Factors Influencing Homeowners in the Process of Retrofit Decision-Making

1 Introduction

Strengthening a home to protect it against hurricane damage requires multiple cognitive and physical steps, including becoming aware of the problem of hurricane risk and the possible solution of strengthening the home, making the decisions to act and how, and following through with the actions required to make it happen. Why do some people proceed through that entire process, and some do not? For the ones that do not get to the end, where along the process do they get stuck and why? What interventions would help them transition to the end, and at what points in the process would those interventions be most effective? These are the questions addressed in this paper.

Though strengthening their homes may well be one of the most cost-effective ways to reduce hurricane damage and increase resilience [1], in general, homeowners tend not to do it [2]. Research to understand homeowner protective action decision-making about structural retrofits has been limited [3]. Further, the previous work has almost exclusively treated the mitigation decision as a binary choice (strengthen or do not) that occurs at a point in time. In a recent exception, Porada et al. [4] introduced a new approach that represents the entire home retrofit process— from a homeowner first becoming aware of the decision through completion of the physical retrofit —and allows the possibility that it may occur over an extended time frame.

The Porada et al. [4] approach includes three key components that to our knowledge had not previously been combined: (1) the Precaution Adoption Process Model (PAPM) as a theoretical framework, (2) a dataset merging retrofit program application and survey data, and (3) a multi-state Markov model as a quantitative representation of the process. The PAPM framework provides a theoretical grounding that guides data collection and modeling and connects to the larger literature. The carefully designed data collection combines program data that tracks participant progress through a real mitigation incentive program with survey data that more specifically connects to the PAPM framework and enhances understanding of participant attributes. The multi-state Markov model uses the framework and data to represent the process quantitatively.

In this paper, we extend Porada et al. [4] to determine which attributes of the household, house, and/or incentive program are associated with an increased likelihood of transitioning through the mitigation process. We do this by including explanatory variables in the Markov model, allowing us to address the following research question: What factors (e.g., sociodemographic, perception, property, and incentive program characteristics) are associated with homeowner transitions from one stage to another, and do they vary across stage transitions? The answers are critical for designing effective interventions to promote home strengthening activities because they can help identify which homeowners should be targeted, at what time, and with what type of action.

We illustrate the approach for the same North Carolina application that was used in Porada et al. [4]. The case study focuses on the specific homeowner decision of participating in the North Carolina Insurance Underwriting Association (NCIUA) Strengthen Your Roof program, which helps eligible policyholders pay to strengthen their roof to minimize vulnerability to hurricane wind damage.

In Section 2, we review the literature on household mitigation decision-making and variables identified as possibly affecting it. Following a description of the case study in Section 3, we present the PAPM theoretical framework, data, and multi-state Markov model in Sections 5, 6, and 7, respectively. Section 8 provides the model results, and the paper concludes with a discussion of the study implications and areas for future work.

2 Literature Review

2.1 Household decision-making

Extensive empirical research on household hurricane disaster risk decision-making has been conducted across multiple disciplines. Most of these studies have revolved around household flood or wind insurance purchase (e.g., [5]), preparedness intention (e.g., [6]), or willingness to undertake flood mitigation measures (e.g., [7]).

Within this body of work, relatively few studies have addressed structurally strengthening (i.e., retrofitting) a home. Focusing on wind mitigation, Peacock [8], Ge et al. [9], Carson et al. [10], Petrolia et al. [11], Jasour et al. [12], and Chiew et al. [13] collectively address installation of hurricane shutters, roof anchors, reinforced doors, wind-resistant glass, wind-resistant shingles, and hurricane ties. Structural flood mitigation strategies studied include elevating the home, waterproof sealing, and elevating assets [12, 13, 14, 15, 16, 17, 18].

While the previous work offers insight into household mitigation decision-making, these studies all focus on people already actively making a protective action decision or artificially placed in that context by the study (e.g., when asked a question about what they would do in a specified circumstance). Porada et al. [4] introduced a new approach that examined home mitigation as a process that occurs over an extended time frame - from a homeowner first becoming aware of the decision through completion of the physical retrofit construction activity. In this work, we contribute to the literature on structural retrofit decision-making by expanding on Porada et al. [4] to determine what factors encourage homeowners to transition through the different stages of the mitigation process.

2.2 Variables related to protective action decision-making

The decision-making literature is replete with information the factors influencing a household's protective action decisions. Peacock [8], Kriesel and Landry [19], Grothmann & Reusswig [14], Lindell & Hwang [20], Lindell et al. [21], Botzen et al. [22], Zahran et al. [23], Petrolia et al. [24], Atreya et al. [25], Ge et al. [9], Bubek et al. [26], Jasour et al. [12], Chiew et al. [13], and Stock et al. [27] examined the association between protective action decisions and one or more demographic/socio-economic factors such as household income, age, gender, race and level of education of the homeowner. Peacock [8], Kriesel & Landry [19], Lindell & Hwang [20], Botzen et al. [22], Zahran et al. [23], Ge et al. [9], Petrolia et al. [24], Atreya et al. [25], Jasour et al. [12], and Chiew et al. [13] considered how geographic location and exposure to the hazard influences homeowners in purchasing insurance or implementing structural retrofits to their homes. These variables considered geographic location such as proximity to the coast or location within a floodplain as well as structural properties such as whether a home is elevated, has shutters, or is situated near a seawall or other shoreline protection. Other factors related to the property include median value of home [23], current and expected tenure [8, 9, 24, 13, 27] and occupancy [14, 25]. Peacock [8], Grothmann & Reusswig [14], Lindell & Hwang [20], Zaalberg et al [28], Terpstra [29], Ge et al. [9], Petrolia et al. [24], and Stock et al. [27] approached household decision-making from a psychological lens, exploring how risk perception particularly as it relates to a hazard's likelihood, consequences, and intrusiveness interact with homeowners' decisions to take protective actions. Similarly, Slovic et al. [30], Zaalberg et al. [28], Terpstra [29], and Stock et al. [27] looked at emotions such as worry, dread, and fear and how significant these perceptual factors were in predicting hazard adaptation behavior. Zou et al. [3] uses perceived attributes of the retrofits themselves as variables that may influence the decision-making. Other factors discussed in the literature include the homeowner's perceptions of their knowledge about the hazard [8, 9] and the effectiveness of the protective action [28], self-efficacy [14, 27, 31], and social influence [8, 20, 22, 23, 29]. In this study, we selected explanatory variables from this existing literature to include in the modeling.

3 Case study

North Carolina is highly prone to hurricanes. During the period 1851-2019, on average 2.3 hurricanes affected North Carolina each year, with one making landfall in the state on average every two years [32]. In the past decade alone, North Carolina experienced several devastating hurricanes—Matthew, Florence, Dorian, Isaias, Elsa, and Idalia—which together caused losses of $55 billion [33].

In 1969, the state General Assembly created the North Carolina Insurance Underwriting Association (NCIUA), a tax-exempt association of insurance companies to act as a market of last resort and provide windstorm and hail insurance coverage for property owners with insurable properties in the 18 beach and coastal counties of North Carolina (Figure 1) [34]. In 2022, it had 206,152 policies in force in a coverage area (Figure 1) with 421,008 households [35].

Figure 1: NCIUA and SYR Coverage Map

Created in 2010 by the Insurance Institute for Business and Home Safety (IBHS), the FORTIFIED Home Program [36] defines a set of construction standards that exceed minimum building code requirements for protecting residential buildings against severe weather such as hurricanes. Since 2019, NCIUA has partnered with IBHS to run its "Strengthen Your Roof" (SYR) program in which eligible policyholders with insured properties in North Carolina's Outer Banks and Barrier Islands (Figure 1) were offered grants to install FORTIFIED Roofs on their homes. The four grant cycles between 2019 and 2022 offered grants up to $6,000. In 2023, NCIUA increased the grant amount to $8,000. A second similar grant program called "Strengthen Your Coastal Roof" (SYCR) was launched in 2022 for insured properties in the remainder of NCIUA's coverage area (Figure 1). This study focuses solely on program cycles 2019-2022 of the SYR Program.

4 Method Overview

Figure 2 provides an overview of the components of the analysis method introduced in this study. A theoretical model based on the Precaution Adoption Process Model (PAPM) is first developed to characterize the cognitive and behavioral stages a homeowner goes through in strengthening their home

through the SYR program (Section 5). With that theoretical understanding, data is collected from three sources, the SYR program application system, policy and claims data, and a survey. Each observation in the dataset offers information about which stage a homeowner is in at what time (Section 6). Third, the data are used to fit a Markov model that describes the probability of transitioning from one stage to the next (Section 7.1). The fitted Markov model provides as output the impact each explanatory variable has on individual transitions (hazard ratios). Finally, the Markov model transition probabilities are used to simulate the progress of each homeowner in the sample through the stages of the process (Section 7.2), providing a complete description of the process. The simulation is used to evaluate how well the Markov model fits the sample data.. All elements of the study design and instrumentation were reviewed and approved by the University of Delaware Institutional Review Board.

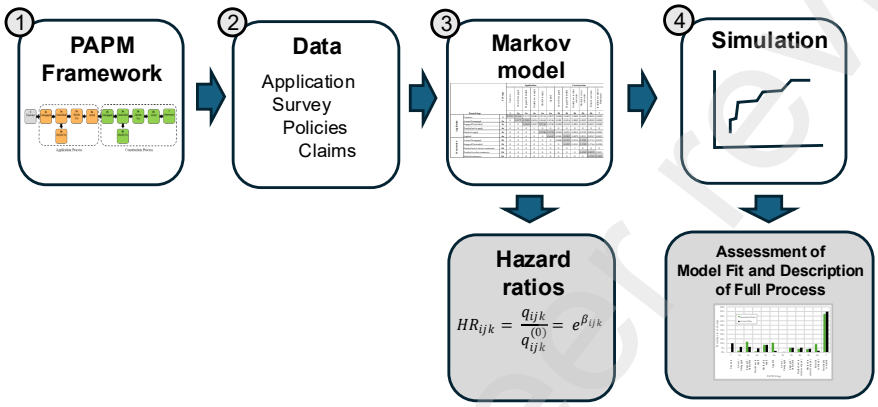

Figure 2: Method overview

5 Theoretical framework: Precaution Adoption Process Model

The Precaution Adoption Process Model (PAPM) is a stage theory framework [37, 38] that posits that the decision to adopt new precautions in response to a hazard can be characterized as a series of cognitive stages. It supposes that (1) individuals at different stages of a precaution adoption process behave in different ways and (2) the decision-making process is dynamic in nature influenced by varying factors at different stages of the process. Weinstein et al. [38] proposed seven stages to define the PAPM (Figure 3). The process of precautionary action begins with three stages of inaction whereby the individual is unaware of the issue (Stage 1), aware of but unengaged by the issue (Stage 2), or engaged by but undecided about acting to address the issue (Stage 3). These three stages of inaction are followed by the individual deciding to not act (Stage 4) or act (Stage 5), taking an action (Stage 6), and maintaining the state of being once the action has been executed (Stage 7). PAPM theory asserts that the factors that govern the transition from one stage to the next may differ across transitions.

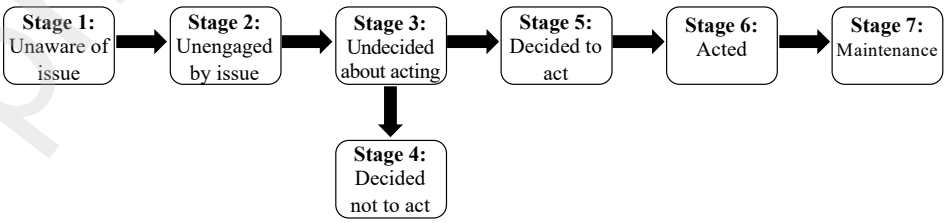

Figure 3: The Precaution Adoption Process Model (PAPM)
Source Adapted from Weinstein et al. [38]

The PAPM framework has mostly been applied in the health sciences to model preventative behavior aimed at reducing health risks [39, 40, 41, 42]. Glik et al. [43] and Jassempour et al. [44] are among the few studies that have used PAPM to model individual decision-making behavior in the context of disaster preparedness, and Stock et al. [27] and Porada et al. [4] are the only studies to date to apply PAPM to natural disaster protective action behavior focusing on household hurricane mitigation decision-making.

In this study, as in Porada et al. [4], the household decision of retrofitting a home using the SYR grant program is considered to be the outcome of two sequential decisions–submitting a grant application and selecting a contractor to implement the retrofit. To reflect this, we applied PAPM in a novel way, by linking two sets of PAPM stages in series (Figure 4). The process begins with the homeowner being unaware of the grant program (Stage 1). Next, they hear about the program but are not actively considering participating in it (Stage 2a). Once they begin weighing the pros and cons of applying for the grant they enter Stage 3a and make a cognitive decision to either apply (Stage 5a) or not (Stage 4a). If they decide to apply for the grant, they act on their decision by submitting an application (Stage 6a). If the application is approved, the homeowner follows a similar series of steps to select a contractor to install the FORTIFIED Roof culminating in Stage 7 when the homeowner has completed the protective action of strengthening their home.

Due to the sequential nature of the two decisions, the completion of the first decision process (submitting an application) leads directly into the beginning of the second (selecting a contractor). As a result, the first PAPM, representing the application process, does not have a termination stage (Stage 7), while the second PAPM, representing the construction process, begins with the homeowner being aware but unengaged (Stage 2). Note that, unlike the other stage-to-stage transitions, homeowners do not solely control the transition from submitting an application (Stage 6a) to being unengaged about selecting a contractor (Stage 2b). Rather, that transition occurs when NCIUA and IBHS approve their SYR application. This also holds true for the transition from selecting a contractor (Stage 6b) to completing the retrofit (Stage 7) which occurs when the contractor completes the roof installation and IBHS grants the policyholder's home the FORTIFIED Roof designation.

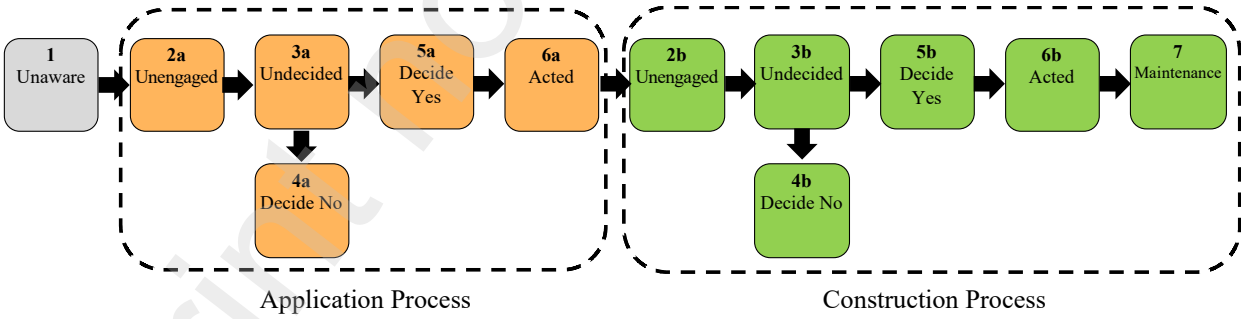

Figure 4: Application of PAPM to SYR Grant Program

6 Data

The dataset compiled for this study includes a row for each observation of each policyholder, and columns describing: (1) policy number n, (2) PAPM stage i, (3) time t, (4) observation type m (transition or snapshot) and (5) explanatory variables, x_j (where $1 \leq j \leq$ number of variables). The first four columns are *stage variables* which collectively place a homeowner in a given PAPM stage at a certain point in time. For a transition observation type, the time represents the time at which the policyholder first

entered the stage. For a snapshot observation type, it represents an arbitrary time at which the policyholder was in an associated stage but does not provide information as to when an individual arrived at that stage or how long they will be there. To investigate stage-to-stage transitions, the dataset includes a minimum of two observations for each policyholder. We added Stage 1 (unaware of the SYR program) snapshot observations on the launch date of the program for all policyholders who did not already have an observation on that date. The remaining columns of the dataset contain *explanatory variables* describing factors that may play a role in influencing a homeowner to transition between one stage to the next. Explanatory variable values remain constant across all observations for a single policyholder.

6.1 Data Sources

Data was collected through (1) the SYR 2022 grant application system, (2) NCIUA policy and claims datasets, and (3) an NCIUA policyholder survey designed by the research team (Table 1). The application system data avoided typical concerns about respondent reliability, but it only offered observations of a subset of stages and only applied to those policyholders participating in the 2022 SYR cycle. The survey complemented the application systems data by adding observations of the missing stages for policyholders who at least started an application in any of the SYR program cycles or who were eligible for SYR 2022 and did not start an application. Both the application system and the survey also provided homeowner/household characteristic information. Finally, the claims and policy datasets added property-related data for the properties under consideration for a grant.

Table 1: Data Sources

Data Sources	Data Types			Who is included
	Current stage	*Past stage*	*Explanatory*	
Application	X		X	Applied in 2022
Survey	X	X	X	Eligible in 2022; started application in 2019, 2020, 2021
Policy/Claims			X	Eligible in 2022; started application in 2019, 2020, 2021

6.1.1 SYR application data

To apply for a grant through the SYR program, eligible homeowners must complete an online application that requests personal, property, and policy information. The SYR 2022 grant application also included questions related to the homeowner's characteristics and their belief systems regarding hurricanes and hazard adjustment behaviors. For each of the 1,668 policyholders who created an account through the SYR 2022 program, the NCIUA internal grant application system provided a weekly report on the status of each homeowner and their responses to the explanatory variable-related questions. The statuses enabled us to create snapshot observations of homeowner stages by assigning each homeowner status to a corresponding PAPM stage [4]. For example, the system status "Application under review by IBHS team" corresponds to "Acted" (Stage 6a). NCIUA also provided timestamps of submitted and canceled applications for policyholders in all program cycles which represented transition observations of a homeowner moving from *deciding to apply* to *applying* (Stage 5a to Stage 6a) and *undecided about applying* to *decided not to apply* (Stage 3a to Stage 4a), respectively.

Some system statuses correspond to multiple possible potential stages. These ambiguous cases were addressed through the incorporation of censored states in the multi-state model, whereby the exact stage of an observation is unknown and instead is assigned a range of possible stages [45].

6.1.2 Policy and claims data

Policy data contained information related to the policyholder's property including age of home, construction type (e.g., masonry, frame, mobile home), location of home (street address and latitude/longitude coordinates, occupancy type (e.g., primary, seasonal, secondary), and whether prior retrofits had been implemented on the property. Claims data included information related to claim payout amounts and length of time since a policyholder submitted their last claim.

6.1.3 Survey data

The NCIUA application system data was augmented by an online survey containing questions about the homeowner's current stage as well explanatory variable-related questions. Survey invitations were sent to 38,942 policyholders who were either eligible for the SYR 2022 program or had at least started an application through the SYR 2019, 2020, or 2021 programs. Policyholders received a link to the online survey by email if available (15,893) or postcard if not (23,049). Nine hardcopy surveys were distributed. Survey invitations were sent in four email waves and two postcard waves between August and December 2022. Each wave was sent to all homeowners, whether they answered the survey in a previous wave or not, to obtain as many observations of as many stages for each homeowner as possible. Homeowners were not contacted further if they indicated in a survey response that they had reached a terminal stage, i.e., Stage 4a, 4b, or 7 (Figure 4).

The survey asked homeowners questions to determine (1) their current PAPM stage at the time of survey completion ("staging questions") and (2) the time they were first in each previous stage ("retro-reporting questions"). The former provide snapshot observations; the latter, transition observations. If a homeowner's answer to the staging question indicated they were at least aware of the SYR grant program (Stage 2a), they were asked retro-reporting questions that prompted them to recall when they first found themselves in all the earlier stages leading to their current stage. Figure 5 shows examples of staging and retro-reporting question.

(a) **Example staging question** [*with the stage each answer corresponds to*]

Which of the following best describes you?

a. I have never heard about the Strengthen Your Roof (SYR) Grant Program before receiving this survey. [*Stage 1, Unaware*]
b. I have never seriously considered applying to the Strengthen Your Roof (SYR) Grant Program. [*Stage 2a, Unengaged*]
c. I am considering applying to the Strengthen Your Roof (SYR) Grant Program, but I have not decided yet. [*Stage 3a, Undecided*]
d. I decided not to apply to the Strengthen Your Roof (SYR) Grant Program. [*Stage 4a, Decide no*]

(b) **Example retro-reporting question**

What is your best estimate of when you first actively considered applying to the SYR Grant Program? Please be as specific as you can. [*Year, Month, Day*]

Figure 5: Example staging and retro-reporting survey questions

Retro-reporting questions asked policyholders to provide the exact date they first arrived in each stage prior to their current one. However, recognizing that memories are imperfect, policyholders were able to respond with only the year and month or only the year if that is all they remembered. More than 80% of retro-reporting questions answered consisted of an incomplete date, i.e., either day or both day and month

were missing. To maximize use of the available data without introducing new assumptions, each incomplete retro-reporting response was converted into a pair of snapshot observations.

6.2 Data description

6.2.1 Stage Variables

Survey responses and SYR 2022 weekly reports from the application system were collected between July 2022 and December 2023. Data was obtained from 3,928 homeowners, representing 10% of all policyholders contacted. The final cleaned dataset contained 3,747 policyholders with 17,254 unique stage observations (Table 2). Homeowners in the 2022 SYR grant program comprised nearly three-fourths of all policyholders and observations in the sample. Observations consisted of 80% snapshot observations and 20% transition observations with 35% derived from the survey and 65% from the SYR application.

Table 2: Final Dataset

Program Year	Number of Policyholders	Observations				Total
		Type		*Source*		
		Snapshot	*Transition*	*Survey*	*Application*	
2019	266	740	249	457	532	989
2020	368	1,197	342	795	744	1,539
2021	375	1,331	351	927	755	1,682
2022	2,738	10,714	2,330	3,791	9,253	13,044
Total	**3,747**	**13,982**	**3,272**	**5,970**	**11,284**	**17,254**

6.2.2 Explanatory Variables

Data was collected through the application system and the online survey for 30 explanatory variables selected based on the extant literature (Section 2.2). They describe demographic/socio-economic characteristics of the homeowner and the household, homeowner perception of the hazard risk and their psychological response to it, social influence, familiarity and perception of the SYR grant program and the FORTIFIED Roof retrofit, and characteristics of the property. Descriptive statistics for the final set of variables are presented in Table 3 and Table 4.

Table 3: Descriptive Statistics of Categorical and Binary Variables

Category	Variable Name	Count
Sociodemographic/ Household	***Gender***	**2,973**
	Male	1,877
	Female	1,096
	Race	**2,766**
	Not White	89
	White	2,677
	Ethnicity	**2,822**
	No	2,755
	Yes	50
	I am not sure	17
	Education	**2,958**
	Did not complete a college degree	412
	Completed at least a college degree	2,546
	Future Time in Current Home	**3,056**
	Plans to move	691
	No plans to move	2,365
	Bottom 25% of Median Income	**2,245**
	Not in bottom quartile	1,708
	In bottom quartile	537
	Top 25% of Median Income	**2,245**
	Not in top quartile	1,892
	In top quartile	353
Psychological/ Perception of Hazard	***Perception of Likelihood of Hurricane Damage***	**3,391**
	Unlikely	470
	Likely	1,506
	Not sure	1,415
	Perception of Likelihood of Hurricane Disruption	**3,388**
	Unlikely	616
	Likely	2,056
	Not sure	716
	Dread	**3,425**
	No	2,503
	Yes	922
	Worry	**3,425**
	No	1,665
	Yes	1,760
	Empowered by Actions to Mitigate	**3,361**
	I disagree	239
	I agree	2,713
	I am not sure	409
Social Influence	***Friend with FORTIFIED Roof***	**3,276**
	No/I don't know	2,144
	Yes	1,132
	Friend SYR Approved	**3,274**
	No/I don't know	2,238
	Yes	1,036
Perception of Knowledge/ Effectiveness	***Perception of Knowledge***	**3,265**
	I know nothing about this	665
	I know at least some about this	2,600
	Encouraged by Perception of Understanding	**3,035**
	Did not encourage me to apply	690
	Encouraged me to apply	2,345
	Encouraged by Perception of Effectiveness	**3,040**
	Did not encourage me to apply	539
	Encouraged me to apply	2,501
Perception of Program/Process	***Encouraged by Perception of SYR Amount***	**3,045**
	Did not encourage me to apply	501
	Encouraged me to apply	2,544
	Encouraged by Perception of Application Process	**3,006**
	Did not encourage me to apply	1,647
	Encouraged me to apply	1,359
	Encouraged by Perception of Construction Process	**2,979**
	Did not encourage me to apply	1,772

	Encouraged me to apply	1,207
	Encouraged by Perception of Finding a Contractor	**2,992**
	Did not encourage me to apply	1,885
	Encouraged me to apply	1,107
Property Characteristics	***Mobile Home***	**3,722**
	Not Mobile Home	3,689
	Mobile Home	33
	Primary Residence	**3,722**
	Owner Occupied/Primary Residence	2,424
	other	1,298
	Previous Mitigation	**3,667**
	No	1,935
	Yes	1,732
	Encouraged by Perception of Roof Condition	**3,058**
	Did not encourage me to apply	1,022
	Encouraged me to apply	2,036

Table 4: Descriptive Statistics of Continuous Variables

Category	Variable Name	Count	Mean	Std Dev
Sociodemographics/Household	***Age of Homeowner***	**1,447**	65.0	10.6
Property Characteristics	***Age of Home***	**3,722**	34.0	15.5
	Last Claim Amount	**3,747**	422.0	4,212.3
	Days since Last Claim	**3,747**	27.0	177.1
	Total Claim Amount in Last 5 Yrs	**3,747**	425.0	4,215.4

7 Multi-state Markov model

7.1 Markov model

Multi-state models are widely used to describe the evolution of a process comprised of many states or stages over a period of time. They are governed by transition intensities $q_{ij}(t)$ representing the instantaneous risk at time t of moving from state i to j (Eq. 1).

$$q_{ij}(t) = \lim_{\delta t \to 0} P(S(t+\delta t) = j \,|\, S(t) = i)/\delta t \tag{1}$$

The effect of the explanatory variables (also referred to as *covariates*) on a homeowner's behavior through the SYR grant process can be examined by modelling the transition intensities as a function of these variables, $q_{ij}(\boldsymbol{z})$, as in Eq. 2 where $q_{ij}^{(0)}$ is the transition intensity from state i to state j with the covariates set to their reference values, $\boldsymbol{\beta}_{ij}^{T}$ represents a vector of the linear covariate coefficients, and $\boldsymbol{z}$ is a vector of covariates [45].

$$q_{ij}(\boldsymbol{z}) = q_{ij}^{(0)} \exp\left(\boldsymbol{\beta}_{ij}^{T}\boldsymbol{z}\right) \tag{2}$$

In this study, we use a homogeneous continuous-time Markov model based on three fundamental assumptions: (1) the probability of an individual transitioning from one state to another is dependent only on the individual's current state and not on any states they may have visited in the past, (2) transition probabilities between any pair of states does not change across any two consecutive time periods, and (3) observation times are intermittent, random, and independent of the individual's current state.

The multi-state Markov model in this study consists of 12 states, each representing a stage in the PAPM application of the SYR grant program with *decided not to apply* (Stages 4a), *decided not to select a contractor* (Stage 4b), and *completed installation/maintenance* (Stage 7) considered absorbing states and all other stages considered transient states. Individuals can only transition to the next higher state except for transitions from *undecided about applying* (Stage 3a) to *decided not to apply* (Stage 4a) or *decided to apply* (Stage 5a) and transitions from *undecided about selecting a contractor* (Stage 3b) to *decided not to select a contractor* (Stage 4b) or *decided to select a contractor* (Stage 5b). This linear progression of stage transitions is captured by the transition intensity matrix, $\boldsymbol{Q}$, in which each (i,j) entry is the transition intensity q_{ij} representing the instantaneous risk of transitioning from state i to state j. In the cases where an instantaneous transition is not possible such as transitioning from being *unaware of the SYR program* (Stage 1) directly to *decided to apply* (Stage 5a) the transition intensity is set to zero. The probability of transitioning from each state i to each state j in time t can be calculated from the transition intensity matrix using Eq. 3, where *Exp* is the matrix exponential [45].

$$P(\Delta t) = Exp(\Delta t Q) \tag{3}$$

The multi-state model was fitted using R software 4.3.0 and the msm package version 1.7.1 [45]. Time was measured in number of days from the beginning of the SYR grant process. Since the dataset includes policyholders from various SYR program years (2019 through 2022), each group of policyholders was assigned a start time corresponding to the launch date for the program cycle in which they participated.

7.2 Simulation

Once the transition probability matrix, **P**, has been estimated, we can simulate individuals progressing through the process it represents (Figure 2, Step 4). This serves two purposes. First, it can help evaluate how well the fitted model matches the raw data. If we simulate a sample of policyholders similar to the one in the dataset, the distribution of individuals across stages at each time should approximately match the same distribution in the raw data. Second, we can use the model to gain insight into the process. While the raw data is incomplete, offering only a few observations for each individual at different points in time, the simulation provides a complete description of the process for the whole simulated population.

As discussed in Section 7.1 and Porada et al. [4], we assume each policyholder started at Stage 1 of the SYR mitigation process when the program for which they were eligible launched, i.e., they could not be unaware of the program before it officially existed. The simulations of policyholders participating in program cycles 2019 through 2021 and those in 2022 who started but did not submit an application by the program deadline were ended on December 31, 2022 (the 2022 program application deadline). The simulation of policyholders who successfully submitted an application through the 2022 program were ended on December 31, 2023 since these homeowners were able to continue onto the construction stages of the mitigation process throughout 2023.

8 Results

8.1 Model description and fit

The model fitted in this study is based on the same dataset and of similar form as that in Porada et al. [4], with the important distinction that the model herein includes the effects of covariates in computing transition intensities (Equation 2) while the model in Porada et al. [4] does not. Including those covariates for the first time enables insights into the factors associated with stage-to-stage transitions. Nevertheless, we expect conclusions related to the model fit and the duration of each stage to be similar to those in Porada et al. [4]. As expected, the model-estimated transition intensities, q_{ij}, from the two papers are highly correlated (ρ=0.97).

Transition probabilities can be easier to understand and interpret than transition intensities. Each value in cell (*i, j*) of Table 5 represents the conditional probability of a homeowner being in stage *j* after 1 month given they are currently in stage *i*. In most cases, there is at least an 80% probability that a homeowner will remain in the same stage or move up one stage in the SYR process after one month (Table 5). Seventy percent of individuals who are *undecided about applying* for the grant (Stage 3a) and 75% of those who *selected a contractor* (Stage 6b) will still be there after one month. However, as discussed in Section 4, the transitions from Stages 6a and 6b are not solely controlled by the homeowner.

Table 5: Probability Transition Matrix (t = 1 month)

			Application						Construction					
		To Stage	Unaware	Aware/Unengaged	Engaged/Undecided	Decided not to apply	Decided to apply	Applied	Aware/Undecided	Engaged/Undecided	Decided not to select contractor	Decided to select contractor	Selected contractor	Installation complete/ Maintenance
	From Stage		**1**	**2a**	**3a**	**4a**	**5a**	**6a**	**2b**	**3b**	**4b**	**5b**	**6b**	**7**
Application	Unaware	**1**	0.5321	0.3341	0.1174	0.0003	0.0136	0.0023	0.0000	0.0002	0.0000	0.0000	0.0000	0.0000
	Aware/Unengaged	**2a**	0	0.5271	0.3888	0.0016	0.0660	0.0146	0.0001	0.0016	0.0000	0.0002	0.0000	0.0000
	Engaged/Undecided	**3a**	0	0	0.6949	0.0057	0.2156	0.0708	0.0005	0.0102	0.0001	0.0019	0.0003	0.0000
	Decided not to apply	**4a**	0	0	0	1	0	0	0	0	0	0	0	0
	Decided to apply	**5a**	0	0	0	0	0.5206	0.3703	0.0024	0.0803	0.0016	0.0199	0.0046	0.0003
	Applied	**6a**	0	0	0	0	0	0.6167	0.0041	0.2491	0.0078	0.0913	0.0287	0.0023
Construction	Aware/Undecided	**2b**	0	0	0	0	0	0	0.0000	0.4353	0.0338	0.3382	0.1733	0.0193
	Engaged/Undecided	**3b**	0	0	0	0	0	0	0	0.4303	0.0341	0.3390	0.1766	0.0200
	Decided not to select a contractor	**4b**	0	0	0	0	0	0	0	0	1	0	0	0
	Decided to select a contractor	**5b**	0	0	0	0	0	0	0	0	0	0.4249	0.4899	0.0851
	Selected a contractor	**6b**	0	0	0	0	0	0	0	0	0	0	0.7508	0.2492

Shaded cells are those with the highest values in each row.

Figure 6 summarizes the average duration homeowners spend in each of the transient PAPM stages of the SYR program. The model suggests that the total process of applying for a grant and installing a FORTIFIED Roof through the SYR program takes on average 461 days to complete, compared to 464 days presented in Porada et al. [4]. Homeowners spent 100 more days in the application stages (265 days) than in the construction stages (176 days). Notably, 38% of the total time was spent in the first three stages of the process where the homeowner is either *unaware of the program* (Stage 1), *aware but unengaged in the application process* (Stage 2a), or *undecided about applying* for the grant (Stage 3a). The time spent in these stages equals the time spent in all of the construction stages combined, reinforcing

the PAPM theory that the cognitive stages leading up to a decision to act are an important and time-consuming part of the decision process. As in Porada et al. [4], the single stage where homeowners spent the most time was *undecided about applying* for a grant (Stage 3a) comprising 18% of the total time and 29% of the application stages (37% excluding the time spent in *applied*, Stage 6a). Also similar to the results from Porada et al. [4], the time spent being aware but *unengaged in the application process* (Stage 2a) suggests that even after becoming aware of the SYR grant program, policyholders did not immediately begin actively considering whether to retrofit their homes. This finding aligns with the work of Stock et al. [27], which concluded that one-third of homeowners are in an unengaged stage (Stage 1 or 2, Figure 3) of the retrofit decision process.

PAPM Stage			Days
Application	*Unaware*	**1**	47.5
	Unengaged	**2a**	46.8
	Undecided	**3a**	82.4
	Decide Yes	**5a**	46.0
	Applied [1]	**6a**	62.1
Construction	*Unengaged*	**2b**	0.4
	Undecided	**3b**	35.6
	Decide Yes	**5b**	35.1
	Selected Contractor [1]	**6b**	104.7
			460.5

[1] Transition dictated by external factors and does not depend on the policyholder's decision-making

Figure 6: Mean Sojourn Times

To assess how well the model fits the data, we compared the final stage distributions for the actual raw data and model-based simulated data (Figure 7). For the simulated data, each policyholder's final stage is their stage as of December 31, 2022 or December 31, 2023 depending on the policyholder's program cycle. For the actual data, each policyholder's final stage is the stage at the time of the last observation for that person. For 488 policyholders (13%), their final observation was more than three months prior to the end of their data collection, so it is possible that it was not truly their final stage at December 31, 2022 or 2023. Despite this inconsistency, the comparisons in Figure 7 are instructive.

Figure 7 suggests the model underestimates the number of policyholders who did not move beyond being *unaware* (Stage 1), *unengaged about applying* (Stage 2a), or *decided not to apply* (Stage 4a) while overestimating policyholders who were *undecided about applying* (Stage 3a), *applied* (Stage 6a) or *selected contractors* (Stage 6b) but did not continue. These modest differences may at least in part be due to the final stage definition for the actual data. In particular, the actual data may underestimate how far in the process a policyholder got if the last observation occurred before they stopped progressing through the stages.

In general, the difference in percentage of policyholders in each stage between the model and the actual data does not exceed 10% for any one stage. Furthermore, a Kolmogorov-Smirnov test comparing the two distributions resulted in a p-value of 0.838, suggesting there is no evidence of a statistically significant difference between the two distributions, and the model is a good fit for the data.

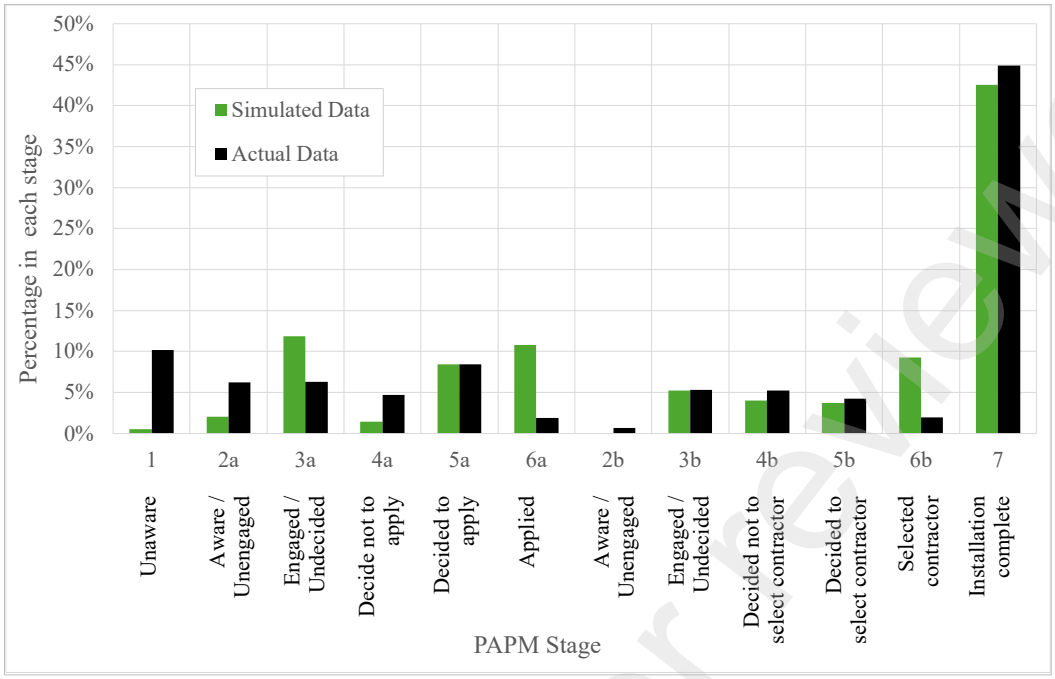

Figure 7: Last PAPM Stage Observed of Each Policyholder

8.2 Factors that affect stage transitions

The impact of each covariate on individual transitions in the SYR grant process is described by the hazard ratios in

Table **6**. In the context of multi-state models, a hazard ratio, HR_{ijk}, quantifies how a covariate k modifies the instantaneous risk of transitioning from state *i* to state *j*. It is expressed as a ratio of transition intensities for the pair of states (Equation 4), where $q_{ij}^{(0)}$ and q_{ijk} are the transition intensities from state *i* to state *j* with the covariate *k* set to the reference value and the non-reference value, respectively; and β_{ijk} is the coefficient for covariate *k* for the transition from state *i* to state *j*. A hazard ratio greater than 1 implies that a homeowner with the characteristic represented by the non-reference value of covariate *k* is more likely to make a transition from state *i* to state *j* than a homeowner with the characteristic represented by the reference value of that same covariate. For example, in Table 6 (a), the reference value for gender is "male" and the non-reference value is "female". A gender hazard ratio of 1.76 for the transition from *Decide yes* to *Selected contractor* (Stage 5b to 6b), for example, means that women are 1.76 more likely to make that transition than men. Shaded cells denote covariates that are statistically significant at a 0.05 significance level for a given transition. Bold hazard ratios highlight covariates greater than 2 or less than 0.5 for the associated transition. The greater a hazard ratio's deviation from 1, the stronger the influence a covariate has on a specific transition compared to other significant covariates.

$$HR_{ijk} = \frac{q_{ijk}}{q_{ij}^{(0)}} = e^{\beta_{ijk}} \tag{4}$$

Table 6: Covariate hazard ratios by PAPM transition

PAPM Transition					Sociodemographic/Household							
					Age	Gender	Race	Ethnicity	Education	Future Time in Current Home	Bot. 25% Median Income	Top 25% Median Income
Application	*Unaware*	*to*	*Unengaged*	HR_12a	1.01	**0.32**	0.98	0.87	0.98	1.09	1.25	0.66
	Unengaged	*to*	*Undecided*	HR_2a3a	0.98	**0.42**	1.86	1.52	0.73	1.31	1.09	1.05
	Undecided	*to*	*Decide No*	HR_3a4a	1.00	1.73	1.32	3.26	3.22	**0.21**	**0.35**	1.19
	Undecided	*to*	*Decide Yes*	HR_3a5a	0.98	**0.43**	3.63	3.43	2.01	**0.41**	1.54	0.82
	Decide Yes	*to*	*Applied*	HR_5a6a	1.00	1.72	1.10	1.35	0.65	1.53	0.83	1.15
	Applied	*to*	*Unengaged*	HR_6a2b	0.98	0.96	1.00	1.15	0.93	1.09	0.97	1.08
Construction	*Unengaged*	*to*	*Undecided*	HR_2b3b	0.97	**3.92**	3.54	8.46	**0.07**	**3.05**	0.58	1.28
	Undecided	*to*	*Decide No*	HR_3b4b	1.01	1.00	1.04	1.26	0.78	0.90	0.93	1.06
	Undecided	*to*	*Decide Yes*	HR_3b5b	0.99	0.99	2.71	2.62	0.72	0.86	1.14	1.07
	Decide Yes	*to*	*Selected Contractor*	HR_5b6b	0.99	1.76	2.77	2.69	**0.29**	1.16	1.65	0.76
	Selected Contractor	*to*	*Unengaged*	HR_12a	1.00	0.99	1.15	1.03	0.98	0.94	0.98	0.97
*This row denotes the attribute that makes homeowners more likely to make a given transition if **HR < 1***					younger	male	white	not Hispanic	no college degree	may move	not in bot. 25%	not in top 25%
*This row denotes the attribute that makes homeowners more likely to make a given transition if **HR > 1***					older	female	non-white	Hispanic	college degree	no plans to move	in bot. 25%	in top 25%

(a) sociodemographic and household characteristics

PAPM Transition					Perception of Knowledge/Effectiveness			Perception of Program/Process			
					Perception of knowledge	Encouraged by Perception of Understanding	Encouraged by Perception of Effectiveness	Encouraged by Perception of SYR Amt	Encouraged by Perception of App Process	Encouraged by Perception of Construction Process	Encouraged by Perception of Finding a Contractor
Application	*Unaware*	*to*	*Unengaged*	HR_12a	**3.96**	1.71	1.67	**2.04**	1.20	1.16	1.88
	Unengaged	*to*	*Undecided*	HR_2a3a	0.96	**2.25**	**3.04**	**3.92**	**3.09**	**2.57**	1.43
	Undecided	*to*	*Decide No*	HR_3a4a	1.16	**0.32**	**0.25**	**0.18**	**0.37**	**0.44**	**0.46**
	Undecided	*to*	*Decide Yes*	HR_3a5a	1.85	**3.20**	**4.36**	**3.98**	**2.02**	**2.90**	**3.34**
	Decide Yes	*to*	*Applied*	HR_5a6a	1.48	**2.81**	1.10	1.70	1.30	1.39	1.14
	Applied	*to*	*Unengaged*	HR_6a2b	1.13	0.90	1.03	1.68	0.74	0.77	0.85
Construction	*Unengaged*	*to*	*Undecided*	HR_2b3b	0.49	0.59	0.94	1.36	0.56	0.54	0.53
	Undecided	*to*	*Decide No*	HR_3b4b	0.92	0.88	1.31	1.70	0.81	0.98	0.98
	Undecided	*to*	*Decide Yes*	HR_3b5b	1.06	**2.53**	5.42	5.60	0.83	1.69	1.68
	Decide Yes	*to*	*Selected Contractor*	HR_5b6b	1.18	1.32	**0.47**	0.83	0.95	1.45	1.35
	Selected Contractor	*to*	*Unengaged*	HR_12a	1.08	0.89	0.92	0.89	0.93	0.98	0.95
*This row denotes the attribute that makes homeowners more likely to make a given transition if **HR < 1***					no knowledge	no					
*This row denotes the attribute that makes homeowners more likely to make a given transition if **HR > 1***					has knowledge	yes					

(b) perceptions of retrofit and program

PAPM Transition					Feelings Towards Hazard/Perceptions of Hazard				Self-Efficacy	Social Influence	
					Perception of Likelihood Damage	Perception of Likelihood Disruption	Worry	Dread	Empowered by Actions	Friend w/ FORTIFIED Roof	Friend SYR Approved
Application	*Unaware*	*to*	*Unengaged*	HR_12a	0.97	1.08	1.02	1.22	0.93	**2.87**	**3.68**
	Unengaged	*to*	*Undecided*	HR_2a3a	**2.42**	**2.21**	1.41	1.02	1.20	1.23	1.60
	Undecided	*to*	*Decide No*	HR_3a4a	0.61	0.90	1.01	0.62	1.96	0.59	**0.36**
	Undecided	*to*	*Decide Yes*	HR_3a5a	1.73	**2.52**	1.45	0.52	1.71	**2.10**	1.57
	Decide Yes	*to*	*Applied*	HR_5a6a	0.79	0.68	1.05	1.34	1.34	1.30	1.20
	Applied	*to*	*Unengaged*	HR_6a2b	1.62	1.41	1.17	0.91	1.01	1.32	1.40
Construction	*Unengaged*	*to*	*Undecided*	HR_2b3b	**0.16**	0.59	0.51	6.30	0.59	6.70	4.59
	Undecided	*to*	*Decide No*	HR_3b4b	0.61	0.51	0.82	0.83	1.85	0.65	0.65
	Undecided	*to*	*Decide Yes*	HR_3b5b	0.85	0.67	1.44	1.61	1.89	1.29	1.13
	Decide Yes	*to*	*Selected Contractor*	HR_5b6b	**2.01**	1.91	1.33	1.22	0.88	1.58	1.42
	Selected Contractor	*to*	*Unengaged*	HR_12a	0.85	0.79	1.11	0.87	1.04	0.99	1.02
*This row denotes the attribute that makes homeowners more likely to make a given transition if **HR < 1***					not likely	no					
*This row denotes the attribute that makes homeowners more likely to make a given transition if **HR > 1***					likely	yes					

(c) hazard perceptions, self-efficacy, and social influence

PAPM Transition					Property Characteristics							
					Mobile Home	Primary Residence	Previous Mitigation	Encouraged by Perception of Roof Condition	Age of Home	Total Amt Claims Last 5 yrs	Days since Last Claim	Last Claim Amt
Application	*Unaware*	*to*	*Unengaged*	HR_12a	**0.43**	0.69	**6.17**	1.35	1.00	NA	0.99	NA
	Unengaged	*to*	*Undecided*	HR_2a3a	0.85	1.28	1.74	**4.66**	1.00	NA	1.00	NA
	Undecided	*to*	*Decide No*	HR_3a4a	0.31	**2.21**	**0.30**	**0.18**	0.98	NA	NA	NA
	Undecided	*to*	*Decide Yes*	HR_3a5a	2.26	1.57	**4.52**	**2.61**	0.99	NA	NA	NA
	Decide Yes	*to*	*Applied*	HR_5a6a	1.22	1.32	**2.45**	1.43	1.00	NA	1.00	NA
	Applied	*to*	*Unengaged*	HR_6a2b	**0.09**	1.10	1.84	1.50	0.99	NA	1.00	NA
Construction	*Unengaged*	*to*	*Undecided*	HR_2b3b	1	**3.03**	5.38	0.66	0.97	NA	1.01	NA
	Undecided	*to*	*Decide No*	HR_3b4b	5.94	1.01	0.64	1.11	1.01	NA	NA	NA
	Undecided	*to*	*Decide Yes*	HR_3b5b	0.83	1.44	10.98	**2.47**	1.00	NA	NA	NA
	Decide Yes	*to*	*Selected Contractor*	HR_5b6b	1.04	1.36	5.95	1.14	0.99	NA	1.00	NA
	Selected Contractor	*to*	*Unengaged*	HR_12a	0.99	1.10	**4.14**	0.97	0.99	NA	1.00	NA
*This row denotes the attribute that makes homeowners more likely to make a given transition if **HR < 1***					no	yes	no		newer	less		
*This row denotes the attribute that makes homeowners more likely to make a given transition if **HR > 1***					yes	no	yes		older	more		

(d) property characteristics

A review of the shaded cells in Table 6 reveals the prevalence of certain categories of covariates in influencing most or all transitions. How much a homeowner believes they know about FORTIFIED Roofs, their perception of the SYR grant program, how they perceive the potential consequences of future hurricanes on their homes, their social network, and certain property characteristics have a statistically significant impact (at $\alpha = 0.05$) at least 8 out of 11 transitions. The covariates having the strongest influence (i.e., bold numbers in shaded cells) are those related to perceptions of knowledge of the retrofit, perception of the grant program, whether the property had previous mitigation, and the condition of the roof and are concentrated in three transitions within the application process: *unengaged about applying* to *engaged but undecided about applying* (row HR_2a3a), *undecided about applying* to *decided not to apply* (row HR_3a4a), and *undecided about applying* to *decided to apply* (row HR_3a5a).

Other covariates were only statistically significant at a 0.05 significance level in one or two transitions. For example, race and ethnicity only influenced the transition from being *unengaged about applying* to being *engaged but undecided about applying* (row HR_2a3a) but did not play a statistically significant role (at $\alpha = 0.05$) in influencing any other transitions. Similarly, homeowners living in mobile homes were less likely to become aware of the SYR program (row HR_12a) and a lot less likely to move from the application phase to the construction phase of the process (row HR_6a2b). A homeowner's median household income relative to the top quartile of median income for all respondents was relevant for homeowners becoming aware about the grant program (row HR_12a) and for homeowners moving from merely deciding to select a contractor to actually selecting one (row HR_5b6b). The varying importance of covariates across transitions and their diverse influences underscore the necessity of implementing a staged approach in the process. This approach reveals that each transition is influenced by distinct factors, requiring that interventions aimed at encouraging homeowners to move through the grant program must be tailored for each specific pair of stages throughout the process.

Table **6** highlights key factors that create awareness of the SYR program (hazard ratios in the HR_12a row), such as having some knowledge of FORTIFIED Roofs, being encouraged by the SYR grant amount, knowing people who have installed a FORTIFIED Roof or received an SYR grant, and having had previous mitigation work on the eligible property. The remainder of this section focuses on evaluating the combination of covariates that are critical in driving (1) homeowner engagement (Stage 2a/b to Stage 3a/b), (2) a homeowner's decision to act (Stage 3a/b to Stage 4a/b or Stage 5a/b), and (3) a homeowner taking an action (Stage 5a/b to Stage 6a/b).

8.2.1 Engagement

Stock et al. [27] concluded that one-third of homeowners are unengaged in retrofitting decisions, which underscores the significance of understanding the transition between being *aware but unengaged* (Stage 2a/b) and being *engaged but undecided* (Stage 3a/b). Attention is directed to the transition between Stages 2a and 3a, as Figure 6 shows that homeowners spend a negligible amount of time in the *unengaged stage of the construction phase* (Stage 2b). Analyzing the transition between Stages 2a and 3a can provide insights into the factors fostering engagement in initiating the decision-making process regarding SYR grant applications. The results suggest that a non-white, Hispanic male homeowner with no college degree who intends to remain in his current home is 1.86*1.52*1.31=3.70 times more likely to consider retrofitting his home through the SYR program compared to a White, non-Hispanic male homeowner with no college degree who does not intend to remain in his current home. Moreover, homeowners who express worry about hurricanes, perceiving them as potential sources of damage and disruption, are also more likely to contemplate the advantages and drawbacks of retrofitting. Additionally, knowing others with familiarity of FORTIFIED Roofs whether through the SYR program or elsewhere also significantly influences homeowners to initiate the application process. Being embedded in a social network familiar with the SYR program and/or FORTIFIED Roofs can positively shape a homeowner's perceptions of the effectiveness of the retrofit and of the program itself. These perceptions in turn encourage homeowners to apply for a grant as shown by the high hazard ratios in

Table **6** (b). Finally, a homeowner encouraged by the condition of their roof was also almost 5 times more likely to start the application process than a homeowner who was not. These factors collectively may capture a homeowner's attention enough for them to begin weighing the pros and cons of structurally strengthening their home through the SYR program.

8.2.2 Decided to Act

The sociodemographic profile for homeowners more likely to move from *indecision* to *making a decision to apply* for a grant (Stage 3a to 5a) differed from those transitioning from *unengagement* to *engagement in the application process* (Stage 2a to 3a). College-educated males not committed to staying in their current home displayed a greater propensity to decide to apply than other homeowner types[1]. Being in the bottom quartile for median household income emerged as a statistically significant covariate for this transition as well at a 0.05 significance level. While gender, education, expected future tenure, and median income were significant factors for homeowners deciding to apply, sociodemographic characteristics did not play a major role in transitioning from *undecided* to *deciding to select a contractor* (Stage 3b to 5b). Homeowners who decided to apply and who decided to select a contractor shared negative emotions towards future hurricanes, were influenced by their social network's experience with FORTIFIED Roofs or the SYR program, and believed their actions could have a real impact on the degree to which they experienced suffering and loss due to future storms. A homeowner's understanding of the retrofit and their perceptions of both the construction process and the condition of their roof were factors that greatly influenced a homeowner's decision to apply. Homeowners who believed they had some knowledge or were encouraged by their understanding of FORTIFIED Roofs and who viewed the construction process favorably were at least three times more likely to apply than those who did not. The same preferences that encouraged homeowners to apply also prompted homeowners to select a contractor but the effect of these variables was less pronounced in this transition (Stage 3b to 5b) as shown by the lower hazard ratio values. One explanation for this observation could be related to the time homeowners spend in the undecided stages (Stages 3a and 3b). Figure 6 indicates that on average homeowners spend

[1] Homeowners were asked how many years they planned to stay in their current home, with the option to indicate no plans to move. Responses were recoded into a binary variable: "plan to move" for those reporting a number of years and "no plans to move". The median response for those who specified the number of years they planned to stay in their current home was 15 years, indicating that "plan to move" may be misleading and may include long-term intentions.

more time making a decision about applying (82 days) than making a decision about selecting a contractor (36 days). It is likely that much of the weighing of the pros and cons of implementing the retrofit happens before submitting an application, making the homeowner more susceptible to various influences as they gather information to make a decision. By the time the homeowner reaches the stage of deciding whether they will select a contractor to perform the retrofit, they have already invested significant time and effort in the process, leaving little to figure out.

8.2.3 Acted

Figure 6 highlights that even after homeowners made the *decision to apply*, they remained in that stage (Stage 5a) for 46 days on average before actualizing that decision by *submitting an application* (Stage 6a). Part of this time may be spent gathering the necessary information to complete the grant application. However, additional barriers may also delay the application submission. Weinstein [37] explored the gap between intentions and actions in adopting a precaution. He found that over 60% of individuals queried agreed that their lack of follow through had to do with the perceived burden of taking the action. This finding aligns with the observation that homeowners who had a favorable perception of the application and/or construction processes were more likely to submit an application and select a contractor implying that those who *decided to act but never submitted an application* (Stage 5a) were discouraged from following through on their intentions by the grant process, potentially viewing it as cumbersome. The model also suggests that women without a college degree who plan to stay in their current home are more likely to submit an application, even though college-educated men who do not plan to remain in their current home are more likely to reach the decision to apply. This inconsistency between the person making the decision and the person executing it may increase the time between deciding and acting, compared to if the same person both made and followed through on the decision. Once again, feelings of worry and dread, knowing others with FORTIFIED Roofs on their homes or who were approved for an SYR grant, and having a sense of understanding about the retrofit encouraged homeowners both to submit an application and to select a contractor; however, the effects of these variables on the transition to act were not as pronounced as they were in promoting engagement or arriving at the decision to apply.

8.2.4 Recommendations

The knowledge gained from examining the types of homeowners most likely to make each of the three critical transitions (Sections 8.2.1 through 8.2.3) can be helpful in tailoring future generations of incentive programs to promote increased engagement and ultimately take the protective action of installing a FORTIFIED Roof. Section 8.2 reveals that a homeowner's perception of their knowledge of FORTIFIED Roofs and their effectiveness and how they perceive their current roof, their view of the process of applying for a grant and selecting a contractor, their social network's experience with the retrofit and/or the grant program, and their feelings about how hurricanes will affect their homes and their lives are substantial influences on how a homeowner navigates the decision-making process of installing a FORTIFIED Roof, particularly in the application-related stages of the process. This is important because it focuses efforts to increase homeowner participation in the program on the application phase of the program. Providing question and answer sessions about the program and how to navigate the application and construction processes prior to the open application period can help to demystify the programs' offerings and break down the process into a series of manageable steps. In addition, offering information sessions detailing the functionality of FORTIFIED Roofs in safeguarding homes from hurricane winds throughout the open application period, along with insights into the long-term cost savings associated with investing in such retrofits can work to bolster homeowners' confidence in the retrofit itself and the value proposition it offers. This approach not only raises awareness of the fact that homes with standard roofs in SYR eligible territories are highly likely to experience damage from future storms, but it also reinforces the notion that opting for a FORTIFIED Roof in the short term represents a sound investment, potentially averting the need for multiple repairs to a standard roof that may exceed the cost of a

FORTIFIED Roof throughout the lifespan of a house. Creating a set of frequently asked questions regarding the program or the retrofit based on homeowner feedback from these sessions and posting it on the program website can effectively make this information easily accessible. This resource can assist those who could not attend the sessions and serve as a reference for homeowners when questions arise throughout the entire mitigation process. Offering a Spanish version of the information on both the SYR program and FORTIFIED Roofs may also be considered. Section 8.2.1 also highlighted how the condition of a homeowner's roof significantly influences their engagement in the application process. Conducting a brief survey of roof age after finalizing the eligibility list for a given cycle year could help identify properties with roofs nearing their design life. Directly contacting these homeowners between the time notification letters about the new program cycle are sent out and the beginning of the application period may focus their attention and encourage them to apply for the grant sooner. Leveraging homeowners' social networks may also prove beneficial in increasing participation and follow through in the program given the impact we saw of social influence on several application stage transitions. For example, incentivizing previous policyholders who installed a FORTIFIED Roof through the SYR program to publicize their experience either by installing SYR signs on their lawns or by directly referring family, friends, and neighbors who might be eligible for an SYR grant to the program's website may lead to homeowners becoming engaged in the application process sooner since the information is coming from a trusted source. Promoting the program on social media group platforms such as neighborhood groups, local school boards, community recreation centers and other groups with high female membership can serve to spread the word within communities and place the issue of retrofitting front and center of homeowners' minds and conversations. Finally, collaborating with local roofing contractors, who frequently interact with homeowners seeking to replace their roofs, can be an effective way to spread awareness of the benefits of a FORTIFIED Roof and the opportunities provided by the SYR grant program to afford one.

In addition to the practical applications for the SYR program, the results from this study also contribute to the body of knowledge on household decision-making to date by suggesting that the decision to retrofit can be considered a multi-stage process where each stage transition is influenced by different factors. This staged approach deviates from conventional models which treat retrofit decisions as binary decisions (retrofit or not) and apply a set of variables to that single decision. By using a staged approach, researchers can explore specific parts of the retrofit decision-making process, gaining insights into the factors that motivated homeowners to reach a particular stage, the obstacles that keep them there, and the incentives that could move them to the next stage. This methodology has potential for broader applications to test the generalizability of these findings across different types of mitigation programs, geographic regions, and hazard types.

9 Conclusions and future work

In this study, we applied the PAPM stages of decision-making to identify which attributes of homeowners and/or their properties are associated with an increased likelihood of transitioning through mitigation stages in a grant incentive program such as the SYR program. Specifically, we extended the work of Porada et al. [4] by incorporating 30 explanatory variables into the Markov model, examined the average duration a homeowner spent in each stage, and analyzed which variables increased the likelihood of a homeowner transitioning between each pair of PAPM stages. Finally, we demonstrated how the results from this analysis could be used to increase engagement, participation, and follow through in home strengthening activities by providing examples of specific actions that can be incorporated into the SYR program or other similar mitigation initiatives.

The results from the case study herein suggest that the average homeowner takes approximately 461 days from the time the incentive program begins and they are unaware of it through installation and approval of a FORTIFIED Roof on their homes, with 62% of the total time spent in the application-related stages.

The stage in which people spent the most time was being engaged in the application process but *undecided about whether they will actually apply* (Stage 3a). Homeowners' understanding of FORTIFIED Roofs and their effectiveness and positive perceptions of the grant amount and the process largely encouraged homeowner engagement in the application phase and further encouraged homeowners to decide to apply for the grant. The condition of a policyholder's roof also played a major role in triggering a homeowner to move beyond simply being aware of the program and becoming actively engaged in it. Knowing people who installed a FORTIFIED Roof or were approved for an SYR grant raised awareness of the program and encouraged homeowners to apply. Finally, the study found that while men were more likely to arrive at the decision of applying for a grant, women were more likely to act on that decision by submitting an application and/or selecting a contractor.

Based on our results, we outlined several target areas that could raise awareness of the SYR program and FORTIFIED Roofs and increase participation including targeting homeowners with older roofs early in the program; offering sessions to answer questions regarding the program and explain the retrofit while highlighting the structural and financial benefits; engaging previous homeowners who have installed FORTIFIED Roofs and other community groups to reach homeowners through their social networks; and partnering with local contractors to validate the efficacy of the retrofit and promote the program. It should be noted that NCIUA has already implemented some recommendations by hosting consumer education sessions for policyholders and insurance agents ahead of the SYR 2023 grant cycle. These sessions offered a detailed breakdown of the grant application process and an overview of FORTIFIED Roofs provided by an IBHS representative. NCIUA also invited a locally certified IBHS contractor to address questions about the construction process and currently has an extensive FAQ page on their website.

Future efforts can use data gathered from the Strengthen Your Coastal Roof (SYCR) 2022 program, which covers properties in coastal territories further inland from the SYR eligible territories, to assess how variables such as distance to the coast affect how homeowners transition through the stages of the program. Similarly, we can investigate how an increase in the grant amount may impact homeowner mitigation behavior by comparing the current study to data from the SYR 2023 grant program which offers an additional $2,000 in grant money. More generally, this modeling approach can also be extended to other mitigation incentive programs related to hurricanes or other hazards. We can also revise how we apply the PAPM stages to the SYR program. For instance, we may reconsider including stages with few observations and negligible mean sojourn times such as Stage 2b (*unengaged in selecting a contractor*). Additionally, more consideration is needed in addressing transitions that are not solely the result of homeowner decisions, such as moving from *submitting an application* to *being unengaged about selecting a contractor* (Stage 6a to Stage 2b) or transitioning from *selecting a contractor* to *completing the roof installation and receiving the FORTIFIED Roof designation* (Stage 6b to Stage 7).

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Data Statement

Due to third party restrictions the data used in this study must remain confidential and cannot be shared.

Author Contributions: CRediT

Maria Porada: Software, Validation, Formal analysis, Investigation, Data curation, Writing – original draft, Visualization **Rachel Davidson**: Conceptualization, Methodology, Validation, Resources, Writing

– review and editing, Supervision, Project administration, Funding acquisition **Joseph Trainor:** Conceptualization, Methodology, Resources, Writing – review and editing **Linda Nozick:** Validation, Writing – review and editing **Meghan Millea:** Writing – review and editing **Jamie Kruse:** Conceptualization **Farah Nibbs:** Resources, Writing – review and editing **Gina Hardy:** Resources, Writing – review and editing

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Factors Influencing Homeowners in the Process of Retrofit Decision-Making

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1

PAPM Framework

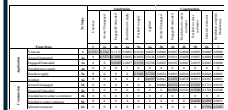
2

Data

Application
Survey
Policies
Claims

3

Markov model



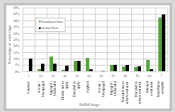
4

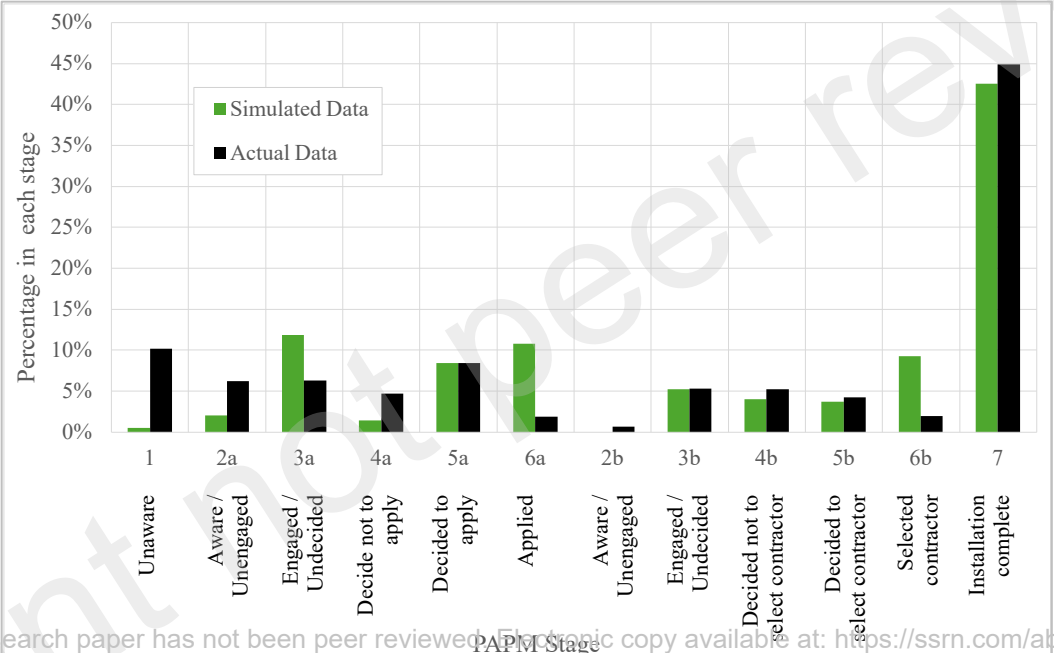
Simulation

Hazard ratios

$$HR_{ijk} = \frac{q_{ijk}}{q_{ijk}^{(0)}} = e^{\beta_{ijk}}$$

Assessment of Model Fit and Description of Full Process





PAPM Stage			Days
Application	*Unaware*	**1**	47.5
	Unengaged	**2a**	46.8
	Undecided	**3a**	82.4
	Decide Yes	**5a**	46.0
	Applied[1]	**6a**	62.1
Construction	*Unengaged*	**2b**	0.4
	Undecided	**3b**	35.6
	Decide Yes	**5b**	35.1
	Selected Contractor[1]	**6b**	104.7
			460.5

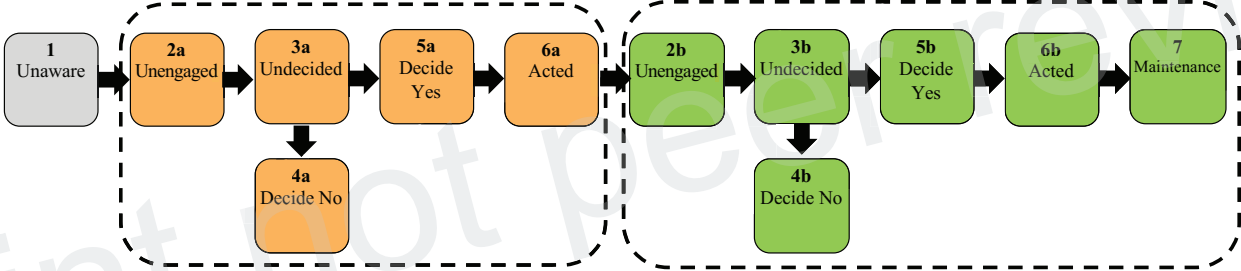
(a) **Example staging question** [*with the stage each answer corresponds to*]

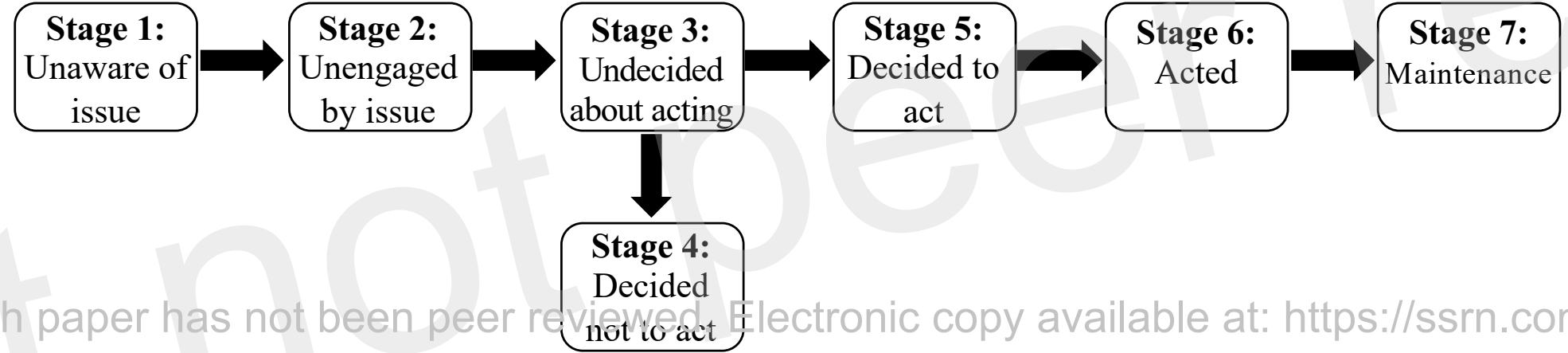
Which of the following best describes you?

a. I have never heard about the Strengthen Your Roof (SYR) Grant Program before receiving this survey. [*Stage 1, Unaware*]
b. I have never seriously considered applying to the Strengthen Your Roof (SYR) Grant Program. [*Stage 2a, Unengaged*]
c. I am considering applying to the Strengthen Your Roof (SYR) Grant Program, but I have not decided yet. [*Stage 3a, Undecided*]
d. I decided not to apply to the Strengthen Your Roof (SYR) Grant Program. [*Stage 4a, Decide no*]

(b) **Example retro-reporting question**

What is your best estimate of when you first actively considered applying to the SYR Grant Program? Please be as specific as you can. [*Year, Month, Day*]





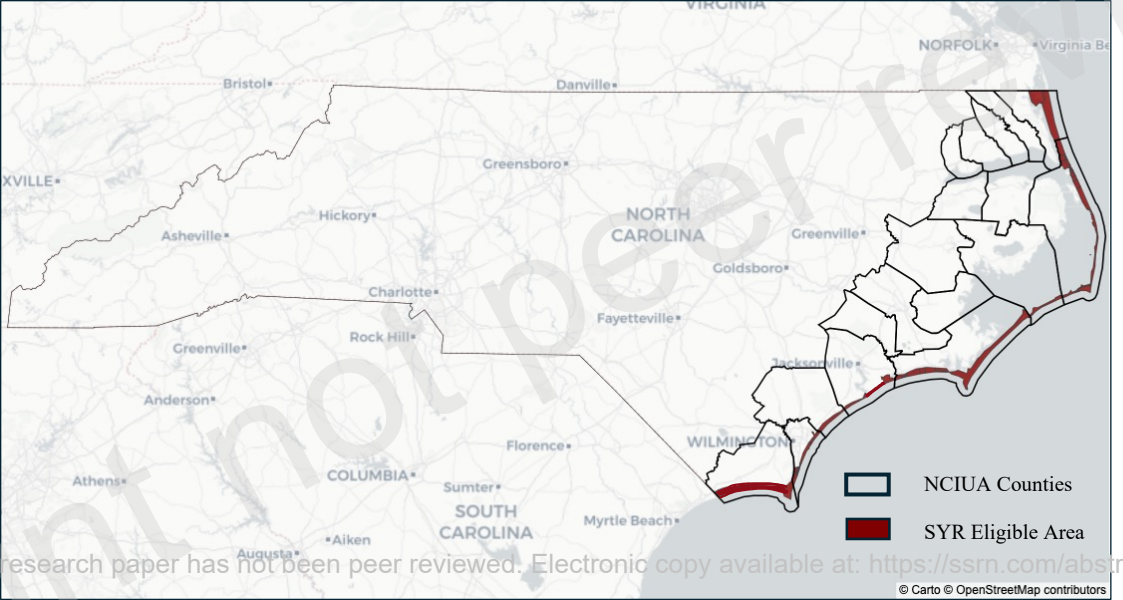


Figure 1: NCIUA and SYR Coverage Map
Map of the 18 coastal counties covered by NCIUA. The SYR program applies exclusively to properties located on the barrier islands.

Figure 2: Method overview

Figure 3: The Precaution Adoption Process Model (PAPM)

Figure 4: Application of PAPM to SYR Grant Program
Shows two PAPMs in series to represent the two decisions being made by homeowners participating in the SYR grant program.

Figure 5: **Example staging and retro-reporting survey questions**

Figure 6: **Mean Sojourn Times**
Average number of days homeowners spent in each transient stage of the SYR process

Figure 7: **Last PAPM Stage Observed of Each Policyholder**
Distribution of policyholders by the stage reached at the conclusion of the data collection period