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Optimal house elevation for reducing flood-related losses

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ABSTRACT

FEMA recommends that houses in coastal flood zones be elevated to at least 1 foot above the base flood elevation (BFE). However, this guideline is not specific and ignores characteristics of houses that affect their vulnerability. An economically optimal elevation level (OEL) is proposed that minimizes the combined cost of elevation and cumulative insurance premiums over the lifespan of the house. As an illustration, analysis is performed for various coastal houses in Ortley Beach, NJ. Compared with the strategy of raising houses to 1 foot above BFE, the strategy of raising houses to their OELs is much more economical for the homeowners. Elevating to the OELs also significantly reduces government spending on subsidizing low-income homeowners through, for example, a voucher program, to mitigate flood risk. These results suggest that policy makers should consider vulnerability factors in developing risk-reduction strategies. FEMA may recommend OELs to homeowners based on their flood hazards as well as house characteristics or at least providing more information and tools to homeowners to assist them in making more economical decisions. The OEL strategy can also be coupled with a voucher program to make the program more cost-effective.

1. Introduction

Among all natural hazards, floods are the most costly, especially in low-lying areas (Kunreuther and Michel-Kerjan, 2009; Michel-Kerjan, 2015; Michel-Kerjan and Kousky, 2010; Perry, 2000). The number of Presidential disaster declarations associated with floods in the United States has increased substantially over the past 50 years (Kunreuther, 2015). The increase in coastal population and assets contributes to a rise in damage and economic losses (Pielke Jr., et al., 2008; Aerts et al., 2014). Climate studies predict more intensive storm surge flooding in the future owing to storm activity change and sea level rise (Lin et al., 2012, 2016; Buchanan et al., 2015) and thus more damage and losses (Lin and Shullman, 2017). Coastal residents can undertake self-protection measures to mitigate the negative impact from the increasing flood hazard in advance, through risk reduction measures (e.g., raising houses) and/or risk transfer (i.e., flood insurance) (Kunreuther and Slovic, 1978; Lewis and Nickerson, 1989; Quiggin, 1992). The marginal return from spending on long-term risk mitigation may be significantly higher than the spending on ex-post recovery (Davlasheridze et al., 2017).

In the US, a homeowner can purchase flood insurance through the National Flood Insurance Program (NFIP) created in 1968 as a partnership between the federal government and local communities. The Federal Emergency Management Agency (FEMA) manages the program and delineates flood zones for local communities and specifies the base flood elevation (BFE) for Special Flood Hazard Areas (SFHA)[1]. The BFE represents the 100-year flood level (i.e. the elevation that has a 1-percent probability of being equaled or exceeded by the flood level in any given year). The American Society of Civil Engineers (ASCE) standard for flood design and construction indicates the minimum requirement for building construction in flood hazard areas that are subject to the building code. Under the regulations of both ASCE 24[2] and NFIP, FEMA requires coastal houses with repetitive losses and/or substantial damage from flood events to be elevated to at least 1 foot above the BFE and recommends all houses in SFHA to be elevated to this level (FEMA, 2011). However, this requirement/recommendation does not provide guidance for homeowners about how many feet exactly their houses should be raised to. The minimum of this requirement, 1 foot above the BFE (also called "1-foot freeboard", FEMA, 2014a), may be used as a gen-

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[1] The SFHA refers to 100-year flood zones that include A zones (e.g., AE zone, AO zone, etc) and V zones (e.g., VE zone and V1-V30 zones).

[2] ASCE 24 refers to the Flood Resistant Design and Construction Standard by ASCE. This standard provides minimum requirements for flood-resistant design and construction of structures located in flood hazard areas.

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eral mitigation guide by homeowners. Some local engineering companies providing home elevation services also suggest that their clients elevate their homes to the lowest required levels that fulfill the local policy [3]. More importantly, this elevation strategy reflects only the severity of the hazards (through BFE) but not the vulnerability characteristics of the houses. A previous study notes that flood risk should be determined by both flood hazard and house exposure values (Czajkowski et al., 2013). We further argue that house elevation and, more generally, risk mitigation measures should be determined by considering both the flood hazard and the vulnerability/exposure characteristics, such as house value, size, lifespan, and ground elevation.

In addition to the problem with risk reduction requirement, flood insurance in the NFIP is heavily subsidized and does not reflect the actual risk[4]. Recent studies have argued that providing premium discounts misleads homeowners about their risk; instead, the premium should be risk-based and reflect the expected losses (Michel-Kerjan and Kunreuther, 2011; Kunreuther et al., 2013; National Research Council, 2015; Kunreuther, 2016). Risk-based insurance encourages risk mitigation by rewarding individuals who invest in flood mitigation measures with reduced premium. However, the risk-based, higher insurance premium may induce affordability problems for homeowners who currently pay subsidized premiums (Kunreuther et al., 2013). To address this issue, Kousky and Kunreuther (2014) propose a means-tested voucher program to assist low- and moderate-income homeowners to pay for flood insurance and undertake risk reduction measures such as elevating their houses. Kousky and Kunreuther (2014) show that a voucher program coupled with elevating houses to "1-foot freeboard" is often more cost-effective than the voucher subsidizing insurance alone. Here we argue that the voucher program is even more economically effective if the coupled mitigation strategy takes into account house vulnerability characteristics.

We propose that an economically optimal elevation level (OEL) for coastal houses can be estimated through a cost-benefit analysis (CBA). Specifically, the OEL can be calculated as the level that minimizes the sum of the upfront elevation cost and present value of cumulative annual expected losses over the lifespan of a house. As the annual expected loss is the main component of the risk-based insurance premium, OEL also minimizes the sum of elevation cost and cumulated insurance premium. In addition to hazard variables (e.g., BFE), this OEL varies with vulnerability variables such as house characteristics (e.g., house value, size, and ground elevation), lifespan, and discount interest rate, because they affect the elevation cost and total expected future losses/premiums. Homeowners will benefit from applying the OEL as they will pay less overall. When policymakers consider applying a voucher program to address affordability issues, the voucher cost will be reduced if houses are elevated to their OELs because, by definition, OEL generates the lowest total and thus voucher costs.

In the following sections, we first introduce the calculation of OEL and voucher cost (Section 2). Second, we analyze OEL for three actual houses located in Ortley Beach, NJ, and illustrate how OEL varies with various hazard and vulnerability variables. We also examine OEL for all houses in the AE and VE flood zones in Ortley Beach and compare the economic benefit of the OEL strategy vs. the "1-foot freeboard" strategy at the community scale (Section 3). Then, still using Ortley Beach as a study area, we investigate how OEL plays a role in designing an effective and economical voucher program (Section 4). Finally, we summarize the main findings and propose future research (Section 5).

2. Methods

2.1. Calculation of OEL

The OEL minimizes the sum of the upfront elevation cost and present value of the cumulative expected annual losses over the lifespan of a house. Let h^* be the OEL above the ground; it is defined as:

$$h^* = argmin_h \left(C(h) + \sum_{t=1}^{s} \frac{1}{(1+r)^t} E(h) \right) \tag{1}$$

where $C(h)$ is the cost function of house elevation with respect to elevation height h, and it can be obtained from FEMA's "Homeowners' Guide to Retrofitting" (FEMA, 2009, 2014a); $E(h)$ is the expected annual loss when the house elevation is h feet above the ground; t represents time and s is the lifespan of the house in years; and r is the discount interest rate.

In this study, we consider a constant expected annual loss ($E(h)$). When effects of climate change and sea level rise on the flood hazard are accounted for, this annual quantity will change with time. Eq. (1) can be used similarly to calculate the OEL that accounts for these dynamic climate effects, except with $E(h)$ replaced by $E(h,t)$, the time-varying expected annual loss accounting for the temporal variation of the flood hazard and vulnerability (Lin and Shullman, 2017; Gilroy and McCuen, 2012; Ettinger et al., 2016). In contrast, the "1-foot freeboard" strategy depends on a static flood hazard measure and cannot incorporate the temporal evolution of the hazard. Therefore, the OEL formulation, which considers potential losses over the lifecycle of the house, provides a more convenient way to account for the long-term, dynamic climate change effects.

Also, the expected annual loss ($E(h)$) may be replaced by the risk-based annual insurance premium, as the former is the main component of the latter. When homeowners are making elevation decisions, they may consider either the elevation upfront cost and the expected annual damage or the elevation upfront cost and the annual insurance premium if they are required or choose to purchase insurance to transfer the residual risk after mitigating the flood risk. Thus, $E(h)$ may be considered as either the expected annual loss or the risk-based annual insurance premium. (If the effects of climate change are accounted for, $E(h,t)$ can be considered as the time-varying expected annual loss or risk-based annual insurance premium.) In this study, we consider $E(h)$ as the risk-based insurance premium, and it is calculated based on the FEMA flood insurance manual (FEMA, 2014b) and NFIP rating system (FEMA, 2014c).

To compare the economic benefit of the OEL strategy vs. the "1-foot freeboard" strategy, we consider their difference in the total cumulative cost of elevation and insurance. We define "saving" as the difference in the total cumulative cost if we elevate a house to 1 foot above BFE compared to its OEL. When the OEL happens to be 1 foot above the BFE, the saving is zero. Otherwise, the saving will always be positive because OEL generates the minimized total cost (Eq. (1)). Let h_1 be the height of "1 foot above the BFE" reference to the ground (note that the original BFE value is in reference to NAVD88[5]). The saving between "1-foot freeboard" and the OEL, $S(h_1, h^*)$, is the following:

[3] Personal communication with construction companies by phone in Toms River, New Jersey on Oct 25, 2015.

[4] The significant losses from Hurricane Katrina (2005) led Congress to pass the Biggert-Waters Flood Insurance Reform Act of 2012 (BW-12), which would increase the insurance premiums to reflect the actual risk. However, the Act aroused discussion of affordability issues among low- and moderate-income homeowners. In March 2014, the passage of the Homeowner Flood Insurance Affordability Act (HFIAA-14) delayed the premium increases.

[5] NAVD88 is the vertical control datum of orthometric height in the United States of America based on the General Adjustment of the North American Datum of 1988