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Article

Risk margin estimation and budget-constrained optimal allocation of outstanding claims reserves across accident years: A case study of the Nigerian agricultural insurance corporation

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Abstract: The implications of insurance risk margins for insurers are extensive, impacting their competitive position, financial stability, and overall business strategy. Inadequate risk margins can lead to significant financial losses and regulatory sanctions, endangering their reputation and long-term viability. This study examines the insurance claims for general accident and subsidized agriculture business classes of the Nigerian Agricultural Insurance Corporation (NAIC) from 2007 to 2019. The chain ladder technique is employed to estimate ultimate claims. By incorporating claims variability using the Mack model, we estimate a more appropriate risk margin for outstanding claims. Additionally, we frame the allocation of outstanding claims as an optimization problem and compute the optimal reserves for each accident year, constrained by 90% of the insurer's overall budget, assuming log-normally distributed claims. Our findings indicate that although the total ultimate reserves for the general accident class is much lower than that of the subsidized agriculture, the former's aggregated coefficient of variation for all accident years combined is much higher, with a value greater than one. This suggests that NAIC's general accident class of business is highly susceptible to systemic risk contagion. Moreover, a significant underestimation of the risk margin is observed when variability analysis is not considered. Consequently, Nigerian insurance regulators are urged to mandate variability analysis in the claims reserve estimation within annual financial reports.

Keywords: independent risk; optimal allocation; chain ladder; lognormal distribution; risk aggregation

1. Introduction

In recent years, the insurance industry has witnessed significant transformations driven by advancements in technology, changes in consumer behavior, and regulatory developments. One of the key challenges faced by insurers is managing insurance risk effectively to ensure their financial stability and long-term viability as they play a crucial role in mitigating financial risks for individuals and businesses, thus providing a safety net against unexpected events. The fundamental aspect of insurance operations is the management of unpaid claims, which can have significant implications for the financial health and stability of an insurer.

Insurance risk margins thus play a significant role in this regard, as they help insurers account for uncertainties associated with unpaid claims across different accident years. The concept of insurance risk margins refers to the additional amount of capital that insurers set aside to cover potential losses from unpaid claims. These margins serve as a buffer against adverse events and fluctuations in claims experience, ensuring that insurers can meet their obligations to policyholders and regulators. The variability of unpaid claims across accident years poses a significant challenge for insurers, as it reflects the uncertainty inherent in the insurance business.

One of the key drivers of variability in unpaid claims is the inherent unpredictability of events that give rise to insurance claims. Natural disasters, economic downturns, changes in regulatory requirements, and shifts in market conditions can all impact the frequency and severity of claims across different accident years. Insurers must account for these uncertainties when setting their insurance risk margins to avoid underestimating their exposure to potential losses. Another factor contributing to the variability of unpaid claims is the long-tailed nature of certain insurance lines, such as liability and workers' compensation. Claims in these lines can take years to develop fully, making it challenging for insurers to accurately predict the ultimate cost of settling these claims. This uncertainty requires insurers to adopt sophisticated modeling techniques and actuarial methods to estimate their future liabilities and allocate appropriate reserves. The allocation of unpaid claims across accident years is another critical aspect of insurance risk management. Insurers must determine how to distribute their reserves effectively to ensure that they have sufficient funds to cover future losses while meeting regulatory requirements and maintaining solvency. The allocation of reserves involves a careful balancing act between conservatism and prudence, as insurers seek to strike the right balance between financial stability and profitability.

There are a few studies that have examined the variability and optimal allocation of insurance risk margins. Denuit and Robert [1], analyzed the variability of risk margins in non-life insurance using a simulation approach. They found that the variability of risk margins is affected by various factors such as claim frequency, claim severity, and underwriting margins. This study laid the foundation for subsequent research on the determinants of insurance risk margins. Hardy and Young [2], further investigated the allocation of risk margins across accident years in property-liability insurance. They found that the allocation of risk margins varies depending on the nature of the risks covered by the insurer, with higher-risk lines of business requiring larger risk margins. Cai and Wüthrich [3] conducted a comprehensive analysis of the factors influencing the variability and allocation of risk margins in life insurance. They found that economic conditions, mortality rates, and policyholder behavior all play a role in determining the size and allocation of risk margins in life insurance products bringing to the fore the need for a multidimensional approach to assessing risk margins. Chukwudum [4] focused on an African insurance dataset so as to determine the structural relationship between the over-dispersed Poisson bootstrap claims reserves and the estimated technical provisions. Other studies that have addressed the issue of risk margins in claims reserving include [5–7].

Jeanne and Sandri [8] presented an intertemporal optimization model to analyze optimal reserve management for economies that are closed (financially) and dealing with current account shocks. By focusing on welfare-based measures, the model was able to define the opportunity cost of reserves and highlight differences from traditional metrics. The research emphasized the importance of actively utilizing reserves in response to shocks rather than solely maintaining a specific reserve target. They suggested incorporating risk aversion and other shocks into the model, as well as applying it to managing commodity and sovereign wealth funds. Zhao et al. [9] focused on managing insurance policies in accordance with the new International Financial Reporting Standards 17. They employed the paid-incurred chain ladder method to project future unpaid losses - combining incurred claims and paid losses information.

Within the context of bilateral risk-sharing agreements as a means of achieving Pareto efficiency [10] focused on optimal insurance contracts. The author explored the concept of budget-constrained optimal insurance, considering scenarios of ambiguity and belief heterogeneity. The findings indicated that optimal indemnities may not include deductible provisions, and they can even be negative for minor losses or in cases where no loss occurs. Watt and Loubergé [11] further stated that the traditional economic theory of insurance often assumes that the risk needing insurance is external and fixed. However, in real-life consumer insurance, the level of risk is often a deliberate choice (such as the type of car purchased or the level of investment in insurable assets) made within budget constraints. While the standard model yields numerous theorems, they may not hold up when risk is considered an endogenous choice with budget constraints. Thus, they introduced a two-state model of insurance demand incorporating a budget constraint and allowing the insurable risk to be a decision variable. Studies from [12,13] also take into account budget constraints when allocating reserves.

In this paper we draw insights from [2] to investigate same (risk margin across accident years) for the Nigerian climate using the Nigerian Agricultural insurance Corporation (NAIC) as the case study, and further consider a budget-constrained optimized risk margin allocation process. Generally, Nigerian insurance companies' annual statements do not incorporate adequate variability and risk margin analysis for claims and this poses a great challenge in the industry. Moreover, there are no studies (to the authors' best knowledge) that have examined risk margin allocation of claims for insurance companies in sub-Saharan Africa.

The paper is structured as follows. Section 2 provides the source and format of the dataset used while Section 3 details the different techniques applied. The empirical analysis comes up in Section 4 together with policy recommendations for insurers and insurance regulators. Section 5 concludes.

2. Source and nature of data

A boost in agriculture is core for maintaining food security across the globe particularly in developing countries. Therefore the need for insurance in this sector critical. This has motivated several scholars to focus on analyzing agriculture related datasets and issues. Singh and Agrawal [14] showcased the performance of agriculture insurance schemes in India while [15] examined the accessibility and acceptability of agricultural insurance among smallholder farmers in Ghana's agriculture sector. Other studies on agriculture insurance and related risks include [16–20].

The Nigerian agricultural insurance corporation

The NAIC was established in 1987 under the Nigerian Agricultural Insurance Scheme (NAIS). NAIC was created with the aim of providing insurance coverage and financial support to farmers and agricultural enterprises in Nigeria. NAIC's establishment was prompted by the need to address the high risk associated with agriculture, such as crop failure, livestock disease outbreaks, and natural disasters, which often lead to substantial financial losses for farmers. The corporation was designed to lessen these risks and provide a safety net for farmers, guaranteeing their financial stability and encouraging investment in the agricultural sector. Hansen et al. [21] provides a concise summary of the goals of NAIC as promoting agricultural loans, assisting NAIS through Public Sector Corporation, and increasing production. To fulfill its role, NAIC offers a range of insurance products and services, including crop insurance, livestock insurance, farm indemnity insurance, farm all-risk insurance, and weather index-based insurance. These insurance policies cover various risks faced by farmers, helping them recuperate from losses and sustain a stable income.

In addition to insurance products, NAIC also supports agricultural subsidies in Nigeria. The corporation works closely with the federal government and other stakeholders to plan and implement agricultural subsidy programs. These subsidies are provided to farmers to alleviate the cost of inputs, such as fertilizers, seeds, and machinery, making these resources more affordable and accessible to farmers. NAIC's support in agricultural subsidies contributes to the overall development of the agricultural sector in Nigeria. It helps to increase agricultural productivity, enhance food security, and promote economic growth in the country

Historical claims data (presented as a runoff triangle) was collected from the 2019 annual financial report of NAIC for both general accident and subsidized agriculture (*https://naic.gov.ng/*). Only general accident is presented in **Table 1**. It covers years 2007–2019. Here, the losses are either reported or paid and there are 13 development years for both the general accident claims and subsidized agriculture. It is also assumed that the claims are full runoff at the 13th month. The issue of repeated entries for development years 5–13 was quickly spotted from the data. This poses a limitation to the analysis and brings to the fore, the problem of data reliability within NAIC.

Table 1. Runoff triangle for NAIC's general accident historical claims data.

		Development Year (DY)											
Accident year	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
2007	11,987	34,907	34,949	34,949	34,949	35,565	35,565	35,565	35,565	35,565	35,565	35,565	35,565
2008	4668	4668	4668	4668	4668	4668	4668	4668	4668	4668	4668	4668	
2009	4679	5745	5745	5745	5745	5745	5745	5745	5745	5745	5745		
2010	1628	11,018	11,018	13,884	15,790	15,790	15,790	15,790	15,790	15,790			
2011	12,016	13,191	13,209	13,209	14,031	14,031	14,031	14,031	14,031				
2012	12,487	19,234	19,276	19,466	19,466	19,466	19,466	19,466					
2013	2221	4778	4778	4778	4778	4778	4778						

Table 1. (*Continued*).

	Development Year (DY)											
Accident year	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
2014	3895	18,258	18,994	19,088	19,130	19,130							
2015	2235	11,202	13,066	13,138	13,387								
2016	2348	7604	8530	8579									
2017	801	1851	1934										
2018	7108	8210											
2019	1801												

3. Methodology

The different models employed to analyze the datasets are presented in this section.

3.1. The chain ladder

The chain ladder reserving technique proposed by [22] is used within runoff triangles' framework to estimate the outstanding and ultimate claims. The basic chain ladder method is as follows:

The exists development factors,

$$\hat{f}_{\mathrm{j}} = \frac{\sum_{i=I}^{I-j+} C_{ij}}{\sum_{i=I}^{I-j+} C_{ij-1}} \tag{1}$$

The factors are then used to forecast the future cumulative claim reserves by applying them to cumulative claims on each row as follows:

$$\hat{C}_{\mathrm{ij}} - i + 2 = \hat{C}\mathrm{ij} - i + 1 \times \hat{f}_j - i + 2 \text{ for some } 2 < j < J$$

and for *K*th row we have

$$\hat{C}_{ik} = \hat{C}_{ik} - \mathrm{i} \times \hat{f}_j \text{ for some } 2 < j < J \text{ and } 3 - i + n < k < n.$$

3.2. Coefficient of variation, column variance and row variance

These measures are used to determine the variability of unpaid claim estimates. Assessing column variance, row variance, and coefficient of variation (CoV) allows for a better understanding of the dispersion and stability of the claim development patterns, aiding in the selection of appropriate reserve levels. The CoV is simply the ratio of the standard deviation to the mean.

Sample variance

$$\mathrm{var}(x_1) = \frac{\sum_1^n (x_i - \bar{x})^2}{n-1} \tag{2}$$

Sample covariance

$$\mathrm{cov}(x_1, y_1) = \frac{\sum_1^n (x_i - \bar{y})(y_i - \bar{y})}{n-1} \tag{3}$$

The analytical formula of the row variance, α^2 and column variance σ^2 are respectively:

$$\alpha^2 = \frac{1}{N-d-1}\sum\nolimits_{1\le j\le N-d} c(j,d)\left(\frac{c(j,d+1)}{c(j,d)} - f(d)\right)^2 \tag{4}$$

$$\sigma^2 = c^2(j,N)\sum\nolimits_{N+1-j\le d\le N-1}\frac{\alpha^2(d)}{f^2(d)}\left(\frac{1}{c(j,d)} + \frac{1}{\sum_{1\le k\le N-d} c(k,d)}\right) \tag{5}$$

where N, d, j and f are respectively the ultimate reserve, development years (DY), accident year (AY) and development factor. c(.,.) generally represents the cumulative loss, specifically $c(j,d)$ is the cumulative loss for accident year j in development year d.

$$E[F(d)] = \sum_w \frac{c(w,d)}{\sum_w c(w,d)} \times \frac{c(w,d+1)}{c(w,d)} = \frac{\sum_w c(w,d+1)}{\sum_w c(w,d)} \tag{6}$$

The ultimate estimate is:

$$E[c(w,n)|D] = c(w,d) \times F(d) \times D(d+1) \times \ldots \times F(n-1)$$

where D is known data.

3.3. Mack method for covariance

The Mack method is widely used in actuarial science for estimating the reserve variability in the chain-ladder method. For two different development periods j and k, the covariance $\mathrm{cov}(C_{i,j}, C_{i,k})$ is calculated using

$$\mathrm{cov}(C_{i,j}, C_{i,k}) = \sum\nolimits_{l=j+1}^{k} C_{i,l-1}^2 \sigma_l^2 \prod\nolimits_{m=j}^{l-1} f_m \tag{7}$$

$C_{i,l-1}$ is the cumulative claim amount up to period k and $\prod_{m=j}^{l-1} f_m$ is the product of development factors from period j to $l-1$.

3.4. Lognormal distribution for estimating the confidence limit

We assume that the loss data comes from a lognormal distribution, hence the upper 90% of the overall unpaid claims is estimated using the lognormal distribution. The parameters of the lognormal (μ and δ) are estimated using method of moments as shown below:

$$\mu = Ln\left(\frac{\mu_x}{\sqrt{\left(1+\frac{\delta_X^2}{\mu_X^2}\right)}}\right) = Ln\left(\frac{\mu_X^2}{\sqrt{\mu_X^2+\delta_X^2}}\right) \tag{8}$$

$$\delta = \sqrt{\mathrm{Ln}\left(1+\frac{\delta_X^2}{\mu_X^2}\right)} \tag{9}$$

where μ_X and δ_X are respectively the empirical mean and standard deviation. The 90th percentile of standard normal distribution is 1.28.

3.5. Optimization problem

The general form of an optimization problem is as follows. Given a function $f(x) : R^n \to R$ and a set $S \subset R^n$, we want to find an $x^* \in R^n$ that solves

$$min_x f(x)\ subject\ to\ x \in S \tag{10}$$

f is called the objective function while S is called the feasible region.

4. Empirical analysis

The Chain ladder method is applied to the runoff triangle to determine the ultimate losses and outstanding claims. All the analyses are performed using Excel for both the general accident and subsidized agriculture. In **Table 2**, the general accident projected and ultimate claims (which is along the 13th DY) indicates that the variability of the claims reserves comes into play from AY 2015 and not from AY 2008 as should be the case. This issue is attributable to the original historical nature of the data provided by NAIC. Having same value across the DYs for AY 2008 to AY 2014 implies no variance is observed. This results in a column (**Table 3**) and row (**Table 4**) variance of zero for the constant years.

Table 2. Projected future claims for general accident.

	Development year (DY)												
Accident year	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
2007	11,987	34,907	34,949	34,949	34,949	35,565	35,565	35,565	35,565	35,565	35,565	35,565	35,565
2008	4668	4668	4668	4668	4668	4668	4668	4668	4668	4668	4668	4668	4668
2009	4679	5745	5745	5745	5745	5745	5745	5745	5745	5745	5745	5745	5745
2010	1628	11,018	11,018	13,884	15,790	15,790	15,790	15,790	15,790	15,790	15,790	15,790	15,790
2011	12,016	13,191	13,209	13,209	14,031	14,031	14,031	14,031	14,031	14,031	14,031	14,031	14,031
2012	12,487	19,234	19,276	19,466	19,466	19,466	19,466	19,466	19466	19,466	19,466	19,466	19,466
2013	2221	4778	4778	4778	4778	4778	4778	4778	4778	4778	4778	4778	4778
2014	3895	18,258	18,994	19,088	19,130	19,130	19,130	19,130	19,130	19,130	19,130	19,130	19,130
2015	2235	11,202	13,066	13,138	13,387	13456.6	13456.6	13456.6	13,456.6	13,456.6	13,456.6	13,456.6	13,456.6
2016	2348	7604	8530	8579	8779.89	8825.51	8825.51	8825.51	8825.51	8825.51	8825.51	8825.51	8825.51
2017	801	1851	1934	1981.13	2027.52	2038.05	2038.05	2038.05	2038.05	2038.05	2038.05	2038.05	2038.05
2018	7108	8210	8440.02	8645.69	8848.14	8894.11	8894.11	8894.11	8894.11	8894.11	8894.11	8894.11	8894.11
2019	1801	3834.24	3941.66	4037.71	4132.24	4153.73	4153.73	4153.73	4153.73	4153.73	4153.73	4153.73	4153.73
sum of DY	67,874	140,666	136,167	137,504	131,944	119,173	100,043	95,265	75,799	61,768	45,978	40,233	35,565
sum of DY except last row	66,073	132,456	134,233	128,925	118,557	100,043	95,265	75,799	61,768	45,978	40,233	35,565	
Development factors		2.13	1.03	1.02	1.02	1.01	1	1	1	1	1	1	1

Table 3. Results from age to age factor analysis for general accident.

AY	Age to age factor											
2007	2.91	1.00	1	1	1.02	1	1	1	1	1	1	1
2008	1	1	1	1	1	1	1	1	1	1	1	
2009	1.23	1	1	1	1	1	1	1	1	1		
2010	6.77	1	1.26	1.14	1	1	1	1	1			
2011	1.0978	1.00	1	1.06	1	1	1	1				
2012	1.54	1.00	1.01	1	1	1	1					
2013	2.15	1	1	1	1	1						
2014	4.67	1.04	1.005	1.00	1							
2015	5.01	1.17	1.01	1.02								
2016	3.24	1.12	1.01									
2017	3.24	1.045										
2018	1.16											
Column variance	10,327.75	32.05	66.88	27.44	0.96	0	0	0	0	0	0	0

Table 4. Estimating variability of unpaid claims (row variance, row standard deviation and CoV) for general accident.

Accident year	Ultimate Reserve	IBNR	Row variance	Row standard deviation	CoV
2007	35,565	0	0	0	0
2008	4668	0	0	0	0
2009	5745	0	0	0	0
2010	15,790	0	0	0	0
2011	14,031	0	0	0	0
2012	19,466	0	0	0	0
2013	4778	0	0	0	0
2014	19,130	0	0	0	0
2015	13,456.556	70	14,259.458	119.413	1.717
2016	8825.511	247	177,258.748	421.021	1.708
2017	2038.054	104	31,686.94676	178.008	1.711
2018	8894.112	684	835,720.041	914.177	1.336
2019	4153.73	2,353	18,367,636.55	4285.748	1.822
Total	156,541	3457	19,426,561.74	5918.368	8.293

The **Table 4** provides the results of the ultimate reserves of the AY data, including IBNR (incurred but not reported) reserves, row variance, row standard deviation, and CoV. Notably, from 2007 to 2014, there is no IBNR, variance, or standard deviation, indicating stable and fully developed claims. From 2015 onwards, increasing IBNR reserves and rising variances highlight growing uncertainties in claims development. The CoV values, ranging from 1.336 to 1.822, reflect the relative variability of the reserves for these years. The total ultimate reserve is 156,541 with significant increases in IBNR and variability in recent years, emphasizing the need for careful reserve management.

A similar calculation is carried out for subsidized agriculture (**Table 5**). The column variance in this case is shown in **Table 6.**

Table 5. Projected future claims for subsidized agriculture.

	Development year (DY)												
Accident year	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
2007	75,111	177,429	192,000	192,000	192,000	192,000	192,000	192,000	192,000	192,000	192,000	192,000	192,000
2008	89,600	267,921	270,534	270,551	270,551	270,551	270,551	270,551	270,551	270,551	270,551	270,551	270,551
2009	204,926	278,050	297,461	297,461	298,741	298,741	298,741	298,741	298,741	298,741	298,741	298,741	298,741
2010	120,328	162,994	162,994	162,994	162,994	162,994	162,994	162,994	162,994	162,994	162,994	162,994	162,994
2011	95,941	112,152	112,773	112,893	112,893	112,893	112,893	112,893	112,893	112,893	112,893	112,893	112,893
2012	100,481	271,399	280,694	281,035	281,035	281,035	281,035	281,035	281,035	281,035	281,035	281,035	281,035
2013	97,613	160,896	179,680	179,680	179,680	179,680	179,680	179680	179,680	179,680	179,680	179,680	179,680
2014	137,163	203,158	208,443	208,419	208,833	208,833	208,833	208,833	208,833	208,833	208,833	208,833	208,833
2015	106,115	247,164	249,242	250,167	251,227	251,227	251227	251,227	251,227	251,227	251,227	251,227	251,227
2016	100,495	208,141	265,150	265,194	265,567.54	265,567.54	265,567.54	265,567.54	265,567.539	265,567.539	265,567.54	265,567.54	265,567.54
2017	35,573	365,080	393,121	393,373.10	393,927.19	393,927.19	393,927.19	393,927.19	393,927.19	393,927.19	393,927.19	39,3927.19	393,927.19
2018	35,776	180,717	192329.09	192,452.42	192,723.50	192,723.50	192,723.50	192,723.5	192,723.50	192,723.50	192,723.50	192,723.50	192,723.50
2019	106,305	233,607.93	248,618.56	248,777.99	249,128.41	249,128.41	249,128.41	249,128.41	249,128.41	249,128.41	249,128.41	249,128.41	249,128.41
sum of DY	1,305,427	2,635,101	2,612,092	2,220,394	1,957,954	1,706,727	1,497,894	1,318,214	1,037,179	924,286	761,292	462,551	192,000
sum of DY except last row	1,199,122	2,454,384	2,218,971	1,955,200	1,706,727	1,497,894	1,318,214	1,037,179	924,286	761,292	462,551	192,000	
Development factors		2.198	1.06	1.00064	1.001	1	1	1	1	1	1	1	1

Table 6. Age to age factor analysis for subsidized agriculture.

AY	Age to age factor											
2007	2.36	1.08	1	1	1	1	1	1	1	1	1	1
2008	2.99	1.01	1.00	1	1	1	1	1	1	1	1	
2009	1.36	1.07	1	1.004	1	1	1	1	1	1		
2010	1.35	1	1	1	1	1	1	1	1			
2011	1.17	1.01	1.001	1	1	1	1	1				
2012	2.70	1.03	1.001	1	1	1	1					
2013	1.65	1.12	1	1	1	1						
2014	1.48	1.03	0.99	1.002	1							
2015	2.33	1.01	1.004	1.004								
2016	2.07	1.27	1.00									
2017	2.07	1.077										
2018	5.05											
Column variance	67, 571.55	1171.05	0.31	0.77	0	0	0	0	0	0	0	0

Post-2015, the data in **Table 7** shows increasing IBNR and significant variability, especially in 2018 and 2019, reflecting higher uncertainty and risk in claims development. The CoV values indicate relative variability, with a notably high variance in 2019.

Table 7. Estimating variability of unpaid claims (row variance, row standard deviation and CoV) for subsidized agriculture.

Accident year	Ultimate Reserve	IBNR	Row variance	Row standard deviation	CoV
2007	192,000	0	0	0	0
2008	270,551	0	0	0	0
2009	298,741	0	0	0	0
2010	162,994	0	0	0	0
2011	112,893	0	0	0	0
2012	281,035	0	0	0	0
2013	179,680	0	0	0	0
2014	208,833	0	0	0	0
2015	251,227	0	0	0	0
2016	265,567.539	374	244,604.366	494.575	1.324
2017	393,927.190	806	750,776.8501	866.474	1.075
2018	192,723.503	12,007	171,196,522.7	13,084.209	1.0898
2019	249,128.412	142,823	9,194,308,945	95,886.959	0.671
Total	3,059,301	156,010	9,366,500,849	110332.2168	4.1599

The substantial variation between the predicted ultimate claims for general accident (**Table 4**) and subsidized agricultural (**Table 7**) insurance underscores the differing risk profiles and exposure levels associated with each line of business. Additionally, the higher IBNR reserve for subsidized agricultural insurance compared to general accident insurance reflects the inherent uncertainty and volatility in predicting claims in the agricultural sector, necessitating a more significant provision for potential future losses.

Using the relationship between development periods, we estimate the covariance. The aggregate the covariance calculations across different accident years, which provides us with an understanding of the overall reserve variability is found to be 4426.29 for general accident (**Table 8**) and 96995.33 for subsidized agriculture (**Table 9**).

The aggregated CoV for all accident years combined is then obtained by dividing the aggregate covariance by the total IBNR. Thus we obtain 1.28 (4428.2874/3457) for general accident and 0.62173 for subsidized agriculture. This implies that the variation between the accident years for general accident is quite high compared to its mean and hence is more exposed to systemic risk contagion, posing serious danger to NAIC.

Table 8. The covariance matrix of reserves (using the Mack method) between different development periods for general accident.

	AY1	**AY2**	**AY3**	**AY4**	**AY5**	**AY6**	**AY7**	**AY8**	**AY9**	**AY10**	**AY11**	**AY12**	**AY13**
AY1	0	0	0	0	0	0	0	0	0	0	0	0	0
AY2	0	0	0	0	0	0	0	0	0	0	0	0	0
AY3	0	0	0	0	0	0	0	0	0	0	0	0	0
AY4	0	0	0	0	0	0	0	0	0	0	0	0	0
AY5	0	0	0	0	0	0	0	0	0	0	0	0	0
AY6	0	0	0	0	0	0	0	0	0	0	0	0	0
AY7	0	0	0	0	0	0	0	0	0	0	0	0	0
AY8	0	0	0	0	0	0	0	0	0	0	0	0	0
AY9	0	0	0	0	0	0	0	0	14,259.44	948.86	219.118	956.24	446.582
AY10	0	0	0	0	0	0	0	0	948.86	177,258.7	3798.29	16,575.8	7741.25
AY11	0	0	0	0	0	0	0	0	219.12	3798.29	31,686.95	12,434.8	5807.30
AY12	0	0	0	0	0	0	0	0	956.24	16,575.84	12,434.8	835,720	33,801.04
AY13	0	0	0	0	0	0	0	0	446.58	7741.25	5807.30	33,801.1	183,667,637
overall standard deviation of the overall reserve estimator for all accident years combined													4426.29

Table 9. The covariance matrix of reserves (using the Mack method) between different development periods for subsidized agriculture.

	AY1	**AY2**	**AY3**	**AY4**	**AY5**	**AY6**	**AY7**	**AY8**	**AY9**	**AY10**	**AY11**	**AY12**	**AY13**
AY1	0	0	0	0	0	0	0	0	0	0	0	0	0
AY2	0	0	0	0	0	0	0	0	0	0	0	0	0
AY3	0	0	0	0	0	0	0	0	0	0	0	0	0
AY4	0	0	0	0	0	0	0	0	0	0	0	0	0
AY5	0	0	0	0	0	0	0	0	0	0	0	0	0
AY6	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 9. (*Continued*).

	AY1	AY2	AY3	AY4	AY5	AY6	AY7	AY8	AY9	AY10	AY11	AY12	AY13
AY7	0	0	0	0	0	0	0	0	0	0	0	0	0
AY8	0	0	0	0	0	0	0	0	0	0	0	0	0
AY9	0	0	0	0	0	0	0	0	0	0	0	0	0
AY10	0	0	0	0	0	0	0	0	0	244,604.37	41,158	20,136	26,029.25
AY11	0	0	0	0	0	0	0	0	0	41,158.01	750,777	40,370	52,185.74
AY12	0	0	0	0	0	0	0	0	0	750,776.85	40,370.4	2×10^8	20,251,062
AY13	0	0	0	0	0	0	0	0	0	26,029.25	52,185.7	2×10^7	9.19×10^9
overall standard deviation of the overall reserve estimator for all accident years combined													96,995.33

4.1. Formulating the outstanding claims capital allocation as an optimization problem

In order to optimally allocate the constrained budget across the years where volatility is observed, we first formulate the outstanding claims as an optimization problem in Equation (11).

$$\text{Maximize: } f(x_i) = x_i \times (e^{Z_{\alpha}*\sqrt{\delta_i^2 - \frac{\delta_i^2}{2}}}) \text{Subject to: } \sum_{i=1}^{n} f(x_i) \leq \boldsymbol{C}, x_i \geq 0 \quad (11)$$

where C which has been set at the 90% confidence limit. x_i and δ_i^2 respectively represent the outstanding claims and standard deviations for each accident year i. Z_α is the standard normal values at α-level confidence and n, the number of accident years.

In estimating the upper 90% confidence limit of the overall unpaid claims using the lognormal distribution, we make use of the 90th percentile of the standard normal distribution which is 1.28. The aggregate CoV for each class serves as the value that is used to compute the δ^2 parameter of the lognormal (based on Equation (9)) for the total accident years. The overall 90% confidence limit for general accident and subsidized agriculture respectively are obtained as 7509 and 275,409. This is computed using Equation (11) with δ^2 (0.97 and 0.327 respectively for general accident and subsidized agriculture), and x taken as the overall IBNR (3457 and 156,010 respectively for general accident (**Table 4**) and subsidized agriculture (**Table 7**).

From **Tables 10** and **11**, it can be observed that when considered individually, a 90%confidence limit for each accident year gives a total of 7769.001 for general accident and 286569.0582 for subsidized agriculture. This presents an increased cost when compared to the aggregate or overall 90% confidence limit cost values (7509 and 275,409 respectively). NAIC, as well as any other insurance company will prefer the one that provides a reduced cost after taking into account the variability. The aim then, is to allocate the aggregate reduced cost across the accident years such that the same level of confidence is maintained for each year. This is the optimization problem. This is done using goal seek in Excel.

Table 10. Allocating the overall general accident amount (7509) to accident years 9–13 while maintaining the same level of confidence for each accident year.

Accident years (AY)		**CoV**	**Sigma2**	**90% Confidence Limit for each AY**	**Allocating 7509 across accident years**	
					Adjusted confidence limit at 1.21	**Adjusted confidence limit at 1.25**
2015	AY9	1.717	1.373	156.8798	144.526	151.4608
2016	AY10	1.708	1.365	555.787	512.137	536.6423
2017	AY11	1.711	1.368	234.629	216.186	226.5399
2018	AY12	1.336	1.024	1497.3567	1394.937	1452.5727
2019	AY13	1.822	1.464	5324.3476	4892.122	5134.619
Total				7769.001	7159.909	7501.835

It is important to note that although the same level of confidence for each accident year may not be 90%, the overall confidence limit will be 90%. Two out of the several simulated scenarios is presented in the last two columns of **Tables 10** and **11**. In **Table 10**, an adjusted confidence limit at 1.25 provides the closest estimate to 7509 and we see a reduced amount of reserves for each allocated year in comparison to column 5 (that is, 90% confidence limit for each AY).

Table 11. Allocating the overall subsidized agriculture amount (275,409) to accident years 9–13 while maintaining the same level of confidence for each accident year.

Accident years (AY)		**CoV**	**Sigma2**	**90% Confidence Limit for each AY**	**Allocating 275,409 across accident years**	
					Adjusted confidence Limit at 1.217	**Adjusted confidence Limit at 1.218**
2016	AY10	1.32402	1.0127	816.295	766.1495	766.9209
2017	AY11	1.07478	0.7679	1685.85	1595.302	1596.7
2018	AY12	1.08976	0.7828	25,192.34	23,826.5408	23,847.6307
2019	AY13	0.67137	0.3720	258,874.58	249,115.124	249,267.125
SUM				286,569.058	275,303.116	275,478.377

In **Table 11**, the closest estimate was obtained by setting the adjusted confidence limit to 1.217. Thus for both cases (agriculture and subsidized agriculture) when the aggregate CoV is used, a reduced cost on the constrained budget is achieved, which can as well be allocated across the accident years. More importantly we observe, in **Table 12**, a significant underestimation of the IBNR values for each accident year when the variability is not accounted for. A more visual representation (for general accident) depicts the rate at which the IBNR underestimation quickly accumulates as the years progress when variability analysis is overlooked (**Figure 1**). This result strongly suggests setting a risk margin that is almost double the initial reserve.

Table 12. IBNR (outstanding claims) reserve values for each accident year with and without variability analysis.

Accident years	Class of business	2015	2016	2017	2018	2019
IBNR without variability analysis	General accident	70	247	104	684	2353
	Subsidized agriculture		374	806	12,007	142,823
IBNR with variability analysis	General accident	151.46	536.64	226.54	1452.57	5134.62
	Subsidized agriculture		766.92	1596.7	23,847.63	249,267.13

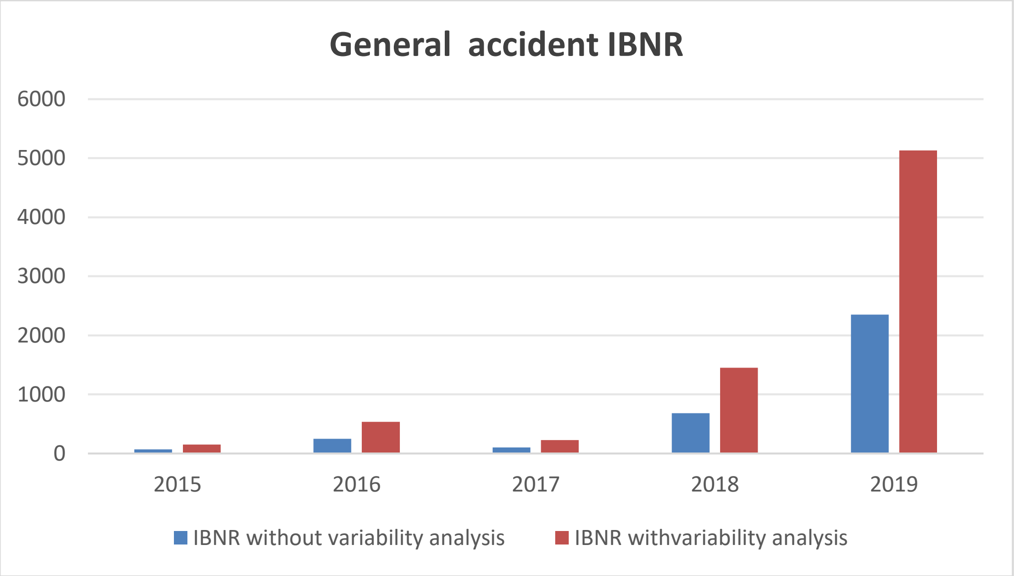

Figure 1. General accident IBNR with and without variability analysis.

4.2. Policy recommendations for insurers and insurance regulators

We recommend that Nigerian insurance regulators should begin to pay keen attention and enforce adequate variability and risk margin assessments in insurance companies' claims reserving computations. The analysis should reflect in their financial annual reports. Specific ways to improve comprehensive risk management include ensuring availability and reliability of data as reliable data is essential for accurate risk assessment and reserve estimation. Insurers and regulators should collaborate to establish standardized data collection and reporting procedures. This includes investing in advanced data management systems and ensuring data integrity through regular audits and validations. Access to high-quality, reliable data will enable insurers to perform more precise variability analyses and improve the accuracy of their risk margin estimations.

Additionally, dynamic reserve management should be adopted and strictly implemented. Dynamic reserve management practices, which should be implemented by insurance regulators are critical as they periodically review and adjust reserves based on real-time data and emerging trends. This approach will allow for more accurate estimation of outstanding claims reserves, taking into account changes in risk exposure and market conditions. The lack of expertise stems from poor training. Hence, actuarial training and certification must be enhanced. The insurance industry should invest in these to ensure that actuaries are proficient in advanced statistical methods, including variability analysis and the Mack model. This can be achieved through partnerships with academic institutions and professional bodies. Well-trained actuaries will be better equipped to perform accurate claims reserve estimations, thereby improving the overall risk management capabilities of insurers.

Insurance regulators should develop and implement comprehensive risk management frameworks that integrate both quantitative and qualitative risk assessment methods. These frameworks should encompass not only independent risks but also internal and external systemic risks. A holistic view of all potential risk factors will provide insurers with the required tools to make more informed decisions regarding reserve allocations and risk margins, ultimately enhancing their competitive position and financial stability.

5. Conclusion

This study highlights the substantial underestimation of outstanding claims reserves when variability analysis is omitted, which directly and significantly affects the insurer's estimated risk margin. Although the nature of the data obtained from NAIC poses some limitations on the analysis, our findings demonstrate that, given a constrained budget, insurers can leverage the aggregate coefficient of variation across all accident years to reduce costs, as opposed to considering each accident year's coefficient of variation individually. The reduced costs were then optimally allocated across each year while maintaining the same level of confidence. As this study only considered independent risks, further research should incorporate internal and external systemic risks that Nigerian insurers face.

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