \mathcal{R}_{-\alpha}$.

Such regular variation does not enable us to derive explicit asymptotic formulas for the tail probabilities of $S_n$ and $M_n$.

Our idea is to borrow from the recent literature some techniques regarding the well-developed concept of convolution equivalence.
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Convolution Equivalence

A distribution \( V \) on \([0, \infty)\) is said to be convolution equivalent if for some \( \alpha \geq 0 \), the following hold simultaneously:

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\lim_{x \to \infty} \frac{V(x - y)}{V(x)} = e^{\alpha y}, \quad y \in (-\infty, \infty),
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and

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\lim_{x \to \infty} \frac{V^2(x)}{V(x)} = \text{exists and is finite}.
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Embrechts (1983, *JAP*) discovered that the generalized inverse Gaussian distribution is of convolution equivalence. Other examples and criteria for \( S(\alpha) \) can be found in Cline (1986, *PTRF*).
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Strongly Regular Variation

Let $\xi$ be a random variable distributed by $U$ on $(-\infty, \infty)$. Denote by $V$ the distribution of $\ln \xi$ restricted to $\xi > 0$, that is,

$$V(x) = 1 - \frac{U(e^x)}{U(0)}, \quad x \in (-\infty, \infty).$$

Note that $U \in \mathcal{R}_{-\alpha}$ if and only if $V \in \mathcal{L}(\alpha)$.

A distribution $U$ is said to be of strongly regular variation, written as $U \in \mathcal{R}^{*}_{-\alpha}$, if $V \in \mathcal{S}(\alpha)$.

Examples and criteria for $\mathcal{R}^{*}_{-\alpha}$ can be shown completely in parallel with those in Embrechts (1983) and Cline (1986).
Let $\xi$ be a random variable distributed by $U$ on $(-\infty, \infty)$. Denote by $V$ the distribution of $\ln \xi$ restricted to $\xi > 0$, that is,

$$V(x) = 1 - \frac{\bar{U}(e^x)}{U(0)}, \quad x \in (-\infty, \infty).$$

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Our Standing Assumption

**Assumption A**  Every convex combination of $F$ and $G$, namely,

$$pF + (1 - p)G, \quad 0 < p < 1,$$

belongs to the class $\mathcal{R}^*_\alpha$.

A merit of Assumption A is that it does not require a dominating relationship between $\overline{F}$ and $\overline{G}$. 
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Some Interesting Special Cases

- $F \in \mathcal{R}_{-\alpha}^*$ and $\overline{G}(x) = o(\overline{F}(x))$; or, symmetrically, $G \in \mathcal{R}_{-\alpha}^*$ and $\overline{F}(x) = o(\overline{G}(x))$

- $F \in \mathcal{R}_{-\alpha}^*$, $G \in \mathcal{R}_{-\alpha}$, and $\overline{G}(x) = O(\overline{F}(x))$; or, symmetrically, $G \in \mathcal{R}_{-\alpha}^*$, $F \in \mathcal{R}_{-\alpha}$, and $\overline{F}(x) = O(\overline{G}(x))$

- $F \in \mathcal{R}_{-\alpha}^*$, $G \in \mathcal{R}_{-\alpha}^*$, and the function $b(x) = \overline{F}(e^x)/\overline{G}(e^x)$ satisfies that $b(xy) \asymp b(x)$ for every $y > 0$
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Main Result

Theorem 1  
Recall $M_n$ in (1). Under Assumption A we have

\[ \Pr (M_n > x) \sim A_n \overline{F}(x) + B_n \overline{G}(x), \]

\[ A_n = \sum_{i=1}^{n} (EY^\alpha)^i \quad \text{and} \quad B_n = \sum_{i=1}^{n} EM^\alpha_{n-i+1} (EY^\alpha)^{i-2}. \tag{2} \]

Furthermore, if $EY^\alpha < 1$, then relation (2) holds for $n = \infty$:

\[ \Pr (M_\infty > x) \sim A_\infty \overline{F}(x) + B_\infty \overline{G}(x), \]

\[ A_\infty = \frac{EY^\alpha}{1-EY^\alpha} \quad \text{and} \quad B_\infty = \frac{EM^\alpha_\infty}{EY^\alpha(1-EY^\alpha)}. \tag{3} \]
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Comments on Theorem 1

Formulas (2) and (3) appear to be linear combinations of $\bar{F}$ and $\bar{G}$.

Hence, if one of $\bar{F}$ and $\bar{G}$ dominates the other, then this term remains in the formulas but the other term vanishes. Otherwise, both terms should simultaneously appear in the formulas.

Therefore, our result gives a unified answer to the question cited in the beginning of this talk.
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Contribution to computing ...
Comments on Theorem 1

This result also represents a theoretical contribution to probability theory. Similar problems have been extensively investigated by a series of papers in the framework of random difference equations:

- Kesten (1973, *AM*)
- Vervaat (1979, *Advances in AP*)
- Hult and Samorodnitsky (2008, *Bernoulli*)
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Future Research

- Look for **more general** distributional assumptions on the insurance risk and financial risk, under which an exact asymptotic formula for $\Pr(M_\infty > x)$ can be derived.

- Introduce **positive dependence** structures:
  - between insurance risks $\{X_n\}$
  - between financial risks $\{Y_n\}$
  - between insurance risks $\{X_n\}$ and financial risks $\{Y_n\}$

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