Insurance and Retrofit in Managing Urban Natural Disaster Risk


ABSTRACT

This paper briefly describes a new math modeling framework designed to improve understanding and design of policies to manage urban natural disaster risk. The framework represents four types of stakeholders (homeowners, primary insurers, reinsurers, and government); considers both insurance and retrofit as risk management strategies; and includes four mathematical models (homeowner decision-making, primary insurer decision-making, insurer competition; and loss estimation). A case study application for hurricane risk to residential buildings in North Carolina shows how the framework can be used to compare alternative policies, such as offering a retrofit subsidy or mandating insurance purchase. The 2010-2011 Christchurch, New Zealand earthquakes highlight the need for future framework development to address losses associated with building damage as fully as possible, including not just direct repair costs, but indirect losses as well.

Introduction

Retrofit and insurance are two primary mechanisms to manage natural disaster risk to a city’s buildings. A retrofit is a physical change to a building designed to reduce its vulnerability to damage, such as, installing hurricane shutters. Insurance is a mechanism that can be used to spread risk. Both have great potential to help manage risk, but they are often underutilized, resulting in more difficult post-disaster recovery periods. The authors recently developed a new math modeling framework to help understand and improve a city’s natural disaster risk management, including interactions among key stakeholders and between retrofit and insurance. In this paper, we briefly describe the framework, present sample results from a case study application for hurricane risk to residential buildings in North Carolina, and finally discuss implications of the 2010-2011 Christchurch, New Zealand earthquakes on the framework’s potential usefulness and future development. The framework is described more fully in [1-3].

Natural Disaster Risk Management Modeling Framework

The framework includes four interacting mathematical models and represents four types of

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stakeholders (Fig. 1). Primary insurers make simultaneous pricing and risk transfer choices given homeowner demand and reinsurance pricing. The interaction of insurers in the primary insurance market is represented as Cournot-Nash competition which determines a market equilibrium price for insurance and take-up rate of reinsurance by primary insurers. Within the Cournot-Nash model, a two-stage stochastic programming optimization represents each primary insurer’s decisions, with the objective of maximizing total profit over time and constraints on insolvency rate and minimum yearly profitability and capacity. Each homeowner responds to market prices by choosing from a menu of available insurance and/or retrofit options. Reinsurer and government roles are represented as exogenous variables that can affect the insurer-insured interactions. The models are integrated with a regional catastrophe loss estimation model. The loss model is a simulation combining hazard, inventory, and damage modules to compute a probability distribution of losses for each group of buildings (defined by location and building type) and each possible hazard event (e.g., hurricane) in the study area, with and without retrofits of various types. The framework can be used to evaluate and compare alternative policies and programs (e.g., government subsidy for insured homeowners to encourage retrofit, or mandatory insurance purchase with a cap on premiums). The effects of each policy can be determined for each stakeholder group separately to help identify those that are best for everyone.

![Figure 1. Regional natural disaster risk management modeling framework.](image)

**Case Study Application**

We conducted a full-scale case study application of the framework for hurricane risk to residential buildings in the Eastern half of North Carolina. It included a set of 97 probabilistic hurricane events in 2000 thirty-year scenarios, each with 600 time steps; 932,000 buildings in 732 geographic area units; two risk regions \( v \in \{H, L\} \) based on location 0-2 miles from the coast (higher risk) or not (lower risk); 8 building categories; 192 possible building resistance levels; up to 143 possible retrofits; a single layer of catastrophe risk excess of loss reinsurance; and losses due to structural, non-structural, and interior damage. To date, we have implemented the framework with retrofit but no insurer competition, and with insurer competition but no retrofit.

We first show results of four runs for the case of a single insurer in the market (i.e., no insurer competition): No retrofit allowed (Run 1); retrofit allowed (Run 2); retrofit allowed with a government subsidy for 75% of the retrofit cost for insured homeowners (Run 3); and mandatory insurance with a 50% subsidy of the retrofit cost paid by both government (75%) and insurer (25%) and the maximum allowable price set at \( p_v = $2.35 \) per dollar coverage (Run 4).
Table 1 summarizes for each run, the response the models predict for insurer and homeowners, and the resulting outcome for each of the key stakeholders. It shows, for example, that when retrofit is allowed in addition to insurance (Run 2 vs. Run 1), retrofits reduce homeowners’ loss distributions and therefore insurers must reduce the price $p_e$ for homeowners to be willing to buy insurance. While lower prices lead to increased insurance penetration rates (retrofit is primarily a complement, not substitute for insurance), the net effect is that average annual insurer profit is reduced from $57 to $35 million when retrofit is allowed. With a 75% retrofit cost subsidy for insured homeowners (Run 3) or when insurance is mandatory with a 50% subsidy and capped price (Run 4), more homeowners insure and retrofit (because they are linked by the requirement that homeowners be insured to receive the subsidy), which reduces the regional losses and helps both increase insurer profit and reduce homeowners’ expenditures on average.

Table 1. Results for each run, and outcomes by stakeholder, on average annual basis.

<table>
<thead>
<tr>
<th>Run</th>
<th>Price per dollar coverage</th>
<th>Reinsurance usage</th>
<th>Penetration rate</th>
<th>Insurer net profit ($M)</th>
<th>Homeowner expenditures per home ($b)</th>
<th>Reinsurer profit ($M)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>High risk $p_H$</td>
<td>Low risk $p_L$</td>
<td>High</td>
<td>Low</td>
<td>Insure</td>
<td>Retrofit</td>
</tr>
<tr>
<td>1. No retrofit</td>
<td>2.83</td>
<td>2.42</td>
<td>1.8</td>
<td>10%</td>
<td>---</td>
<td>57</td>
</tr>
<tr>
<td>2. Retrofit, no subsidy</td>
<td>2.14</td>
<td>2.18</td>
<td>2.8</td>
<td>13%</td>
<td>37%</td>
<td>35</td>
</tr>
<tr>
<td>3. Retrofit, 75% subsidy</td>
<td>2.97</td>
<td>3.41</td>
<td>2.6</td>
<td>26%</td>
<td>44%</td>
<td>65</td>
</tr>
<tr>
<td>4. Retrofit, mand. insure</td>
<td>2.35</td>
<td>2.35</td>
<td>2.5</td>
<td>57%</td>
<td>52%</td>
<td>68</td>
</tr>
</tbody>
</table>

a Expected number of times reinsurance is triggered (i.e., loss exceeds attachment point) in 30 years. b Expenditures include any premium, deductible, retrofit cost, or damage loss. c Retrofit subsidy is available only to insured homeowners. d Insurance penetration is <100% when “mandatory” because constraints on premium homeowners can pay remain.

Figure 2. For high risk region (0-2 mi. from coast), (a) CCDF of annual expenditures for average homeowners; (b) price per dollar coverage $p_H$ vs. number of insurers; and (c) annual insolvency probability vs. number of insurers when reinsurance is more or less expensive.

Examining uncertainty in the expenditures, Fig. 2a shows, for example, the distribution of annual expenditures is reduced for both the average insured and uninsured homeowner in the high risk region in Run 4 vs. Run 1. Focusing on the no retrofit case (Run 1), we now show how the noncooperative equilibrium solutions change as the number of insurers increases from monopoly to decreasingly concentrated oligopoly (2 to 10 insurers) with relatively inexpensive and expensive reinsurance options. For the high risk region, Fig. 2b shows that as the number of insurers increases, the price per dollar coverage $p_H$ declines quickly. At five primary insurers, the price stabilizes at about twice the fair price of $1.35, ensuring profitability for oligopolies and implying an imperfectly competitive outcome from the Cournot-Nash game. As additional competitors drive down the price in the high risk areas, the insurance penetration increases from
about 11% (1 insurer) to 27% (10 insurers). Even when reinsurance is relatively inexpensive, with more than five insurers, it becomes more expensive relative to their profits, and thus they choose less reinsurance, increasing the probability of insolvency (Fig. 2c). Many other results are available too, including decisions and outcomes for homeowners disaggregated by location and building type; specific retrofit strategies selected; and results for other possible policies.

**Implications of 2010-2011 Canterbury, New Zealand earthquakes**

While catastrophe insurance penetration is low in the United States, it is quite high in New Zealand due to the existence of New Zealand’s Earthquake Commission (EQC), a government organization that provides earthquake insurance at a low rate to residential policyholders, and a requirement of earthquake insurance purchase to get a home mortgage. The on-going recovery of Christchurch offers insights into the effects of insurance on a city’s post-disaster recovery and future directions for the type of modeling described herein. In particular, the Christchurch experience highlights the importance of including in this type of modeling all substantial direct and indirect impacts associated with extensive damage to housing and other infrastructure. Additional impacts that must be accounted for (beyond direct repair costs) include deaths and injuries, as well as the substantial psychological stress, disruption, and uncompensated expenses involved in filing insurance claims, doing building repairs, and dealing with extended displacement from homes, workplaces, and community facilities. While these effects are difficult to quantify, any cost-benefit calculation that neglects them systematically underestimates the benefits of retrofit vs. insurance. Having insurance to help pay for recovery is generally better than not having it, but avoiding damage, disruption, and stress in the first place is even better.

**Conclusions**

This paper briefly describes a new math modeling framework that can be useful for understanding and designing policies and programs to manage regional natural disaster risk. Its application is demonstrated for a case study of hurricane risk to residential buildings in North Carolina, but the approach is intended to be applicable to other hazards and regions.

**Acknowledgments**

This publication was prepared by the Univ. of Delaware, Cornell Univ., and East Carolina Univ. using Federal funds under award 60NANB10D016 from the National Institute of Standards and Technology, U.S. Department of Commerce. The statements, findings, conclusions, and recommendations are those of the author(s) and do not necessarily reflect the views of the National Institute of Standards and Technology or the U.S. Department of Commerce.

**References**

