Identifying the drivers of private flood precautionary measures in Ho Chi Minh City, Vietnam

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Abstract. Private flood precautionary measures have proven to reduce flood damage effectively. Integration of these measures into flood response systems can improve flood risk management in high risk areas such as Ho Chi Minh City (HCMC). Since uptake of such measures is voluntary, it is important to know what drives householders to implement precautionary measures. In this study, we developed a framework representing the uptake of private precautionary measures based on Protection Motivation Theory and Transtheoretical Model. Using empirical survey data collected from 1000 flood prone households in HCMC, we implemented lasso and elastic net regression to identify the drivers of private precaution. The measures were classified into structural measures and non-structural measures based on whether structural changes to the building were required. The households were classified into proactive and reactive households based on whether their decision to reduce risk (i.e., uptake precautionary measures) was preceded by experiencing flood. The data-driven model revealed that the household's level of education, the degree of belief in the government to implement regional flood protection measures and the degree of belief that in case of flooding, one has to deal with the consequences of flooding by themselves positively influence the proactive uptake of non-structural measures. Among the households that experienced flooding before implementing the measures, the uptake was found to be driven by the severity of the experienced damage. For the same group of households, perceiving high severity of future flood impacts was found to negatively influence the uptake of structural flood precautionary measures. These results highlight that efforts to improve the implementation of private precautionary measures should consider the socio-economic characteristics of the household, their past flood experience and their perception of flood risk management for communicating flood risk and incentivizing private precaution.

1 Introduction

Floods affect 54 million people and cause 58 billion EUR of damage globally per year (Alfieri et al., 2017). Flood damage are predicted to rise further due to socio-economic and climate change (Botzen et al., 2019a). Ho Chi Minh City, Vietnam is one of the cities most exposed to flood risk under current socio-economic conditions (Hallegatte et al., 2013). During the rainy season, a combination of high tide, heavy rains, high flow volume in the Saigon and Dong Nai Rivers result in regular flooding in several parts of the Ho Chi Minh City (Woetzel et al., 2020). The flood risk is increasing due to an increasing trend of precipitation events due to climate change, ongoing urbanization, increasing population and infrastructure density and land subsidence (Duffy et al., 2020; Khoi and Trang, 2016; Phi, 2007; Woetzel et al., 2020).

Reducing flood risk has become a necessity which has led to high investments by the government in extensive flood defence systems (Cao et al., 2021). Based on the design specifications, there is a possibility that conventional large-scale flood protection infrastructure may fail due to rising flood hazard levels. The growing city also poses a challenge to implement regional measures as new settlements rapidly develop. Hence, a transition to integrated flood risk management strategies is imperative (Botzen et al., 2019a; Nguyen et al., 2021). This means, complementing large-scale protection structures with small scale private precautionary measures (Du et al., 2020; Scussolini et al., 2017; Yang et al., 2018).

Private precautionary measures include elevating buildings, shielding with water barriers, waterproof sealing, fortification, flood adapted use, flood adapted interior fitting and safeguarding of hazardous substances (Chinh et al., 2016). Elevating and dry-proofing buildings in HCMC was found to reduce expected annual flood damages by 52-55% and 82% respectively (Scussolini et al., 2017). Another study conducted in Shanghai by Du et al. (2020) reported 69% reduction in expected annual flood damages from wet-proofing. Despite evidence demonstrating the loss-reducing potential of private precautionary measures, their implementation is commonly voluntary and hardly any official funding is provided (Barendrecht et al., 2020; Chinh et al., 2016; Garschagen, 2015). Past studies have indicated that households are often not willing to take the responsibility of implementing property-level precautionary measures (Bamberg et al., 2017; Barendrecht et al., 2020). At household level, certain indicators including education, income, household composition, occupation, social networks and place attachment were identified to influence protective actions (Ji et al., 2021; Okayo et al., 2015).

In order to bridge the knowledge gap in understanding the level of flood preparedness and uptake of private precautionary measures, several studies have applied Protection Motivation Theory (PMT) to identify the drivers that motivate households to uptake protective measures (Babcicky and Seebauer, 2019; Bubeck et al., 2018). In order to include a household's willingness to uptake measures, the PMT was complemented with a Transtheoretical Model (TTM) (Weyrich et al., 2020). TTM is a behavioural change model which emerged from clinical psychology and represents decision stages which indicate an individual's degree of readiness to act upon danger to protect themselves from a risk (Bočkarjova et al., 2009).

In this study, we develop empirical, data-driven analysis based on the combined PMT-TTM framework to understand what drives households in HCMC, Vietnam to uptake private precautionary measures.

The paper is organized as follows – section 2 explains Data and Methods, in specific, the empirical household survey data used in the study (2.1), the PMT-TTM theoretical model (2.2) and the statistical analysis (2.3); section 3 presents and discusses the results, including, the prevalence and cost of the different measures (3.1) and drivers of precautionary measures (3.2); section 4 concludes the paper.

2 Data and methods

2.1 Household Survey

The empirical data used in the study was obtained from a structured household survey in selected districts of HCMC during September - October 2020. A total of 8 wards in 4 districts were surveyed which includes Binh Thanh, District 8, Binh Tan, and Nha Be as presented in Figure 1.

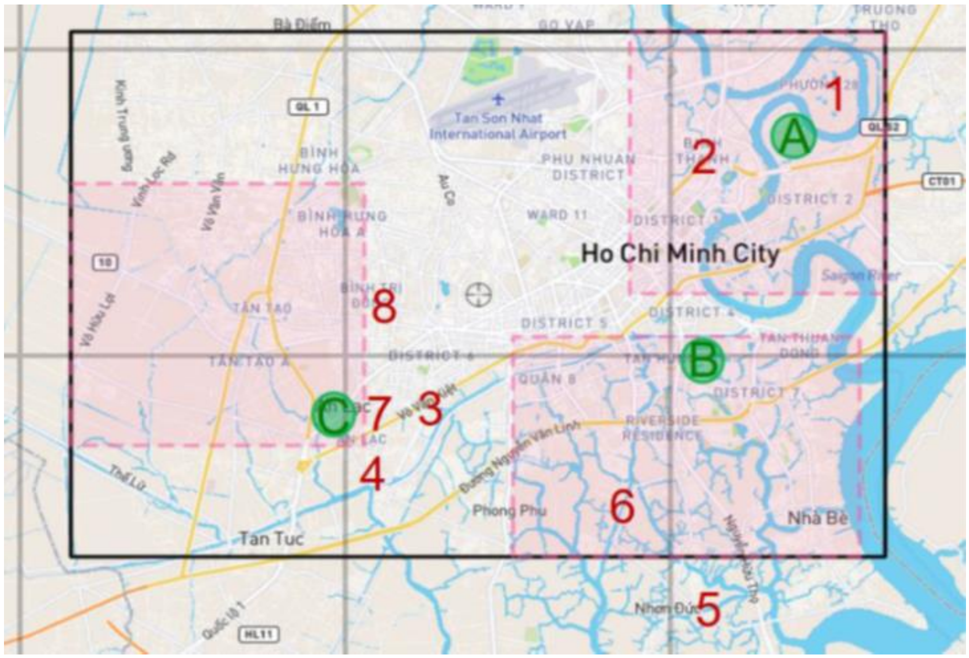

Figure 1: Survey areas (n=8) in Ho Chi Minh City. Red numbers are the sites of the main survey in 2020 and green letters are areas of the pre-test survey in December 2019 (Yang et al., 2020).

The survey collected 1000 valid responses from local households which suffered from floods in the last 10 years. The questions were drafted based on expert knowledge from flood risk researchers, social scientists and local stakeholders in HCMC. The survey areas (Binh Thanh, District 8, Binh Tan, and Nha Be) were established in order to cover a broad range of socio-economic profiles and flood types such as tidal, fluvial, pluvial and compound flooding in the city. Within the survey areas, the households were chosen in random. A survey pre-test involving 60 households from three districts (Binh Tan, District 7 and District 2) was conducted in December 2019 in order to test the validity of the questionnaire. The questionnaire was revised, based on the responses from the pre-test. The questionnaire covered aspects concerning two past flood events experienced by the households - the most recent and the most serious event in the last 10 years. The questions pertained to the hazard and damages suffered by the households, implementation of precautionary measures, early warning quality and lead time, household's risk perception and socio-economic profile. In order to maintain consistency, this study uses responses only from the main survey.

2.2 Theoretical framework

The PMT-TTM (Protection Motivation Theory - Transtheoretical Model) framework is used to conceptualize the cognitive processes driving the uptake of private precaution considering the different risk reducing decision stages. PMT was first proposed by Rogers W. (1983) to explain the effect of fear appeals on health-related behavior in health psychology. Gradually, its application was extended to research in natural and environmental hazards, such as droughts, earthquakes, volcanic hazards, tornadoes, wildfires and flood risks (Babcicky and Seebauer, 2019). PMT comprises two cognitive processes - threat appraisal and coping appraisal, which determine the changes in an individual's coping intentions. Threat appraisal is described as a person's assessment of a threat's damaging potential to valuables, assuming no personal change in behaviour; Coping appraisal is described as the person's evaluation of their ability to cope with or avert the threat (Grothmann and Reusswig, 2006). In this study, threat appraisal is represented by how the households perceive current and potential future flood risk; coping appraisal is represented by how able the households feel about resisting the impacts of flooding. PMT is extended to include a household's socio-economic and building characteristics, past flood experiences and perception of dependency on government protection measures.

The TTM focuses on individual's decision-making and what changes the behaviour leading to changes in decision-making stage. The conventional ordered decision stages are pre-contemplation, contemplation and action stages (Block and Keller, 1998; Poussin et al., 2014). In the context of flood preparedness, a TTM represents the households' decision stages – i.e. degree of readiness to implement private precaution to protect themselves from flood impacts. Based on their characteristics, the households with protective behaviour may be categorized into proactive (voluntarily implement risk reduction measures), reactive (implement risk reduction measures as a reaction to experiencing a serious flood event) with respect to specific measures. The combined PMT-TTM has the capability to identify the factors that motivate households to uptake private precaution and the factors that help in changing the decision stages of households (e.g. reactive to proactive households). The PMT-TTM (Protection Motivation Theory - Transtheoretical Model) was first introduced by Block and Keller (1998). For instance, Weyrich et al. (2020) developed different risk reduction stages to focus on the quality of protective behaviour while Bočkarjova et al. (2009) implemented intention stages to understand the risk reducing behavioural intention.

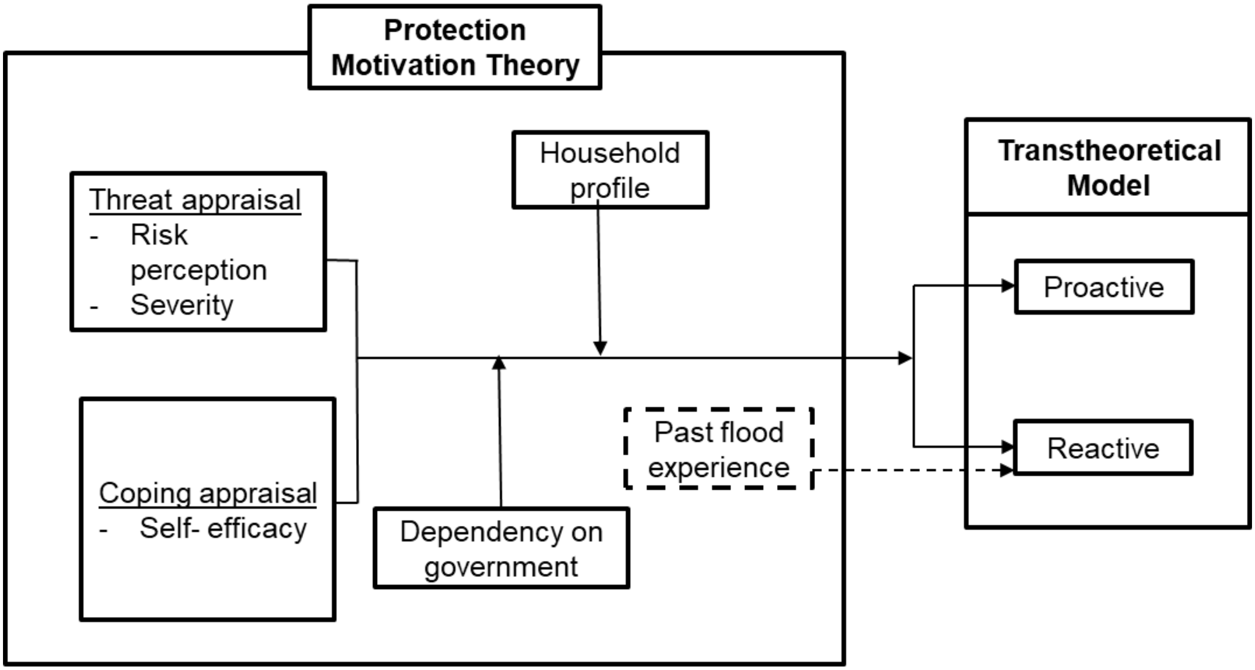

Figure 2: Protection Motivation Theory and Transtheoretical model (PMT-TTM) framework consisting of PMT and TTM blocks, Past flood experience is represented as dashed-lines since it differentiates the reactive households from proactive households.

In this study, the framework aims to identify drivers influencing the uptake of flood precautionary measures among households. In this context, we conceptualized two risk reducing stages, namely, the proactive stage and reactive stage. Households in proactive stage are those who voluntarily participate in risk reduction measures even before experiencing a serious flood event since 2010, i.e. in the last 10 years from the date of the survey. On the other hand, households from reactive stage undertake protective measures as a response to a serious flood event (Figure 2). The corresponding question and choices from the household survey is presented below.

Question: Which of the following precautionary measures (Table 1) have you implemented and when did you implement it:

[1] Before the serious event in the last 10 years

[2] Before the recent event

[3] Before both events (serious and recent)

[4] After both events

[5] Did not implement

In addition to the timeline of implementation, the survey also collects data on the cost of implementing the measure. The corresponding question is presented below.

Question: If you implemented the measure, how much did it cost to implement the measure? _______ million VND

Table 1: Categorisation of private flood precautionary measures into structural and non-structural measures

Measure	Description	Category
Elevate	Elevating the building ground floor or foundation to prevent the water from entering the building.	Structural measures
Install flood protection	Installation of flood protection systems for sealing doors, windows and basements.	
Wet proofing valuables	Protecting valuables and expensive contents such as electronics/computers by placing them at elevation above flood water level.	Non-structural measures
Water barriers	Purchasing water barriers to prevent the flood water from entering the house.	
Pumping equipment	Purchasing pumping equipment to pump out flood water.	
Water resistant material	Using water resistant material for the house, e.g., water resistant paint.	
Electricity control at higher level	Installing electricity control systems such as power supply boards and meter boards at higher elevation.	

PMT includes six aspects: (1) risk perception, (2) severity, (3) self-efficacy, (4) household profile, (5) dependency on government, and (6) past flood experiences (Figure 2). The survey responses that represent these aspects and potentially influence the uptake of precautionary measures were selected (see, Appendix A for the Questionnaire). Additionally, since TTM classifies the household based on their risk-reducing stage, households belonged to the TTM groups (proactive and reactive) based on when the measure was implemented. In addition to when the measure was implemented, the implementation cost of each measure is also recorded during the household survey. Each precautionary measure is categorized into the structural or non-structural measures (Table 1). Structural measures require making permanent changes to the construction of the building – e.g. elevate or installing flood protection. These measures have the potential to be included in building codes especially for new constructions. On the other hand, non-structural measures do not result in permanent changes to the building structure. The categorization into structural and non-structural measures help account for the permanence aspect of the measures in the study. For each precautionary measure category, if a household implemented any one of the measures before the serious event [1] or before both events [3], the household is grouped into the proactive risk reducing stage. If a household implemented any one of the measures before the recent event [2] or after both the events [4], the household is grouped into the reactive risk reducing stage. Therefore, a household that belongs to the proactive risk reducing stage for structural measure category can belong to the reactive risk reducing stage with respect to non-structural measure category. From these two levels of classification, risk reducing stages and precautionary measure categories, four groups of households were formed as illustrated in Table 2.

Table 2: Household groups classified based on type of implemented precautionary measure (Structural and Non-Structural measures) and risk-reducing stages (proactive and reactive).

		Precautionary Measure Type	
		Structural	**Non-Structural**
Risk Reducing Stages	**Proactive**	Structural- Proactive (SP)	Non-Structural-Proactive (NSP)
	Reactive	Structural- Reactive (SR)	Non-Structural -Reactive (NSR)

2.3 Statistical Analysis

In order to identify the drivers influencing uptake of precautionary measures in each household group, responses from the questionnaire survey pertaining to the PMT-TTM framework (see, Appendix A) are considered as the explanatory variables and regressed against a binary indicator of uptake of measures (i.e. response variable) (see, section 2.2). In this respect, Lasso and elastic net regression models are applied. Since the response variables follow binomial distribution, a logit regression is implemented. Lasso regression determines the extent of influence by an explanatory variable on the response variable by imposing λ times L1 penalty on the residual sum of squares to compute the Lasso estimate as defined by Eq. (1) (Hastie et al., 2008):

$$\hat{\beta}^{lasso} = argmin\, \beta \left\{\frac{1}{2}\sum_{i=1}^{N}(y_i - \beta_0 - \sum_{j=1}^{p} x_{ij}\beta_j)^2 + \lambda \sum_{j=1}^{p} |\beta_j|\right\} \quad (1)$$

Here, x represents the explanatory variables, y is the response variables, β_0 is the intercept, β represents regression coefficients of explanatory variables, p is the number of input explanatory variables, and N is the number of observations or households interviewed (N=1000). L1 penalty is $\sum_{j=1}^{p} |\beta_j|$ while $\lambda \geq 0$ is a complexity parameter that controls the amount of regression coefficient shrinkage and is determined by cross validation. Larger the value of λ, greater is the shrinkage (Hastie et al., 2008). Lasso regression performs variable selection while maintaining the stability by imposing a penalty on the size of regression coefficients (Tibshirani, 1996) and shrinking it towards zero when there is low correlation between explanatory variable and response variable. The nature of this constraint tends to produce some coefficients that are exactly equal to zero and eliminates the explanatory variables corresponding to these coefficients (Tibshirani, 1996). However, when a number of explanatory variables (p) is greater than the number of observations (N), only N variables are selected before Lasso saturates and when a group of variables have high pairwise correlation, then lasso randomly selects one variable from the group. The naïve elastic net regression as illustrated in Eq. (2) overcame this limitation (Zou and Hastie, 2005).

$$\hat{\beta}^{naive\ elastic\ net} = argmin\ \beta \left\{\sum_{i=1}^{N}(y_i - \beta_0 - \sum_{j=1}^{p} x_{ij}\beta_j)^2 + \lambda_2 \sum_{j=1}^{p} \beta_j^2 + \lambda_1 \sum_{j=1}^{p} |\beta_j|\right\} \quad (2)$$

Where, $\alpha = \frac{\lambda_2}{\lambda_1+\lambda_2}$

It possesses the characteristic of the L1 penalty term, $\sum_{j=1}^{p} |\beta_j|$ (lasso regression), and the L2 penalty term, $\sum_{j=1}^{p} \beta_j^2$ (ridge regression). It overcomes the limitation of lasso regression as L1 lasso penalty term performs automatic variable selection while L2 ridge penalty encourages grouped selection by shrinking together the coefficients of correlated explanatory variables (Hastie et al., 2008). Hyperparameter α estimates the contribution of L1 and L2 penalty by assigning a value between 0 and 1. However, Eq. (2) was unable to perform satisfactorily as its solution path incurred double-shrinkage and did not produce optimal variance-bias trade-off. Rescaling naive elastic net equation by $(1+\lambda_2)$ as shown in Eq. (3) automatically achieved optimality and is known as elastic net regression (Zou and Hastie, 2005).

$$\hat{\beta}^{\ elastic\ net} = (1+\lambda_2)\ \hat{\beta}^{\ naive\ elastic\ net} \quad (3)$$

Cross-validation is applied to these models to prevent over-fitting. In this study, 10-fold cross-validation is implemented to the available dataset by partitioning 10 disjoint subsets of approximately equal size by randomly sampling data from the dataset without replacement. The model is trained using 9 subsets and validated with the remaining 1 subset. This procedure is repeated until each of the 10 subsets has served as a validation subset. The average of their performance metrics is the model performance. Thereafter, the deviance metric is used to measure the performance of lasso and elastic net regression models. Deviance measures the goodness-of-fit based on the difference of likelihood between a fitted model and a saturated model ($\hat{\beta}$). The likelihood of a saturated model is 1, as the number of estimated parameters is equal to the number of data points. Deviance ranges from 0 to infinity, where lower deviance value indicates the model has a better data fit. The formula of deviance (D) is as presented in Eq. (4).

$$D = -2log\ lik\ (\hat{\beta}) \quad (4)$$

The lasso and Elastic-Net regression models are applied to empirical data pertaining to the four household groups - Structural-Proactive (SP), Non-Structural-Proactive (NSP), Structural-Reactive (SR), and Non-Structural-Reactive (NSR). For each household group, the absolute variable coefficient values associated with the lowest deviance value are derived from lasso and elastic-net regression. Thereafter, weighted median is computed from normalized variable coefficients where the reciprocal of deviance acts as weights. Since the explanatory variables used in the model correspond to the aspects of the PMT-TTM framework, the variable importance based on a weighted median value greater than 0.5 are considered to drive the uptake of precautionary measures in the household groups.

3 Results and discussion

3.1 Implementation of private precautionary measures

In this section, an overview of how many households have implemented specific precautionary measures and the cost of implementation of the measures are presented. The measure ‘Elevate’, i.e. elevating the building ground floor was implemented the most (Figure 3). Despite the average cost of elevating a building being 78 million VND which is much higher than implementation costs of all other precautionary measures (Figure 4). 54.2% of the households (n=542) have reactively undertaken this measure (i.e., implementation after experiencing the serious event in the last 10 years and before the recent event or implementation after experiencing the serious and the recent flood event) and 25.5% (n=255) have adopted it proactively (i.e., implementation before experiencing the serious event in the last 10 years or implementation before experiencing both the serious and the recent events). The second most often implemented measure is purchasing ‘Mobile barriers’ which is closely followed by ‘Wet proofing valuables’ (i.e. Protecting valuables and expensive contents by placing them at elevation above flood water level), with implementation prevalence of 47.7% (n=477) and 46% (n=460), respectively. Furthermore, 33.3% (n=333) of the households have bought pumping equipment to pump out flood water and 26.2% (n=262) have installed electricity control at higher level. Only 7.7% (n=77) of the households used water resistant materials. The average cost of purchasing pumping equipment and mobile barriers were 3.2 and 1.4 million VND, respectively. Average costs of wet proofing valuables, installing electricity control at higher level and installation of flood protection systems were the least amounting to 0.5, 0.6 and 0.9 million VND, respectively. Despite the relatively low implementation cost of installing flood protection (sealing windows, doors), this measure has the lowest implementation prevalence of 3.3% (n=33).

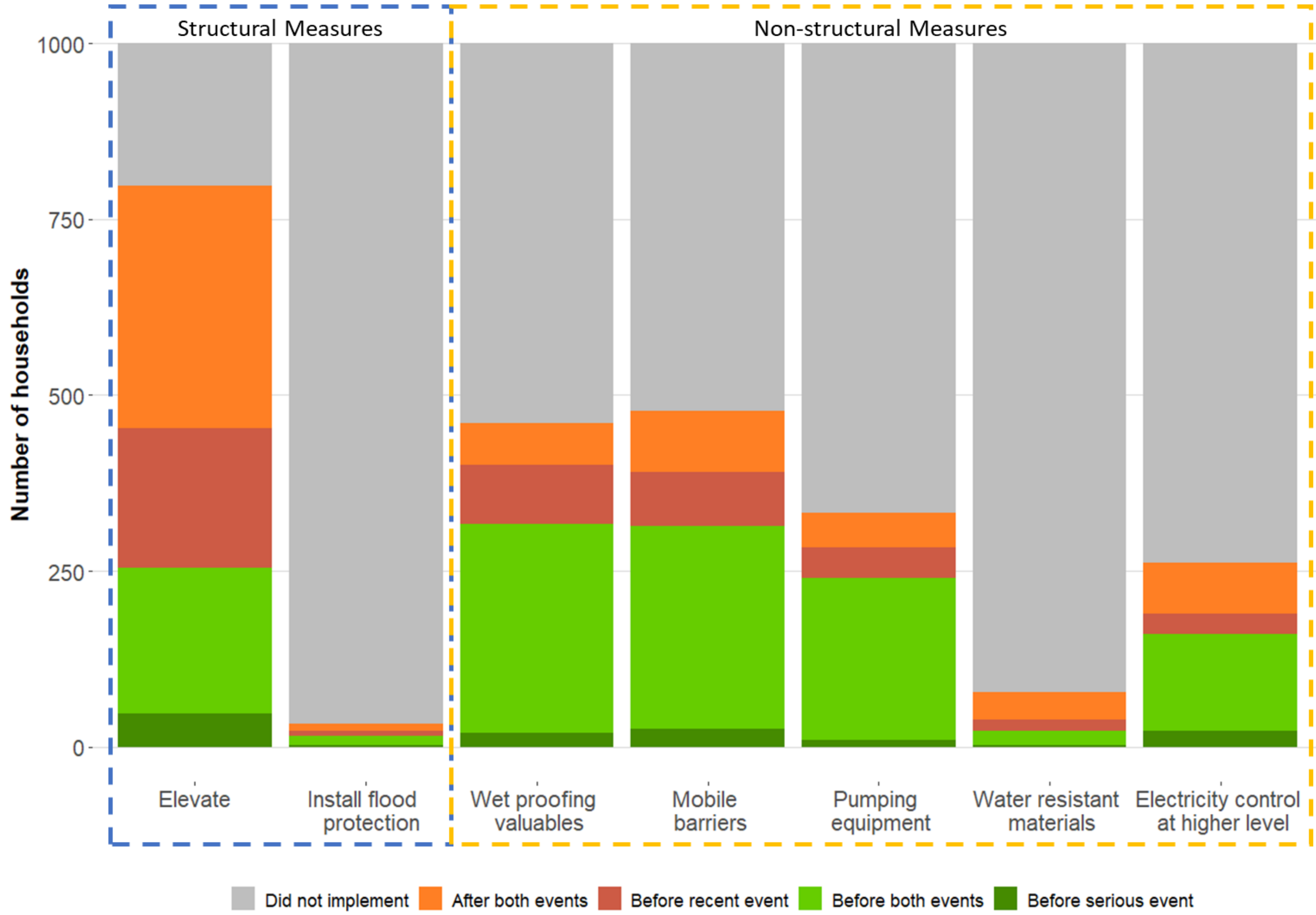

Figure 3: Number of households that implemented structural and non-structural private precautionary measures with respect to the temporal precedence considering the most serious event in the last 10 years and the most recent event. The yellow dashed-line box encloses non-structural measures and the blue dashed-line box encloses structural measures. The shades of green – "Before both events" and "Before serious event" indicate proactive households; the shades of orange – "After both events" and "Before recent event" indicate reactive households.

Among the precautionary measures, the elevation of the building has a special position. Despite the high cost of elevating the house, this measure which prevents the floodwater from reaching the living area, is very popular in HCMC and helps to live with floods. The process to elevate can be done to the entire building or only a new elevated ground floor can be constructed within the building (FEMA, 2007; Garschagen, 2014). Hence, houses are often built elevated or are elevated during renovations, which is frequently done by households in HCMC. It might be decisive that the building codes have been subscribing a minimum elevation of buildings in Vietnam since 2008 (Garschagen, 2014) and discouraged the implementation of only wet-proofing measures. Most respondents have structurally elevated their houses after experiencing flood events (Figure 3), which occur frequently almost during every rainy season in HCMC.

3.2 Drivers of private precautionary measures

The most important drivers of private precaution for the different household groups are identified, based on a list of potential influencing variables representing the aspects of the PMT-TTM framework (Appendix A).

Table 3: Most important variables influencing implementation of precautionary measures (Importance: 0 - no importance; 1 - high importance, Coefficients: positive - encourages uptake of measures; negative - discourages uptake of measures, all the models resulted in a deviance of approximately 1.3.

Household group	Variable name (importance > 0.5)	Variable description	Coefficients		
			lasso	elastic net	Average
Structural Reactive households	House damage (1)	Level of house damage experienced due to previous flood events.	1.16	1.02	1.09
	House impact (0.83)	Degree of belief one's house will be more severely affected due to floods in the future.	-0.97	-0.85	-0.91
Non- Structural Proactive households	Government protection (1)	Degree of belief the government will implement effective flood protection measures.	0.40	0.40	0.40
	Education (0.97)	Level of education attained within a household	0.34	0.38	0.36
	No help (0.75)	Degree of belief one has to deal with the consequences of flooding by oneself.	0.24	0.29	0.26
Non-structural Reactive households	House damage (1)	Level of house damage experienced due to previous flood events.	0.37	0.26	0.31
	Flood frequency (0.89)	Number of previous flood events experienced since 2010.	0.36	0.23	0.29

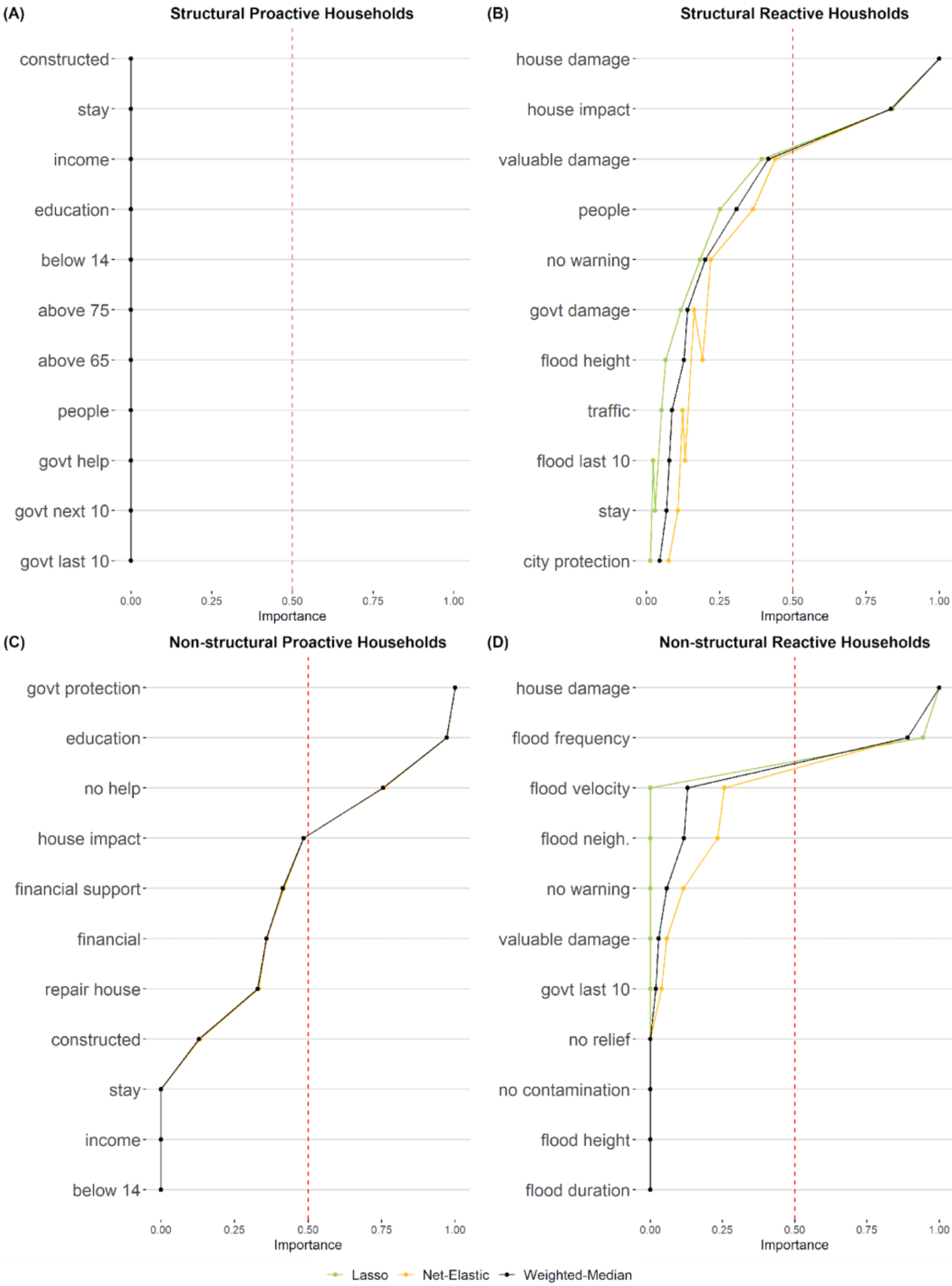

Figure 4: Drivers of private precautionary measures for (A) structural proactive households; (B) structural reactive households; (C) non-structural proactive households; and (D) non-structural reactive households (Variables on the y-axis correspond to variable names in Appendix A).

In the case of the Structural-Reactive household group, the variables, 'house damage' and 'house impact' are identified as the most important influencing variables with importance values of 1 and 0.83, respectively (Figure 4(b), Table 3). Average coefficient value of 'House damage' computed from lasso and elastic net regression is 1.09, which implies that experiencing high levels of damage in the past flood events, increases the probability of the household adopting structural precautionary measures. On the other hand, 'House impact' variable with an average coefficient value of -0.91 (note the negative coefficient) indicates that households which strongly believe that their house will be more severely affected by flooding in the future are less likely to adopt structural precautionary measures. The 'House impact' variable relates to the severity factor of threat appraisal (Appendix A). This is in accordance with results of several previous studies which have found that perceived increase of severe flood damage in the future causes a sense of helplessness and incapacity to adapt further, thus, discouraging the implementation of structural measures (Babcicky and Seebauer, 2019; Gebrehiwot and van der Veen, 2015; Grothmann and Reusswig, 2006).

The variables, 'Government protection', 'Education' and 'No help' are identified to be important for the Non-Structural-Proactive household group with importance values of 1, 0.97 and 0.75, respectively (Figure 4(c), Table 3). Their corresponding regression coefficient values (average) are 0.40, 0.36 and 0.26, respectively. Households with high belief in 'Government protection' (i.e. government will establish effective flood protection measures) are motivated to adopt non-structural measures proactively. These households trust the flood protection measures implemented by the government and also undertake action for protecting their property in case of flooding. Trust in government's flood risk management has been also found to be a driver for protective behavioural intention in the Netherlands (Bočkarjova et al., 2009) and for uptake of structural measures in New York city, US (Botzen et al., 2019b). 'Education' was found to be the next important driver indicating that households with higher levels of education are more likely to proactively uptake non-structural measures, which require the householders to understand flood risk and choose appropriate precautionary measures. It has been shown before that the level of education impacts householder's ability to understand flood risk and capture flood forecasting information (Paul and Hossain, 2013). 'No help' is the third important variable which represents the belief of the households that they have to solely cope with the consequences of a flood event. The households that recognize their responsibility to deal with flood impacts and have high belief in their abilities to protect themselves often proactively uptake private precaution (Botzen et al. 2019b; Gebrehiwot and van der Veen, 2015).

The uptake of Non-Structural measures in the reactive household group is driven by 'House damage' and 'Flood frequency' with importance values of 1 and 0.89, respectively (Figure 4(d), Table 3). Average regression coefficient of 'House damage' is 0.31 and of 'Flood frequency' is 0.29. Similar to the Structural-Reactive households, 'House damage' (i.e. high damage levels experienced from previous flood events) also drives the decision of implementing non-structural measures. 'Flood frequency' indicates the number of flood events experienced in the last 10 years. Households who experienced a large number of flood events show high uptake of non-structural precautionary measures. These findings reassure that experiencing flooding and damage due to flooding encourage protective behaviour among households (Ansari, 2018; Bočkarjova et al., 2009).

A limitation of the analysis is that, the structural proactive household group did not reveal any significant influencing variable (Figure 4a). One potential reason is that many proactive households that have implemented structural measures would have often implemented them while constructing the house or they might have also bought the house with the measure already implemented. In both these cases, we are not able to ascertain whether the householder made a conscious choice to implement the measure. The study is limited to the householder's independent decision stages based on the questionnaire survey. Hence, there are several external factors such as building code requirements by the government, influence by neighbourhood networks that are not considered in this study. This calls for a future research based on comprehensive participatory approach with institutional stakeholders and private householders to develop a systemic understanding of the external factors influencing the uptake of private precaution. The identified drivers of private precaution in proactive households can be used to better motivate all the households exposed to flooding to uptake of private precaution. For example, risk communication could focus on the measures undertaken by the government to improve flood protection enhancing the trust in government; information and guidance on the responsibility of households to protect themselves and deal with their flood damage should be provided; retrospectively, the self-efficacy of households that experienced flooding may be increased by providing them with information on the effectiveness of private precaution and incentivizing the uptake.

4 Conclusion

A Protection Motivation Theory - Trans Theoretical Model (PMT-TTM) framework was used to analyse empirical data from a household survey consisting of 1000 households in order to identify the drivers of private precaution in HCMC, Vietnam. The analysis shows that factors which positively influence the uptake of private precaution in proactive groups are level of education, belief that the government takes actions to reduce flood risk and being aware one has to deal with the consequences of flooding by themselves. Further, the perceived increase of severe flood damage in the future discouraged the reactive implementation of structural measures. A limitation of the study is that no influencing drivers could be identified for undertaking structural precautionary measures proactively. This is attributed to the strong possibility that proactive elevation means that the buildings are built elevated and not a result of decision-making from the householder to structurally alter the building as a precautionary measure. This calls for a participatory research approach to account for external drivers and feedback processes influencing private precaution which are outside the scope of a structured questionnaire survey. Based on the results of this study, we recommend that, all households (especially the ones with low levels of education), should be made aware of the future risk, protection measures by the government and also their individual responsibility to protect their houses. Risk communication and awareness campaigns covering these aspects has the potential to motivate the households to proactively implement precautionary measures.

5 Appendix A

This section presents the questions and their corresponding responses from the household survey corresponding to the Protection Motivation Theory (PMT) framework (see, Figure 2).

Aspect from PMT	Variable name	Question	Data type	Responses
Risk Perception	Flood last 10	Did the flood change during the last 10 years?	Ordinal	1. Much increased 2. Increased 3. No change 4. Decreased 5. Much decreased
	Flood next 10	Do you expect changes of flood in the next 10 years?	Ordinal	1. Much increased 2. Increased 3. No change 4. Decreased 5. Much decreased
	Economic loss	How likely would you have economic losses?	Ordinal	Scale (1-5) 1: Unlikely 5: extremely likely
Severity	Traffic	Would traffic and road system be collapsed in your living/working area?	Ordinal	Scale (1-5) 1: Unlikely 5: extremely likely
	House impact	My house will be more severely affected by floods in future	Ordinal	Scale (1-5) 1: strongly disagree 5: Strongly agree
	Financial	Would you face a serious financial problem or even bankrupt?	Ordinal	Scale (1-5) 1: Unlikely 5: extremely likely
	Health	Would you or your family members be suffering health impacts?	Ordinal	Scale (1-5) 1: Unlikely 5: extremely likely
Self-Efficacy	House economy future	What do you expect for your household economy in next 10 years for dealing with flooding?	Ordinal	1: Richer (e.g. for preparing and repairing your house) 2: Poorer 3: Same
	Change livelihood	How likely would you change your livelihood to another way of earning income?	Ordinal	Scale (1-5) 1: Unlikely 5: extremely likely
	Resist flood	Could your residential or shop house resist in such extreme flood scenario?	Ordinal	Scale (1-5) 1: Unlikely 5: extremely likely

	Repair house	Would you like to fortify and repair your houses?	Ordinal	Scale (1-5) 1: Unlikely 5: extremely likely
	Relocate	Would you move away (relocate residential)?	Ordinal	Scale (1-5) 1: Unlikely 5: extremely likely
	Financial support	Could you get financial support from any person or organizations?	Ordinal	Scale (1-5) 1: Unlikely 5: extremely likely
Household Profile	People	How many people are living in your household?	Discrete	-
	Above 65	Out of these, how many are 65 years and older?	Discrete	-
	Above 75	How many are 75 years and older?	Discrete	-
	Below 14	How many are 0-14 years old?	Discrete	-
	Education	Which is the highest educational attainment in your household?	Ordinal	1. No member never went to school 2. primary school 3. secondary school 4. high school 5. university bachelor/Vocational training 6. master 7. PhD or higher
	Income	How high is the available income per month (million VND)?	Ordinal	1: less than 1m 2: 1m – 5m 3: 5m – 10m 4: 10m – 20m 5: 20m – 30m 6: 30m – 50m 7: 50m – 80m 8: 80m – 100m 9: >100m
	Stay	Since when have you been living in this location?	Discrete	-
	Constructed	When was the house constructed?	Discrete	-
Dependency on government	City protection	city provides a good protection against floods	Ordinal	Scale (1-5) 1: strongly disagree 5: Strongly agree

	Flood warning	Flood warnings by the local government officials are helpful	Ordinal	Scale (1-5) 1: strongly disagree 5: Strongly agree
	Government protection	The government will take care of good and effective flood protection measures.	Ordinal	Scale (1-5) 1: strongly disagree 5: Strongly agree
	Government damage	Flood risk and damage have been increasingly borne by government	Ordinal	Scale (1-5) 1: strongly disagree 5: Strongly agree
	No help	Households or shops/firms are left alone to taking care of flood	Ordinal	Scale (1-5) 1: strongly disagree 5: Strongly agree
	Flood neighbourhood	You are generally satisfied with the flood management in your neighbourhood	Ordinal	Scale (1-5) 1: strongly disagree 5: Strongly agree
	Government last 10	What was the change of government support in dealing with floods in the last 10 years?	Ordinal	1: Maintained 2: Reduced 3: Increased
	Government next 10	What do you think the local government will do to deal with floods in the next 10 years?	Ordinal	1: Maintained 2: Reduced 3: Increased
	Government help	Would you expect help from government?	Ordinal	Scale (1-5) 1: Unlikely 5: extremely likely
Past flood experience	Flood frequency	How many times have you been flooded since 2010 (i.e., flood water entering your house)?	Ordinal	1: 1-5 (less than once a year) 2: 6-10 (about once a year) 3: 11-20 (1-2 times a year) 4: 21-50 (2-5 times a year) 5: 51-100 (5-10 time a year) 6: over 100 (more than 10 time a year)
	Flood duration	Duration of inundation at the house (hours)	Continuous	-
	Flood height	Highest water point from your ground floor (cm)	Continuous	-

	No contamination	The flood water contained the following contaminants	Binary	1: No contamination 0: Contamination
	Flood velocity	flow velocity on the road/street	Ordinal	1: calm 5: torrential
	No warning	Type of warning	Binary	1: Did not receive warning 0: Received Warning
	House damage	What was the damage to your house/business building because of the flood?	Ordinal	1: No damage; 2: Minor damages - Usable; 3: Moderate damages; 4: Major damages – needs repair; 5: Complete damage – needs replacement,
	Valuable damage	In the residential part of your house, what furniture, appliances, other contents were damaged and how much were the values?	Ordinal	1: No damage; 2: Minor damages - Usable; 3: Moderate damages; 4: Major damages – needs repair; 5: Complete damage – needs replacement,
	No relief	What kind of relief helps did you receive in the flood emergency?	Binary	1: Did not receive relief 0: Received Relief

6 Code availability

The code used for our analysis can be provided upon request.

7 Author contributions

Conceptualization/Research Design: T.V., N.S., H.K., M.G.; Data Analysis and model development: T.V., N.S.; Visualization: T.V.; Interpretation of results: T.V., N.S., H.K., L.E.Y; Writing - Original Draft: T.V.; Writing - review & editing: T.V., N.S., H.K. M.G. and L.E.Y; Supervision: N.S., H.K.

8 Competing interests

The authors have no competing interests to declare.

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