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Analysis of the Application of the Integrated Catastrophe Risk Model Method for the Flood Insurance Program

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Abstract

As the flood rises continue to grow, well-designed insurance programs are becoming an important instrument in flood risk management. One of the obstacles in the flood insurance program is the method used to calculate the premium value. This thesis refers to the Integrated Catastrophe Risk Model (ICRM) which consists of two probability events and stochastic optimization procedures with respect to observation of site-specific risk. The application of the model is illustrated in the study area simulation data. In this thesis, analysis of various aspects of trade-off, new ex-post variables, opportunity occurrence 1 and 2 and minimization of loss function. From the results of research based on these four aspects it can be concluded that the use of Integrated Catastrophe Risk Model method in the optimal flood insurance program.

Keywords: flood risk, integrated catastrophe risk model, loss-sharing program

1. Introduction

Floods are the most frequent disasters in Indonesia, flood losses are also increasing along with the increasing intensity of floods in various regions (Hapsari & Zenurianto, 2016; Padawangi & Douglass, 2015; Marfai, et al., 2015). Losses from flooding can disrupt economic prosperity and economic stability in Indonesia. For this reason, efforts are needed to suppress the intensity of flooding and the resulting losses. One of the most appropriate solutions to this problem is flood insurance. but what is still an obstacle to the flood insurance program is the method used to calculate the premium value of the flood insurance itself.

Based on this description, in this study the authors tried to analyze the optimal use of the Integrated Catastrophe Risk Model method in the flood insurance program (Tsai & Chen, 2010; Khan, et al., 2020; Harrison, et al., 2001; Van Westen, 2013).

2. Object and Research Methodology

The object of this study is an analysis of the premium calculation method for the flood insurance program. The research method used in this study is the Integrated Catastrophe Risk Model (ICRM) method (Prakash & Viswanathan, 2019; Raikes, et al., 2021; Olaogbebikan, & Oloruntoba, 2019).

2.1. General Integrated Catastrophe Risk Stochastic Model

In order to take into account the various risk management stakeholders, this regional study is divided into sub-regions or locations $j = 1..m$.Suppose n agents $i = 1,\dots,n$ (insurance, government, re-insurance, funds) involved in *loss sharing programs* (Dastous, et al., 2008) Agents are those who have contracts with locations to cover their losses. Each agent i has an initial fund or risk reserve R^0 which generally depends on the magnitude of the disaster event. Consider that the planning horizon includes $t = 0,,\dots,n$ time intervals. Reserve risk R^t at every calculated according to the following formula:

$$R_i^{i+1} R_i \quad {}_{j-1}^{\omega} (\pi_{ii}^t \, c_{ii}^t \, (q_{ii}^t)) \quad {}_{j-1}^{\omega} L_j^1 \, (\omega_t) \, q_{ii} \tag{1}$$

Where:

q_{ii}^{t} is the coverage of company (insurance company) i at location j at time t , $\sum_{i-1} q_{ii} \leq 1$

π_{ii}^{t} is the premium from firm) i at location j at time t

$c_{ii}^{t}(q_{ii}^{t})$ are transaction or administrative fees, or other costs

$L_{j}^{1}\ (\omega_{t}\ )$ is the loss (damage) at location j caused by the disaster ω_{t} at time t .

If W_{i}^{0} is the initial wealth (property value), then the wealth of location j at time t + 1 together with :

$$W_{i}^{i+1} W_{i} \quad {}_{j-1}^{\omega} \left(L_{ii}^{v}\left(\omega_{t}\ \right) q_{ii}\ \pi_{ii}^{t}\right) L_{j}^{1}\ \left(\omega_{t}\ \right) t\ 0,1 \ldots . \tag{2}$$

The robustness of an insurance program depends on whether the risk reserves accumulated $R_{i}(x,\omega)$ at random times $t = \tau(\omega)$ from the first catastrophic event are avoided. In a probabilistic sense, bankruptcy is defined by events.

$$E_{j}\ = \left\{\omega : R_{i}^{i(\omega)}(x,\omega) < 0\ \right\} = 1, \ldots, n \tag{3}$$

$$E_{2}\ = E_{21} \cup E_{22} \cup \ldots \cup E_{2m} \tag{4}$$

Where:

$$E_{2j} = \left\{(f) q_{j}\ L_{j}^{\tau(\omega)}(\omega) - \pi_{j}\ \tau(\omega) < 0\ \right\} \text{ for } j = 1,\ldots,m \text{ and } q_{j}\ L_{j}^{\tau}(\omega) = 0, t\ < (\omega)$$

Events (3.3) and (3.4) determine the stability (resilience) of an insurance program, in other words its systemic solvency under probabilistic constraints of the type:

$$pr\ ob[E_{1} E_{2}] \leq \bar{P} \tag{5}$$

where p is the critical probability threshold of program systemic bankruptcy. Unfortunately, direct use of the probabilistic constraints (2.5) in the ICRM model is practically impossible because of the often discontinuous and analytically rigorous character constants they owe to the discrete distribution of random ω vectors. Therefore, section 2.2 formulates the main ICRM models as a convex STO problem with a specific non-refined risk (penalty) function that makes it possible to obtain an optimal solution implicitly drives this type of constraint (see (2.9) and (2.10)). this problem is effectively solved by the linear programming method (see Equations (2.11) to (2.14)).

2.2. Integrated Catastrophe Risk Model for the Study Area

In the case study it is assumed that only one "aggregate" insurance or disaster fund operating in the region, regardless of cost$q_{jj}^{t}(q_{jj}^{t})$ as well as assume that $\pi_{ii}^{t} = \pi_{j}\ \tau$, that is, the accumulated premiums before the occurrence of the first flood are proportional with arrival time $\tau(\omega)$.

The main concern regarding the systemic bankruptcy of a flood insurance program is to avoid as much as possible the probability/probabilities of events (2.6) and (2.7):

$$E_{j}\ = \left\{\omega\ \textstyle\sum_{j} \pi_{j}\ \tau(\omega) - q_{j}\ L_{i}^{i(\omega)}(\omega) < 0\ \right\} \tag{6}$$

$$E_{2}\ = E_{21} \cup E_{22} \cup \ldots \cup E_{2m} \tag{7}$$

$$E_{2j} = \left\{(f) q_{j}\ L_{j}^{\tau(\omega)}(\omega) - \pi_{j}\ \tau(\omega) < 0\ \right\} \text{ for } j = 1,\ldots,m$$

Where q_{j} is the insurance coverage for the location j, π_{j} is the rate of premium paid by location, $L_{j}^{\tau(\omega)}(\omega)$ is the stochastic loss for the location caused by a random flood event ω at time $t = \tau(\omega)$.

In section 3.3.2, the stochastic model has been formulated for the optimization version of the convex or general function. The problem can be formulated as minimizing the function:

$$F(x) = E \textstyle\sum_{j}(1-q_{j}) L_{i}^{i(\omega)}(\omega) +\ \alpha E\ Max\ (0, \sum_{j} q_{j}\ L_{i}^{i(\omega)}(\omega) - -\pi_{j}\ \tau(\omega) + \sum_{j} B_{j} E \max\left\{0, \pi_{j}\ \tau(\omega) - q_{j} L_{i}^{i(\omega)}(\omega)\right\} \tag{8}$$

Coefficients α and β_{j} regulates the trade-off between the premium rate and the total coverage. The coefficient α can also be defined as the credit price that will buy the program (funds) if its reserves fall below a critical level. If we consider a multilayer insurance program, then the choice of α determines the involvement of the government in PPP (Public Private Partnership), The coefficient β_{j} determines the desired level of non-overpayments from the demand side of this insurance program.

Minimization of the function (3.8) makes it possible to achieve supply-demand probabilism strong insurance equilibrium is characterized by systemic insolvency constraints by quantile-type (3.5).

The following is the systemic risk balance formula:

$$F(x) =\ \alpha\ \Pr ob\left[\textstyle\sum_{j} q_{j} L_{i}^{i(\omega)}(\omega) - \pi_{j}\ \tau(\omega) \geq 0\right] +\ \beta_{j}\ \Pr ob\left[\pi_{j}\ \tau(\omega) - q_{j}\ L_{i}^{i(\omega)}(\omega) \pi_{j}\ \tau(\omega) \geq 0\right] = 0 \tag{9}$$

Here is checked role α, β_{j} by formulating an unrestricted STO model (3.8) with a non-smooth risk (Penalty) function into the constraints of linear programming models (2.11) through (2.14) in a larger space of decision variables $\pi_{j}^{s} q_{j}\ c_{j}^{s} \varepsilon^{s}$ Decisions c_{j}^{s} and ε^{s} represents a new ex-post decision, for example, credit government assistance, which is carried out after observing stochastic losses $L_{i}^{i(\omega)}$ This variable makes it possible to eliminate overpayments and underpayments from insurance companies and insureds in order to secure the systemic solvency of flood programs. In numerical calculations it is assumed that disasters, namely, floods, represented by scenario s = 1,...,s which induces the random loss scenario $L_{i}^{i} = L_{i}^{i(\omega)}(\omega)$ for $t = \tau(\omega^{s})$ at location j = 1,...,m with probability$p_{i}\ s =$

$\sum_s p = 1$ using scenario S , the model defined by equation (3.8) is equivalently replaced by model: minimize represents a new ex-post decision, for example, credit.

$$F(x) = \sum_{s-1}^{s} p_s \sum_{j} q_j \,(1 - q_i) L_i^i + a \sum_{s-1}^{s} p_s \sum_{s-1}^{s} C_1^s + \beta \sum_{s-1}^{s} p_s \,\omega^s \tag{10}$$

Under constraints:

$$c_j^s \geq 0 \ \omega^s \geq 0, \mathrm{s} = 1,...,s \tag{11}$$

$$\sum_j (q_j \, L_i^i \text{ -} \pi_j \ \tau) \ \geq \omega^s \tag{12}$$

$$\pi_j \ \tau - q_j L_i^i \geq c_j^s \tag{13}$$

Models (3.11) to (3.14) include the new ex-post adaptive decision variables c_j^s and ε^s to adjust strategic decisions $x = (\pi_{j,} q_j)$ for all event scenarios flood $s = 1,\ldots,s$ at all locations $j = 1,\ldots,m$. This approach converts the model non-smooth stochastic optimization (3.8) into linear optimization problems (3.11) to (3.14) which are solved by the linear programming method.

2.3. Linear Programming

Mathematical model of the formulation of the general problem of allocating resources for various activities, is referred to as a linear programming model. This linear programming model is a form and arrangement in presenting problems to be solved by engineering linear programmer. Linear programming problems in general can be written in the following general form.

$$\text{Max/ Min } z(x_1, x_2,...,x_n) \sum_{s-1}^{s} c_i \, x_i \tag{14}$$

with constraints:

$$\sum_{s-1}^{s} c_j \, x_j \left(\begin{matrix} \leq \\ = \\ \geq \end{matrix}\right) b_{j=} 1,2\ldots, m. \tag{15}$$

And

$$x_j \geq 0, j = 1,2\ldots, m. \tag{16}$$

Description:

z = objective function
x_j = type of activity (decision variable)
a_{jj} = resource requirement i to produce each unit of activity *j*
b_j = amount of resource i available
c_j = increase in the value of z if there is an increase in one unit of activity *j*
a, *b*, *c* are also known as model parameters
m = number of available resources
n = number of activities.

3. Results And Discussion

3.1. Research Data

The research data used is simulation data in the form of insurance company coverage area data at each study location, insurance company premiums at each study location based on flood zones and data on flood losses for 6 years.

3.2. Integrated Catastrophe Risk Model

3.2.1. Calculation of Risk Reserves

At this stage the value of $\mathrm{R^t}$ t is calculated for each t. For example, calculated values $\mathrm{R^t}$ in year 0 , with the following calculation:

$$\mathrm{R}^0 \sum_{s-1}^{s} \pi_j \ \ (0) - q_i L_i^i \ (\omega)$$

$$\mathrm{R}^0 = (\pi_1 \ 0) - q_1 L_1^{(0)} \ (\omega)) + (\pi_2 \ 0) - q_2 L_2^{(0)} \ (\omega)) + (\pi_3 \ 0) - q_3 L_3^{(0)} \ (\omega)) + (\pi_1 \ 0) - q_4 L_4^{(0)} \ (\omega)) \ + (\pi_1 \ 0) - q_5 L_5^{(0)} \ (\omega))$$

$$R^0 = -367500000 + 236500000 + 320000000 + 1173000000 + 86000000$$
$$R^0 = 1448000000$$

For years 1 to 5, the value of R^t calculated as above. Results the calculation of each risk reserve can be seen in Table 1.

Table 1: Calculation of Risk Reserves

Year (t)	Location (j)	Coverage (q)	premi (π_{ij}^t)	Losses (L_i^i)	Reserves (R)
0	1	0.5	857500000	2450000000	
0	2	0.24	752500000	2150000000	
0	3	0.09	500000000	2000000000	1448000000
0	4	0.01	1207500000	3450000000	
0	5	0.21	537500000	2150000000	
1	1	0.5	945000000	2700000000	
1	2	0.23	770000000	2200000000	
1	3	0.09	525000000	2100000000	929500000
1	4	0.03	1015000000	2900000000	
1	5	0.34	537500000	2150000000	
2	1	0.4	1050000000	3000000000	
2	2	0.23	1155000000	3300000000	
2	3	0.1	600000000	2400000000	1431000000
2	4	0.05	1085000000	3100000000	
2	5	0.3	525000000	2100000000	
3	1	0.55	1120000000	3200000000	
3	2	0.25	1120000000	3200000000	
3	3	0.08	675000000	2700000000	1008500000
3	4	0.06	1102500000	3150000000	
3	5	0.27	550000000	2200000000	
4	1	0.6	1137500000	3250000000	
4	2	0.25	1137500000	3250000000	
4	3	0.11	562500000	2250000000	732000000
4	4	0.07	1102500000	3150000000	
4	5	0.24	562500000	2250000000	
5	1	0.7	1225000000	3500000000	
5	2	0.3	1050000000	3000000000	
5	3	0.25	650000000	2600000000	-1225000000
5	4	0.15	1050000000	3000000000	
5	5	0.55	625000000	2500000000	

3.2.2. Calculation of Asset Value / Wealth

At this stage the value of W_i^i is calculated using the results from table 3.1. for each t.
In this calculation For example, calculating the value of W_i^i in year 0, with the following calculation:

$$W_i^t = a_1 L_i^{i(\omega)}(\omega) - \pi_j \ \tau(\omega)$$
$$W_i^t = a_1 L_i^{i(\omega)}(\omega) - \pi_j \ \tau(\omega)$$
$$W_i^t = 0{,}5 \text{ x } 2450000000 - 857500000$$
$$W_i^t = 367500000$$

For years 1 to 5, the value of W_i^t calculated as above. Results the calculation of each risk reserve can be seen in Table 2.

Table 2: Location Wealth Calculation

Year (T)	Location (J)	Coverage (Q)	Premi (π_{jj}^{t})	Losses (L_i^i)	Lq	Riches (W)
0	1	0.5	857500000	2450000000	1225000000	367500000
0	2	0.24	752500000	2150000000	516000000	-236500000
0	3	0.09	500000000	2000000000	180000000	-320000000
0	4	0.01	1207500000	3450000000	34500000	-1173000000
0	5	0.21	537500000	2150000000	451500000	-86000000
1	1	0.5	945000000	2700000000	1350000000	405000000
1	2	0.23	770000000	2200000000	506000000	-264000000
1	3	0.09	525000000	2100000000	189000000	-336000000
1	4	0.03	1015000000	2900000000	87000000	-928000000
1	5	0.34	537500000	2150000000	731000000	193500000
2	1	0.4	1050000000	3000000000	1200000000	150000000
2	2	0.23	1155000000	3300000000	759000000	-396000000
2	3	0.1	600000000	2400000000	240000000	-360000000
2	4	0.05	1085000000	3100000000	155000000	-930000000
2	5	0.3	525000000	2100000000	630000000	105000000
3	1	0.55	1120000000	3200000000	1760000000	640000000
3	2	0.25	1120000000	3200000000	800000000	-320000000
3	3	0.08	675000000	2700000000	216000000	-459000000
3	4	0.06	1102500000	3150000000	189000000	-913500000
3	5	0.27	550000000	2200000000	594000000	44000000
4	1	0.6	1137500000	3250000000	1950000000	812500000
4	2	0.25	1137500000	3250000000	812500000	-325000000
4	3	0.11	562500000	2250000000	247500000	-315000000
4	4	0.07	1102500000	3150000000	220500000	-882000000
4	5	0.24	562500000	2250000000	540000000	-22500000
5	1	0.7	1225000000	3500000000	2450000000	1225000000
5	2	0.3	1050000000	3000000000	900000000	-150000000
5	3	0.25	650000000	2600000000	650000000	0
5	4	0.15	1050000000	3000000000	450000000	-600000000
5	5	0.55	625000000	2500000000	1375000000	750000000

3.2.3. Calculation of the Probability of Disaster Events One and Two

In this stage, the combined probability of one and two disaster events is determined.
From table 3.3 it is obtained:

$$E_1 \;= \{\omega_s\} \; and \; E_{21} = \{\quad\}$$

$$E_{21} = \{\omega_0, \omega_1, \omega_2, \omega_3, \omega_4, \omega_5\}$$

$$E_{21} = \{\omega_0, \omega_1, \omega_2, \omega_3, \omega_4\}$$

$E_{21} = \{\omega_0, \omega_1, \omega_2, \omega_3, \omega_4, \omega_5\}$ as well as Prob $(E_1 E_2) = 1$

So that p (critical probability threshold of program systemic bankruptcy) is 1

3.2.4. Optimization Models

In this stage, the formation of a loss optimization model is carried out which is given as following:

$$F(x) = E\sum_j (1-q_j) L_i^{i(\omega)}(\omega) + \; \alpha E \; Max \; (0, \sum_j q_j \, L_i^{i(\omega)}(\omega) - -\pi_j \;\; \tau(\omega)$$

$$+\sum_j B_j E \max\left\{0, \pi_j \;\; \tau(\omega) - q_j L_i^{i(\omega)}(\omega)\right\}$$

From the calculations obtained from 3.2.1 to 3.2.4, the Minimization optimization model is obtained:

$$Z_{mm} = 1102333000\,00 + \; 204166667\alpha + 281916667 B_2 + 298333333 \, B_3 + 904416667 \, B_4 + 18083333.3 B_5 \quad (17)$$

With Constraints:

$$1102333000\,00 + 204166667\alpha + B_2 + B_3 + B_4 + 18083333.3 B_5 \quad (18)$$

Next, optimization is carried out with the help of Maple Software:

- With (optimization) :
  Use LPSsolve to minize a linear of two variables object to four linier constrainsts

$$LPSilve = 110233300000 + 204166667\alpha + 281916667B_2 + 298333333\,B_3 + 904416667\,B_4 + 18083333.3B_5\,\{-a + 6B_2 + B_3 + B_4 + B_5 = 0\}$$

$$[1.1023330000010^{11}, a = 0, B_2 = 0,\ B_3 = 0, B_4 = 0B_5 = 0]$$

For example, it is assumed that a flood disaster is based on a random flood scenario $s = 1,..6$
Then the following optimization model is obtained:

$$Z_{mm} = 9750725000 + \alpha p_1 C_1^1 + \alpha p_1 C_2^1 + \alpha p_1 C_3^1 + \alpha p_1 C_4^1 + \alpha p_1 C_5^1 + \alpha p_2 C_1^1 + \alpha p_2 C_2^1 + \alpha p_2 C_3^1 + \alpha p_2 C_4^1 + \alpha p_2 C_5^1 + \alpha p_2 C_1^1 + \alpha p_3 C_2^1 + \alpha p_3 C_3^1 + \alpha p_3 C_4^1 + \alpha p_3 C_5^1 + \alpha p_4 C_1^1 + \alpha p_4 C_2^1 + \alpha p_4 C_3^1 + \alpha p_4 C_4^1 + \alpha p_4 C_5^1 + \alpha p_5 C_1^1 + \alpha p_5 C_2^1 + \alpha p_5 C_3^1 + \alpha p_5 C_4^1 + \alpha p_5 C_5^1 \quad (19)$$

With constraints:

$$c_j^s \geq 0\ \omega^s \geq 0, \mathrm{s} = 1,\ldots,s \quad (20)$$

$$\sum_j (q_j\, L_i^i - \pi_j\ \tau)\ \geq \omega^s \quad (21)$$

$$\pi_j\ \tau - q_j L_i^i \geq c_j^s \quad (22)$$

Because the coefficients α, and β_j = 0 then the value:

$$\alpha p_1 C_1^1 + \alpha p_1 C_2^1 + \alpha p_1 C_3^1 + \alpha p_1 C_4^1 + \alpha p_1 C_5^1 + \alpha p_2 C_1^1 + \alpha p_2 C_2^1 + \alpha p_2 C_3^1 + \alpha p_2 C_4^1 + \alpha p_2 C_5^1 + \alpha p_2 C_1^1 + \alpha p_3 C_2^1 + \alpha p_3 C_3^1 + \alpha p_3 C_4^1 + \alpha p_3 C_5^1 + \alpha p_4 C_1^1 + \alpha p_4 C_2^1 + \alpha p_4 C_3^1 + \alpha p_4 C_4^1 + \alpha p_4 C_5^1 + \alpha p_5 C_1^1 + \alpha p_5 C_2^1 + \alpha p_5 C_3^1 + \alpha p_5 C_4^1 + \beta p_5 C_{5-}^1 + \beta p_1 C_1^1 + \beta p_1 C_2^1 + \beta p_1 C_3^1 + \beta p_1 C_4^1 + \beta p_1 C_5^1 = 0 \quad (19)$$

so that $Z_{mm} = 9750725000$

4. CONCLUSION

The conclusions that can be drawn from the results of this study are: (a) No additional variables are needed, so the variables used for premium calculation using the Integrated Catastrophe Risk Model are location (j), premium amount (π), area coverage of the insurance company in the study area (q), and loss years due to flooding that occurred in the study area (L). (b) Obtained value $\alpha, = \beta_j\ = 0$ which means that in the case study this did not happen trade-offs. The variables C_2^1 and ε^1 are zero, which means that there are no new ex-post variables that make it possible to eliminate overpayments and underpayments. Pr*ob* $(E_1 E_2) = 1$which means the insurance company will go bankrupt if a flood occurs every year. As well as obtained value Z_{mm}before the addition of the new ex-post variable is 110233300000 while the Z min value after adding the new ex-post variable is 9750725000. Based on the results of data processing and analysis, the use of the Integrated Catastrophe Risk method in the flood insurance program can be said to be optimal when viewed from its solvency aspect.

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