Evolutionary Stable Strategy for Postdisaster Insurance: Game Theory Approach

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Abstract: Mitigation of the financial impacts associated with natural disasters is becoming an urgent objective at both the national and international levels, as the rate and magnitude of natural disasters are continuing to increase. Using an evolutionary game theory approach, this paper aims to find an equilibrium profile of postdisaster insurance plans purchased by resident families and sold by insurance companies, as well as ex-postdisaster relief implemented by a government agency. This dynamic integrated assessment minimizes the total losses for the three aforementioned associated stakeholders, thus maximizing welfare within natural disaster host community systems. To this end, the authors determined a plausible set of actions and utility functions for the associated stakeholders. Also, they created a hypothetical sample of 1,000 resident families accounting for heterogeneous income levels, three insurance companies offering three unique insurance plans per company—each with different premium and coverage—and two different types of government compensation plans for postdisaster damage mitigation. The proposed model was implemented on the *NetBeans IDE 7.4* platform using the Java programming language for a hypothetical case study. The results indicate that (1) resident families tend to prefer insurance plans with the lowest premium value and coverage; (2) insurance plans with the most comprehensive coverage experienced the least demand; and (3) the evolutionary stable strategy is an oscillating line of chosen plans and insurers as a result of the stochastic and dynamics nature of the factors associated with disaster management. Currently, the authors are working to develop the model further to better account for simultaneous actions by all stakeholders (not only resident families), population growth, changes in financial and income standards, integrating input from available natural hazard prediction software systems (e.g., *HAZUS-MH*), and continuous data. Ultimately, this evolutionary game theory model will be tested on post–Hurricane Katrina data representing real-life physical damage in Hancock County, Mississippi. **DOI: [10.1061/(ASCE)ME.1943-5479.0000357](https://doi.org/10.1061/(ASCE)ME.1943-5479.0000357).** © *2015 American Society of Civil Engineers.*

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Introduction

Natural hazards damages have reached a record level, causing around 800,000 fatalities in the last decade, as well as damages in the infrastructure of over a trillion dollars (Economics of Climate Adaptation Working Group 2009; Stern 2006). Decision makers nationwide, in both the public and private sectors, are concerned about the vulnerability of their individual economies to natural hazards. They are forced to make investment choices under a stochastic environment and overlapping risk factors that consist of wind, flooding, fire, and earthquakes, as well as climate change and their effects on investments. Also, as population and economies continue to grow, the total value at risk from natural hazards will increase (Climatic Change Science Program 2008).

Mitigation of the financial impacts associated with natural catastrophes is becoming an objective focal issue at both the national and international levels, as the rate and magnitude of natural disasters are increasing. According to the Climatic Change Science Program (2008) and the National Association of Insurance Commissioners (2005), recent examples in the United States include the following:

1. Hurricane Andrew in 1992, which caused $20.9 billion in insured losses;
2. the Northridge earthquake in 1994, which resulted in insured losses of $15.9 billion;
3. the four hurricanes Charlie, Ivan, Frances, and Jeanne in 2004, which caused $21.9 billion in insured losses;
4. Hurricane Wilma and Rita in 2005, which resulted in total insurance losses of $11.9 billion;
5. the devastating Hurricane Katrina, also in 2005, which caused economic losses approaching $125 billion;
6. Hurricane Rita, also in 2005, with estimated damages of $10 billion;
7. Hurricane Wilma, also in 2005, which caused a widespread damage of approximately $16.8 billion;
8. Hurricane Ike in 2008, which resulted in $19.3 billion in property damages; and
9. Hurricane Sandy in 2012, which incurred damages of more than $68 billion.

There are important gaps in the knowledge base for disaster risk mitigation. Past studies primarily have addressed the challenge of disaster risk management by segregation of the problem, without concern about the integration of how these parts fit into a decision-making tool that simultaneously integrates the goals, objectives, perceptions, and beliefs of multiple agents in determining a set of social optimum strategies to mitigate the financial impact of future disaster damage.

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Goals and Objectives

Using an evolutionary game theory approach, this paper aims to find an equilibrium profile of postdisaster insurance plans purchased by resident families, sold by insurance companies, and ex-postdisaster relief implemented by a government agency. This should identify the optimal balance between (1) the number of plans offered by insurance companies; (2) the types of plans that should be selected by each type of resident family based on income level; and (3) the compensation ratio that the government will pay for each resident family to offset postdisaster damages. This dynamic integrated assessment minimizes the total losses for the three aforementioned associated stakeholders, thus maximizing welfare within natural disaster host community systems.

Background Information

Research has been conducted by governmental, private, nonprofit, and academic organizations and institutions to study, assess, and solve problems associated with disaster financial mitigation. Most of these valuable efforts generally fall into three main streams: loss estimation models, computational engineering approaches, and risk management using insurance.

Loss Estimation Models

Since the 1980s, a number of major impact assessment models and software systems have been developed to support disaster preparedness and recovery efforts. For example, *HAZUS-MH* is a hazard prediction software program developed by the Federal Emergency Management Agency (FEMA) under a contract with the National Institute of Building Sciences to estimate potential losses from earthquakes, hurricane winds, and floods (*HAZUS-MH*; Pradhan et al. 2007). Loss estimation models provide increasingly comprehensive estimates of regional risk but offer little guidance about how to use that information to make mitigation resource allocation decisions (Dodo et al. 2005). These models can estimate losses in relation to structural damage, content damage, and time-based impacts, and only a small set of predefined mitigation alternatives can be considered (Grossi and Kunreuther 2006). However, they are not able to account for the stakeholders' side, including costs of the alternatives, the budget, and the specific objectives and priorities of each stakeholder (FEMA 2003; Dodo et al. 2005).

Computational Engineering Approaches

Computational engineering approaches have been used extensively for studying and mitigating financial impact of natural catastrophes, including the following:
- Deterministic net present value (NPV): Kappos et al. (1996), Altay (2002), and Kuwata and Takada (2003) calculated the avoided loss as the difference between the losses estimated with and without implementation of the mitigation alternatives.
- Stochastic NPV: Englehardt and Peng (1996) estimated the probability distribution of the benefits associated with revising hurricane requirements and compared it with the cost of implementing the revision. Werner et al. (2002) compared various levels of proposed seismic design or upgrade on both means and standard deviations of losses.
- Multiattribute utility models: Nuti and Vanzi (1998) compared structural upgrading strategies based on various performance indices. Opricovic and Tzeng (2002) compared postearthquake reconstruction plans using multicriteria decision analysis approach.

- Optimization models: Shah et al. (1992) performed integer programming with budget constraints to maximize the NPV of earthquake mitigation investment. Augusti et al. (1994) used dynamic programming to select structural mitigation alternatives. Researchers at the International Institute for Applied Systems Analysis (IIASA) developed a spatial-dynamic stochastic optimization model to select the insurance policy design that maximizes profits and minimizes the risk of insolvency for insurance companies (Ermoliev et al. 2000; Ermolieva et al. 2001; Brouwers et al. 2001). Dodo et al. (2005) developed a linear program for resource allocation in earthquakes that incorporates spatial correlation among a set of mitigation alternatives, associated probabilities, and decision timing.

Risk Management Using Insurance

Insurance is utilized to spread the financial risk of loss resulting from low frequency–high consequence disastrous events (Kunreuther and Michel-Kerjan 2007). Insurance companies have made significant changes in their approaches to provide coverage for natural hazards (Muller 2008; Mills 2007). Capital market participants developed catastrophe bonds, which are a type of security that can be purchased by institutional investors to cover certain insurer risks (Cardenas 2006). Proposals have also been made to the U.S. Congress and regulatory agencies to take additional steps in changing U.S. tax laws and accounting standards to allow insurers to set aside funds on a tax-deductible basis and establish reserves for hazards (Smetters and Torregrosa 2008; Cardenas 2006). However, these reserves lower federal tax receipts and do not necessarily bring about a meaningful increase in the capacity of the insurance industry. This is because insurers may substitute their reserves for other types of capacity (Shear 2005).

Finken and Laux (2009) and Collier et al. (2009) suggested developing contracts with parametric or index triggers (which are insensitive to information asymmetry) to provide low-risk insurers with an alternative to reinsurance contracts and therefore lead to less cross-subsidization in the reinsurance market. Earlier, Michel-Kerjan and Morlaye (2008) suggested using insurance-linked securities instead of insurance and reinsurance for management of catastrophic risks. Jaffee et al. (2008) proposed long-term insurance as an alternative to the standard annual property owners insurance.

More analytically, Picard (2008) investigated the equity-efficiency trade-off faced by policymakers with imperfect information about individual prevention costs. His research highlighted the complementary relationship between individual incentives tax cuts and collective incentive grants to the local jurisdictions where natural hazard insurance plans are enforced. Chen et al. (2008) studied the determinants for the short-run position resulting from ex-ante insufficient premium and the long-run position resulting from ex-postinsurance supply reductions. Greiving et al. (2006) studied the spatial limitations of the Natural Hazard Index for Mega Cities, as well as the Total Place Vulnerability Index, and developed an integrated hazards map that combines regional hazards and vulnerability. Also, research revealed that while catastrophe insurance is more price-elastic than noncatastrophe insurance in cities like New York, responsiveness to price is inelastic in the coastal areas because prices increase only with mandatory purchases by mortgage borrowers (Grace et al. 2004; Kriesel and Landry 2004).

Knowledge Gap

The aforementioned studies illustrate several models that assess disaster damages and examine how to financially mitigate the impacts of disasters on the existing environment and host community.

However, few to none of them discuss the social and individual decision process for selecting an insurance company, given the preferences for different disaster insurance plans. To this end, this research aims to utilize evolutionary game theory to simulate residents' postdisaster learning to determine new optimum disaster insurance plans. This research will also guide insurers on how to determine the array of plan premiums that will eventually be accepted by the community.

Methodology

There is a need for more robust decision-making support tools that minimize the downside variance of the investment and the likelihood of large loss subject to a target net benefit. The authors utilized the following three-step research methodology:

1. Determine the set of possible actions and utility functions that govern the strategy profiles of the associated stakeholders, including resident families, insurance companies, and government.
2. Use the evolutionary stable strategy profile among the aforementioned players using game theory.
3. Apply the proposed model to a hypothetical data set as a proof of concept.

Associated Stakeholders: Actions and Utility Functions

As previously mentioned, the stakeholders are resident families, insurance companies, and the government. The resident families and insurance companies will be represented by a population of players, while the government is represented as a single player. Thus, it is worth noting that selecting a specific insurance plan will affect the resident family player through determining the amount of money spent on the premiums and the compensation obtained from insurers in the case of a natural disaster. This will also affect the insurer in terms of earned revenue (i.e., the amount of premiums collected) and the amount of compensation paid out after a natural disaster. Moreover, after calculating the postdisaster damages for the residential sector and taking into account the compensation by the insurer, the government compensation likewise can be calculated.

Resident Families

Each property owner player has a set of actions to choose from, $A = \{a_{(n,i)}\}$, where A is the set of possible actions and a is the chosen insurance coverage plan n offered by the associated company i. It is assumed that all families are obliged to buy insurance coverage as part of their mortgage agreements. In selecting a plan at each iterative step t, each resident considers his or her current wealth, the indemnity received from the insurance company if a natural hazard causes damages to the residence building, the amount of tax paid, and the compensation paid by the government after a natural disaster event, as shown in Eq. (1)

$$W_p^{t+1} = W_p^t - P_{n,i} - T - D + C_{n,i} + G \qquad (1)$$

where W_p^{t+1} = amount of wealth of a property owner P at time $t + 1$; W_p^t = family's initial amount of wealth at time step t; $P_{n,i}$ = insurance premium paid by a property owner to insurance company i using plan n; T = taxes paid by the property owner to the government; D = damage cost by the natural disaster; $C_{n,i}$ = compensation paid by the insurance company i if the property owner is using plan n based on the intensity and damage resulting from the disaster; and G = compensation paid by the government. As the property owner's wealth declines, taxes remain the same because they are collected nationally; thus, the available

wealth for relief efforts is not contingent on the wealth of the resident property owners of interest. Also, it is worth noting that utility does not govern actions. Generally, players maximize their utility by choosing their optimal actions subject to their beliefs of the actions taken by their rivals. In evolutionary games, the players observe the payoffs of others and mimic those with superior outcomes.

Insurance Companies

A successful strategy for postdisaster damage mitigation should decide on the type of coverage provided by the insurer and the premium structure (Jaffee et al. 2008). However, there are two main concepts that may negatively affect the optimum strategy profile. The first is adverse selection, as the pool will contain mostly high-risk resident families, so the insurance company will keep premiums at a fair rate (Janssen and Karamychev 2005). It is noted, though, that insurers can change their rates to overcome the problem of adverse selection. The second is moral hazard, as losses will not always be in favor of the insured pool, and thus the insurance will not change the situation or mitigate the damage for the insured party (Lee and Ligon 2001; Breuer 2005; Doherty and Smetters 2005). This emphasizes the need of an optimum postdisaster insurance plan strategy profile where a selective value of premiums and coverage values should be determined as well. These issues can be handled if the insurer is allowed to be myopic in their product offerings and learn from their rivals given the distribution of population types per contract.

Several insurance companies are considering offering a variety of insurance plans that range from partial to full coverage. A decision for each company is to determine the distribution and pricing of plans to offer the population of resident families. Accordingly, the insurer utility function is shown in Eq. (2)

$$W_i^{t+1} = W_i^t + \begin{cases} \sum_{p=1}^{P}(P_{n,x} - C_{n,x}) & \text{if } x = i \\ \sum_{p=1}^{P} P_{n,x} & \text{otherwise} \end{cases} \qquad (2)$$

where W_i^{t+1} = insurance company i wealth at $t + 1$. The aggregate monetary utility gained by an insurance company is the difference between the sum of the premiums paid by the resident family and the sum of the indemnities paid to the resident family when a natural hazard occurs.

Government

State protectionism is essential for postnatural disaster relief when there is extensive government postdisaster relief that is combined with voluntary cross-subsidized insurance. This can be achieved in several ways, including subsidizing the insurance costs on families or financially aiding families in reconstructing their damaged homes and reconstructing the state-damaged infrastructure during the disaster event. The government action will determine the financial compensation for damaged houses after a natural disaster event. The government wealth and utility function is simplified to its difference between its current wealth, obtained through tax payments, and compensation paid to the families, as shown in Eq. (3)

$$W_G^{t+1} = W_G^t + \sum_{p=1}^{P}(T_p - G_p) \qquad (3)$$

Evolutionary Game Theory

Game theory is the study of the ways in which strategic interactions among economic agents produce outcomes with respect to the preferences (or utilities) of those agents, where the outcomes in

question might not have been intended by any of the agents (Samuelson 1997). Since Von Neumann and Morgenstern (1994), game theory has been used in many different research areas (such as economics, biology, engineering, political science, computer science, and philosophy) because of its advantage of a natural and plausible representation of strategic interaction between individuals, organizations, and countries (Son and Rojas 2011). In evolutionary games, a large population of individuals, each having his or her own actions and strategies, meet in an environment to determine optimum strategy profiles depending on payoffs (Samuelson 1997). In other words, evolutionary game theory allows imperfect players to learn from observation. The dynamics here are based on the assumption that each strategy is employed by a certain fraction of individuals at each moment of the game (Turocy and Stengel 2001). Inspired by Darwin's theory of survival of the fittest, stakeholders with better-than-average payoffs will be more successful and more likely to survive to go the next round. Those players who chose strategies that resulted in less-than-average payoffs updated their strategic choices to mimic (replicate) those making above-average payoffs (Samuelson 1997). The replicator dynamics govern the law of motion for the game and are unique to each stakeholder group. Thus, one would not expect a resident's final payoff to equal that of the insurance company or government. A basic requirement in evolutionary games is that a set of strategies is evolutionary-stable if, for any mutant strategy (perturbation) in the game, the nonmutants result in a higher payoff (Weibul 1995; Smith and Price 1973). Evolutionary game theory has been applied in economics (Cressman 1995; Friedman 1998) and explored by mathematicians (Hofbauer and Sigmund 2003). However, to the authors' knowledge, evolutionary game theory has not been explored in construction management research.

Proposed Model: Solution Processes

The solution processes for the proposed model consider (1) the postdisaster insurance plans selected by each resident family from the different insurance companies, (2) the premium value charged as per the distribution of contract types offered by each insurer for each plan, and finally, and (3) the government postdisaster damage compensation ratio. As previously stated, the model represents a multiagent evolutionary problem and is solved by the three sequential steps described in the next sections of this paper.

Initial Conditions

In this step, the data associated with the three main stakeholders are entered into the model. For resident families, the model requires the population size, the ratios among different income families (i.e., poor, medium, and high income families), income and current wealth, and a random initial set of selected plans and insurance companies. For the insurance companies, the data include the number of associated insurers, different plans offered, premiums, compensation ratios, and wealth of the insurance companies, including relationships with reinsurance companies. For the government, the tax rate should also be set, as well as an initial percentage of the collected tax amount to be dedicated to post–natural disaster mitigation plan. Finally, nature, as a pseudoplayer, should also be specified in this step, including determination of the type of hazard accompanied by its characteristic parameters such as severity, frequency, and return period. This information will help the model to create an initial random population of players that have their own actions, measure their utility function after the disastrous event, and choose the fittest parents of the population for future evolution.

Updating Utility Functions for Associated Players

First, this step depends on the occurrence of a disaster and what the damage rate for that would be for each family resident. Determining that, the model can estimate the loss and calculate the associated compensation ratio by the insurers and the government. The total change of any player's utility will equal the difference of the utility function prior and after the disaster occurrence as shown in Eqs. (4)–(6)

$$\text{For resident families: } \Delta W_p = W_p^{t+1} - W_p^t \qquad (4)$$

$$\text{For the insurance companies: } \Delta W_i = W_i^{t+1} - W_i^t \qquad (5)$$

$$\text{For the local government: } \Delta W_G = W_G^{t+1} - W_G^t \qquad (6)$$

Through Eqs. (4)–(6), the relative fitness of each player for every stakeholder can be determined as shown in Eqs. (7) and (8)

$$\text{For resident families: Relative Fitness}_p = \frac{\Delta W_p}{\sum_{p=1}^{P} \Delta W_p} \qquad (7)$$
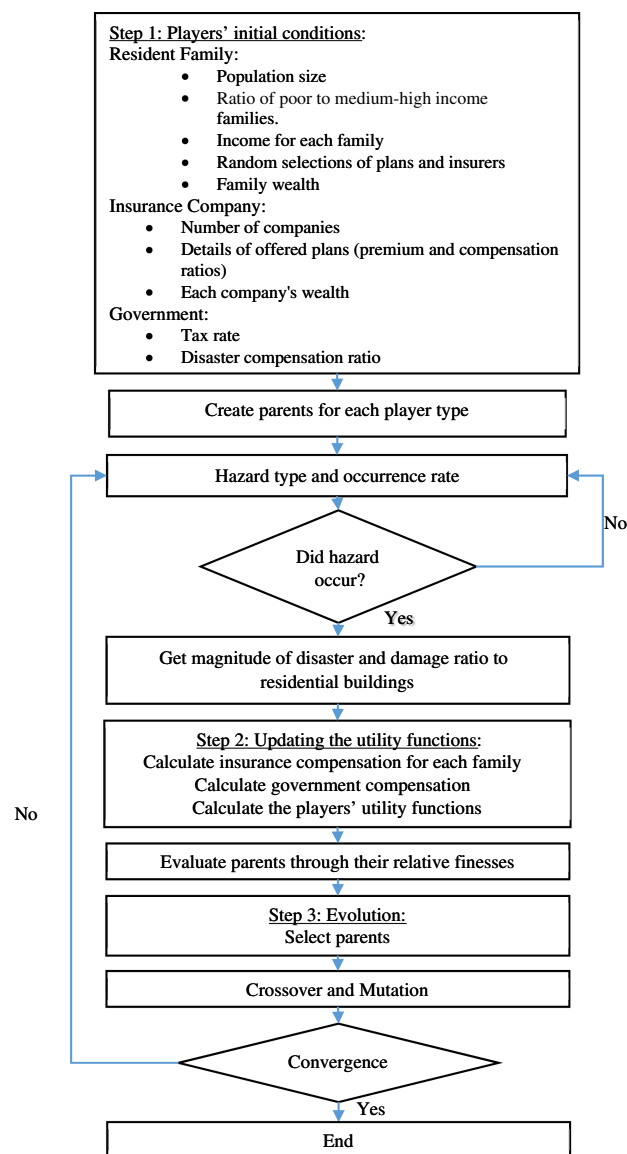

Fig. 1. Model flowchart

Table 1. Insurance Companies Plan Premiums and Coverage Percentages

Insurance company	Plan A		Plan B		Plan C	
	Premium (%)	Coverage (%)	Premium (%)	Coverage (%)	Premium (%)	Coverage (%)
Insurer 1	1.8	70	2	75	2.8	85
Insurer 2	2.2	80	2.8	85	3	95
Insurer 3	2.8	85	3	95	3.28	100

For the insurance companies: $\text{Relative Fitness}_i = \dfrac{\Delta W_i}{\sum_{i=1}^{I} \Delta W_i}$

(8)

This is carried out by dividing the player's (resident family or insurer) change in the utility function's value by the total change in the utility values for all the players of the same type. Thus, the players with higher positive changes in the utility values will have higher relative fitness values, so as other lower relative fitness value players will choose to mimic them via replicator dynamics by duplicating their actions and decisions in the next time steps.

It is worth noting that there is no relative fitness value for the local government because there is only one government player in the game.

Evolution

After determining the updated utility function and relative fitness for every player, the model, as represented by the simulated

stakeholders, can now select the fittest parents for the evolution process. The evolution process in this game determines two parents depending on their relative fitness, and whoever has a better relative fitness value (i.e., more fit) is copied by the other parent to create a new offspring. Also, the evolution contains a subprocess called *mutation*, where sometimes the players will suddenly choose a different decision variable's value so that they may investigate the solution space and avoid falling into a local optimum solution. Accordingly, stakeholders usually adjust to a different contract in the next period and are relying on continual mutations to maintain the friction of adjustment from one period to the next. It is worth stating that the mutation process will affect the population strategy profile only if it is a better choice than the current strategy profiles and when it could not change the population. Thus, it is an evolutionary stable strategy profile. Steps 2 and 3 are repeated until convergence occurs, as shown in Fig. 1 as a flowchart of the model's logical relationships.

Model Implementation

The authors created a hypothetical sample that included (1) 1,000 resident families, taking into account the different levels of income; (2) three insurance companies with three plans available per company, each with its own premium percentage to the family house value and compensation ratio; and (3) two types of government compensation plans for postdisaster damage mitigation. Realizing how complex the evolutionary game theory model between the three associated stakeholders can be, and in order to focus more on the foundational and fundamental steps associated with the
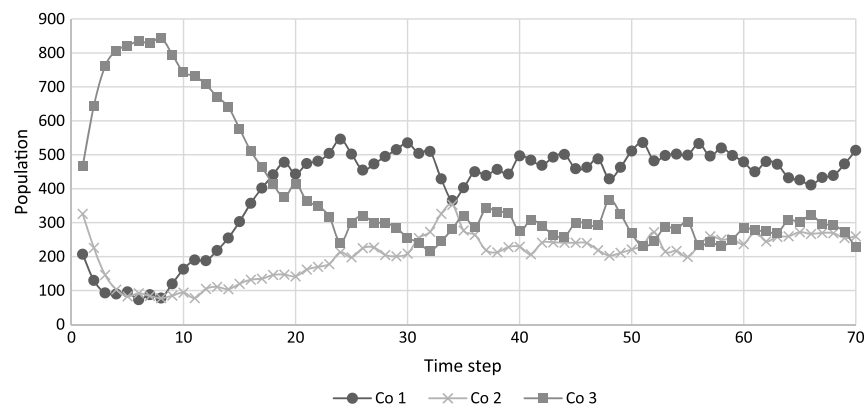
Fig. 2. Overall families' choices of insurance
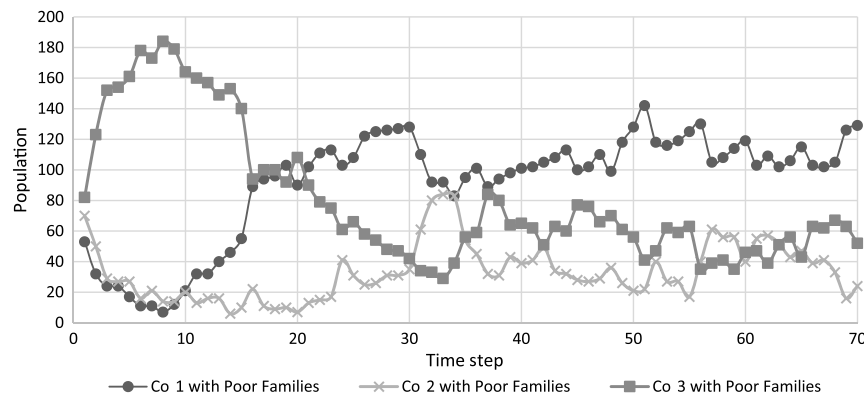
Fig. 3. Insurers and poor families

model development, the authors treated the resident families as the principal controller of the game's environment and insurance companies and the government as supportive players for the analysis. The model was implemented on the *NetBeans IDE 7.4* platform using the Java programming language.

To this effect, the resident family population was randomly created with 20% under the poverty level, 60% of average income, and 20% of high income. The initial insurance plans and insurance company were created randomly for each family; the three generated insurance companies' premium percentages, as well as the coverage compensation ratios, are given in Table 1. In addition,

the government offers plan (A) of compensation percentages of 10%, 15%, and 20% or plan (B) of a compensation percentage 15%, 20%, and 25% of the damages to the property for the high-, medium-, and poor-level income families, respectively. Also, for the sake of simplicity for this model, the probability of windstorm occurrence per time period in the implementation process is set to 95% with damages accounting for a minimum 10% of the house value up to totally damaged (i.e., 100%). The model crossover and mutation probabilities were set to 0.90 and 0.05, respectively. Those values were utilized after several attempts and experimentations. In addition, convergence was checked every
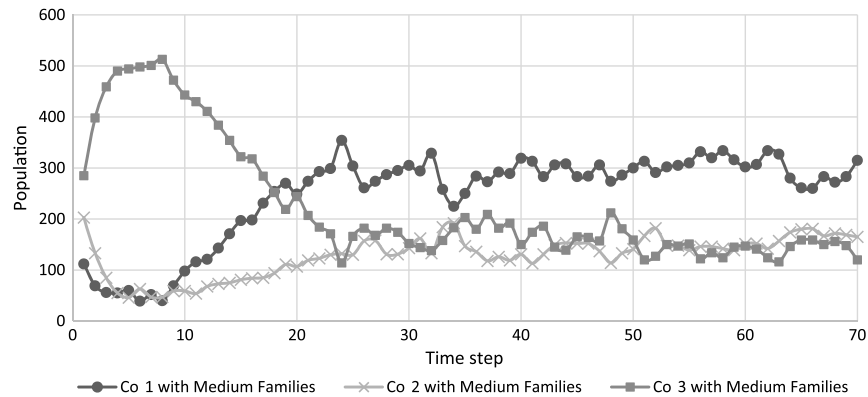

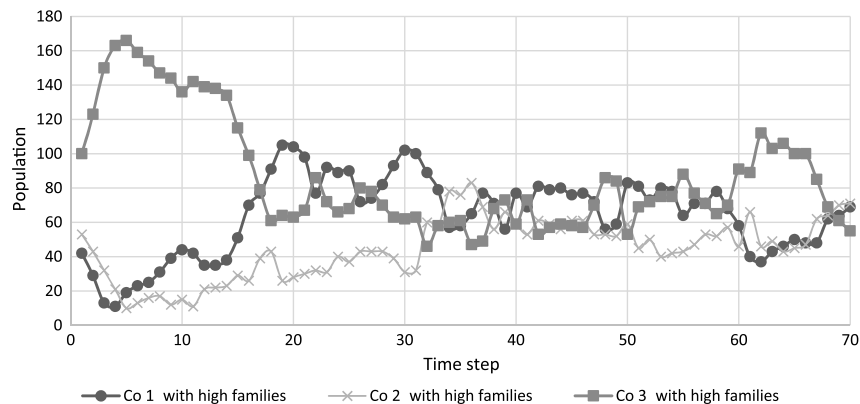**Fig. 4.** Insurers and medium-income families

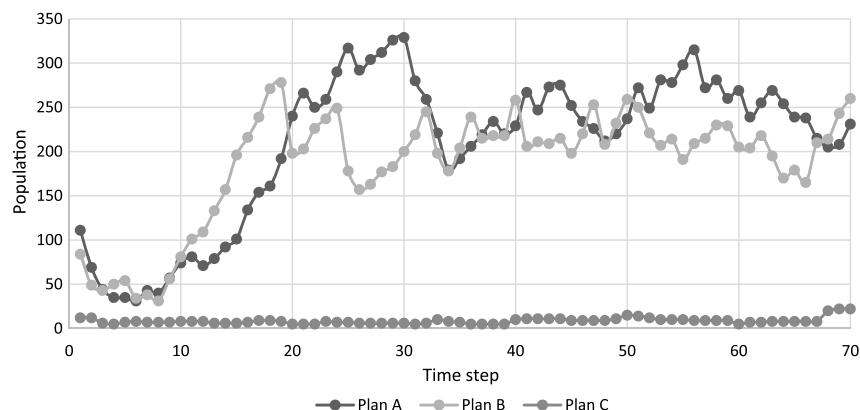**Fig. 5.** Insurers and high-income families

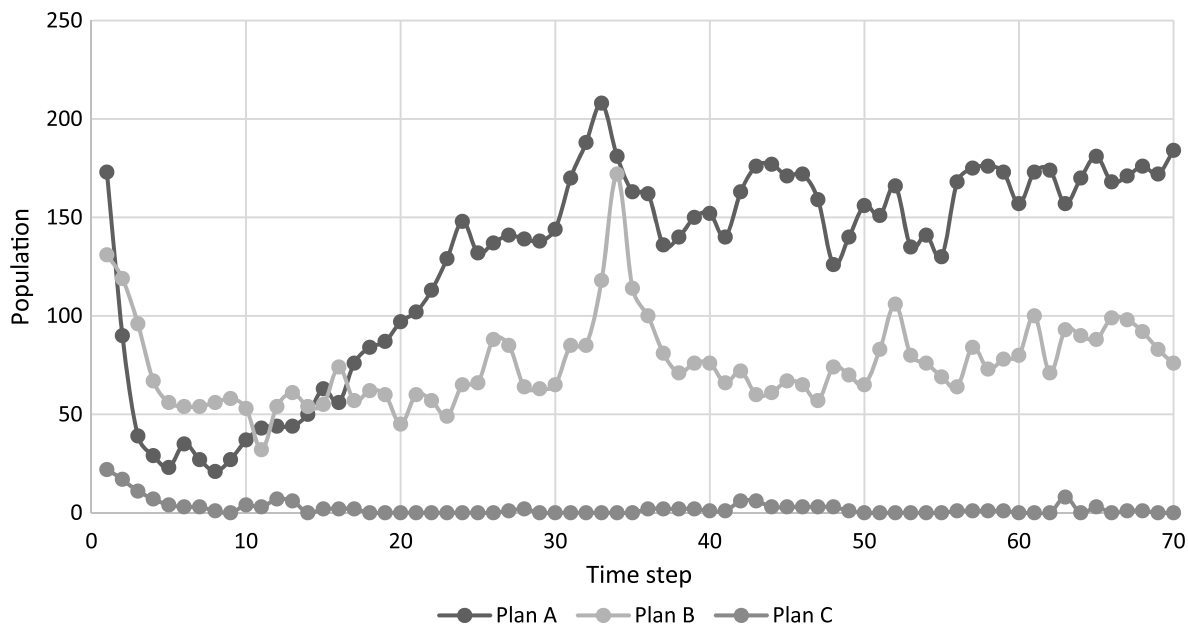**Fig. 6.** Insurer 1 plans and resident family choices

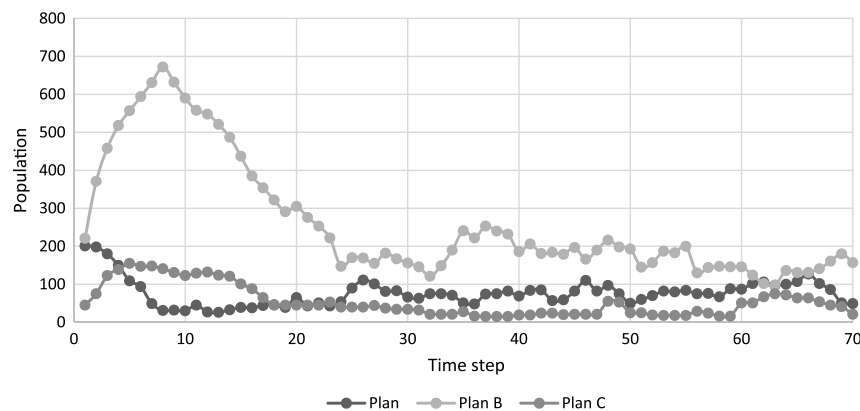**Fig. 7.** Insurer 2 plans and resident family choices

Fig. 8. Insurer 3 plans and resident family choices

10 years to find a similarly steady state when the number of families changing their plans does not exceed 15% of the total family number. The presence of a complete steady state is not practical, as changing weather conditions continues to plague the model's attempts to converge into one.

Results and Analysis

The proposed model output for each of the three player types was extracted from the computer model and analyzed to determine the evolutionary stable strategy profile. As an overview, Fig. 2 illustrates the evolution process of the families in their choices over the three insurers. To this end, it was clear that families tend to avoid the costly premium of insurer 3, even though it gives the highest coverage rates. Figs. 3–5 illustrate the changes in selection of the insurers for each family level.

Reviewing the results illustrated in Figs. 3–5, it is obvious that both poor and medium-income families tended over time to avoid Insurer 3 and preferred Insurer 1 over Insurer 2. This is due to the

high premium costs of Insurer 3's plans that do not pay off, as well as the low ones by Insurers 1 and 2. Also, as Insurer 1 had less premium rates than Insure 2, residents were more inclined to purchase Insurer's 1 plans than Insurer 2. On the other hand, high-income families were found to be indifferent among the three insurers, as the premium costs (whether high or low) took up only a small portion of their income and would all pay off similarly.

Figs. 6–8 illustrate the resident families' choices from the different plans by each insurer. Through these results, it is observed that insurance plans with the most comprehensive coverage received the least demand.

Table 2. Families' Choice Percentage over Insurance Companies

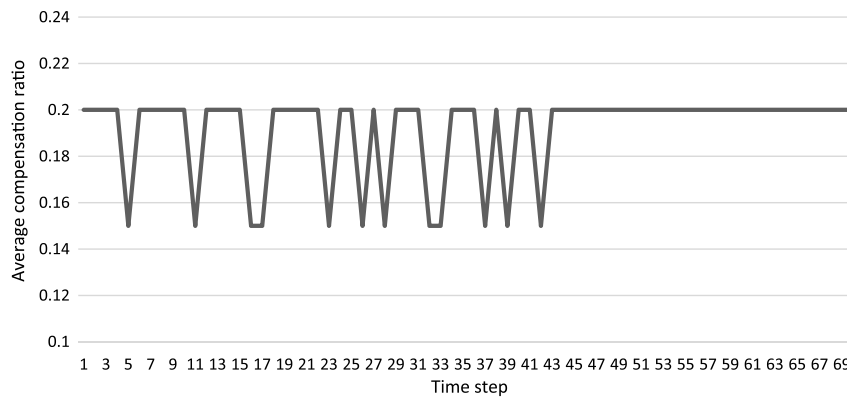| Insurance company	Family income level		
	High (%)	Medium (%)	Poor (%)
Insurer 1	31.15	48.04	56.34
Insurer 2	34.23	28.04	13.90
Insurer 3	34.61	23.91	29.75

Fig. 9. Government average compensation ratio

The aforementioned results illustrated the choices of the three income-level family types over the insurance companies' proposed insurance plans. The results make it advisable for the insurance companies to propose more of the lowest-premium plans to both poor and medium-level-income families to increase their sales, as they are in the most demand, as shown in Figs. 6 and 7. Table 2 summarizes the distribution of each income family category into the three Insures. As for the government, the choice between plans A and B varied through the first two-thirds of the time period and settled on plan B as the evolutionary stable strategy profile, which was more or less the same period when the families' players were becoming deterministic on their plans. Fig. 9 plots the average compensation ratios for the same time period.

Conclusions and Future Work

Natural disaster damages have reached a record level, and decision makers nationwide, in both the public and private sectors, are concerned about the vulnerability of their economies to natural hazards, as they must make investment choices under a stochastic environment and overlapping risk factors. This study utilized the evolutionary game theory to identify the optimal balance between (1) the number of plans offered by insurance companies; (2) the types of plans that should be selected by each type of resident family based on income level; and (3) the compensation ratio that the government will pay for each resident family to offset the post-disaster damages. To this end, the authors developed a computer model on the *NetBeans IDE 7.4* platform using the Java programming language and applied it to a hypothetical case study that involved resident families, insurance companies, and the government. Realizing how complex the evolutionary game theory model between the three associated stakeholders can be, and in order to focus more on the foundational and fundamental steps associated with the model development, the authors treated the resident families as the principal controller of the game's environment and insurance companies and the government as supportive players for analysis. This proof-of-concept analysis revealed that (1) resident families tend to prefer insurance plans with the lowest premium value and coverage; (2) insurance plans with the most comprehensive coverage experienced the least demand; and (3) the evolutionary stable strategy is an oscillating line of chosen plans and insurers as a result of the stochastic and dynamic nature of the factors associated with disaster management.

Based on the results of the hypothetical case study, the authors will develop the model further to take into account simultaneous actions by all stakeholders (not only resident families), as well as population growth and changes in financial and income standards. Also, an effort will be directed toward integrating input from existing natural hazard prediction software systems (e.g., *HAZUS-MH*) with a new evolutionary game theory model for a more precise simulation of the hazard characteristics. Further, the developed model will be enhanced to use continuous functions rather than the discrete ones utilized in the current version of the model, especially for the government's compensation ratio and the insurance companies' premium and insurance coverage values.

Also, based on the positive results associated with the model implementation, the authors are currently applying their model to data associated with Hancock County, Mississippi, for a far more comprehensive analysis. Hancock was the first county to be hit by Hurricane Katrina in 2005, and it is one of the most damaged and devastated counties in the state. To this end, the authors are collecting post-Katrina data sets in Hancock, including damaged transportation systems, damaged public facilities, damaged utilities, damaged housing, economic disruption, environmental damage, disruption to health and safety issues, and social, organizational, and vulnerability indicators (SOVIs). Most of this information is available through a variety of sources, including the Mississippi Emergency Management Agency, the Mississippi Insurance Department, the National Strategic Planning and Analysis Research Center, the Geosystems Research Institute, associated Tax Commissions, the U.S. Census in 2010, geographic information systems, environmental protection agencies, and financial rating agencies.

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