# Understanding the impacts of government spending on retrofits and buyouts to mitigate regional and homeowner impacts from hurricanes

Dahui Liu
*Postdoc Associate, Dept. of Civil and Environmental Engineering, Cornell University, Ithaca, USA*

Linda K. Nozick
*Professor, Dept. of Civil and Environmental Engineering, Cornell University, Ithaca, USA*

Meghan M. Millea
*Professor, Dept. of Economics, East Carolina University, Greenville, USA*

Jamie B. Kruse
*Professor, Dept. of Economics, East Carolina University, Greenville, USA*

Rachel A. Davidson
*Professor, Dept. of Civil and Environmental Engineering, University of Delaware, Newark, USA*

Caroline Williams
*Ph.D. Student, Dept. of Civil and Environmental Engineering, University of Delaware, Newark, USA*

Joseph Trainor
*Professor, Biden School of Public Policy & Administration, University of Delaware, Newark, USA*

ABSTRACT: Hurricanes cost lives, damage and destroy property, and devastate communities. Pairing mitigation tools with insurance improves resilience by reducing structural losses and speeding recovery. This study applies a computational framework to examine how retrofits, buyouts, and insurance can effectively be used to improve resilience. The framework simulates the interaction of decisions made by income-constrained homeowners and insurance carriers in a competitive market with different levels of mitigation spending by the government. Households make decisions to buy insurance, implement retrofits, and accept buyout offers. Their choices reflect property risk, prior experience with hurricanes, income, evolving insurance premiums, and government retrofit grants and buyout offers.

Our work focuses on single-family, wood-framed houses in eastern North Carolina, USA. The computational framework includes models that (1) simulate hurricanes; (2) estimate regional hurricane-induced losses from each hurricane based on an evolving building inventory; (3) incorporate homeowner behaviors; (4) interact insurance pricing with mitigation; and (5) describe the regional economy. We generate a set of 100 simulations in which the housing stock, stakeholder decisions, and hurricane damages are updated annually for 20 years to incorporate the dynamics created by the interactions between hazard events, structural damages, household and insurer decisions, and government-financed mitigation.

We experiment with different government spending levels on mitigation, paired with homeowners' purchase of retrofits and wind and flood insurance to understand the regional economic impacts and homeowner effects. We compare the costs incurred by the government and homeowners' spending to the benefits they receive, which include insurance claims paid, avoided structural loss from mitigation, and avoided GDP loss. When only insurance is an option, the net benefits over the 20 years total $26.9 billion. When insurance is offered and the government spends $50 million annually, the net benefits increase to $29.9 billion; if they spend $750 million annually, the net benefits increase to $36.9 billion.

According to the National Oceanic and Atmospheric Administration, 30 named storms were recorded during the 2020 hurricane season, 12 of which made landfall in the continental United States (NOAA, 2020). Hurricanes are expensive; they cost lives, cause economic disruption, and damage and destroy people's homes. Understanding how the decisions of homeowners, insurance providers, and policymakers are made and interact can provide a more realistic understanding of how to reduce losses. Retrofits and buyouts reduce the risk to the housing stock, which means fewer losses for homeowners and reduced claim payouts for insurers. In a competitive insurance market, less risk will yield lower premiums charged to homeowners. With lower insurance costs, more people will buy insurance which provides additional insulation from financial hardships and economic disruption, reducing GDP loss for the area. When the impacts of decisions of insurers, homeowners, and the government are considered independently, these mutually beneficial synergies are missed. An integrated dynamic framework incorporates the positive impacts of decisions by one stakeholder group on other stakeholder groups. Government spending on mitigation, such as retrofits and buyouts, provides incentives to nudge individuals into making choices that have positive outcomes for themselves and others.

Our computational framework integrates mitigation offers from the government with homeowners' decisions to adopt retrofits, accept buyout offers, and buy insurance, and insurance carriers' responses to the changing housing stock. While larger mitigation budgets have larger impacts on reducing GDP and structural losses, fiscal stewardship requires consideration of both the benefits and the costs. As additional public dollars are directed to the highest loss-avoidance mitigation interventions, diminishing marginal benefits are realized. This study specifies different budget constraints within a multi-year, interactive computational framework to depict tradeoffs between the costs incurred by the government and the homeowners and benefits realized by homeowners and the economy.

The computational framework we have developed includes the interactions of decisions made by households, insurance carriers, and government policymakers to adopt retrofits, accept buyout offers, and purchase insurance. Damages are estimated using a realistic set of simulated hurricanes impacting spatially distributed single-family, wood-frame houses in the 44 counties of eastern North Carolina. We run the simulations 100 times. Stakeholder decisions and housing stocks are updated annually over 20-year time horizons. We include government spending on retrofits and buyouts, and households' spending on retrofits and insurance premiums as costs. We measure the benefits of mitigation (i.e., retrofit and property acquisition) and insurance in terms of avoided structural losses, avoided GDP losses, and insurance claims paid.

The first section of this paper outlines the components of the computational framework, including the sub-models of the decision-making stakeholders (households, insurers, and policymakers), the geographic context (high- and low-risk areas of eastern North Carolina), hurricane loss modeling, and the decision options available (retrofits, buyouts, and insurance). The model is run under different levels of government spending on mitigation. We run 100 different 20-year scenarios for houses in eastern North Carolina for each level of government spending. The outcomes from this set of experiments are described in Section 2. Section 3 summarizes our results and provides recommendations for future research.

## 1. COMPUTATIONAL FRAMEWORK

The integrated framework, versions of which were previously described in Guo, Liu et al. (2022), Guo, Nozick, et al. (2022), Gao et al. (2016), and Peng et al. (2014), contains three major types of models: (1) decision models for stakeholders; (2) hazard and loss models; and (3) a regional economic model.

### 1.1 Decision models capture behaviors of homeowners, insurers, and the government.

We estimate homeowners' retrofit, acquisition offer acceptance, and insurance purchase decisions using mixed logit models based on household survey data (Chiew et al., 2020; Frimpong et al., 2019; and Wang et al., 2017). Their decisions depend, in part, on property risk, prior experience with hurricanes, income, evolving insurance premiums, and mitigation incentives offered (retrofit grants and buyouts).

The framework assumes private insurers maximize profits while aiming to remain financially solvent by adjusting premium pricing and reinsurance decisions. For wind and flood insurance, the framework relies on the Peng et al. (2014) and Kesete et al. (2014) specifications of insurer behavior and Gao et al. (2016) for competitively priced premiums. We add dynamic price adjustments that react to the previous year's end conditions, including hurricane experience, the cash positions of insurers, and changes in building inventories (Guo, Nozick et al. 2022). After a hurricane, insurance payouts reduce GDP losses and speed recovery. However, they do not reduce structural losses.

Policymakers have limited budgets for buyouts and retrofit grants. We assume each buyout covers the full undamaged market value of the house. Grants cover up to \$10,000 of the estimated cost of retrofits (Guo, Nozick et al. 2022). Acquisition offers and retrofit grants are made from highest to lowest cost-effectiveness until the specified budget limit is reached. Homeowners' adoptions of government-incentivized mitigation strategies initiate mutually beneficial dynamic interactions between homeowners and insurance carriers.

The objective of this paper is to use the computational framework to examine the myriad effects of increasing government spending on mitigation (retrofit grants and buyouts).

### 1.2 Hazard and Loss Models

We simulate a set of probabilistic hurricane events *h*, as in Apivatanagul et al. (2011). Each hurricane scenario includes a map of the maximum peak gust wind speeds, a map of the maximum coastal inundation depths, and an adjusted annual occurrence probability, such that when probabilistically combined they fully represent the long-term probabilistic hazard. A set of *S* long-term *T*-year hurricane occurrence scenarios are developed by simulating occurrence of these events over time. The specification allows for multiple hurricanes within a single year impacting the same area.

The component-based damage and loss model used estimates a probability density function of direct loss for each hurricane scenario *h*. It was developed by the authors, based in part on an early version of the Florida Public Hurricane Loss Model as described in FPHLM (2005) and Pinelli et al. (2004). The residential structural losses depend on building characteristics, including the architectural structure type and building resistance level.

### 1.3 Computable general equilibrium model

The regional economy is represented as a computable general equilibrium (CGE) model based on Lofgren et al.'s (2002) framework and populated with the social accounting matrix data from IMPLAN (IMPLAN, 2017). Hurricane damages are incorporated into the regional macroeconomy model as a reduction in the residential capital stock, computed as the net reduction in home values from hurricane damages, offset by repair expenditures. Repairs are funded by insurance payouts and homeowners' savings. As the model is run, the building inventory is updated yearly to reflect storm damages, retrofits, buyouts, and insurance.

## 2. CASE STUDY

### 2.1 Inputs

We apply the computational framework to a 44-county region in eastern North Carolina. The study area includes 931,902 single-family wood-frame houses. The distribution of building values was estimated using Zillow Transaction and Assessment Dataset (ZTRAX) (Zillow, 2019) data[1]. The total estimated value of these houses in 2017 was \$131 billion. We identify 282,890 (30%) houses as high risk, meaning they are within 2 miles of the coast. We generate 100 different 20-year long-term hurricane loss scenarios for the region (i.e., $S$=100, $T$=20). For each of these 100 scenarios, the building inventory and other conditions are updated annually.

We assume a competitive insurance market in which insurers offer policies with a \$2,500 deductible to homeowners when the premiums would be at least \$100. We assume homeowners buy insurance unless the cost of the policy exceeds 5% of the value of their home, in the high-risk area and 2.5% of the value of their home, in the low-risk region.

Retrofit decisions include any combination of the following options: (1) reinforcing roofs with high wind load shingles or adhesive foam, (2) strengthening openings with shutters or impact-resistant windows, (3) strengthening roof-to-wall connections using straps, (4) elevating house appliances above flood level and installing water-resistant insulation and siding, and (5) elevating the entire house. data from homeowners in North Carolina.

The baseline GDP of this 44-county region was \$116 billion in 2017.

## *2.2 Results*

The costs are spread across household spending on insurance and unsubsidized retrofits and public spending on retrofit grants and buyouts. The government's spending sparks households to engage in protective actions: retrofits improve resistance to damage, and buyouts remove at-risk houses from the capital stock. In this study, we experiment with different levels of government mitigation spending ranging from \$1 billion over 20 years (\$50 million annually) to \$15 billion over 20 years (\$750 million annually).

### *2.2.1 Costs and benefits over the 20 years*

The average costs of mitigation and insurance premiums over the hundred 20-year scenarios are reported in Table 1. When there is no mitigation (first row), homeowners spent \$6.2 billion on insurance. When there is mitigation spending, most of the public sector budget was allocated to buyouts. For example, when the budget is \$15 billion over the 20-year period, \$12.54 billion was spent on buyouts (approximately 83,000 buyouts), with only \$2.46 billion spent on retrofits (approximately 100,000 retrofits). Households consistently spent approximately \$530 million of their own money on retrofits. There is not a discernable substitution effect between publicly and privately funded retrofits which may be due to the low proportion of government mitigation spending allocated to retrofits. However, as the public sector spent more on mitigation, households spent less on insurance due to lower expected loss. When the government spent \$1 billion (\$50 million annually) on mitigation, homeowners spent \$6.09 billion on insurance. When the government spent \$15 billion (\$750 million annually) on mitigation, households only spent \$4.73 billion on insurance. Private and public spending are summed in the last column of Table 1; these total costs are used in Table 2 to calculate the net benefits of mitigation and insurance.

[1] Data provided by Zillow through the Zillow Transaction and Assessment Dataset (ZTRAX). More information on accessing the data can be found at http://www.zillow.com/ztrax. The results and opinions are those of the author(s) and do not reflect the position of Zillow Group

*Table 1: Costs of government-funded mitigation paired with household mitigation and insurance spending*

| ***Public Costs Budget ($B)*** | ***Public Spending*** | | ***Homeowner Spending*** | | | ***Total Costs*** |
|---|---|---|---|---|---|---|
| | ***Buyouts*** | ***Retrofit*** | ***Self-Pay Retrofit*** | ***Insurance*** | ***Total*** | ***Private + Public*** |
| *No mitigation Insurance only* | *0.00* | *0.00* | *0.00* | *6.20* | *6.20* | *6.20* |
| *$1B* | *0.88* | *0.12* | *0.54* | *6.09* | *6.63* | *7.63* |
| *$2B* | *1.84* | *0.16* | *0.53* | *6.04* | *6.57* | *8.57* |
| *$5B* | *4.29* | *0.71* | *0.53* | *5.83* | *6.36* | *11.36* |
| *$10B* | *8.93* | *1.07* | *0.53* | *5.32* | *5.85* | *15.85* |
| *$15B* | *12.54* | *2.46* | *0.52* | *4.73* | *5.25* | *20.25* |

*Table 2: Benefits of government-funded mitigation paired with household mitigation and insurance spending*

| ***Budget ($B)*** | ***Avoided structural loss ($B)*** | ***Insurance claims ($B)*** | ***Avoided GDP loss ($B)*** | ***Total benefits ($B)*** | ***Total Costs ($B)*** | ***Net Benefits ($B)*** | ***Benefit to Cost Ratio*** |
|---|---|---|---|---|---|---|---|
| *No mitigation Insurance only* | *0.00* | *3.58* | *29.53* | *33.11* | *6.20* | *26.91* | *5.34* |
| *$1B* | *0.61* | *3.51* | *33.44* | *37.56* | *7.63* | *29.93* | *4.92* |
| *$2B* | *0.97* | *3.46* | *35.73* | *40.16* | *8.57* | *31.59* | *4.69* |
| *$5B* | *1.88* | *3.16* | *40.61* | *45.65* | *11.36* | *34.29* | *4.02* |
| *$10B* | *3.09* | *2.69* | *46.37* | *52.15* | *15.85* | *36.30* | *3.29* |
| *$15B* | *3.98* | *2.34* | *50.87* | *57.19* | *20.25* | *36.94* | *2.82* |

Table 2 lists the benefits from insurance and mitigation, measured as avoided structural loss from mitigation, insurance claims paid, and avoided GDP loss. Without any mitigation spending, insurance carriers paid $3.58 billion in claims, which supported economic recovery resulting in $29.5 billion in GDP loss avoided. Adding mitigation spending reduced structural losses and lowered insurance payouts. The combination of less structural damage paired with insurance payouts improved the economy's GDP position. For example, when the government spent $5 billion on mitigation, there was $1.88 billion in avoided structural losses, $3.16 billion inflow from insurance payouts, and $40.61 billion loss in GDP loss avoided. These net benefits remain positive over all of the government's mitigation spending levels. While the net benefits increase as the government spends more on mitigation, the changes in net benefits become smaller. This is consistent with the government prioritizing the highest loss-reducing mitigation strategies. Another way to consider the value of the mitigation and insurance investments is to look at the benefit-to-cost ratio reported in the final column of Table 2. When the government spends $1 billion on buyouts and retrofit grants, and homeowners spend $6.63 billion on retrofits and insurance, there are $37.56 billion in total benefits (loss avoided, insurance money inflow, and GDP loss avoided) or $4.92 in benefits per dollar spent. When $15 billion is spent by the government on mitigation and homeowners spent $5.25 billion on insurance and retrofits, the benefit-to-cost ratio is $2.82.

### *2.2.2 GDP loss in year 20*

Figure 1 compares the avoided GDP losses by the different government budgets with (a) mitigation only, no insurance and (b) mitigation paired with insurance. Across the 100 scenarios, median GDP benefits ranged from $4 billion to $28 billion with mitigation only. When the structural loss avoided from mitigation is paired with insurance claims payouts that speed recovery, the median GDP benefits ranged from $28 billion to $46 billion and could be as high as $175 billion for a severe hurricane.

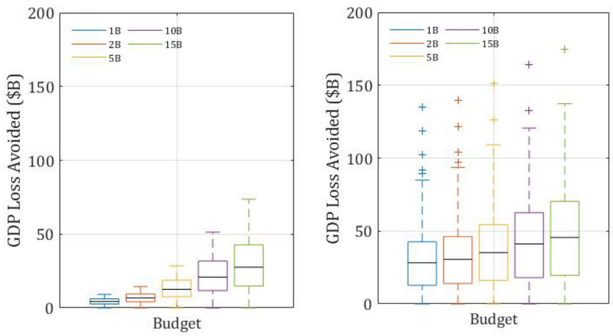



Figure 1a: Mitigation Only Figure 1b: Mitigation Paired with Insurance

*Figure 1: Avoid GDP losses for different government budget levels without and with insurance in year 20*

### *2.2.3 Structural loss over the 20 years*

Figure 2 provides detailed expected structural losses for the 44-county region over the 20-year time horizon. Without any mitigation spending, expected annual structural losses are $522 million. When the government spends $50 million annually ($1 billion in total), the structural loss is reduced by $10 million in the first year and by $2 million in the 20th year, down to a structural loss of $473 million at the end of the simulation. When the government budget is $750 million each year ($15 billion over the 20 years), structural losses decrease by $36 million in the first year and by $5 million in the 20th year which is a structural loss of $217 million in the 20th year.

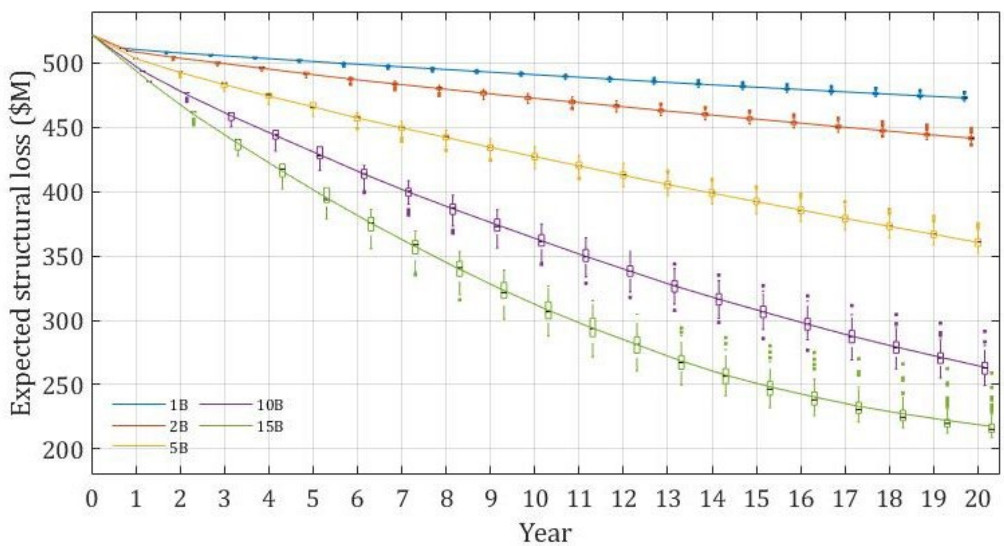
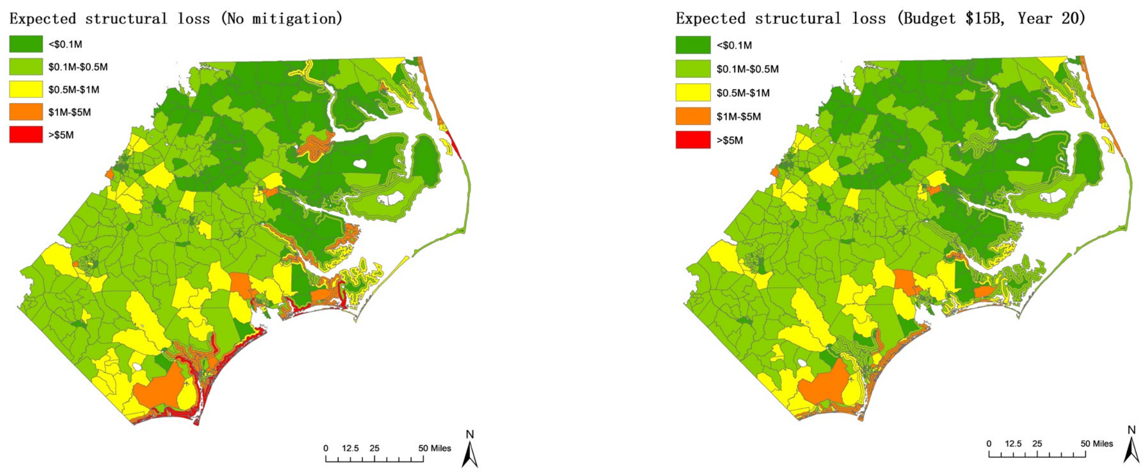



*Figure 2: Expected structural loss for different government budget levels.*

### *2.2.4 Distribution of mitigation impacts in Year 20*

Figure 3 depicts the average distributional effects of residential structural losses by census tract without and with government mitigation in Year 20. Fig 3(a) shows that without mitigation, the high-risk coastal areas in the southern part of the state experience millions of dollars of structural damage. These are heavily populated areas that are not protected by the islands of the outer banks. When $15 billion is spent over 20 years on mitigation, as shown in Fig 3(b), structural losses are noticeably reduced, with no areas where structural losses exceed $5 million.




*(a) Losses in year 20 without mitigation* *(b) Losses at year 20 with $15B*

*Figure 3: Expected structural losses in Year 20 by zone (a) without government investment, and (b) with $15B government investment*

### *2.2.5 Change in homeowners' expenses in Year 20*

In Figure 4, we present how homeowners' out-of-pocket expenses change when insurance is introduced with different levels of government spending on mitigation. Without insurance or mitigation, structural losses are higher and none of them are insured. Several homeowners (1.8%) have high losses that total over $18,000 in Year 20, while 7.1% of homeowners have uninsured losses of at least $1,000 in Year 20. When retrofits (either self-funded or government-funded) and insurance are available, homeowners' voluntarily buy insurance, opt to self-fund retrofits, and still have some uninsured losses. When insurance and mitigation are options and the government funds $1 billion in mitigation, 20.3% of households pay more than $1,000 in expenses, but the proportion of homeowners with high-loss spending decreases. As the government increases its mitigation budget, fewer households pay these high out-of-pocket expenses. For example, with $15 billion in mitigation incentives (retrofits and buyouts), only 9.75% of the households have out-of-pocket expenses over $1,000, and fewer than 1% have out-of-pocket expenses that exceed $10,000 annually. As the government pays more for mitigation, homeowners pay less in terms of premiums, self-funded retrofits, and uninsured losses.

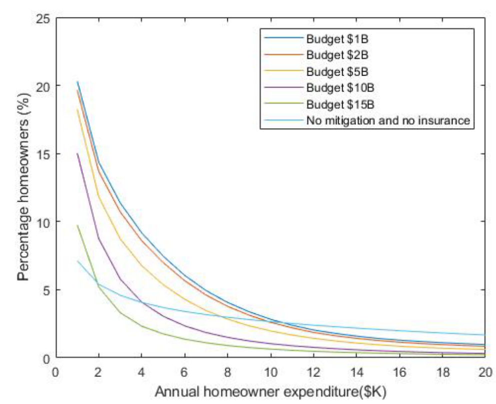



*Figure 4: Percentage of homeowners that pay more than specific threshold levels in year 20 with different mitigation budgets*

## 3. CONCLUSIONS

In this study, we apply a computational framework to evaluate the government and homeowner costs of mitigation (retrofits and buyouts) and insurance relative to the benefits of reduced structural losses, insurance claims paid, and avoided GDP loss. The framework is built to incorporate realistic representations of the strategic decisions of stakeholders (households, insurers, and the government) established through survey data, competitive market assumptions, and budget-constrained decisions. The framework is applied to houses in the 44-county region of eastern North Carolina. The regional economy is described by a computational general equilibrium model populated with county-level data. With the hazard and loss models, we generate a set of 100 20-year scenarios for each mitigation budget assumption. We experiment with government mitigation budgets of $1 billion ($50 million per year over 20 years) to $15 billion ($750 million per year). The per-dollar return decreases as the budget is increased. Yet, even at the $15 billion level, the net benefits from mitigation, paired with insurance, are positive. Mitigation is particularly effective in high-risk areas. Pairing mitigation and insurance reduces losses and is mutually beneficial for the government, homeowners, and insurers. Future research could expand hazard modeling to include the effects of climate change. The loss modeling could expand to include nonresidential, commercial structures. And the economic analysis could be expanded to identify sectoral adjustments within the region.

## 4. REFERENCES

Apivatanagul, P., Davidson, R., Blanton, B., and Nozick, L. (2011). "Long-term regional hurricane hazard analysis for wind and storm surge." *Coastal Engineering,* 58(6), 499–509.

Chiew, E., Davidson, R. A., Trainor, J. E., Nozick, L. K., and Kruse, J. L. (2020). "The impact of grants on homeowner decisions to retrofit to reduce hurricane-induced wind and flood damage." *Weather, climate, and society,* 12(1), 31-46.

Florida Public Hurricane loss Model (FPHLM)., (2005). *Engineering team final report, Vol. I, II, and III.* Florida International University. http://www.cis.fiu.edu/hurricaneloss.

Frimpong, E., Kruse, J., Howard, G., Davidson, R., Trainor, J., and Nozick, L. (2019). "Measuring heterogeneous price effects for home acquisition programs in at-risk regions." *Southern Economic Journal,* 85(4), 1108–1131.

Gao, Y., Nozick, L., Kruse, J., and Davidson, R. (2016). "Modeling competition in a market for natural catastrophe insurance." *Journal of Insurance Issues,* 39(1), 38–68.

Guo, C., Liu, D., Nozick, L., Millea, M., Kruse, J., Williams, C., Davidson, R., and Trainor, J. (2022). "Comprehensive Approach to Reduce Hurricane Risk with a focus on Equity and Economic Prosperity." *Global Alliance of Disaster Research Institute (GADRI) Book Series: Disaster and Risk Research,* Springer Nature.

Guo, C., Nozick, L., Kruse, J., Millea, M., Davidson, R., and Trainor, J. (2022). "Dynamic modeling of public and private decision-making for hurricane risk management including insurance, acquisition, and mitigation policy." *Risk Management and Insurance Review,* 25(2), 173-199.

IMPLAN® model, [2017] Data, using inputs provided by the user and IMPLAN Group LLC, IMPLAN System (data and software), 16905 Northcross Dr., Suite 120, Huntersville, NC 28078 www.IMPLAN.com

Kesete, Y., Peng, J., Gao, Y., Shan, X., Davidson, R., Nozick, L., and Kruse, J. (2014). "Modeling insurer-homeowner interactions in managing natural disaster risk." *Risk Analysis,* 34(6), 1040–1055.

Lofgren, H., Harris, R. L., and Robinson, S. (2002). "A standard computable general equilibrium (CGE) model in GAMS (Vol. 5)." *Intl Food Policy Res Inst.*

NOAA. (2020). https://www.noaa.gov/media-release/record-breaking-atlantic-hurricane-season-draws-to-end

Peng, J., Shan, X., Gao, Y., Kesete, Y., Davidson, R., Nozick, L., and Kruse, J. (2014). "Modeling the integrated roles of insurance and retrofit in managing natural disaster risk: A multistakeholder perspective." *Natural Hazards,* 74, 1043–1068.

Pinelli, J.-P., Simiu, E., Gurley, K., Subramanian, C. and Zhang, L., Cope, A., Filliben, J., and Hamid, S. (2004). "Hurricane damage prediction model for residential structures." *J. Struct. Eng.,* 130(11), 1685–1691.

Wang, D., Davidson, R., Trainor, J., Nozick, L., and Kruse, J. (2017). "Homeowner purchase of insurance for hurricane-induced wind and flood damage." *Natural Hazards,* 88, 221–245.

Zillow. 2019. "ZTRAX: Zillow Transaction and Assessor Dataset, 2019-Q4." Zillow Group, Inc. http://www.zillow.com/ztrax/