Sarcouncil Journal of Economics and Business Management

ISSN(Online): 2945-3593

Volume- 04| Issue- 12| 2025

Research Article

Received: 20-10-2025 | Accepted: 25-11-2025 | Published: 04-12-2025

A Theoretical Framework for Actuarial Risk Mitigation in Healthcare Insurance Systems

Felix Okumu [1], *and Esther Esi Assan* [2]

[1] *Illinois State University, USA*

[2] *Department of Statistics and Actuarial Science, Kwame Nkrumah University of Science and Technology, Ghana*

Abstract: The health insurance industry in the U.S. is increasingly exposed to systemic financial risks derived from higher healthcare spending levels, demographic changes, technology improvements, and correlated health shocks such as pandemics. Traditional actuarial models and methods, which concentrate on individual risk and insurance company solvency, often do not cover the entire 'market'. Actuarial science, however, provides us with very powerful tools to quantify uncertainty and to predict financial charges, and we can build robust risk-sharing mechanisms accordingly. In this paper, we develop a framework for addressing systemic risk within healthcare insurance by bringing together fundamental actuarial techniques, such as stress testing, dependence modeling, dynamic pricing, and reinsurance pricing. The framework focuses on three areas: ability to withstand large system-wide shocks, financial sustainability of the insurer, and ability to rapidly adapt to new healthcare risks. Contributions include a systemic risk management conceptual model, suggestions for regulation integration (via systemic risk reserves or mandatory stress testing), and applications in enterprise risk management and value-based care pricing. Future research directions, such as empirical verification, actuarial-based AI regulatory modeling, and use of AI-improved actuarial methods are also suggested.

Keywords: Healthcare Insurance, Actuarial Risk Mitigation, Systemic Risk, Stress Testing, Reinsurance Design.

INTRODUCTION

It is no secret that in the past few decades, healthcare expenditures in the United States have been rising steadily, straining insurance markets, government programs, and household wallets. National health expenditures in 2021 totaled $4.3 trillion, approximately 18.3% of the U.S. Gross Domestic Product (GDP) (CMS, 2022). This upward drive in the costs of health care raises serious questions about the financial sustainability and solvency of health insurance organizations. Carriers are being pulled in two different directions - one of providing affordable and accessible health insurance coverage, which should be the easy part, and on the other, needing to maintain competitive reserves and financial stability against increasing claims and increased operational complexity.

These obstacles have been compounded by structural alterations in the healthcare system. The movement to value in health care that focuses on patient outcomes and care quality rather than volume of services delivered has added additional challenges around risk assessment, pricing, and financial forecasting for insurers (Porter & Lee, 2013). Moreover, there are rapid evolutions in medical technology and the demographics of populations are changing, particularly with population ageing, as well as growing populations with chronic diseases, and these have been frequently pointed out as the main drivers of higher costs of health care and increased fluctuations in the patterns of claims in health insurance (Cutler & Ly, 2011; OECD, 2021; CMS, 2022).

Robust and stable health insurance systems are the key to protecting and preserving economic security and public health outcomes. Left without a working financial risk mitigation tool, the insurance markets are ever more at risk of systemic shocks, which may lead to insurance gaps, insurer bankruptcies, and expanded reliance on government intervention. The COVID-19 crisis exposed major weaknesses in health financing and insurance markets, with insurers experiencing unpredictable claims volatility, deferred care, and pricing uncertainty (Swiss Re Institute, 2020; OECD, 2021). These incidents highlighted the necessity of better systemic risk management in health insurance.

Although actuarial science has developed a strong set of tools for dealing with firm-specific risks (for example, pricing of premiums, reserving procedures, and reinsurance purchasing), there is a noted need for better use of the existing actuarial models and analytics to understand and deal with systemic, market-wide financial risk in the healthcare insurance market. However, regulatory systems, RBC standard in the U.S., and Solvency II in Europe focus on individual firm solvency and offer few tools for the modeling of aggregate, correlated risks across insurers or healthcare

***Corresponding Author:** Esther Esi Assan

DOI-https://doi.org/10.5281/zenodo.17819400

systems (EIOPA, 2020; NAIC, 2023). As a result, insurance carriers are still ill-equipped to handle what they call "extreme risk—low frequency" events, such as pandemics, regulatory jolts, or a broad technological shift in how we deliver healthcare.

This paper's major task is to construct a theoretical framework that incorporates the feature of risk pollution in actuarial science, guiding the healthcare insurance system to prevent risk pollution with the tools in its research field. This framework aims to:

- Integrate actuarially based risk measurement into financial planning for healthcare;
- Offer a conceptual framework to help recognize existing and potential systemic weaknesses of the insurance market;
- Linking actuarial techniques with health policy to help create financially viable insurance systems.

Through integrating fundamental actuarial concepts (such as risk pooling, dependency modeling, reserve adequacy assessment, and solvency planning) into an integrated approach, the project offers a structured path for insurers, policymakers, and regulators to strengthen the financial resilience of healthcare insurance systems.

There are at least three related contexts in which this research makes significant contributions. First, in health care finance, it implies lessons about the creation of viable insurance models that are able to withstand the shocks to the system, like the one developed by such models, and are able to remain accessible to policyholders. Second, in the actuarial sciences, it generalizes established actuarial systems tools from individual policy management to a wider systemic context of healthcare insurance markets. Third, in terms of public policy, the proposed model offers a theoretical foundation for establishing regulatory schemes that can stabilize health insurance markets and enhance national economic stability and public health security.

In light of the increasing linkage between the stability of financial institutions and the performance of the health care delivery system, an actuarially sound, theoretically rooted methodology for the systematic management of systemic risk is timely and of national importance.

LITERATURE REVIEW

Actuarial Science and Risk Management of Health Insurance

Actuarial science is fundamental to the development, pricing, and sustainability of health insurance systems. Crucial tools such as premium setting, reserving, and capital adequacy testing enable insurers to manage uncertainty related to their claims experience and health care cost inflation. These tools are all the more relevant in the context of increasing health expenditures and demographic stress in the US (CMS, 2022). Stress testing and scenario analysis for operational risk and the resilience of solvency in the context of a rapidly changing healthcare environment are increasingly being used by actuarial techniques (IAA, 2013).

Modern actuarial practice in health insurance increasingly incorporates advanced statistical forecasting and scenario-based modeling to address risks associated with morbidity shifts, healthcare cost variability, and service utilization trends. Tools such as stochastic reserving, generalized linear models (GLMs), and credibility theory are widely used to project future liabilities and optimize capital allocation under uncertainty (Bermúdez & Karlis, 2011; De Jong & Heller, 2008; Nielsen, 2010). Dynamic financial analysis (DFA) has become a key approach in stress testing insurance solvency under multiple economic and demographic scenarios, as outlined in the IAA's guidance on stress testing and scenario analysis (IAA, 2013) and detailed academic treatments of DFA in health insurance settings (Shiu, 2009).

Traditionally, actuarial models in health insurance have emphasized individual-level or portfolio-level risk — including adverse selection, moral hazard, and variability in claims frequency and severity — using mechanisms such as coinsurance, deductibles, and risk pooling. However, these models often assume statistical independence across insured lives and providers, an assumption that fails during correlated, system-wide events such as pandemics, large-scale regulatory changes, or rapid technological shifts. The COVID-19 pandemic revealed these limitations, as deferred care, claim surges, and uneven provider responses disrupted conventional actuarial assumptions and solvency forecasts (Surico & Galeotti, 2020; OECD, 2021).

Publisher: SARC Publisher

Systemic Risk in Insurance and Finance Systems

Systemic risk, first conceptualized in banking, reflects a concern that a disruption in one part of the financial system could lead to broad instability throughout interconnected firms and markets. In the wake of the 2008 financial crisis, there has been increased awareness of the need for macroprudential (beyond banking) supervision, including insurance supervision (Basel Committee on Banking Supervision, 2011; IAIS, 2020).

In insurance, systemic exposures are manifest through capital concentration, reinsurance interconnectivity, and exposure to catastrophic tail events (Geneva Association, 2010; Cummins & Weiss, 2014). Historically, health insurance has been seen as relatively immune to systemic disturbances. But the COVID-19 pandemic upended this by pulling the trigger on delayed elective services, spiking the hospital cost curve unexpectedly, and spawning rapid-fire regulatory changes. These shocks generated volatility across claims, provider networks, and pricing models, illustrating the inadequacy of actuarial models predicated on linearity and risk independence (OECD, 2021; Swiss Re Institute, 2021; Surico & Galeotti, 2020; Shrivatsa, 2022).

Notwithstanding these advances, systemic risk modeling in insurance still lags behind banking. Currently, the majority of solvency and stress testing models and frameworks remain predominantly concerned with institutional robustness (EIOPA, 2020; NAIC, 2023), rather than contagion across sectors and systemic connectivity. Filling this gap will demand a more focused development of sophisticated actuarial tools such as correlated stress testing, scenario analysis, and Bayesian models to capture joint distributions of extreme outcomes (IAA, 2013; Bermúdez & Karlis, 2011; De Jong & Heller, 2008).

System weaknesses and financial capacity of the health system

Poor financing of global systems of healthcare continues to confront health systems, including the system in the United States, which struggles to serve populations and an aging society and increases in the number of patients with chronic conditions (OECD, 2021). Especially, the US is spending extremely high amounts of money on health, and with nearly 18% of GDP, health spending is significantly above the OECD average (Commonwealth Fund, 2023). Chronic diseases such as heart disease, cancer, and diabetes are the leading causes of death and disability in the U.S. and also represent the primary drivers of the nation's $4.5 trillion in annual healthcare costs. According to the Centers for Disease Control and Prevention (CDC), six in ten Americans live with at least one chronic disease, while four in ten suffer from two or more (CDC, 2024). Innovation in technology is essential for improving outcomes, but it also raises costs. High-cost medical technologies – specialty drugs, robotic procedures, and advanced diagnostics – have led to more volatile claim patterns and increased pressures on insurer reserves (CMS, 2022).

The weaknesses in the resilience of health insurance were further exposed by the COVID-19 pandemic. US health plans had a sudden breakage: a massive drop in elective procedures followed by a surge in COVID hospitalizations, both of which rocked traditional actuarial projection models (Swiss Re Institute, 2021; OECD, 2021). Decisions such as coverage mandates and premium grace periods as a result of the pandemic also added more uncertainty to pricing and reserve planning. These events highlighted the importance of incorporating systemic risk factors in actuarial modelling and long-term financial planning for healthcare.

Gaps in Existing Literature

Current regulatory frameworks - for instance, the European Union’s Solvency II and the U.S. Risk-Based Capital (RBC) standards - focus essentially on safeguarding the individual stability of insurance undertakings relative to firm-specific shocks (EIOPA, 2020; NAIC, 2023). Although they may handle idiosyncratic risks efficiently, they pay inadequate attention to aggregate or market-wide risks that have the propensity to affect multiple insurers at the same time, particularly in systemic health industry occurrences.

Furthermore, private health insurers also did not deploy any of the sophisticated systemic risk tools that are now commonplace in banking (e.g., macro-stress testing, tail dependency modeling, and network contagion analysis) (Embrechts, *et al.*, 2013). This is an unfilled vacuum for conceptual models that integrates techniques from actuarial science (such as dependency modeling and stochastic solvency projections) with methodologies for dealing with systemic risk to

Publisher: SARC Publisher

provide a combined approach to prepare the insurers in advance against systemic disturbances.

THEORETICAL FRAMEWORK DEVELOPMENT

Conceptual Approach

This study follows a straightforward theoretical approach, namely the design of a generic actuarial model aimed at addressing overall systemic risk in healthcare insurance systems. Although data is ubiquitous in actuarial literature, its grounding in probability theory, risk theory, and financial mathematics makes it fertile ground for the development of theoretical concepts (Klugman, *et al.*, 2012). This reflects a focus in this framework on internal coherence, internal logical consistency, and consistency with accepted risk paradigms, rather than empirical calibration. It aims to act as a conceptual framework for further empirical verification or simulation validation.

Framework Design Strategy

The approach, which is based on a set of actuarial adaptations tailored to the specifics of healthcare system risk, revolves around four fundamental and inter-related components the framework is organized in:

Risk Identification

The framework is kicked off with forward-looking, scenario-based identification of drivers of systemic risk, such as pandemics, demographic changes, and regulatory change. This follows actuarial stress testing and scenario analysis best practice, presented by the International Actuarial Association (IAA, 2013) and operationalized in Dynamic Financial Analysis (DFA) methods (Shiu, 2009). Such tools are essential for simulating resilience under correlated extreme risk, as happens in health systems.

Risk Quantification

Structural dependencies among claim distributions are considered by the model using multivariate methods such as copulas and Extreme Value Theory (EVT). For instance, the multivariate Archimedean and extreme value copulas are employed to reflect dependence relationships between the claim severities and the claim frequencies across insurance clients and health care providers (Kularatne & Pitt, 2021; Krämer, *et al.*, 2012). Further, EVT methods, in particular those dealing with conditional tail expectations, lend themselves to evaluating exposure to catastrophic health cost events (Embrechts, *et al.*, 2013; Drees, 2012).

Risk Mitigation and Transfer

The approaches that are embedded in the framework are, among others, demographic and geographic diversification, specific reinsurance arrangements, and the application of a dynamic premium component as a function of macro indicators. Reinsurance arrangements, such as surplus stop-loss insurance and catastrophic pool arrangements, are designed to spread high-cost risk across insurers or self-insured organizations (Cummins, & Weiss, 2014). Such initiatives align with sound macroprudential practices employed to mitigate the risk of insurer insolvency in times of system-wide stress.

Regulatory and Policy Integration

Two regulatory innovations are embedded into the framework to promote systemic resilience:

Systemic Risk Reserve: Inspired by counter-cyclical capital buffers under Basel III, this reserve would allow healthcare insurers to accumulate capital during stable periods and deploy it in response to systemic shocks (Basel Committee on Banking Supervision, 2011).

Mandatory Stress Testing: Health insurers would undergo periodic macroprudential stress testing, modeled on the International Association of Insurance Supervisors' (IAIS) Holistic Framework and Global Monitoring Exercise. These exercises assess systemic exposures and support preemptive regulatory intervention (IAIS, 2019).

Theoretical Evaluation

The model is conceptually assessed by measuring three related criteria -resilience, sustainability and adaptability.

Resilience: This principle assesses the ability of insurers to resist systemic shocks—e.g. pandemics or sudden increases in costs—by means of dynamic capital adequacy modelling and stress testing in accordance with the IAIS macroprudential standard (IAIS, 2019).

Sustainability: Sustainability refers to the extent to which the model is sustainable, without overly inflating premiums. Pooling of reinsurance, stop-loss devices, and risk diversifications are integrated to stabilize insurer's activities and guard policyholders (Dionne, 2000; Cummins & Weiss, 2014).

Adaptability: Given an increased participation in new risks such as telemedicine, personalized medicine, and new infectious diseases the framework is meant to be modular. It provides

Publisher: SARC Publisher

periodic updates to risk assumptions and model features, consistent with the DFA and its emphasis on scenario adaptability and flexibility (Shiu, 2009).

By incorporating actuarial tools, systemic risk methodologies, and regulatory insights in a structured manner, it bridges a major doctrine gap in modelling of healthcare insurance. It offers a theoretically sound basis for empirical research to come, to policy-making by regulators, to insurer risk management strategies, and it can be expected to create more robust fairer U.S. healthcare insurance system.

APPLICATION AND IMPLICATIONS

Potential Applications of the Framework

Enterprise Risk Management Integration

Insurers can integrate this systemic framework into their ERM processes. For example, in the U.S., Own Risk and Solvency Assessment (ORSA)—mandated under NAIC Model #505 since 2015—requires healthcare insurers to evaluate current and prospective solvency across stress scenarios. By incorporating our framework's systemic stress scenarios into ORSA, insurers can more accurately adjust capital reserves and premium structures to ensure ongoing solvency (Durán Santomi, *et al.*, 2020; NAIC. 2025).

Dynamic Pricing for Value-Based Care

Our framework supports updating pricing models in evolving value-based care environments. A 2022 McKinsey report highlights how insurers and providers are expanding value-based arrangements, which entail shared financial responsibility for outcomes and costs (Abou-Atme, *et al.*, 2022; SCAI, 2022). Integrating risk quantification tools (e.g. credibility theory) allows insurers to continuously refine premiums based on real-time data, thus aligning financial incentives with care quality.

Reinsurance and Pandemic Risk Transfer

The framework provides guidance for designing health-specific reinsurance or stop-loss products. Swiss Re's 2020 study on pandemic economics details how such instruments were used during COVID-19 and emphasizes the need for structured pandemic risk pools. This framework can inform future treaty design, incorporating systemic event triggers.

Regulatory and Policy Use

Regulators can require insurers to model systemic health events as part of ORSA or new macroprudential standards. Echoing the European Solvency II approach, insurers should conduct regular scenario testing with systemic risk buffers (Jerbi, 2016). Such policy measures would enforce proactive risk management and enhance industry-wide resilience.

Implications for Healthcare Finance, Actuarial Science, and Public Policy

Healthcare Finance

Shifting from reactive claims handling to proactive system-wide risk foresight, the framework enables more stable premium strategies and buffers against cost shocks, aligning financial sustainability with social protection goals.

Actuarial Science

By introducing dependency structures (copulas) and extreme value modeling into health actuarial practice, the framework calls for methodological innovation. These advanced tools support richer clinical and financial risk models, opening avenues for empirical research and simulation studies.

Public Policy

The framework supports policy initiatives for establishing systemic risk buffers, mandated healthcare-specific stress testing, and public-private pandemic reinsurance pools. Such measures echo banking-sector reforms like Basel III, but are tailored to health insurers' role in public health emergency preparedness.

In summary, this framework offers a rigorous and actionable blueprint for applying actuarial theory to healthcare systemic risk — guiding insurers, actuaries, and policymakers toward strengthened financial sustainability and enhanced health system resilience.

CONCLUSION AND RECOMMENDATIONS

This study proposed a theoretical framework for mitigating systemic risk in healthcare insurance, grounded in actuarial principles such as stress testing, dependency modeling, dynamic pricing, and reinsurance design. The framework aims to enhance resilience, sustainability, and adaptability in both insurer operations and regulatory oversight—addressing key gaps exposed by recent systemic healthcare shocks.

Future research should focus on empirically validating the framework using real-world claims, solvency, and pricing data. Simulation studies and longitudinal analyses could assess its performance under evolving demographic and technological conditions. Regulatory integration also warrants

Publisher: SARC Publisher

deeper exploration, particularly in developing systemic oversight tools for healthcare insurers. Additionally, emerging technologies—such as AI and machine learning—offer opportunities to refine actuarial models for complex healthcare risks. Cross-sectoral insights from catastrophe insurance and macroprudential banking could further inform best practices in managing correlated, high-impact events.

REFERENCES

1. Abou-Atme, Z., Alterman, R., Khanna, G., & Levine, E. "Investing in the new era of value-based care." *McKinsey & Company* (2022).
2. Basel Committee on Banking Supervision. "Basel III: A global regulatory framework for more resilient banks and banking systems." *Bank for International Settlements* (2011).
3. Bermúdez, L., & Karlis, D. "Bayesian multivariate Poisson models for insurance ratemaking." *Insurance: Mathematics and Economics* 48(2) (2011): 226–236.
4. Centers for Disease Control and Prevention (CDC). "Chronic Disease Overview." (2024).
5. Centers for Medicare & Medicaid Services (CMS). "National Health Spending Grew Slightly in 2021." (2022).
6. Commonwealth Fund. "U.S. Health Care from a Global Perspective, 2022: Accelerating Spending, Worsening Outcomes." (2023).
7. Cummins, J. D., & Weiss, M. A. "Systemic risk and the US insurance sector." *Journal of Risk and Insurance* 81(3) (2014): 489–528.
8. Cutler, D. M., & Ly, D. P. "The (paper) work of medicine: understanding international medical costs." *Journal of Economic Perspectives* 25(2) (2011): 3–25.
9. De Jong, P., & Heller, G. Z. *Generalized Linear Models for Insurance Data.* Cambridge University Press (2008).
10. Dionne, G. (Ed.). *Handbook of Insurance.* Kluwer Academic Publishers (2000).
11. Drees, H. "Extreme value analysis of actuarial risks: Estimation and model validation." *AStA Advances in Statistical Analysis* 96(2) (2012): 225–264.
12. Durán Santomil, P., & Otero González, L. "Enterprise risk management and Solvency II: The system of governance and the Own Risk and Solvency Assessment." *The Journal of Risk Finance* 21(4) (2020): 317–332.
13. Embrechts, P., Klüppelberg, C., & Mikosch, T. *Modelling Extremal Events: For Insurance and Finance.* Springer (2013).
14. European Insurance and Occupational Pensions Authority (EIOPA). "Opinion on the 2020 review of Solvency II." (2020).
15. Geneva Association. "Systemic Risk in Insurance: An Analysis of Insurance and Financial Stability." (2010).
16. International Actuarial Association (IAA). "Risk Book: Stress Testing and Scenario Analysis." (2013).
17. International Association of Insurance Supervisors (IAIS). "Holistic Framework for the Assessment and Mitigation of Systemic Risk in the Insurance Sector." (2019).
18. International Association of Insurance Supervisors (IAIS). "Global Insurance Market Report (GIMAR)." (2020).
19. Jerbi, H. "ORSA and the Regulator: A Public Policy Overview." (2016).
20. Klugman, S. A., Panjer, H. H., & Willmot, G. E. *Loss Models: From Data to Decisions.* John Wiley & Sons (2012).
21. Krämer, N., Brechmann, E. C., Silvestrini, D., & Czado, C. "Total loss estimation using copula-based regression models." *Insurance: Mathematics and Economics* 53(3) (2013): 829–839.
22. Kularatne, T. D., Li, J., & Pitt, D. "On the use of Archimedean copulas for insurance modelling." *Annals of Actuarial Science* 15(1) (2021): 57–81.
23. Lee, P. M., & Porter, M. "The strategy that will fix healthcare." *Harvard Business Review* (2013).
24. National Association of Insurance Commissioners (NAIC). "Risk-Based Capital." (2024).
25. National Association of Insurance Commissioners (NAIC). "Own Risk and Solvency Assessment (ORSA) Implementation (E) Subgroup." (2025).
26. Nielsen, S. F. *Generalized Linear Models for Insurance Data.* (2010).
27. Organisation for Economic Co-operation and Development (OECD). "Health at a Glance 2021: OECD Indicators." (2021).
28. Shiu, Y. M. "Dynamic financial analysis in the insurance industry." *The Geneva Papers on Risk and Insurance—Issues and Practice* 34(2) (2009): 175–196.
29. Shrivatsa, I. "The impact of the Covid-19 pandemic on health insurers." *Chicago Fed Letter* 471 (2022): 1–5.
30. Society for Cardiovascular Angiography & Interventions (SCAI). "McKinsey Publishes

Publisher: SARC Publisher

Report on the Growth of Value-Based Care and Risk Models in Healthcare." (2022).

31. Surico, P., & Galeotti, A. "The economics of a pandemic: The case of COVID-19." *Wheeler Institute for Business and Development*, London Business School (2020): 1–93.
32. Swiss Re Institute. "The Economics of Pandemics: The Case of COVID-19." (2020).
33. Swiss Re Institute. "Economic Insights Global Life and Health: 2021 to Offer Respite After COVID-19." (2021).
34. World Bank. *Global Economic Prospects, January 2021*. (2021).

Source of support: Nil; **Conflict of interest:** Nil.

Cite this article as:
Okumu, F. and Assan, E. E. "A Theoretical Framework for Actuarial Risk Mitigation in Healthcare Insurance Systems." *Sarcouncil Journal of Economics and Business Management* 4.12 (2025): pp 1-7.

Publisher: SARC Publisher