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Outcome-based Cyber Insurance

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INTRODUCTION & AIM

Motivation
Cyber insurance faces three major challenges:
Cyber losses are highly volatile and heavy-tailed.
Attack frequencies evolve dynamically over time.
Traditional insurance pricing often ignores the effect of cybersecurity investments on future risk.
Moreover, moral hazard may arise when insured firms reduce their security efforts after obtaining coverage.

Research Gap
Existing cyber insurance models generally:
treat cyber incidents using static frequency-severity approaches;
model cybersecurity investments separately from insurance pricing;
neglect the impact of cyber threat dynamics on insurer solvency.

Aim
This work proposes a stochastic actuarial framework that jointly models:
cyber threat evolution,
cybersecurity investments,
aggregate losses,
insurance pricing and solvency.
The objective is to design **Outcome-Based Cyber Insurance Contracts** that reward effective cybersecurity investments through lower premiums.

METHOD

Latent Cyber Risk Dynamics
The cyber threat environment is represented by a latent intensity process:

$$d\lambda_t = \kappa(\theta(z_t) - \lambda_t)dt + dG_t$$

where:
λ_t= cyber risk intensity; κ = mean reversion parameter; $\theta(z_t)$ = long-run risk level;
z_t= cybersecurity investment; G_t= Gamma subordinator.

Why Gamma-OU?
The model captures: ✓ positivity ✓ cyber attack clustering ✓ persistent shocks
✓ heavy-tailed fluctuations ✓ sudden systemic cyber events

Investment-Risk Link
Cybersecurity investment affects the long-run equilibrium level:

$$\theta(z) = \theta_0 \; \psi(z)$$

Three vulnerability functions are considered:
1) Gordon–Loeb 2) Hausken 3) Wang
Higher investment reduces vulnerability and therefore lowers future cyber risk.

RESULTS & DISCUSSION

Main Theoretical Results
Cyber incidents arrive according to a Cox process:

$$N_t | \lambda_t \sim \text{Poisson}(\int_0^t \lambda_s ds)$$

Aggregate losses are

$$S_t = \sum_{i=1}^{N_t} Y_i$$

where:
N_t = number of incidents
Y_i= loss severity

Result 1 – Overdispersion
The model produces:

$$Var(N_t) > E[N_t]$$

which is consistent with empirical cyber-loss data.

Result 2 – Attack Clustering
Positive Gamma jumps generate temporary increases in cyber risk intensity, creating clusters of cyber incidents.
This reproduces realistic cyber attack waves and systemic vulnerability episodes.

Result 3 – Investment Effect
Increasing cybersecurity investment:
reduces the equilibrium intensity;
lowers expected losses;
decreases premium levels.

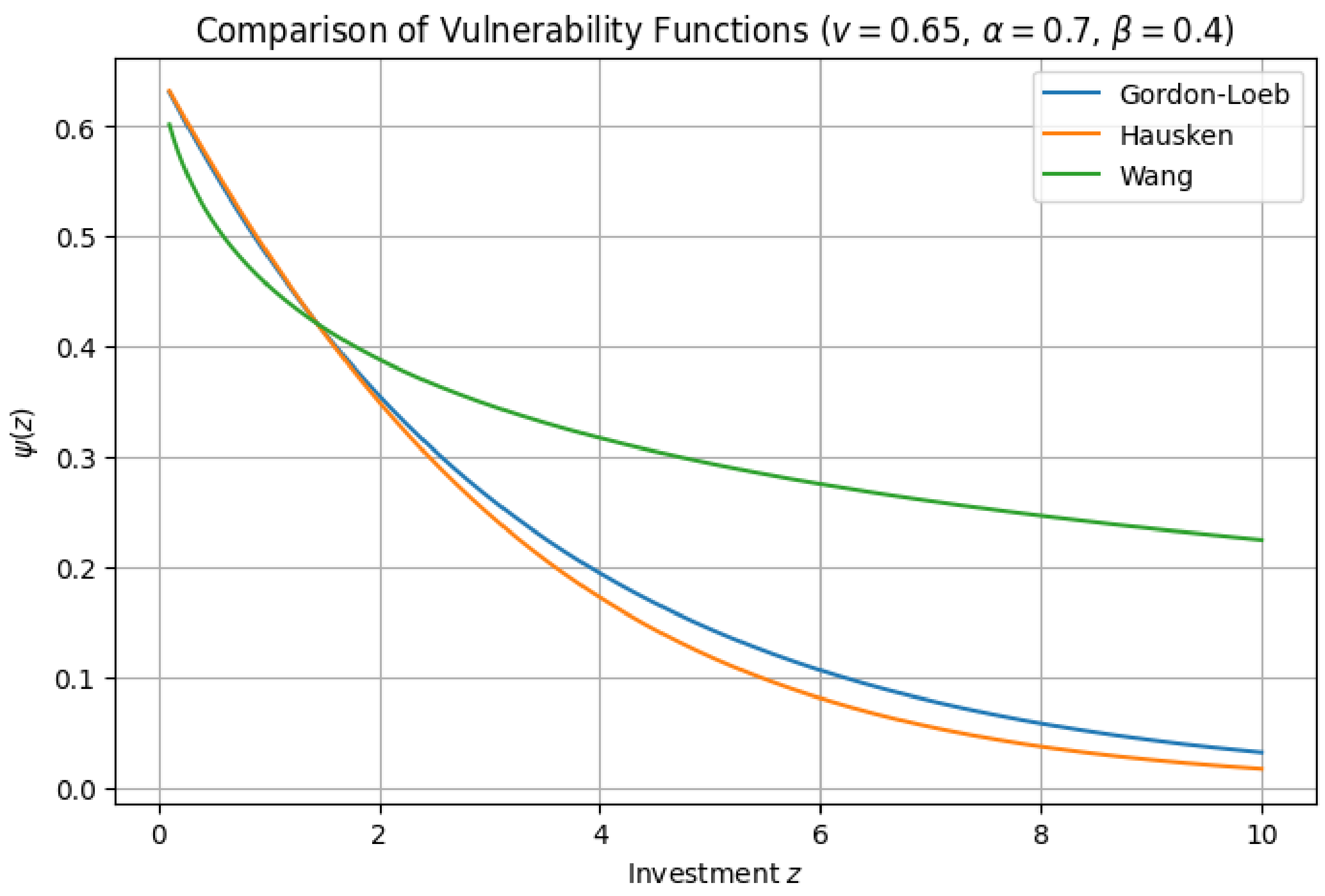
$$\partial E[\pi_t]/\partial z_t < 0$$

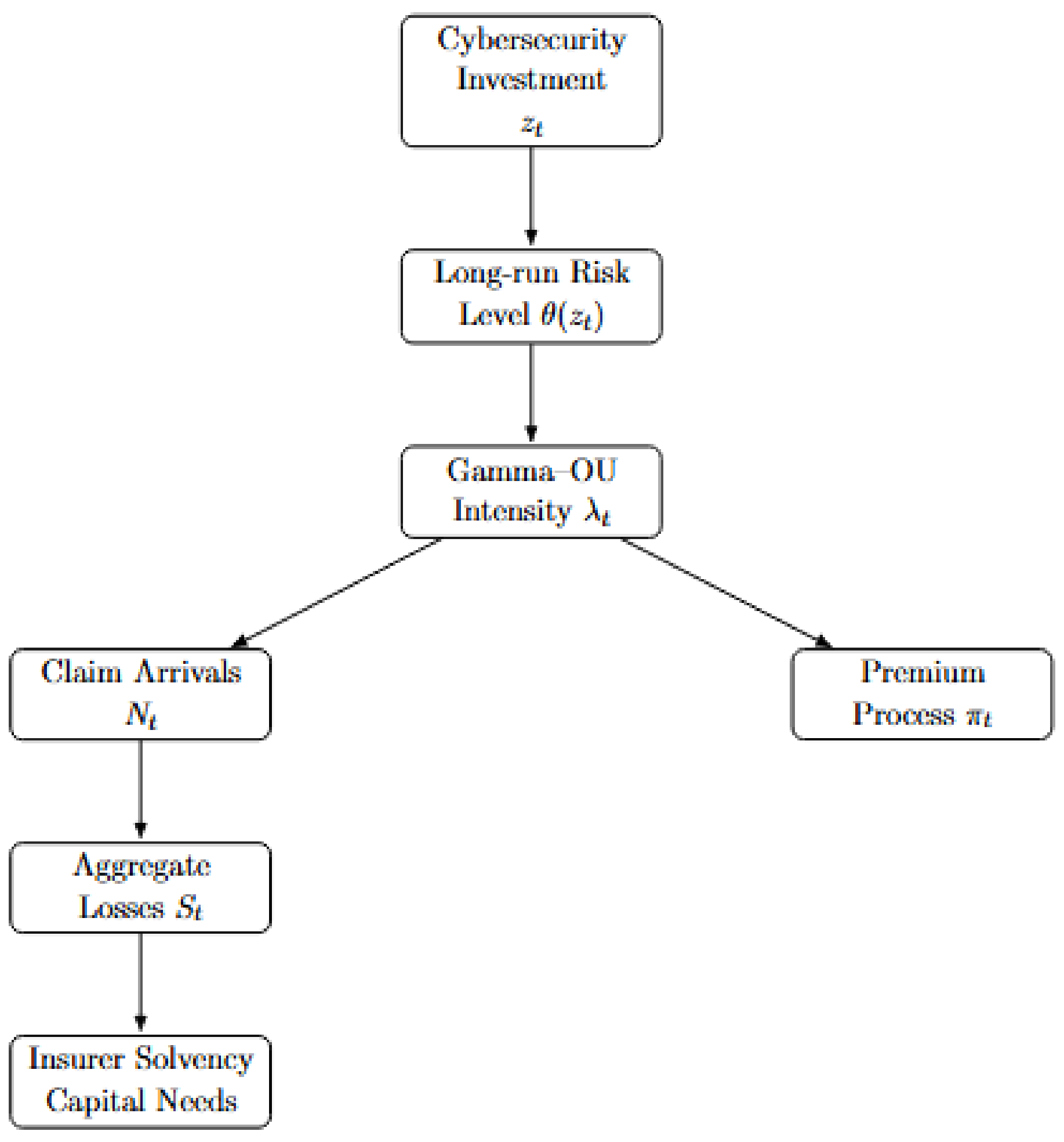
Outcome-Based Pricing
Premiums are determined as:

$$\pi_t = E\left[S_T - S_t \mid F^\lambda \right] + \ell_t$$

where:
first term = actuarially fair premium;
second term = solvency loading (TVaR-based).
This creates direct incentives for firms to improve cybersecurity.

Key Contribution
The same latent cyber-risk process drives:
claim arrivals, aggregate losses, premium dynamics, solvency capital requirements.
This provides a fully integrated insurer-oriented framework.





CONCLUSIONS

A Gamma-OU Cox framework for cyber insurance is developed.
Cybersecurity investments directly affect the stochastic cyber-risk environment.
Outcome-based pricing reduces moral hazard.
Premiums are dynamically linked to security performance.
The model integrates actuarial pricing, cyber risk modelling and insurer solvency analysis within a single framework.

FUTURE WORK/ REFERENCES/ACKNOWLEDGMENT

Future Research
Hawkes self-exciting cyber attacks.
Regime-switching cyber environments.
Portfolio dependence among firms.
Bayesian learning and real-time updating.
Calibration using real cyber-loss datasets.

Key References
Gordon & Loeb (2002)
Barndorff-Nielsen & Shephard (2001)
Awiszus et al. (2023)
Zeller & Scherer (2022)
Mazzoccoli & Naldi (2020–2022)