Are Private Defensive Expenditures against Storm Damages Affected by Public Programs and Natural Barriers? Evidence from the Coastal Areas of Bangladesh

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Abstract

This paper introduces a household model of private investment in storm protection under an endogenous risk framework to determine how *ex-ante* self-protection and *ex-post* self-insurance spending by coastal households to mitigate storm-inflicted damages are affected by the availability of public programs and the presence of a mangrove forest. The theoretical results show that ex-ante publicly constructed physical barriers and mangroves are complements to self-protection but substitutes to self-insurance. However, ex-post public disaster relief and rehabilitation programs are substitutes to self-protection but complements to self-insurance. Our empirical analysis of coastal households in Bangladesh impacted by Cyclone Sidr reveals partial support for crowding out and crowding in effects of public investments and programs. Households located in a mangrove protected area invest more in self-protection and less in self-insurance. Other controls, such as household socioeconomic characteristics, also influence and add a degree of complexity to the relationship.

Key words: self-protection; self-insurance; Cyclone Sidr; mangroves; Bangladesh

JEL Classifications: D81, Q51, Q54.

1. Introduction

Coastal areas with high population densities and widespread poverty are experiencing more damage as a result of cyclones and storm surges (IPCC, 2007; World Bank, 2010). For example, one of the more exposed areas is coastal Bangladesh, due to its unique geographical and geomorphological characteristics that makes it susceptible to frequent and severe storms (IPCC, 2007; Karim and Mimura, 2008, Dasgupta et al. 2009). In such an unfavorable environment, it is becoming increasingly difficult for the government to support enough public initiatives to properly protect the vulnerable coastal communities (World Bank, 2010). Poor households in these areas are forced to undertake private defensive strategies to insulate themselves against the risk of damages from coastal storms. However, these private behavioral responses are likely to be influenced by four factors: (1) the household's expectation of natural disaster damages; (2) whether the household is protected *ex-ante* (i.e. before the disaster) by any publicly constructed protective barriers and embankments; (3) the household's awareness that *ex-post* public disaster relief and rehabilitation programs are likely to be implemented; and (4) the presence of any "natural barriers", such as a mangrove forest, to protect life and property. The purpose of the following paper is to explore how these four factors influence the private defensive strategies of poor coastal households threatened by the risk of storm damages to their property.

Individuals have the tendency to place a low probability on a future natural disaster occurring, even if it is considered to have a high negative consequence (Kahneman & Tversky, 1984; Camerer and Kunreuther, 1989; Kunreuther et al., 2001). Such lack of concern about impending natural disasters might inhibit investment in risk reduction strategies (Brechin, 2003; Norgaard, 2009; Grothman and Reuswigg, 2006). In addition, individuals tend not to insure themselves against natural disaster risks when they believe help will be available from outside sources, either via public-sponsored programs or private charities (Browne and Hoyt, 2000; Lewis and Nickerson, 1989; Kunreuther and Pauly, 2006). In the disaster insurance literature, this phenomenon is referred to as "charity hazard" (Browne and Hoyt, 2000; Raschky and Weck-Hannemann, 2007). In this paper, we refer to the similar tendency as the *crowding out effect*, if a household partially or fully reduces defensive expenditures because it is better protected by publicly constructed dams and embankments that are implemented before a storm event or it is aware of likely rise in government spending on disaster relief or coastal rehabilitation programs after a storm occurs. Conversely, if a household increases defensive expenditures due to public programs, then this phenomenon is referred as a *crowding in effect*.

In addition, the private defensive strategies of poor coastal households may be influenced by the presence of mangroves and other "natural barriers" to storms. Various studies show that mangroves are effective in protecting life and property in coastal areas due to their ability to attenuate the waves caused by storm surges (Alongi, 2008; Barbier et al., 2008; Das and Vincent 2009; Koch et al., 2009; Wolanski, 2007). As a result, households living in close proximity to mangroves might undertake different defensive actions in response to the perceived threat of a storm compared to households without such "natural barrier" protection.

Given the possible influence of public programs and mangroves on private defensive strategies we explore two key issues in this paper. First, we examine whether public protection programs, such as ex-post public disaster relief and rehabilitation programs and ex-ante publicly constructed protective barriers, dams, and embankments, lead to less defensive expenditures by the household. Second, we determine whether or not the household in close proximity to a mangrove forest also results in less defensive expenditures to mitigate storm damages.

In order to examine these issues, we classify a household's defensive expenditures into two categories: (1) *self-protection expenditures* are actions that decrease the probability of a household incurring property damages from a storm event; thus, they are a form of *ex-ante* prevention; and, (2) *self-insurance expenditures*, a form of ex-post adaptation, are private investments in human, physical, and social capital by the households to reduce their losses in the event of storm-inflicted damages. For coastal households in Bangladesh, examples of self-protection include converting a mud-built house to brick, raising the height of the homestead, moving the house inside an embankment, taking refuge in a neighbor's house, and locating further away from the shoreline to a safer place. Examples of self-insurance include income source diversification, crop and plot diversification, private transfers in terms of remittances and charities, reciprocal gift exchanges, and inter-and intra-household income transfers based on insurance motives (or informal risk sharing). All these possibilities are directly or indirectly resulting from household private investments in human, physical, and social capital to reduce the severity or magnitude of damages to property as a result of a major storm event.

Since the self-protection and self-insurance actions can reduce the probability and severity of storm-inflicted damages, the storm surge risk becomes endogenous (Ehrlich and Becker 1972). We develop a household model of private investment in storm protection under an endogenous risk framework where the representative household chooses the level of self-protection and self-insurance against cyclone-induced storm surge damage. Although a similar framework has been employed to infer a household's value for health risk changes from pollution and other hazards (Agee & Crocker, 1996; Berger *et al.,* 1987; Bresnahan *et al.,* 1987; Harrington & Portney, 1987; Shogren & Crocker, 1992), our paper is the first to employ this approach in the context of a natural disaster risk faced by developing country households, and also to examine the possible influence of exogenous factors, such as public programs and a natural protection barrier. Our theoretical model indicates that the influence of public programs on private storm protection actions depend on whether they are implemented before any storm occurs or afterwards. The model also explicitly shows the possible influence of mangroves on private defensive strategies against storm risks. We also identify four types of corner-solution behavioral responses to reduce the likelihood and severity of facing monetary losses or damages to property from a major storm event. These corner solutions might arise because of a household's inability to afford private storm protection, which may be a realistic outcome for a poor household in a developing country. Finally, we examine these influences empirically with a case study based on a survey of 500 households in southwest coastal Bangladesh that were affected by Cyclone Sidr in November 2007.

The rest of the paper is organized as follows. Section 2 explains the household model of private investment on storm protection while Section 3 discusses the empirical and econometric estimations. Section 4 describes the process of data collection and offers a brief description of the study area. Section 5 reports the results and analyzes them. Section 6 outlines conclusions and policy recommendations.

2. The Household Model of Private Investment in Storm Protection

Assume that a representative rural household lives in a coastal area exposed to the threat of a severe cyclone-induced storm surge event that could inflict property loss. This storm surge risk has two characteristics: (1) the range of possible adverse consequences, and (2) the probability distribution across consequences. In this paper, we measure the adverse effects as monetary losses to property in terms of the damages to houses, trees, livestock and poultry, and agricultural crops. To keep the exposition simple, we assume that there is one adverse storm event. Since we are interested in the household's defensive actions when it is fully exposed to a storm surge event, we do not consider non-storm states.

We assume that a household's private spending on storm protection can influence its probability of experiencing property damage through self-protection, whereas the severity of any damages resulting from the storm surge is reduced through self-insurance. For the sake of simplicity, the model does not consider any health-related impacts, such as injury and loss of life as a result of the storm event.

The probability of damages to property fully exposed to a storm for representative household *i* located in village *j* is

$$\pi_{ij}(.) \equiv \pi_{ij}\left(Z_{ij}; G_{ij}, M_{ij}, C_{ij}\right) \tag{1}$$

where Z_{ij} is the level of self-protection expenditures that decrease the probability of facing ex-post property damages;[1] G_{ij} is the household's access to ex-ante public protection programs, such as disaster preparedness programs and publicly constructed embankments or dams that reduce the probability that the household incurs flooding damages; M_{ij} is a vector of characteristics capturing the role of mangroves as a natural storm protection barrier, such as the area of the nearby mangrove forest, distance between the mangrove forest and the household, directional location of the household relative to the coast and the mangroves, etc., and, lastly, C_{ij} is a vector of characteristics of a severe cyclone-induced storm surge, such as storm surge height and wind velocity, direction and distance of the cyclone path from the household location, etc.

When exposed to a storm, each household faces monetary losses. We can state this ex-post damage to property as

$$L_{ij} = L_{ij}(A_{ij}; R_{ij}) \tag{2}$$

where A_{ij} is the level of self-insurance expenditures that involve actions to reduce the severity of ex-post property damage, and R_{ij} is the household's access to ex-post public sponsored disaster relief and rehabilitation programs. We expect the severity or magnitude of the property losses to decrease if the household invests in self-insurance actions and enjoys accessibility to public-assistance programs designed specifically to reduce the severity of the event.

The household is assumed to maximize a *von Neumann-Morgenstern utility index* over wealth (consumption). Considering the two possible states of nature, let $U_{ij}^{L}(.) \equiv U_{ij}\left(W_1\right)$ denote the household utility when the household faces storm-inflicted monetary losses to property and $W_1 \equiv (I_{ij} - A_{ij} - Z_{ij} - L_{ij}(.))$ is the net wealth considering the property loss. In W_1, a household's full income is represented by I_{ij}, its level of self-protection expenditures by Z_{ij}, and its level of self-insurance expenditures by A_{ij}. On the other hand, let $U_{ij}^{NL}(.) \equiv U_{ij}(W_2)$ denote the household utility when it faces no storm damages and $W_2 \equiv (I_{ij} - A_{ij} - Z_{ij})$ is the net wealth. Since we are dealing with two possible states of nature as a result of full exposure to a major storm, we suggest that storm-inflicted damages lower household utility since a household's exposure to a damaging storm event lower its wealth (consumption) level. This could be interpreted as, $U_{ij}^{L}(.) < U_{ij}^{NL}(.)$. Furthermore, we assume that the utility functions are strictly increasing, concave, and twice continuously differentiable over wealth (consumption). Given these assumptions, the household maximization problem is[2]

$$\underset{Z,A}{Max}\, E(U) = \begin{bmatrix} \pi(Z;G,M,C)\cdot U((I-A-Z-L(A;R)) \\ +(1-\pi(Z;G,M,C))\cdot U((I-A-Z) \end{bmatrix}$$

$$\Rightarrow \left[\pi\left(Z;G,M,C\right)\cdot U(W_1) + (1-\pi(Z;G,M,C))\cdot U(W_2)\right] \tag{3}$$

Expression (3) says that expected utility, which is to be maximized, is the sum of the utilities of facing damages and no damages, weighted by their respective probabilities.

The first-order conditions with respect to the level of self-insurance and self-protection lead to

$$-\pi(.)\cdot U^{'}(W_1)\left[1+\frac{\partial L}{\partial A}\right] = U^{'}(W_2)\cdot\left[(1-\pi(.))\right] \quad (4)$$

$$-\frac{\partial \pi(.)}{\partial Z}\cdot\left[U(W_1)-U(W_2)\right] = \pi(.)\cdot U^{'}(W_1)+(1-\pi(.))\cdot U^{'}(W_2) \quad (5)$$

where $U^{'}(W_1)$ and $U^{'}(W_2)$ are the marginal utilities of wealth (consumption). Expression (4) reveals that a household could employ self-insurance to reduce the severity of storm surge damages up to the point where the expected marginal benefits of self-insurance, as defined by the net reduction in loss, equal expected marginal costs. Expression (5) indicates that a household could employ self-protection up to the point where the expected marginal benefits of self-protection, as defined by the decreased chance of storm damages weighted by the utility difference between the two states, equal expected marginal costs.

Appendix A shows the full solution to household's maximization problem based on equation (4). We analyze four types of behavioral responses from the household to reduce the likelihood and severity of facing storm-induced damages to property: (a) both self-protection and self-insurance, i.e. the interior solution of the above model; (b) self-protection only, i.e. a corner solution; (c) self-insurance only, i.e. a corner solution; and (d) no self-protection and self-insurance.

For the second-order sufficiency conditions associated with (3), the sign of the cross-partial derivatives with respect to self-protection and self-insurance expenditures cannot be determined even if the household is considered to be averse to storm risks. We show later in this paper how imposing additional restrictions in determining the signs of these cross-partial derivatives plays a significant role in determining the key comparative static results.

2.1 Comparative Static Analysis of Self-protection and Self-insurance

A household's choice of self-protection and self-insurance to reduce extensive storm-inflicted damage is influenced by its access to government protection programs as well as its proximity to mangroves. We examine these effects through comparative static analysis of the interior solution of the model. The full results are depicted in Appendix B, and they show that we cannot determine the directions of the relationships between a household's private defensive strategies and the public programs (both ex-ante and ex-post) unless we impose additional conditions on the model. Likewise, the relationship between a household's private defensive strategies and its proximity to mangroves remains ambiguous without additional conditions, which are also shown in Appendix B.

The results from the comparative static analysis reveal the following propositions.

PROPOSITION 1: For a risk-averse household, *ex-ante* government spending on public programs G leads to crowding-in of self-protection Z, i.e. $\frac{\partial Z}{\partial G} > 0$ but crowding-out of self-insurance A, i.e. $\frac{\partial A}{\partial G} < 0$. That is, public protection programs act as a complement to self-protection but as a substitute to self-insurance. The proof of Proposition 1 depends on Conditions 1 and 2 (derived in Appendix B), which are,

Condition 1. $H_{AZ} = H_{ZA} < 0$. That is, assuming self-protection and self-insurance to be stochastic substitutes.[3] This implies that the marginal utility of self-protection, Z, decreases if more self-insurance, A, activities are taken by the household and vice-versa.

Condition 2. $\frac{\partial^2 \pi(.)}{\partial G \partial Z} < 0$. This suggests that more ex-ante government programs, G, can accentuate the influence of self-protection, Z, in reducing the probability of facing storm-inflicted damages to property.

If either of these conditions is violated, then the signs of $\frac{\partial Z}{\partial G}$ and $\frac{\partial A}{\partial G}$ remain ambiguous.

Supporting evidence for Condition 2 abounds based on the contemporary literature on the relationship between public and private investment (Blejer and Khan, 1984; Greene and Villanueva, 1991; Erenburg, 1993; Ramirez, 1994, 2000; Oshikoya, 1994; Mitra, 2006). Findings by Erenburg (1993) reveal that public infrastructure capital has a stimulating effect on private investment in equipment and machinery. Using a panel data on developing economies for 1980 to 1997, Erden and Holcombe (2005) showed that a 10% increase in public investments lead to a

2% increase in private investments. Blejer and Khan (1984) for a panel of developing countries and Oshikoya (1994) for a panel of African countries presented evidence that public infrastructure investments has a positive impact on private investment. Kollamparambil and Nicolau (2011) study on South Africa found that public investment on infrastructure and social sectors is likely to enhance private investment; whereas, Hussain et al. (2004) detected positive influence of public development expenditures, such as infrastructure, health and education, on private investment based on annual time series data of Pakistan between 1975 and 2008. Mistra (2006) and Sterven (2004) also presented evidence of crowding-in over the long run and crowding-out over the short run following their research on India. However, all these findings do not convincingly show whether public expenditures that lower risks would also increase the return on private investments that lower the same risks, we consider the direction of the sign for an increase of an ex-ante government spending on the optimum levels of self-protection and self-insurance is an empirical question. For our research, we consider the positive influence of ex-ante government spending on public programs on infrastructures such as roads and embankments on private self-protection expenditures.

PROPOSITION 2: For a risk-averse household, it is not possible to determine the direction of the influence of ex-post public-assisted disaster relief and rehabilitation programs on ex-ante self-protection and self-insurance. However, for a risk-neutral household and with some additional restrictions, self-protection Z declines (i.e., becomes a substitute) but self-insurance A increases (i.e., becomes a complement) if households have more access to ex-post public-assisted disaster relief and rehabilitation programs R, i.e. $\frac{\partial Z}{\partial R} < 0$ and $\frac{\partial A}{\partial R} > 0$. The proof of Proposition 3 for a risk-neutral household depends on Conditions 3-5.

Condition 3. The probability of facing ex-post storm inflicted property damages, $\pi(.)$, is strictly quasi-convex with respect to self-protection expenditure, Z: $\frac{\partial \pi(.)}{\partial Z} < 0; \frac{\partial^2 \pi(.)}{\partial Z^2} > 0.$ This implies that the probability of facing monetary losses to property as a result of a cyclone induced storm surge decreases for a household if it invests more in self-protection expenditure.

Condition 4. A strict quasi-convex relationship exists between storm-inflicted monetary losses to property and self-insurance expenditures, $\frac{\partial L}{\partial A} < 0$; $\frac{\partial^2 L}{\partial A^2} > 0$. This means that monetary losses to property decrease as a household commits more self-insurance expenditure.

Condition 5. $\frac{\partial^2 L(.)}{\partial R \partial A} < 0$. Condition 5 states that more ex-post public-assisted disaster relief and rehabilitation programs, R, accentuate the effect of self-insurance in reducing monetary loss or damages to property as a result of a severe storm event.

Conditions 3 and 4 are self-explanatory. However, Condition 5 requires justifications and supporting evidence. Condition 5 proposes that access to more *ex-post* public disaster relief and rehabilitation programs can further accentuates the effectiveness of self-insurance in reducing storm-inflicted monetary loss or damages to property. Based on empirical findings on twelve (12) low-and middle-incomes countries that encountered economic crises and natural disasters, Skoufias (2003) highlighted some ex-post public strategies that can be more effective in protecting households from adverse aggregate shocks. Baez and Mason (2008) suggests how ex-post public complimentary policies through education, training, and critical information after a natural disaster event in Latin American countries can empower households with characteristics that enhance their capacity to diversify their income and crop portfolios. Following our theoretical model, these outcomes do assume that the household is risk neutral. The behavioral response of risk-averse households is much more difficult to discern. Hence, further understanding of the possible direction of the sign requires empirical analysis.

PROPOSITION 3: For a risk-averse household, the storm protection services of mangrove forests M increases the household's self-protection Z, i.e., $\frac{\partial Z}{\partial M} > 0$, but decreases self-insurance A, i.e. $\frac{\partial A}{\partial M} < 0$. That is, storm protection provided by mangroves acts as a complement to self-protection but as a substitute to self-insurance.

The proof and results of Proposition 3 rely on Condition 1 and Condition 6 in Appendix B.

Condition 6. $\frac{\partial^2 \pi(.)}{\partial M \partial Z} < 0$. This condition states that more storm protection from mangroves, M, accentuates the influence of self-protection, Z, in reducing the probability of facing damages to property conditional on the storm event.

One possible explanation for Condition 6 is the *ecological rationality* assumption which relies on how individuals develop adaptive behavior against positive or negative outcomes of an event by forming simple heuristics based on their past experiences, patterns of available information, or repeated exposure associated with that event (Smith, 2003; Todd and Gigerenzer, 2007). Using the ecological rationality assumption, one can argue that a poor coastal household might be forced to allocate more for self-protection to reduce their likelihood of facing storm-inflicted damages if there is uncertainty regarding whether mangroves can actually protect their properties against major storms. This could be further fuelled by the possibility of households protected by mangroves having lower expectations of receiving ex-post public-assistance programs, since they are presumed to cope better from major storms. However, such interpretations cannot be justified considering the theoretical setup of our model. The direction of the sign of the effect of more storm protection of mangroves on the optimum levels of self-protection is an empirical question. On the other hand, the negative relationship between increasing storm protection capacities of mangroves and private self-insurance among the mangroves-protected households is more reasonable.

Table 1 summarizes the comparative statics results with the accompanying conditions. An interesting pattern emerges from these results. Factors that are in place before a storm occurs, such as government protection programs and mangroves, are complements to self-protection expenditures by the household, whereas these exogenous influences are substitutes for self-insurance by the household. The latter effect implies that, if the household is receiving protection from mangroves and government spending programs, then it is less likely to have to allocate expenditures for *ex-post* reduction in losses incurred from a storm. Also, if the household is already protected by mangroves and public programs, it can enhance its welfare by using complementary self-protection measures to reduce the risk of storm damage even further. On the other hand, the increased availability of relief and rehabilitation programs implemented after the storm occurs reduces self-protection by the household but increases its self-insurance. If the household expects more post-disaster programs to be implemented, it is less likely to take *ex-ante* actions to reduce the probability of storm damage to its property. Interestingly, though, if more *ex-post* relief and rehabilitation is available, the household may allocate more expenditure to self-insure against damages. As disaster relief and rehabilitation programs are normally community-wide or district-level efforts, such public programs may also spur individual households to adopt their own measures to safeguard their income and property after the storm. This outcome does assume that the household is risk neutral, however. The behavioral response of, for example, risk-averse households is much more difficult to discern.

3. Empirical Analysis

Based on the above propositions on the possible influence of public programs and mangrove forests on a household's private self-protection and self-insurance decisions, we formulate four hypotheses to be tested empirically:

> $\mathbf{H_1}$: Expected storm-inflicted damage is an important determinant of a household's participation in and expenditures on private defensive strategies in terms of self-protection and self-insurance;
>
> $\mathbf{H_2}$: A household living inside *ex-ante* publicly constructed embankments invests more in self-protection and less in self-insurance activities against expected storm-inflicted damages;
>
> $\mathbf{H_3}$: The presence of *ex-post* public disaster relief and rehabilitation programs leads a household to invest less in self-protection and more in self-insurance activities against expected storm-inflicted damages;
>
> $\mathbf{H_4}$: A household living in close proximity to mangroves invests more in self-protection and less in self-insurance.

Hypothesis $\mathbf{H_1}$ underlies all three propositions, as it suggests that the expectation of facing future storm-inflicted damages would encourage a household to employ more private defensive actions. Hypotheses $\mathbf{H_2}$, $\mathbf{H_3}$ and $\mathbf{H_4}$ directly follow Propositions 1, 2 and 3 respectively. Hypothesis $\mathbf{H_1}$ is tested by estimating whether actual property damages have positive relationships with households' participation in self-protection and self-insurance. A positive relationship would confirm that storm-inflicted damage is an important determinant of a household's defensive choices. To test hypotheses $\mathbf{H_2}$, $\mathbf{H_3}$, and $\mathbf{H_4}$, we estimate how a household's self-protection and self-insurance spending changes as a result of an increase in access to ex-ante public protective spending; an increase in exposure to mangrove forests; and an increase in access to ex-post government-sponsored relief and rehabilitation programs.

Based on the extended analysis in Appendix A with interior solutions as well as potential corner solutions involving zero expenditures on either self-protection or self-insurance, we can translate the four possible types of household's behavioral responses into a binary decision (0,1) of whether a household undertake any private defensive strategies in terms of self-protection and self-insurance. For households that decide to participate in self-protection and self-insurance actions, they incur additional self-protection and self-insurance expenditures compare to households that do not participate in such private storm protection actions. However, if not all households participate in self-protection or self-insurance activities, then there will be sample selection bias if an OLS regression is applied on households optimal self-protection expenditures, Z^*, and self-insurance expenditures, A^*. This problem arises because it may not be possible to make inferences about the determinants of the level of defensive spending for all households. Such sample selection bias is especially problematic if a household may not be able to allocate resources for defensive actions due to reasons other than its inability to afford such actions. Hence, we adopt the Heckman model (Heckman, 1979) as the most appropriate econometric approach to overcome such sample selection bias.

Following Heckman (1979), the exact econometric specifications for self-protection and self-insurance to empirically test our theoretical household model of private investment in storm protection are as follows,

(i) For Participation equation for self-protection:

$$d^{Z^*} = X_1^{'} \cdot \zeta_{1k} + \mu \quad \text{where } X_1^{'} = [1 \quad G \quad M \quad R \quad C \quad \psi], \; k = 1,\ldots \ldots 6; \quad \mu : N(0,1)$$

$$d^Z = 1 \quad \text{if } d^{Z^*} \geq 0$$

$$d^Z = 0 \quad \text{otherwise}$$

(7)

(ii) For Outcome equation to level of self-protection,

$$Z^* = X_2^{'} \cdot \zeta_{2k} + \phi \quad \text{where } X_2^{'} = [1 \quad G \quad M \quad R \quad C \quad \psi], \; k = 1,\ldots \ldots 6; \quad \phi : N(0,\sigma_\phi^2)$$

$$Z = Z^* \quad \text{if } d^Z = 1$$

$$Z = 0 \quad \text{if } d^Z = 0$$

Expression (7) states that a separate set of factors as reflected under the vectors of explanatory variables, X_1 and X_2 influence the household participation decision equation for self-protection and the level of self-protection expenditures equation conditional on participation. Similar econometric specifications can be determined for self-insurance participation and expenditures.

For robustness checks, we test for the dependency between the error terms of the participation and the outcome equations. If the errors are dependent, then the Heckman method should be applied; whereas, if the errors are independent, then the two-part model should be considered (Cragg, 1971; Manning et al., 1981; Lee and Maddala, 1985; Jones, 1989; Leung and Yu, 1996; Puhani, 2000; Madden, 2008). However, Leung and Yu (1996) and Puhani (2000) suggested that the two part-model is likely to outperform the Heckman model (1976, 1979) when there exists high collinearity between the inverse Mills ratio term and the explanatory variables. Considering these additional factors, we estimate both the full information maximum likelihood (FIML) and the two-part model, and compare the results. We also employed joint estimation of self-protection and self-insurance choices using a bivariate probit model, which replicates the seemingly unrelated regression estimation (SURE) form as suggested by Zellner (1962). This alternative econometric specification is applicable assuming the two defensive strategies of self-protection and self-insurance of a household are jointly determined.

4. Case Study Area and Survey

Meteorologists and researchers consider Cyclone Sidr, which made landfall on the south-western coastal areas of Bangladesh on 15th November 2007 to be the most severe storm event to strike

Bangladesh recently. It had a diameter of nearly 1000 km and sustained wind speed up to 240 km per hour accompanied by a maximum tidal surge height of 5.2 meters (or around 17 feet) in some affected areas (GOB, 2008). Although early warning systems contributed to successful evacuation of the coastal people which resulted in fewer human casualties, there was extensive damage to houses, live-stock, crops, and trees. In addition to the government-assisted early warning systems installed under the cyclone-preparedness program (CPP), one of the most significant factors to contribute to reduced loss of life and property in coastal areas was the Sundarban, the world's largest mangrove forest (UNEP and WCMC, 2008; Iftekhar and Saenger, 2008).[4]

Based on the location of Sundarban mangrove forest and the track of the Cyclone Sidr, we adopted the following procedure to designate and demarcate the study area: First, we selected an area located on the southwest coast of Bangladesh that falls under the high cyclone risk zone.[5] Applying Geographic Information Systems (GIS), we followed the track of the Cyclone Sidr and the position of the Sundarban mangrove forest in order to identify the areas that would be suitable for the analysis (see Fig.1). Using GIS, we identified both the protected (P) and the non-protected (NP) coastal areas. We define as "protected" (P) any area that is located behind the Sundarban mangrove forest and is located in a clockwise direction from Cyclone Sidr. Conversely, we define as "non-protected" (NP) any area that is not located behind the Sundarban mangrove forest and is in either a clockwise or counter-clockwise direction from Cyclone Sidr. We then applied 'random area sampling' to select the unions that fall under protected (P) and non-protected (NP) areas.[6] The unions were chosen based on their location at an equal distance on either side along the track of Cyclone Sidr.

Taking into consideration the fact that Bangladesh is most vulnerable to severe cyclone and storm surge events during the pre-monsoon (April-June) and post-monsoon (October-November) seasons, we conducted the household survey during the post-monsoon season. Around 500 households were surveyed from 35 villages in 18 unions using a weighted stratified random sampling method. Out of the 18 unions, 8 unions fall under the protected areas while the rest fall under the non-protected areas. We selected the households randomly from each union based on the Bangladesh Population Census Data.

We conducted personal interviews with the head of the household using trained enumerators speaking the local language under our guidance and employing the questionnaire we developed. The questionnaires were pre-tested in October 2008, and the final survey was conducted in November, 2008. Since we conducted the household survey within a year after Cyclone Sidr, we were able to obtain information, based on both actual records and recollections of the event, on household involvement in private self-protection and self-insurance activities. In addition, we collected information on important demographic and socio-economic characteristics of each household. We also obtained secondary data on the storm characteristics of Cyclone Sidr and additional geophysical information on the Sundarban mangrove forest.

Table 3 reveals the general demographic and socio-economic characteristics of the 500 households in the two case study areas, where 220 households fall under the protected area (P) and the rest fall under the non-protected area. For the protected areas, males comprised 84.1% of the respondents, whereas, for non-protected areas, they accounted for 71.8%. The average age of the respondents was around 42 to 43 years old. 52.1% of the respondents in the protected areas had completed primary school education, while it was 45.5% in the non-protected areas. Less than 30% had secondary school education in both areas. The average household size was five members in the protected areas, and six in the non-protected areas, which is approximately the national average household size in Bangladesh. Nearly all the respondents (more than 90%) had been living in the same village since birth. Day labor is the most common occupation (36%) among households in the protected areas, and agriculture (40%) in non-protected areas. Business activities come second as an occupation in both case study areas representing 13-16% of the respondents. In both areas, most of the households own the houses they live in. Regarding the structure of the house, most house walls are made of wood while the roofs are made of tin or corrugated iron sheet. More than 20 percent of the houses in non-protected areas are two storied; whereas, in the protected areas, less than 10 percent of the total houses are two storied. Less than 50 percent of the households in both study areas made any changes to their dwellings to reduce exposure to storm surge-inflicted damages although more than half believe that their houses face some storm damage risk due to their location at low elevations. Less than one third of the households have access to electricity while access to a cell phone use is close to 50%. In protected and non-protected areas, most households obtain drinking water from ponds, canals, rivers, and preserved rain water, and in the non-protected areas, households rely on tube-wells, ponds, canals, and rivers.

In the survey, self-protection expenditures were designated and measured by adding the approximate amount that a household invested to pursue each self-protection action. This information was based on a follow-up question to those households who responded affirmatively to the earlier question regarding whether they had pursued any self-protection actions to avoid Cyclone Sidr-inflicted damages to their property. The average amount spent on self-protection in the protected area was US $1,825 per household; whereas, in the non-protected areas it was US $768 per household. On the other hand, we could not directly determine the level of self-insurance expenditures due to data limitations in identifying all types of self-insurance except for private inward remittances. Besides remittances, in the survey, approximate self-insurance expenditures are determined by also taking into account the medical expenditures associated with the Cyclone Sidr-inflicted health damages since such expenses could be supported by informal risk sharing mechanism through inter-and intra-household income transfers as part of economic resilience against a future natural disaster risk event. Following the endogenous risk literature, setting asides funds for medicines, certain foods, and medical check-ups can reduce a household's vulnerability of illness against a harmful event and hence, such redistribution of income towards less favorable states could be treated as a form of self-insurance (Ehrlich and Becker, 1972; Gruber and Yellowitz, 1999; Nyman, 1999). Considering the abject poverty and limited insurance markets facing the Bangladesh coastal communities, self-insurance in the form of redistribution of income to reduce property and health losses from a major storm event represents a more rationalistic thinking given a household's level of wealth with precautionary savings motives.

Based on the results from our survey, the average expenditure on self-insurance in the protected area was US $93 per household, and in the non-protected area, US $407 per household. The wealthier households in both areas spend a significant proportion of their income on storm protection actions as opposed to the poorer households. One possible explanation is that the wealthier households are willing and able to allocate more for self-protection and self-insurance since they expect to incur more storm-inflicted monetary losses to property. Damages from

Cyclone Sidr to households in the non-protected areas (US $1,478 per household) were higher than for those households located in the protected areas (US $1,327 per household).

Consistent with our theoretical model, not all the households surveyed engaged in defensive actions against storms. Among the households, only 22% participated in self-protection and 23% households in self-insurance. Only 8.87% applied both self-protection and self-insurance. Of the 496 households surveyed, 13% participated in only self-protection activities, 14% in only self-insurance activities, and 9% in both activities. In the protected areas, of the 216 households, 13% participated in only self-protection activities, 12% in only self-insurance, and 16% in both activities. In the non-protected areas, of the 280 households, 13% participated in only self-protection activities, 16% in only self-insurance, and 4% in both activities. Average household income (US $1,005) and the average land area (5,261 hectares) were lowest for households not participating in any self-protection and self-insurance activities. However, both average household income (US $1,182) and the average land area (8,053 hectares) were largest for households participated in both self-protection and self-insurance activities.

In terms of accessibility to public protection programs, 82% of the households in the non-protected areas live inside an embankment while only 35% of the households in protected areas live inside an embankment. Similarly, 62% of households in the non-protected areas live close to a cyclone shelter, and 44 % in the case of households in the protected areas. Thus, households in the non-protected areas appear to have more access to publicly funded protection facilities compared to households in the protected areas. Regarding public programs for disaster relief and rehabilitation, households in both areas had equal access to relief programs, although households in the protected area had better access to rehabilitation programs.

5. Estimation Results and Discussion

Our empirical analysis is based on the full sample of the household survey. Table 3 shows the summary statistics for the explanatory variables used in our regression. Tables 4 and 5 present the results of the full information maximum likelihood (FIML) of the full sample selection model for self-protection.[7] Table 4 displays various estimations of the selection equation of the probability of a household participating in self-protection activities, and Table 5 shows the results from the corresponding outcome equation for the effects on the level of self-protection expenditures conditional on participation. Both tables report four regression specifications starting with a basic model (regression 1), which include as explanatory variables damages inflicted by Cyclone Sidr, pre-Cyclone Sidr household income, distance from the coast, asset holdings based on ownership of homestead, cropland, and pond area, and other socio-economic characteristics.[8] For the other regression specifications, additional controls are progressively added starting with mangroves characteristics (regression 2), then, public programs (regression 3), and finally, the storm characteristics of Cyclone Sidr (regression 4).

Following the concepts of ecological rationality (Smith, 2003; Todd and Gigerenzer, 2007), We assume that households with previous encounters of damaging storm events has led to them subsequently invest a portion of their time and money to insulate them against future storm-inflicted damage. In addition, households' current level of income can also influence their preference to locate in coastal areas that are not protected by mangroves but these areas are more likely to receive relief from government because they represent poorer and easily accessible communes. To deal with the exogenous sources of variations on household's location preferences, we included in our estimation analysis a variable that captures households' location preferences based on their previous experiences with major storm events.

To control for exogenous sources of variations on households' behavioral responses to public relief, we applied a household's access to electricity and access to phone as instruments. This is motivated by following the literature on the political economy of government responsiveness to natural calamities which shows that the likelihood of receiving aid from the government is higher if the affected communities possess higher radio coverage, have stronger political support for the incumbent government, and easier accessible network (Besley & Burgess, 2000, 2002; Franchen *et al.* 2012).

The regression results suggest that storm-inflicted damage is an important determinant of households' participation in ex-ante self-protection. The coefficient for the damage variable is positive and highly significant in all regression specifications. Although not highly significant in the full regression model (4), the coefficients for the log and the square of the log of a household's pre-Cyclone Sidr income display positive and negative signs respectively under all specifications. This suggests that the probability of a household participating in ex-ante self-protection activities has an inverted U-shaped relationship with income, initially increasing, but then declining. Hence, it is more likely that a middle-income household will pursue self-protection compared to a poor or wealthy household. The coefficient of ownership of homestead, cropland, and pond area--a proxy for the household's asset holding--remains positive and significant throughout. Results also show that a household is more likely to participate in self-protection if it has fewer children and has less access to credit compared to other households. However, a household is less likely to participate in self-protection if it plans to migrate in the future. The elevation of the surrounding area is rarely significant in explaining the decision of the household to undertake self-protection. The directional distance between the household and the track of the Cyclone Sidr has a positive influence on a household undertaking self-protection, although these actions are less likely if the households fall into counter-clockwise direction from the storm.

With regard to the role of mangroves, regression 2 indicates that a household in a protected area is more likely to participate in self-protection, though this influence turns out to be insignificant when other controls like public programs and storm characteristics are progressively added to the model. On the other hand, the location of the household with respect to the coast and the mangroves may possibly affect the household's participation in self-protection. Although the coefficient for MDIR is statistically significant only at the 10% level in regressions 2 and 4, this result suggests that a household located to the south and southwest direction relative to the coast and the Sundarban mangrove forest is less likely to participate in self-protection compared to a household that is oriented differently. Since location relative to the Sundarban mangrove forest may determine how well the household is protected by this natural barrier, a household that faces in a less favorable direction may be compelled to undertake more self-protection actions. Similarly, results for regression 4 show that the distance between the mangrove forest and the union where the household's village is located has a negative and significant relationship with self-protection, again suggesting that close proximity to a natural storm protection barrier may reduce the need for self-protection. Whether or not a household is protected by an embankment appears to have no statistically significant impact on whether it is more likely to participate in self-protection. Ex-post public disaster relief leads to households participating less in self-protection activities although this effect is not significant at the 10% level. Regression 3 indicates that the presence of public disaster rehabilitation leads a household to undertake self-protection, but this influence is insignificant when storm characteristics are added to the model.

Table 5 reports the results of the outcome equation for self-protection expenditures conditional on participation. The results confirm H_1 that storm-inflicted damage is an important determinant of a household's level investment in self-protection. The coefficients for the log and the square of the log of pre-Cyclone Sidr income are strongly significant in all regression specifications, with negative and positive signs respectively. That is, conditional on participation, a household's level of self-protection expenditures exhibits a U-shaped relationship with income, initially declining, but then increasing. Once a household decides to participate, if it is poor or rich, it is likely to spend more on self-protection activities compared to middle-income households. The results in Table 5 indicate that a household invests more in self-protection if it has access to credit but invests less if it is a member of any village-level organization, and if its house is located in higher elevations. A household located in a protected area invests more in self-protection, implying that H_4 cannot be rejected. However, the coefficients of the other mangrove variables such as location of the household with respect to the mangrove and its distance to the nearest forest are not statistically significant. A Household located inside an embankment invests more in self-protection, which suggests that H_2 cannot be rejected. However, public disaster relief and rehabilitation programs do not appear to have a statistically significant influence on a household's self-protection spending.[9]

Table 6 shows the estimation results for self-insurance. Due to data limitations on determining the level of self-insurance expenditures, we cannot estimate both the FIML estimator and the two-part model. Instead, we estimate separate regressions for the decision to participate in self-insurance by performing Probit estimation and a separate Tobit estimation to deal with the censored nature of the self-insurance expenditures. In addition, the estimations include a household's income before Cyclone Sidr and after. Because self-insurance actions take place once a disaster occurs, a household's income can vary significantly between what it was *before* and *after* a major storm event. For instance, while a household's pre-cyclone income might have come from subsistence agriculture, its post-cyclone income might come from day labor because the agriculture crops have been destroyed as a result of the cyclone. Our results show that there is low correlation either between the log of pre-income and log of post-income or between the square log of pre-income and the square log of post-income. These correlation outcomes along with the t-tests confirm the difference between the sources of income before and after the Cyclone Sidr event.

The Probit estimation in Table 6 reveals that self-insurance is also an important private defensive strategy against storm-inflicted damages, and damages are an important determinant of a household's participation in self-insurance. The coefficient for a household living inside an embankment has a negative sign and significant only at the 10 % level although this effect disappears in regression 4. However, the coefficients of both *ex-post* public disaster relief and rehabilitation programs are positive and highly significant, which implies that the probability of a household participating in self-insurance increases if the household has more access to these programs. The coefficient for a household living within the mangrove protected area has a negative sign and is statistically significant. This suggests that a household living in such an area is less likely to undertake self-insurance. On the other hand, households located close to the mangroves are more likely to participate in self-insurance. Among the socio-economic controls, a household is more likely to participate in self-insurance if it has more children whereas it is less likely to participate if it is a member of a village-level organization. A household is also more likely to participate in self-insurance if it is located further away from the coast. None of the income variables have a significant influence on the probability of self-insurance. This might imply that other factors rather than income play a major role on household's choice to undertake self-insurance. Finally, none of the storm characteristic variables are strongly significant in the regressions for participation in self-insurance.

Table 6 also shows the censored Tobit model results for estimating the level of self-insurance expenditures of the households, starting with the basic model (column 6-9). The results confirm H_1 that storm-inflicted damage is an important factor in the household's level of self-insurance investment. Under all specifications, the coefficient of the nominal value of storm-inflicted property damages remains positive and highly significant. The coefficients of the log and square log of post-Cyclone Sidr income (i.e., household income after Cyclone Sidr) are highly significant with negative and positive signs respectively. That is, a household's self-insurance expenditures exhibit a significant U-shaped relationship with post- Cyclone Sidr income, initially declining, but then increasing. This suggests that low-and high-income households allocate more for self-insurance compared to middle-income households. For the socio-economic characteristics, the coefficient on age and years of education has a positive sign and is significant at the 5 percent level. These outcomes suggest that if the head of the household is older and possesses a higher level of education in terms of more education years, then the household invests more in self-insurance. In addition, households invest more in self-insurance if they have more children and their houses are located in lower elevations. None of the storm characteristic variables are strongly significant in the regressions for investment in self-insurance. Households within mangrove protected areas invest less in self-insurance. This finding cannot reject the H_4 that close proximity to mangroves causes households to invest less in self-insurance. Households living further away from mangroves also invest less in self-insurance. The direction that the household faces with respect to the mangroves appears to have no influence on its self-insurance expenditure. Regarding public programs, a household located inside an embankment invests more in self-insurance. Thus, this result rejects H_2. However, access to public disaster relief and rehabilitation programs do not affect household self-insurance spending since they are not statistically significant.

To check the results for robustness, we also examined whether a household's self-protection and self-insurance choices are treated as joint rather than separate decisions. The joint estimation of the two private storm protection strategies is based on a bivariate probit model applying a seemingly unrelated regression (SUR). Using two separate columns for each of the four regression specifications, Table 7 reports the joint estimation results. A Lagrange multiplier test is performed to see whether the probit models can be estimated separately. The null hypothesis of separate estimations of the probit models of self-protection and self-insurance is rejected at 5% level for the basic model and the regression with mangrove variables only. However, the null hypothesis can only be rejected at the 10% level when public programs and the storm characteristics are progressively added to the model. However, we cannot perform joint estimation on either the conditional outcome equation for self-protection (see Table 5) or the

Tobit regression for self-insurance (see Table 6) as there are not enough data points for the level of self-protection and self-insurance expenditures.

In addition, Table 7 indicates that most of the results from the previous analysis hold when the joint estimation of the seemingly bivariate probit model is performed. Although there is evidence of an inverted U-shaped relationship between income and private storm protection choices, only the log and square of the log of a household's pre-cyclone income for self-protection are statistically significant. However, this latter effect disappears in regression 4 with storm surge characteristics included. The coefficient of ownership of homestead, cropland, and pond area – a form of assets holding – remains positive for both private storm protection choices. But it is highly significant throughout only for self-protection. Regarding the role of mangroves and public programs, joint estimation leads to same findings when we performed separate estimations of the probability of a household participating in self-protection and self-insurance choices in Table 5 and Table 7.

To summarize, our empirical results indicate that: (i) storm-inflicted damage is an important determinant of a household's decision to undertake self-protection and self-insurance; (ii) a household protected by an embankment invests more in both self-protection and self-insurance; (iii) public disaster relief and rehabilitation programs have no impact on self-protection or self-insurance expenditures of a household; (iv) a household located in a mangrove protected area invests more in self-protection and less in self-insurance, and a household further away from the forest spends less on self-insurance, but the location of the household with respect to the forest is inconclusive; (v) Income has a strong influence on a household's investment in self-protection and self-insurance; and finally, (vi) other socio-economic, demographic, and geo-physical factors seem to have considerable influence and add a degree of complexity to the defensive strategies of households.

6. Conclusion

This paper seeks to understand two key issues that influence the way coastal communities protect themselves from the increasing frequency and severity of global climate change induced cyclones and storm surges. First, our analysis aims to determine whether public protection programs, such as *ex-post* public disaster relief and rehabilitation programs and *ex-ante* publicly constructed embankments, have the potential to partially or fully crowd out private storm protection actions by poor coastal households threatened by a damaging storm. Second, we also seek to determine whether living in close proximity to a natural storm protection barrier, such as mangrove forests, lessens private storm protection actions of households.

In order to examine these two issues, we introduced a theoretical model using an endogenous risk framework to determine possible influence of government programs and mangroves on a household's decision to invest in self-protection and self-insurance. Our theoretical model identifies four types of behavioral responses based on both interior as well as possible corner solutions to reduce the likelihood and severity of facing monetary losses or damages to property from a major storm event. The corner solutions might arise because of a household's inability to afford private storm protection, which may be a realistic outcome for a poor household in a developing country. Results following the comparative statics analysis that the influence of public programs depend on whether they are implemented before any storm occurs or afterwards. *Ex-ante* publicly constructed protective barriers, embankments or dams that reduce the probability of flooding from storm surges are complements to self-protection expenditures but substitutes to self-insurance. One possible explanation is that, because a household is better protected by such physical structures, it knows that less self-insurance expense are required to mitigate any damages resulting from a subsequent storm. Thus, dams, embankments and protective barriers that the government builds before the storm tends to *crowd out* the self-insurance expenditures of a household. On the other hand, the household may also determine that the probability of it being inflicted by storm damages will be reduced even further if it also undertakes its own self-protection activities before the storm occurs. Hence, the result of *ex-ante* public construction of protective barriers may *crowd in* complementary investments in self-protection by the protected household.

In contrast, *ex-post* public programs that are implemented after a storm event, such as public disaster relief and rehabilitation programs are substitutes to self-protection but complements to self-insurance. If a household knows that such relief and rehabilitation programs are available after the storm, then it may decide to allocate less expenditure to its own *ex-ante* self-protection measures and thus have more funds available for self-insurance that complements the *ex-post* government efforts. Consequently, public disaster relief and rehabilitation programs might *crowd out* private self-protection but *crowd in* self-insurance by a household. However, our empirical analysis of coastal households in Bangladesh impacted by Cyclone Sidr finds only partial support for some of these crowding in and crowding out effects of public investments and programs. A household protected by a publicly constructed embankment built before the storm invests more in both self-protection and self-insurance. In contrast, *ex-pos*t public disaster relief and rehabilitation programs have no impact on self-protection or self-insurance spending by a household.

Our theoretical model also explicitly shows the possible influence of mangroves on private defensive strategies against storm risks. Households protected by mangroves pursue more self-protection but less self-insurance. The likely explanation for this effect is similar to that for a publicly constructed embankment, dam or other protective barrier. Because the household knows it is better protected by a nearby mangrove forest, it needs to spend less on self-insurance for damages inflicted by a storm. On the other hand, the presence of a natural barrier may encourage the household to invest more in self-protection to reduce even further the risks of storm damage to its home and other property. We conduct an empirical investigation employing household survey data to explore this possible influence of mangroves on private storm protection, which is a novel contribution of this paper to the literature.[10] A household located in an area protected by mangroves invests more in self-protection and less in self-insurance. Although a household located further away from mangroves invests less in self-insurance, there is no corresponding influence on self-protection expenditures. The location of the household with respect to the mangrove forest does not appear to influence either self-protection or self-insurance expenditure.

We tested the key hypotheses resulting from the model based on data obtained from a household survey of 35 villages comprising 500 households in the southwest coastal areas of Bangladesh affected by Cyclone Sidr in November 2007. Our estimation results indicate that storm-inflicted damage is an important determinant of households' decision to undertake self-protection and self-insurance. A household living inside an *ex-ante* publicly constructed embankment invests more in self-protection and in self-insurance. However, the household's awareness that *ex-post* public disaster relief and rehabilitation programs are likely to be implemented has no impact on self-protection and self-insurance spending. Our results also show that a household protected by mangroves invests more in self-protection and less in self-insurance. A household located further away from the mangroves invests less in self-insurance, although there is no corresponding influence on self-protection expenditures. The location of the household with respect to the mangrove forest has no influence on either self-protection or self-insurance. Household characteristics, such as income access to credit, the age and education of the head of the household, and if the house is located in higher elevations, also influence defensive expenditures. On the other hand, none of the storm characteristics variables have significant influence on household self-protection and self-insurance investment.

Regarding policy implications, our empirical results support efforts by a government to invest public protection programs that are implemented before a storm occurs since they encourage more investment in self-protection and self-insurance by the coastal households. Besides implementing *ex-ante* publicly constructed embankments or other protective barriers, a government could also disseminate knowledge through public led disaster preparedness and educational programs to encourage adoption of more private storm protection actions. By encouraging the coastal communities to pursue private storm protection strategies in conjunction with *ex-ante* public programs, government can discourage 'relief dependency' among the coastal households after a storm occurs. As a result, government can make its *ex-post* disaster relief and rehabilitation programs more efficient as well as effective in reducing storm-induced damages among coastal households.

As our results also indicate that households in mangrove protected areas invest more in self-protection but less in self-insurance, a government could also encourage mangrove plantation combined with publicly constructed embankments as part of its *ex-ante* public storm protection programs. However, government should avoid planting mangroves in inappropriate environmental settings which might reduce long-term ecological sustainability of a coastal area, as found in Sri Lanka (Feagin *et al.*, 2009) and Thailand (Barbier 2007 and 2008). In addition, policies could promote plantation of trees other than mangroves, as evidence from coastal

Bangladesh reveals that dense plantation of coconuts, beetle nuts, and banana trees around the house can also provide some protection against storm damages (Paul and Routray, 2010).

Policies that help diversify post-storm household income would also enhance the ability of households to cope with storm-inflicted damages to their property. In addition, government can earmark more funds under its *ex-post* disaster relief and rehabilitation programs for the households with more elderly and children members as well as that are located in lower elevations. Since our results indicate that these types of households invest more in self-insurance, such program can create more incentives for these households by subsidizing their self-insurance investment. Conversely, government can ease regulations for financial institutions and non-governmental organizations (NGOs) by lending credit to the households that are willing to invest in self-protection because our results show that households invest more in self-protection if they have better access to credit.

With uncertainties surrounding the wave attenuation capacity of mangroves from tidal waves that are too extreme in magnitude (Alongi, 2008; Wolanski, 2007; Cochard *et al.*, 2008) and the government's own capacity to protect the coastal communities from intense storm events (The World Bank, 2010), it is justifiable for the government to encourage more collective and individual participation in private storm protection actions in both mangrove protected and non-mangroves protected areas. The government should also ensure that these programs are sustainable in the long run taking into account the widespread poverty and limited insurance markets facing the Bangladesh coastal communities.

Appendix A

Given the expressions (1)-(3), the household optimization framework with non-negative inequality constraints is,[11]

$$\underset{Z,A,X}{Max}\, EU = \left[\pi\left(Z;G,M,C\right)\cdot U^{L}\left(X\right)+\left(1-\pi\left(Z;G,M,C\right)\right)\cdot U^{NL}\left(X\right)\right]$$

subject to

$$\begin{aligned} & X + Z + A + L(A;R) \le I && \text{(income constraint)} \\ & X \ge 0 && \text{(composite good consumption constraint)} \\ & Z \ge 0 && \text{(self-protection constraint)} \\ & A \ge 0 && \text{(Self-insurance constraint)} \end{aligned} \qquad \text{(A.1)}$$

Given the problem, the Lagrangian function is,

$$\mathfrak{L}(Z,A,X,\lambda)=\left[\pi(Z;G,M,C)\cdot U^{L}(X)+\left(1-\pi(Z;G,M,C)\right)\cdot U^{NL}(X)\right] \\ +\lambda\cdot\left[I-X-Z-A-L(A;R)\right] \tag{A.2}$$

The first-order Kuhn-Tucker conditions are

$$Z:\quad \frac{\partial\mathfrak{L}}{\partial Z}=\frac{\partial\pi}{\partial Z}\left(U^{L}-U^{NL}\right)-\lambda\leq 0$$
$$Z\cdot\frac{\partial\mathfrak{L}}{\partial Z}=0$$
$$Z\geq 0$$

(A.3)

$$A:\quad \frac{\partial\mathfrak{L}}{\partial A}=\left[-\left(1+\frac{\partial\mathfrak{L}}{\partial A}\right)\cdot\lambda\right]\leq 0$$
$$A\cdot\frac{\partial\mathfrak{L}}{\partial A}=0 \tag{A.4}$$
$$A\geq 0$$

$$X:\quad \frac{\partial\mathfrak{L}}{\partial X}=\pi\cdot\frac{\partial U^{L}}{\partial X}+(1-\pi)\cdot\frac{\partial U^{NL}}{\partial X}-\lambda\leq 0$$
$$X\cdot\frac{\partial\mathfrak{L}}{\partial X}=0 \tag{A.5}$$
$$X\geq 0$$

$$\lambda:\quad \frac{\partial\mathfrak{L}}{\partial\lambda}=I-X-Z-A-L(A;R)\geq 0$$
$$\lambda\cdot\frac{\partial\mathfrak{L}}{\partial\lambda}=0 \tag{A.6}$$
$$\lambda\geq 0$$

Starting with expression (A.5), assuming a representative household has positive consumption of the composite good, i.e. $X>0$,

$$\frac{\partial\mathfrak{L}}{\partial X}=0 \\ \Rightarrow \pi(.)\cdot U_{X}^{L}+\left(1-\pi(.)\right)\cdot U_{X}^{NL}=\lambda \tag{A.7}$$

Expression (A.7) reveals that a household will prefer to have positive consumption of composite good if the expected marginal benefit from consuming the composite good under both states of the world, i.e. adverse and non-adverse states, is equivalent to its shadow price. The shadow prices of the composite good X can also be expressed as the marginal imputed cost (opportunity cost) of consuming the good or the expected marginal utility of income.

Considering a household will exhaust its budget, which is equivalent to say $\lambda > 0$ and $\frac{\partial \mathfrak{L}}{\partial \lambda} = 0$ from expression (A.6), we will now proceed with our discussion on the four types of household behavioral responses to reduce the likelihood and the severity of experiencing damages to property from a major storm. For all types, we assume that a household will always tends to consume the composite good at least at the subsistence level, i.e. $X \geq X^0$.

Type (a): Interior Solution of Both Self-protection and Self-insurance

From (A.3), if $Z > 0$, then the first order condition with respect to Z is an unconstrained maximum of the Lagrangian.

$$\frac{\partial \mathfrak{L}}{\partial Z} = 0 \quad \Rightarrow \frac{\partial \pi}{\partial Z} \cdot \left(U^L - U^{NL} \right) = \lambda \tag{A.9}$$

Expression (A.9) implies that a household will pursue self-protection up to the point where the expected marginal benefit of self-protection is equal to its expected marginal imputed cost (opportunity cost) or the expected marginal utility of income. The latter can also be identified as the shadow price or virtual price of self-protection.

Similarly, from (A.4), if $A > 0$, then,

$$\frac{\partial \mathfrak{L}}{\partial A} = 0 \quad \Rightarrow \left[-\left(1 + \frac{\partial L}{\partial A} \right) \right] \cdot \lambda = 0 \tag{A.10}$$

Since $\lambda > 0$, we can infer from expression (A.10) and by re-arranging terms,

$$-\frac{\partial L}{\partial A} = 1 \tag{A.10.1}$$

Expression (A.10.1) suggests that a household could pursue self-insurance strategies if the marginal benefit of self-insurance, as defined by the averted monetary loss to damages to property, is equal to its marginal cost. The latter can be characterized as the unit cost of self-insurance based on our simplification that the price of the self-insurance is \$ 1.

Thus, given certain assumptions about a household's utility in states of damage or no damage and its level of composite good consumption, expressions (A.9) and (A.10.1) ensure that an interior solution exists for a household that where it allocates resources both for self-protection and self-insurance.

Type (b): Self-protection only corner solution

For the corner solution where the household allocates resources only for self-protection $(Z > 0)$ but not for self-insurance $(A = 0)$, we have the following based on expression (A.4),

$$\frac{\partial \mathfrak{L}}{\partial A} \leq 0 \quad \Rightarrow \left[-\left(1 + \frac{\partial L}{\partial A} \right) \right] \cdot \lambda \leq 0 \tag{A.11}$$

But since $\lambda > 0$,

$$\left[-\left(1 + \frac{\partial L}{\partial A} \right) \right] \leq 0 \quad \text{or,} \ -\frac{\partial L}{\partial A} \leq 1 \tag{A.11.1}$$

Thus, expression (A.11.1) implies that a household will not pursue self-insurance if it considers the marginal benefit from self-insurance to be lower than the marginal cost (i.e. the unit cost equivalent to price) of self-insurance.

In addition, we consider that condition (A.9) should hold to ensure that a household has positive allocation for self-protection $(Z > 0)$. Hence, given conditions (A.9) and (A.11.1) under certain assumptions, we can express the self-protection only corner solution $\left(Z > 0;\ A = 0;\ \text{and}\ X \geq X^{0}\right)$.

Type (c): Self-insurance only corner solution
In the case of self-insurance only corner solution, it follows from expression (A.3) that we should have,

$$\frac{\partial \mathfrak{L}}{\partial Z} \leq 0 \quad \text{or,} \quad \frac{\partial \pi}{\partial Z} \cdot \left(U^{SE} - U^{NSE}\right) \leq \lambda \qquad \text{(A.12)}$$

where expression (A.12) indicates that a household will not practice self-protection if and only if it perceives that the expected marginal benefit of self-protection is less than or equal to the expected marginal imputed costs of self-protection (i.e. the shadow price of self-protection). But unlike previously, we will consider that expression (A.10.1) and (A.12) hold to ensure we can express the self-insurance only corner solution $\left(Z = 0;\ A > 0;\ \text{and}\ X \geq X^{0}\right)$.

Type (d): No self-protection and self-insurance
For no self-protection and no self-insurance case, we argue that the conditions such as (A.11.1) and (A.12) hold so that a household considers that the expected marginal benefits from self-protection and self-insurance are lower than the expected costs of their take up.

Appendix B
Proof of PROPOSITION 1. Comparative analyses results show that we cannot determine the direction of the relationship between a household's averting behavior and ex-ante public protection spending unless we impose additional restrictions.

Using the first order conditions (4) and (5) of the main paper and the implicit function theorem, the comparative static effects of a decrease in G on the optimal levels of self-protection Z yields,

$$\frac{\partial Z^{*}}{\partial G} = \frac{\begin{vmatrix} -\dfrac{\partial F^{1}}{\partial G} & H_{ZA} \\ -\dfrac{\partial F^{2}}{\partial G} & H_{AA} \end{vmatrix}}{|H|} \Rightarrow \frac{\begin{vmatrix} -\dfrac{\partial EMB_{Z}}{\partial G} & H_{ZA} \\ -\dfrac{\partial EMB_{A}}{\partial G} & H_{AA} \end{vmatrix}}{|H|} = \frac{\overbrace{H_{AA} \cdot \left(-\dfrac{\partial EMB_{Z}}{\partial G}\right)}^{\text{direct effect}} + \overbrace{H_{AZ} \cdot \left(\dfrac{\partial EMB_{A}}{\partial G}\right)}^{\text{indirect effect}}}{|H|} \qquad \text{(B.1)}$$

where, $F^{1} \equiv EMB_{Z}$ is the first order condition with respect to self-protection, i.e. the expected marginal benefits of self-protection based on expression (4); $F^{2} \equiv EMB_{A}$ is the first order condition with respect to self-insurance, i.e. the expected marginal benefits of self-insurance based on expression (5); H_{AA} is the own-partial of self-insurance; and H_{ZA} is the cross-partial of self-protection and self-insurance. Both partials are based on the Hessian matrix $|H| = \begin{vmatrix} H_{ZZ} & H_{ZA} \\ H_{AZ} & H_{AA} \end{vmatrix}$.

In expression (B.1), the first term in the numerator on the right hand side is the direct effect of the ex-ante public spending on self-insurance while the second term is the indirect effect.

Likewise, the comparative static effects of a decrease in G on the optimal level of self-insurance A yields,

$$\frac{\partial A^*}{\partial G} = \frac{\begin{vmatrix} H_{ZZ} & -\frac{\partial F^1}{\partial G} \\ H_{AZ} & -\frac{\partial F^2}{\partial G} \end{vmatrix}}{|H|} \Rightarrow \frac{\begin{vmatrix} H_{ZZ} & -\frac{\partial EMB_Z}{\partial G} \\ H_{AZ} & -\frac{\partial EMB_A}{\partial G} \end{vmatrix}}{|H|} = \frac{\overbrace{H_{ZZ} \cdot \left(-\frac{\partial EMB_A}{\partial G} \right)}^{\text{direct effect}} + \overbrace{H_{AZ} \cdot \left(\frac{\partial EMB_Z}{\partial G} \right)}^{\text{indirect effect}}}{|H|} \qquad \text{(B.2)}$$

where, $F^1 \equiv EMB_Z$ is the first order condition with respect to self-protection, i.e. the expected marginal benefits of self-protection based on expression (4); $F^2 \equiv EMB_A$ is the first order condition with respect to self-insurance, i.e. the expected marginal benefits of self-insurance based on expression (5); H_{AA} is the own-partial of self-insurance; and H_{ZA} is the cross-partial of self-protection and self-insurance. Both partials are based on the Hessian matrix $|H| = \begin{vmatrix} H_{ZZ} & H_{ZA} \\ H_{AZ} & H_{AA} \end{vmatrix}$.

In expression (B.2), the first term in the numerator on the right hand side is the direct effect of the ex-ante public spending on self-protection while the second term is the indirect effect.

Expression (B.1) and (B.2) show that the sign and magnitude of the direct effect depends on how a change in ex-ante public spending affects the expected marginal benefits of self-protection $\left(\frac{\partial EMB_Z}{\partial G} \right)$ and the expected marginal benefits of self-insurance $\left(\frac{\partial EMB_A}{\partial G} \right)$. In addition, it depends on the signs of H_{ZZ} and H_{AA} which are both negative by the second-order conditions. Like the direct effect, the indirect depends on the influence of ex-ante public spending on the expected marginal benefits of self-protection and self-insurance. However, it also depends on the signs of the cross partials of self-protection and self-insurance $(H_{AZ} = H_{ZA})$ which cannot be determined.

Substituting the influence of ex-ante public programs, G, on the expected marginal benefits of self-protection, $\frac{\partial EMB_Z}{\partial G}$, and the expected marginal benefits of self-insurance, $\frac{\partial EMB_A}{\partial G}$, in expression (B.1) leads to

$$\frac{\partial Z}{\partial G}=\frac{\overset{'-'}{H_{AA}}\cdot\left[\begin{array}{l}-\overbrace{\frac{\partial^2\pi(.)}{\partial G\partial Z}}^{'?'}\cdot\overbrace{\left(U(W_1)-U(W_2)\right)}^{'-'}\\+\overbrace{\frac{\partial\pi}{\partial G}}^{'-'}\cdot\overbrace{\left(U^{'}(W_1)-U^{'}(W_2)\right)}^{'+'}\end{array}\right]+\overset{'?'}{H_{ZA}}\cdot\left[\begin{array}{l}-\overbrace{\frac{\partial\pi(.)}{\partial G}}^{'-'}\cdot\overbrace{U^{'}(W_1)}^{'+'}\cdot\overbrace{\left(1+\frac{\partial L}{\partial A}\right)}^{'-'}\\+\overbrace{U^{'}(W_2)}^{'+'}\cdot\overbrace{\frac{\partial Q(.)}{\partial G}}^{'-'}\end{array}\right]}{|H|} \qquad \text{(B.3)}$$

Similarly, Substituting the influence of ex-ante public programs, G, on the expected marginal benefits of self-protection, $\frac{\partial EMB_Z}{\partial G}$, and the expected marginal benefits of self-insurance, $\frac{\partial EMB_A}{\partial G}$, in expression (B.2) yields

$$\frac{\partial A}{\partial G}=\frac{\overset{'-'}{H_{ZZ}}\cdot\left[\begin{array}{l}\overbrace{\frac{\partial\pi(.)}{\partial G}}^{'-'}\cdot\overbrace{U^{'}(W_1)}^{'+'}\cdot\overbrace{\left(1+\frac{\partial L}{\partial A}\right)}^{'-'}\\-\overbrace{U^{'}(W_2)}^{'+'}\cdot\overbrace{\frac{\partial\pi(.)}{\partial G}}^{'-'}\end{array}\right]+\overset{'?'}{H_{AZ}}\cdot\left[\begin{array}{l}\overbrace{\frac{\partial^2\pi(.)}{\partial G\partial Z}}^{'?'}\cdot\overbrace{\left(U(W_1)-U(W_2)\right)}^{'-'}\\+\overbrace{\frac{\partial\pi}{\partial G}}^{'-'}\cdot\overbrace{\left(U^{'}(W_1)-U^{'}(W_2)\right)}^{'+'}\end{array}\right]}{|H|} \qquad \text{(B.4)}$$

It is not possible to sign expression (B.3) and (B.4) unambiguously. They can only be signed if the following conditions hold,

Condition 1. $H_{AZ}=H_{ZA}<0$. That is, assuming self-protection and self-insurance to be stochastic substitutes.[12] This implies that the marginal utility of ex-ante self-protection, Z, decreases if more ex-ante self-insurance, A, activities are taken by the household and vice-versa.

Condition 2. $\frac{\partial^2\pi(.)}{\partial G\partial Z}<0$. This suggests that more ex-ante government protection activities G can accentuate the influence of self-protection, Z, in reducing the probability of facing storm-inflicted damages to property.

Assuming conditions (1) and (2) are met, it is possible to sign - expressions (B.1) and (B.2) accordingly.

$$\frac{\partial Z}{\partial G}=\frac{\overbrace{H_{AA}}^{"-"}\cdot\overbrace{\text{2nd bracketed term}}^{"-"}+\overbrace{H_{ZA}}^{"-"}\cdot\overbrace{\text{4th bracketed term}}^{"-"}}{|H|}=\frac{"+"\ +\ "+"}{|H|}>0$$

$$\frac{\partial A}{\partial G}=\frac{\overbrace{H_{zz}}^{"-"}\cdot\overbrace{\text{2nd bracketed term}}^{"+"}+\overbrace{H_{AZ}}^{"-"}\cdot\overbrace{\text{4th bracketed term}}^{"+"}}{|H|}=\frac{"-"\ +\ "-"}{|H|}<0 \qquad \text{(B.5)}$$

Therefore, under additional restrictions, comparative statics result show that ex-ante government protection spending, G, is a complement to ex-ante self-protection, Z, but is a substitute to ex-ante self- insurance, A.

Proof of PROPOSITION 2. Starting with the risk-averse case, comparative results on the influence of ex-post government risk-reducing programs like disaster relief and rehabilitation activities on household averting behavior show that the direction of the relationship can be determined only under certain restrictions. Comparative static results show

$$\frac{\partial Z^*}{\partial R} = \frac{\begin{vmatrix} -\frac{\partial F^1}{\partial R} & H_{ZA} \\ -\frac{\partial F^2}{\partial R} & H_{AA} \end{vmatrix}}{|H|} \Rightarrow \frac{\begin{vmatrix} -\frac{\partial EMB_Z}{\partial R} & H_{ZA} \\ -\frac{\partial EMB_A}{\partial R} & H_{AA} \end{vmatrix}}{|H|} = \frac{\overbrace{H_{AA}\cdot\left(-\frac{\partial EMB_Z}{\partial R}\right)}^{\text{direct effect}} + \overbrace{H_{AZ}\cdot\left(\frac{\partial EMB_A}{\partial R}\right)}^{\text{indirect effect}}}{|H|} \tag{B.6}$$

$$\frac{\partial A^*}{\partial R} = \frac{\begin{vmatrix} H_{ZZ} & -\frac{\partial F^1}{\partial R} \\ H_{AZ} & -\frac{\partial F^2}{\partial R} \end{vmatrix}}{|H|} \Rightarrow \frac{\begin{vmatrix} H_{ZZ} & -\frac{\partial EMB_Z}{\partial R} \\ H_{AZ} & -\frac{\partial EMB_A}{\partial R} \end{vmatrix}}{|H|} = \frac{\overbrace{H_{ZZ}\cdot\left(-\frac{\partial EMB_A}{\partial R}\right)}^{\text{direct effect}} + \overbrace{H_{AZ}\cdot\left(\frac{\partial EMB_Z}{\partial R}\right)}^{\text{indirect effect}}}{|H|} \tag{B.7}$$

Expressions (B.6)-(B.7) reveal that the sign and magnitude of the direct effects depend on the own partials, H_{ZZ} and H_{AA}, as well as how a change in the ex-post public-assisted disaster relief and rehabilitation programs influences expected marginal benefits of self-protection, $\frac{\partial EMB_Z}{\partial R}$, and self-insurance, $\frac{\partial EMB_A}{\partial R}$. Conversely, the indirect effects depend on the cross partials, H_{ZA} and H_{AZ}, and the influence of ex-post public-assisted disaster relief and rehabilitation programs on the expected marginal benefit of self-protection and self-insurance.

Under the risk-averse assumption, results reveal that the direction of the relationship between ex-ante public programs and the private averting strategies remain ambiguous because it is not possible to determine the direction of influence of ex-post public programs, R, on the expected marginal benefits of self-protection $\left(EMB_Z = \frac{\partial EU}{\partial Z_{ij}}\right)$. However, if the households are assumed to be risk neutral, then it is possible to establish the direction of the relationships by imposing the additional restriction.

Substituting the influence of ex-post public programs, R, on the expected marginal benefits of self-protection, EMB_Z, and the expected marginal benefits of self-insurance, EMB_A, in expressions (B.6) and (B.7) lead to,

$$\frac{\partial Z}{\partial R}=\frac{\overset{(-)}{H_{AA}}\cdot\left[\overbrace{\frac{\partial\pi(.)}{\partial Z}}^{(-)}\cdot\overbrace{U^{'}(W_1)}^{(+)}\cdot\overbrace{\frac{\partial L(.)}{\partial R}}^{(-)}-\overbrace{\pi}^{(+)}\cdot\overbrace{U^{''}(W_1)}^{(-)}\cdot\overbrace{\frac{\partial L}{\partial R}}^{(-)}\right]+\overset{(?)}{H_{ZA}}\cdot\left[\begin{array}{l}-\overbrace{\pi(.)}^{(+)}\cdot\overbrace{U^{'}(W_1)}^{(+)}\cdot\overbrace{\frac{\partial^2 L(.)}{\partial R\partial A}}^{(?)}\\+\overset{(+)}{\pi(.)}\cdot\overbrace{\left(1+\frac{\partial L(.)}{\partial A}\right)}^{(-)}\cdot\overbrace{U^{''}(W_1)}^{(-)}\cdot\overset{(-)}{\frac{\partial L}{\partial R}}\end{array}\right]}{|H|} \tag{B.8}$$

Under the first term of the numerator, the bracketed portion representing $\frac{\partial EMB_Z}{\partial R}=\frac{\partial F^1}{\partial R}$ cannot be signed. Therefore, the sign of $\frac{\partial Z}{\partial R}$ remains ambiguous.

On ex-ante self-insurance, A,

$$\frac{\partial A}{\partial R}=\frac{\overset{(-)}{H_{ZZ}}\cdot\left[\begin{array}{l}\overbrace{\pi(.)}^{(+)}\cdot\overbrace{U^{'}(W_1)}^{(+)}\cdot\overbrace{\frac{\partial^2 L(.)}{\partial R\partial A}}^{(?)}\\+\overbrace{\pi(.)}^{(+)}\overbrace{\left(1+\frac{\partial L(.)}{\partial A}\right)}^{(-)}\cdot\overbrace{U^{''}(W_1)}^{(-)}\cdot\overbrace{\frac{\partial L(.)}{\partial R}}^{(-)}\end{array}\right]+\overset{(?)}{H_{AZ}}\cdot\left[-\overbrace{\frac{\partial\pi(.)}{\partial Z}}^{(-)}\cdot\overbrace{\frac{\partial L(.)}{\partial R}}^{(-)}\cdot\overbrace{U^{'}(W_1)}^{(+)}+\overset{(+)}{\pi(.)}\cdot\overset{(-)}{U^{''}(W_1)}\cdot\overset{(-)}{\frac{\partial L}{\partial R}}\right]}{|H|} \tag{B.9}$$

It is not possible to sign expression (B.9) unambiguously because we cannot determine the directions of the influence of ex-post public assisted relief and rehabilitation program on the expected marginal benefit of self-protection $\left(\frac{\partial EMB_Z}{\partial R}=\frac{\partial F^1}{\partial R}\right)$under the indirect effect. Moreover, additional restrictions need to be imposed to sign the term $\frac{\partial^2 L}{\partial R\partial A}$ and the cross partial H_{ZA}.

Assuming household to be risk neutral, comparative static results show

$$\frac{\partial Z}{\partial R}=\frac{\overbrace{-\pi\cdot\frac{\partial^2 L}{\partial A^2}}^{(-)}\cdot\overbrace{\frac{\partial\pi}{\partial Z}\cdot\left(\frac{\partial L}{\partial R}\right)}^{(+)}-\overbrace{\left(-\frac{\partial\pi}{\partial Z}\cdot\frac{\partial L}{\partial A}\right)}^{(-)}\cdot\overbrace{\left(\pi\cdot\frac{\partial^2 L}{\partial R\partial A}\right)}^{(?)}}{|H|} \tag{B.10}$$

$$\frac{\partial A}{\partial R}=\frac{\overbrace{-\frac{\partial^2\pi}{\partial Z^2}\cdot L(.)}^{(-)}\cdot\overbrace{\pi\cdot\frac{\partial^2 L}{\partial R\partial A}}^{(?)}-\overbrace{\left(-\frac{\partial\pi}{\partial Z}\cdot\frac{\partial L}{\partial A}\right)}^{(-)}\cdot\overbrace{\frac{\partial L}{\partial R}\cdot\frac{\partial\pi}{\partial Z}}^{(+)}}{|H|} \tag{B.11}$$

Under the risk neutral case, it is possible to sign both (B.10) and (B.11) if the following condition holds:

Condition 3. The probability of facing ex-post storm inflicted property damages, $\pi(.)$, is strictly quasi-convex with respect to ex-ante self-protection expenditure, $Z: \frac{\partial\pi(.)}{\partial Z}<0; \frac{\partial^2\pi(.)}{\partial Z^2}>0.$

This implies that the probability of facing monetary losses to property as a result of a cyclone induced storm surge decreases as household self-protection expenditure increases.

Condition 4. A strict quasi-convex relationship exists between storm-inflicted monetary losses to property and ex-ante self-insurance expenditures, $\frac{\partial L}{\partial A} < 0; \frac{\partial^2 L}{\partial A^2} > 0$. This means that monetary losses to property decrease as a household commits more self-insurance expenditure.

Condition 5. $\frac{\partial^2 L(.)}{\partial R \partial A} < 0$. Condition 5 states that more ex-post public-assisted disaster relief and rehabilitation programs, R, accentuate the effect of self-insurance in reducing monetary loss or damages to property as a result of a severe storm event. If Conditions (5) along with the other conditions hold, then it is possible to sign expression (B.10) and (B.11) indicating the following relationship

$$\frac{\partial Z}{\partial R} = \frac{H_{AA} \cdot \overbrace{\text{2nd bracketed term}}^{"+"} - H_{ZA} \cdot \overbrace{\text{4th bracketed term}}^{"+"}}{|H|} = \frac{"-" \; - \; "+"}{"+"} < 0$$

$$\frac{\partial A}{\partial R} = \frac{H_{ZZ} \cdot \overbrace{\text{2nd bracketed term}}^{"-"} - H_{AZ} \cdot \overbrace{\text{4th bracketed term}}^{"+"}}{|H|} = \frac{"+" \; - \; "-"}{"+"} > 0 \qquad \text{(B.12)}$$

Expression (B.12) shows that ex-ante self-protection, Z, is expected to go down but ex-ante self-insurance, A, is expected to go up if households have more access to ex-post government-assisted disaster relief and rehabilitation programs, R. Consequently, one might observe a 'crowding out effect' on households' self-protection but a 'crowding in effect' of self-insurance as a result of an increase in R, assuming the household to be risk neutral. It is not possible to come to a conclusion if the household is risk averse.

Proof of PROPOSITION 3. Comparative analyses could examine the plausible impact of mangrove forests as a natural storm protection barrier on household defensive behavior. The initial comparative static results reveal that we require additional restrictions to establish any relationship between the two variables.

Comparative static results on the influence of mangrove forests, M, on self-protection, Z, reveals

$$\frac{\partial Z}{\partial M} = \frac{\overset{"-"}{H_{AA}} \cdot \left[\begin{array}{l} -\overbrace{\frac{\partial^2 \pi(.)}{\partial M \partial Z}}^{"?"} \cdot \overbrace{\left(U(W_1) - U(W_2)\right)}^{"-"} \\ + \frac{\partial \pi}{\partial M} \cdot \overbrace{\left(U'(W_1) - U'(W_2)\right)}^{"+"} \end{array} \right] + \overset{"?"}{H_{ZA}} \cdot \left[\begin{array}{l} -\frac{\partial \pi(.)}{\partial M} \cdot \overbrace{U'(W_1)}^{"+"} \cdot \overbrace{\left(1 + \frac{\partial L}{\partial A}\right)}^{"-"} \\ + \overbrace{U'(W_2)}^{"+"} \cdot \frac{\partial \pi(.)}{\partial M} \end{array} \right]}{|H|} \qquad \text{(B.13)}$$

Similarly, it is possible to state the influence of M on ex-ante self-insurance A as

$$\frac{\partial A}{\partial M}=\frac{\overset{-}{H_{ZZ}}\cdot\left[\frac{\partial\pi(.)}{\partial M}\cdot U^{'}(W_1)\cdot\left(1+\frac{\partial L}{\partial A}\right)-U^{'}(W_2)\cdot\frac{\partial\pi(.)}{\partial M}\right]+\overset{?}{H_{AZ}}\cdot\left[\frac{\partial^2\pi(.)}{\partial M\,\partial Z}\cdot\left(U(W_1)-U(W_2)\right)-\frac{\partial\pi}{\partial M}\cdot\left(U^{'}(W_1)-U^{'}(W_2)\right)\right]}{|H|} \tag{B.14}$$

As before, it is not possible to sign expression (B.13) and (B.14) unambiguously unless we impose additional restrictions. It is possible to sign them using condition 6 (i.e., $H_{AZ}=H_{ZA}<0$) as well as by introducing the following restriction.

Condition 6. $\frac{\partial^2\pi(.)}{\partial M\,\partial Z}<0$. This condition states that more storm protection from mangroves, M, accentuates the influence of self-protection, Z, in reducing the probability of facing damages to property conditional on the storm event. Condition 6 suggests that the marginal probability of facing damages to property conditional on the storm event as a result of self-protection expenditures Z decreases at an increasing rate for an increase in the household's exposure to the storm-protection services of mangrove forests M.

Assuming it is possible to meet conditions (4) and (7), expressions (B.13) and (B.14) show

$$\frac{\partial Z}{\partial M}=\frac{\overset{-}{H_{AA}}\cdot\overbrace{\text{2nd bracketed term}}^{-}+\overset{-}{H_{ZA}}\cdot\overbrace{\text{4th bracketed term}}^{-}}{|H|}=\frac{"+"\;+\;"+"}{|H|}>0$$

$$\frac{\partial A}{\partial M}=\frac{\overset{-}{H_{zz}}\cdot\overbrace{\text{2nd bracketed term}}^{+}+\overset{-}{H_{AZ}}\cdot\overbrace{\text{4th bracketed term}}^{+}}{|H|}=\frac{"-"\;+\;"-"}{|H|}<0 \tag{B.15}$$

With additional restrictions, the comparative statics result now demonstrates that exposure to greater storm protection services of mangrove forests, M, leads to decrease in a households' ex - ante self-protection strategies, Z. However, it causes an increase in a household's ex-ante self-insurance actions, A.

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Tables

Table 1: Comparative Static Results of the Household Model of Defensive Strategies

Ex-ante self-protection (Z)		
	Conditional Result	**Requirements for Signing Conditional Result**
Access to ex- ante public protection spending	$\frac{dZ}{dG} > 0$	1. $H_{AZ} = H_{ZA} < 0$ 2. $\frac{\partial^2 \pi(.)}{\partial G \partial Z} < 0$
Exposure to mangrove forest	$\frac{dZ}{dM} > 0$	1. $H_{AZ} = H_{ZA} < 0$ 2. $\frac{\partial^2 \pi(.)}{\partial M \partial Z} < 0$
Access to ex-post relief and rehabilitation programs	$\frac{dZ}{dR} < 0$ (Holds only for risk neutral households)	$\frac{\partial^2 L(A,R)}{\partial R \partial A} < 0$
Ex- post self-insurance (A)		
Access to ex- ante public protection spending	$\frac{dA}{dG} < 0$	1. $H_{AZ} = H_{ZA} < 0$ 2. $\frac{\partial^2 \pi(.)}{\partial G \partial Z} < 0$
Exposure to mangrove forest	$\frac{dA}{dM} < 0$	1. $H_{AZ} = H_{ZA} < 0$ 2. $\frac{\partial^2 \pi(.)}{\partial M \partial Z} < 0$
Access to ex-post relief and rehabilitation programs	$\frac{dA}{dR} > 0$ (Holds only for risk neutral households)	$\frac{\partial^2 L(A,R)}{\partial R \partial A} < 0$

Table 2: Summary Statistics of Household based on the Study Area

Household Characteristics		Value	
		Protected	Non-protected
Respondent average age (mean)		42.89	41.69
Respondent Gender (%)	Male	84.09	71.79
	Female	15.91	28.21
Literacy rate of Respondent (%)	Illiterate	7.83	8.36
	Primary School	52.07	45.45
	High School	26.73	27.27
Respondent Occupation (%)	Farmer	24.09	39.78
	Fisherman	6.82	7.17
	Trader	15.91	13.26
	Service	6.36	6.45
	Wage worker	35.91	11.93
Respondent is Head of household (%)		81.36	63.08
Respondent living in the village since birth (%)		91.82	90.68
Average number of family members (Min-Max)		4.97 (1-11)	5.66 (0-25)
Average number of adults (Min-Max)		3.68 (1-10)	4.43 (1-15)
Average number of children (Min-Max)		1.89 (1-7)	1.72 (1-10)
Average number of males at work (Min-Max)		1.33 (1-4)	1.55 (1-7)
Type of Wall used for dwelling at present (%)	Katcha/ Earthen	18.26	5.02
	Tin/ C.I. Sheet	21.46	46.58
	Pacca (brick)	9.13	11.42
	Wood	37.44	42.92
	Jhupri/ Chon	10.50	17.35
Type of Roof used for dwelling at present (%)	Katcha/ Earthen	0.46	1.07
	Tin/ C.I. Sheet	73.97	80.71
	Pacca (brick)	2.28	1.79
	Wood	4.57	2.50
	Jhupri/ Chon	18.72	13.93
Nature of House in past (%)	Same	52.51	74.29
Floors of House at present (%)	Ground floor	90.91	78.85
	Up to first floor	9.09	21.15
Tenure of Residence (%)	Rented	3.67	3.94
	Owned	89.45	92.11
Elevation status of the house (%)	High land	6.82	5.00
	Mid land	37.27	41.07
	Low land	55.91	53.93
Size of homestead (Mean in hectare)		0.13 ha	0.14 ha
Type of latrine (%)	Sanitary	7.73	21.94
	Ring/slab	83.18	64.03
	Katcha	9.55	12.95
Source of drinking water – multiple responses (%)	Deep Tube well	0.45	26.43
	Tube well	12.27	33.57
	Pond/ River	67.73	31.79
	Rain water	48.64	15.36
	Filtered Pond	24.09	11.79
Percentage with electricity connection		21.46	31.79
Percentage with access to cell phone		48.18	45.16
Average household income (US $ /year)		815.47	857.19
Main source of energy- multiple responses (%)	Wood/ Coal	93.52	98.55
	Twigs/ Leafs	83.80	61.82

Table 3: Summary statistics of the Key variables used for Regression Analysis

Variable	Definition	No. of observations	Mean	Standard Deviation
L(DAMAGE)	Log of the nominal value of Cyclone Sidr inflicted damages (in Tk.)	493	10.885	1.1381
L(PREINC)	Log of Pre-Cyclone Sidr HH Income (in Tk.)	449	11.569	1.079
L(PREINC2)	Square of the log of Pre-Cyclone Sidr HH Income (in Tk.)	449	135.02	25.28
L(POSTINC)	Log of Post-Cyclone Sidr HH Income (in Tk.)	489	10.648	1.262
L(POSTINC2)	Square of the log of Post-Cyclone Sidr HH Income (in Tk.)	489	114.96	24.44
AREA	Area of homestead, crop land, and the pond (in decimal)	500	142.6	24.441
DCOAST	Distance from the coast (in Km.)	500	44.10	18.248
AGE	Age of the respondent (in years)	497	42.221	13.252
EDUYR	Average years of respondent education	492	6.868	3.643
CREDIT	If household has access to credit (=1, 0 otherwise)	492	0.5752	0.4948
MEMBER	If household is a member of village level organizations (=1, 0 otherwise)	486	0.1934	0.3954
MFRATIO	Male/ Female ratio of the household	498	1.248	0.7933
CHILDREN	Number of children in the household	500	1.26	1.1896
LOCCLE	If household house is always exposed to major storm given its location (=1, 0 otherwise)	498	0.032	0.177
HELEV2	If household falls into medium elevation area (=1, 0 otherwise)	500	0.394	0.4891
HELEV3	If household falls into high elevation area (=1, 0 otherwise	500	0.058	0.2339
MIGRATION	If planning to migrate in the future (=1, 0 otherwise)	494	0.328	0.469
ELEC	If household has access to electricity (=1, 0 otherwise)	499	0.273	0.4457
PHONE	If household has access to phone (=1, 0 otherwise)	499	0.465	0.4993
PROTECTED	If household falls into the mangrove protected area (=1, 0 otherwise)	500	0.44	0.497
MDIST	Distance between the union and the mangrove forest (in km.)	500	7.536	7.981
MDIR	If household is located to the south or the southwest direction relative to the coast and the Sundarban mangrove forest (=1, 0 otherwise)	500	0.548	0.498
EMB	If household is protected by the embankment (=1, 0 otherwise)	497	0.6097	0.4883
ARELIEF	If household has access to relief (=1, 0 otherwise)	499	0.8938	0.3084
AREHABN	If household has access to rehabilitation (=1, 0 otherwise)	492	0.5508	0.4979
SURGEHT	Approximate average Cyclone Sidr induced Storm surge height (in meter)	500	3.982	0.7085
STORMEXP	If household falls into counter-clockwise direction from Cyclone Sidr (=1, 0 otherwise)	500	0.42	0.4941
STORMDIS	Directional Distance between Household and the Track for the Cyclone Sidr (in km)	500	15.839	10.124

Table 4: Full information maximum likelihood (FIML) of the sample selection model for participation (selection) in ex-ante self-protection: Sample includes the entire study area [a]

Selection Equation (dependent variable is the probability of households participating in ex-ante self-protection)								
Variable	(1)		(2)		(3)		(4)	
	Coeff.	Marg. Eff.	Coeff.	Marg. Eff.	Coeff.	Marg. Eff.	Coeff.	Marg. Eff.
CONSTANT	-15.568		-16.554		-16.843		-14.660	
	(-1.98)**		(-2.08)**		(-2.00)**		(-1.76)**	
L(DAMAGE)	0.1768	0.0477	0.1978	0.0523	0.2128	0.0536	0.1899	0.0466
	(2.44)***		(2.66)***		(2.74)***		(2.43)***	
L(PREINC)	2.084	0.5617	2.325	0.6135	2.391	0.6024	1.956	0.4801
	(1.59)*		(1.76)**		(1.70)**		(1.41)*	
L(PREINC2)	-0.0857	-0.0231	-0.095	-0.0251	-0.0968	-0.0244	-0.0794	-0.0195
	(-1.55)*		(-1.71)**		(-1.63)*		(-1.36)*	
AREA	0.0006	0.0001	0.0006	0.0001	0.0005	-0.0019	0.0006	0.0001
	(2.33)***		(2.03)**		(1.83)**		(1.75)**	
DCOAST	0.0114	0.0031	0.0014	0.0004	0.0063	0.0016	0.0074	0.0018
	(2.90)***		(0.19)		(0.80)		(0.74)	
AGE	-0.0022	-0.0006	-0.0041	-0.0011	-0.0076	-0.0019	-0.0079	-0.0019
	(-0.39)		(-0.72)		(-1.25)		(-1.26)	
LOCCLE	0.2067	0.0604	0.0014	0.0004	-0.3833	-0.08	-0.3487	-0.0719
	(0.55)		(0.00)		(-0.98)		(-0.85)	
EDUYR	0.0155	0.0042	0.0111	0.0029	0.0081	0.0020	0.0094	0.0023
	(0.70)		(0.49)		(0.35)		(0.39)	
CREDIT	-0.2543	-0.0696	-0.3426	-0.0923	-0.4249	-0.1097	-0.4291	-0.1080
	(-1.63)**		(-2.12)**		(-2.52)***		(-2.48)***	
MEMBER	0.2653	0.0763	0.2216	0.0618	0.3358	0.0925	0.2864	0.0761
	(1.37)*		(1.09)		(1.58)*		(1.29)*	
CHILD	-0.1209	-0.0326	-0.1243	-0.0328	-0.1293	-0.0326	-0.1184	-0.0291
	(-1.77)**		(-1.74)**		(-1.63)**		(-1.40)*	
ELEC	0.0167	0.0045	0.11	0.0297	0.1526	0.0397	0.1747	0.0446
	(0.10)		(0.64)		(0.88)		(0.95)	
PHONE	-0.3537	-0.095	-0.3107	-0.0817	-0.3589	-0.0901	-0.3236	-0.0792
	(-2.28)**		(-2.00)**		(-2.30)**		(-1.92)**	
HELEV2	0.2783	0.0774	0.2791	0.0759	0.1666	0.0429	0.1308	0.0327
	(1.75)**		(1.70)**		(0.97)		(0.68)	
HELEV3	0.2539	0.075	0.1936	0.0549	0.289	0.0815	0.4260	0.1233
	(0.81)		(0.60)		(0.87)		(1.25)	
MIGRATION	-0.073	-0.0195	-0.2386	-0.0605	-0.2605	-0.0627	-0.2093	-0.0495
	(-0.45)		(-1.35)*		(-1.46)*		(-0.98)	
PROTECTED			0.5425	0.1463	0.3569	0.0914	-0.6388	-0.1519
			(1.62)*		(1.05)		(-1.25)	
MDIST			-0.0315	-0.0083	-0.0299	-0.0075	-0.0486	-0.0119
			(-1.32)*		(-1.18)		(-1.81)**	
MDIR			-0.4869	-0.1275	-0.4535	-0.1136	-0.5583	-0.1361
			(-1.51)*		(-1.33)*		(-1.61)*	
EMB					-0.2133	-0.0548	-0.270	-0.068
					(-1.04)		(-1.02)	
ARELEIF					-0.4091	-0.1189	-0.3663	-0.1028
					(-1.55)*		(-1.34)*	
AREHABN					0.3635	0.0902	0.2299	0.0559
					(2.02)**		(1.21)	
SURGEHT							0.2925	0.0718
							(1.40)*	
STORMEXP							-0.7539	-0.1713
							(-1.92)**	
STORMDIS							0.0342	0.0084
							(3.15)***	

[a] Z-tests are shown in parentheses beneath coefficient estimates. Significance levels: ***1%, **5%, *10%.

Table 5: Full information maximum likelihood (FIML) of the sample selection model for the outcome in self-protection conditional on participation: Sample includes the entire study area [a,b]

Outcome Equation (dependent variable is the level of household ex-ante self-protection expenses (in Tk.) conditional on participation in self-protection activities)								
	(1)		(2)		(3)		(4)	
Variable	Coeff.	Marginal Effect	Coeff.	Marginal Effect	Coeff.	Marginal Effect	Coeff.	Marginal Effect
CONSTANT	5012499 (2.61)***		4824857 (2.36)***		2950481 (1.47)*		2777406 (1.33)*	
L(DAMAGE)	31414.17 (2.09)**	44923.1	24557.77 (1.57)*	40554.6	29679.57 (1.88)**	49160.5	31806.89 (1.95)**	45494.81
L(PREINC)	-935330.2 (-3.01)***	-776090.8	-899233.7 (-2.75)***	-711072.6	-575624.9 (-1.75)**	-356740.2	-521966 (-1.56)*	-374203.1
L(PREINC2)	42147.74 (3.20)***	35599.76	40958.9 (2.96)***	33272.25	26576.42 (1.89)**	17713.34	24181.45 (1.69)**	18158.33
AGE	449.59 (0.45)	281.23	546.27 (0.56)	211.068	-42.049 (-0.04)	-736.54	-242.53 (-0.26)	-701.92
EDUYR	-2545.32 (-0.62)	-1361.56	-5409.89 (-1.27)	-4507.78	-4036.27 (-0.95)	-3293.11	-3939.07 (-0.93)	-3537.97
CREDIT	60455.59 (2.05)**	41081.37	68927.8 (2.29)**	41332.78	84707.43 (2.73)***	45990.64	71259.19 (2.29)**	42720.4
MEMBER	-57153.8 (-1.57)*	-37143.19	-52587.16 (-1.36)*	-34848.24	-61786.5 (-1.55)*	-31531.49	-49364.74 (-1.20)	-34437
HELEV2	-50837.99 (-1.63)*	-29703.08	-58545.41 (-1.90)**	-36105.7	-61397.25 (-1.92)**	-46199.14	-47904.82 (-1.66)**	-40963.73
HELEV3	-55360.76 (-1.01)	-36327.12	-81923.15 (-1.50)*	-66475.8	-121005.4 (-2.11)**	-95085.01	-91877.5 (-1.54)*	-68853.65
PROTECTED			68426.17 (1.51)*	112066.5	114195.1 (2.29)**	146762.2	145357.8 (1.50)*	105508.6
MDIST			1065.49 (0.30)	-1486.69	1483.77 (0.41)	-1255.26	-158.71 (-0.04)	-3278.65
MDIR			-34526.22 (-0.68)	-73922.3	-48006.21 (-0.96)	-89521.16	-67997.52 (-1.40)*	-103706.2
EMB					92285.14 (2.20)**	72824.25	117533.6 (2.06)**	101743.1
ARELEIF					-21934.62 (-0.41)	-58372.31	-44006.35 (-0.86)	-69109.94
AREHABN					-17993.46 (-0.54)	-15334.42	-3048.42 (-0.10)	12152.6
SURGEHT							-42107.52 (-1.04)	-25373.06
STORMEXP							24155.5 (0.31)	-25939.13
STORMDIS							-1273.51 (-0.49)	1265.82
RHO	-0.700009 (-4.07)***		-0.7477589 (-4.21)***		-0.8336851 (-6.20)***		-0.7919759 (-3.90)***	
SIGMA	138735.6 (6.25)***		136971.7 (5.41)***		137969.1 (5.27)***		129815.8 (4.45)***	
LOG LIKE.	-1308.99		-1300.28		-1229.22		-1222.58	
LR test (ρ=0)	5.16** (χ^2=1)		4.12* (χ^2=1)		6.14** (χ^2=1)		3.65 (χ^2=1)	
LR test (prob>χ^2)	0.0231		0.0425		0.000		0.0560	
CENS. OBS.	315		315		309		309	

[a] Under FIML, the LR stat to test independence between the error terms of the participation and outcome equations provide strong evidence against the null in all cases. That is, we reject the null or accept the dependence between the error terms.
[b] Z-tests are shown in parentheses beneath coefficient estimates. Significance levels: ***1%, **5%, *10%.

Table 6: Probit and Tobit Model for Ex-post Self-insurance

Variable	**Probit Model** [a] (dependent variable is the probability of households participating in self-insurance)				**Tobit Model** [b] (dependent variable is the level of household ex-post self-insurance expenditures in Taka)			
	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
CONSTANT	-5.556 (-2.22)**	-5.448 (-2.04)**	-6.683 (-2.35)***	-5.766 (-1.92)**	387428.9 (3.53)***	388326.1 (3.52)***	357000.4 (3.20)***	428488.2 (3.56)***
L(DAMAGE)	0.0923 (1.50)*	0.0832 (1.33)*	0.0730 (1.07)	0.0543 (0.79)	9793.67 (3.26)***	9584.08 (3.24)***	10291.85 (3.44)***	10127.24 (3.37)***
L(POSTINC)	0.6360 (1.31)	0.6619 (1.29)*	0.6617 (1.23)	0.6649 (1.22)	-130195.5 (-6.13)***	-130509.5 (-6.21)***	-129021.6 (-6.13)***	-131729.7 (-6.25)***
L(POSTINC2)	-0.0307 (-1.24)	-0.0315 (-1.20)	-0.0284 (-1.04)	-0.0280 (-1.01)	7267.94 (6.64)***	7243.68 (6.67)***	7180.74 (6.60)***	7329.67 (6.73)***
AREA	0.00002 (0.06)	-0.00008 (-0.30)	-0.00009 (-0.38)	-0.00013 (-0.53)	0.7022 (0.06)	-2.106 (-0.17)	-1.910 (-0.15)	-1.593 (-0.13)
DCOAST	0.0117 (2.76)***	0.0211 (2.72)***	0.0302 (3.38)***	0.0238 (2.15)**	-46.081 (-0.24)	762.35 (2.20)**	886.99 (2.34)***	447.89 (0.95)
AGE	0.0024 (0.46)	0.0032 (0.60)	0.0015 (0.26)	0.0025 (0.42)	432.58 (1.74)**	445.73 (1.81)**	424.28 (1.69)**	442.43 (1.75)**
EDUYR	-0.0414 (-1.85)**	-0.0337 (-1.47)*	-0.0331 (-1.35)*	-0.0332 (-1.35)*	1498.51 (1.47)*	2183.19 (2.13)**	2349.95 (2.29)**	2365.25 (2.31)**
CREDIT	0.1359 (0.96)	0.2324 (1.56)*	0.1739 (1.08)	0.1742 (1.07)	3207.58 (0.48)	7940.03 (1.18)	9088.85 (1.33)*	8787.12 (1.29)*
MEMBER	-0.4831 (-2.36)***	-0.6923 (-3.17)***	-0.8197 (-3.50)***	-0.8227 (-3.47)***	739.53 (0.08)	-6456.38 (-0.70)	-7200.24 (-0.77)	-6517.14 (-0.70)
CHILD	0.0952 (1.59)*	0.1159 (1.87)**	0.1503 (2.31)**	0.1584 (2.39)***	13108.13 (4.56)***	14150.84 (4.95)***	14053.71 (4.85)***	13571.03 (4.65)***
MIGRATION	0.0248 (0.16)	0.0499 (0.30)	0.1028 (0.56)	0.1904 (1.02)	-4938.25 (-0.68)	2271.79 (0.30)	1944.53 (0.25)	2919.96 (0.36)
ELEC	0.3372 (2.02)**	0.3885 (2.23)**	0.4097 (2.20)**	0.4221 (2.23)**	-2779.96 (-0.35)	-5137.66 (-0.63)	-5726.66 (-0.70)	-7504.53 (-0.90)
HELEV2	-0.0042 (-0.03)	-0.1881 (-1.17)	-0.1784 (-1.04)	-0.1803 (-0.99)	-8206.32 (-1.18)	-15536.18 (-2.18)**	-15403.54 (-2.11)**	-11114.02 (-1.41)*
HELEV3	0.2806 (0.94)	0.2349 (0.77)	0.4257 (1.29)*	0.5306 (1.56)*	-16811.23 (-1.10)	-17389.07 (-1.15)	-15976.48 (-1.04)	-12461.09 (-0.80)
PROTECTED		-0.7958 (-2.51)***	-1.289 (-3.68)***	-1.117 (-2.31)**		-56169.82 (-3.76)***	-52976.78 (-3.46)***	-48332.69 (-2.32)***
MDIST		-0.0499 (-2.09)**	-0.0572 (-2.15)**	-0.0553 (-1.98)**		-1748.22 (-1.62)*	-2113.72 (-1.87)**	-2014.65 (-1.70)**
MDIR		0.1043 (0.32)	-0.0557 (-0.15)	0.0201 (0.05)		10926.43 (0.74)	5752.64 (0.37)	9379.12 (0.59)
EMB			-0.2765 (-1.49)*	-0.0289 (-0.13)			12148.98 (1.47)*	17964.47 (1.79)**
ARELEIF			0.7493 (2.24)**	0.7314 (2.18)**			12978.14 (1.14)	11824.92 (1.04)
AREHABN			0.9098 (5.36)***	0.9161 (5.30)***			-6969.99 (-0.95)	-5460.13 (-0.73)
SURGEHT				-0.2876 (-1.45)*				-10935.65 (-1.29)*
STORMEXP				0.0723 (0.21)				-10575.4 (-0.74)
STORMDIS				0.0126 (1.26)				-4.919 (-0.01)
Log Like.	-222.30	-214.113	-188.25	-186.28	-3464.78	-3454.87	-3399.99	-3398.75
LR Chi2	36.39	52.77	98.05	102.00	106.04	125.85	129.34	131.82
OBS.	444	444	432	432	447	447	435	435

[a] For the Probit model, Z-tests are shown in parentheses beneath coefficient estimates. Significance levels: ***1%, **5%, *10%.
[b] For the Tobit model, t-tests are shown in parentheses beneath coefficient estimates. Significance levels: ***1%, **5%, *10%.

Table 7: Seemingly Bivariate Probit Model of Self-protection and Self-insurance [a]

Variables	Basic Model		With Mangroves Characteristics		With Public Programs		With Storm Surge Characteristics	
	SPROT	SINSUR	SPROT	SINSUR	SPROT	SINSUR	SPROT	SINSUR
CONSTANT	-13.044 (-1.73)**	-5.295 (-2.03)**	-13.417 (-1.73)**	-5.126 (-1.88)**	-13.232 (-1.59)*	-7.407 (-2.59)***	-10.777 (-1.29)*	-6.446 (-2.15)**
L(DAMAGE)	0.1479 (2.11)**	0.0850 (1.32)*	0.1716 (2.36)***	0.0824 (1.26)	0.1953 (2.55)***	0.1124 (1.54)*	0.1659 (2.15)**	0.1120 (1.51)*
L(PREINC)	1.757 (1.40)*		1.892 (1.47)*		1.868 (1.34)*		1.298 (0.93)	
L(PREINC2)	-0.0706 (-1.34)*		-0.0761 (-1.41)*		-0.0752 (-1.28)*		-0.0514 (-0.88)	
L(POSTINC)		0.5997 (1.18)		0.5944 (1.13)		0.5725 (1.07)		0.5604 (1.04)
L(POSTINC2)		-0.0302 (-1.17)		-0.0300 (-1.12)		-0.0255 (-0.94)		-0.0235 (-0.86)
AREA	0.0006 (2.27)**	0.0005 (1.55)*	0.0006 (1.92)**	0.0004 (1.17)	0.0006 (1.90)**	0.0005 (1.55)*	0.0006 (1.90)**	0.0005 (1.61)*
DCOAST	0.0075 (1.83)**	0.0133 (3.08)***	0.0069 (0.89)	0.0237 (3.07)***	0.0086 (1.00)	0.0326 (3.65)***	0.0136 (1.32)*	0.0251 (2.29)**
AGE	-0.0027 (-0.50)	0.0029 (0.55)	-0.0037 (-0.67)	0.0034 (0.63)	-0.0059 (-1.00)	0.0004 (0.07)	-0.0068 (-1.13)	0.0015 (0.25)
EDUYR	0.0144 (0.64)	-0.0444 (-1.94)**	0.0122 (0.53)	-0.0383 (-1.64)*	0.0089 (0.38)	-0.0439 (-1.75)**	-0.0088 (-0.36)	-0.0441 (-1.76)**
CREDIT	-0.2127 (-1.44)*	0.2229 (1.50)*	-0.2784 (-1.82)**	0.2637 (1.72)**	-0.3500 (-2.18)**	0.1789 (1.08)	-0.3489 (-2.13)**	0.1643 (0.98)
MFRATIO	-0.1262 (-1.29)*	-0.0163 (-0.18)	-0.1009 (-1.03)	-0.0289 (-0.31)	-0.1160 (-1.13)	0.0053 (0.05)	-0.1296 (-1.22)	0.0285 (0.27)
CHILD	-0.1307 (-1.92)**	0.0651 (1.09)	-0.1463 (-2.09)**	0.0779 (1.27)	-0.1724 (-2.31)**	0.1070 (1.65)**	-0.1519 (-1.95)**	0.0988 (1.50)*
ELEC	-0.1023 (-0.58)	0.3626 (2.16)**	-0.0237 (-0.13)	0.3858 (2.20)**	0.0282 (0.15)	0.4318 (2.29)**	0.0944 (0.49)	0.4063 (2.14)**
PHONE	-0.2920 (-1.83)**	-0.1279 (-0.81)	-0.3075 (-1.90)**	-0.1686 (-1.06)	-0.3701 (-2.19)**	-0.3246 (-1.90)**	-0.3217 (-1.80)**	-0.3036 (-1.74)**
PROTECTED			0.1231 (0.39)	-0.6596 (-2.16)**	0.0526 (0.16)	-0.9193 (-2.76)***	-0.9809 (-1.99)**	-0.3422 (-0.70)
MDIST			-0.0516 (-2.12)**	-0.0415 (-1.76)**	-0.0424 (-1.67)**	-0.0378 (-1.48)*	-0.0638 (-2.38)***	-0.0284 (-1.05)
MDIR			-0.5943 (-1.82)**	-0.0725 (-0.22)	-0.4897 (-1.41)*	-0.1886 (-0.53)	-0.6559 (-1.85)**	-0.0895 (-0.24)
EMB					-0.1584 (-0.79)	-0.1362 (-0.71)	-0.2225 (-0.86)	0.0925 (0.37)
ARELEIF					-0.3935 (-1.57)*	1.179 (2.58)***	-0.3161 (-1.20)	1.163 (2.52)***
AREHABN					0.3546 (2.03)**	0.9375 (5.19)***	0.1825 (0.98)	1.0021 (5.41)***
SURGEHT							0.3665 (1.85)**	-0.3435 (-1.78)**
STORMEXP							-0.7162 (-1.91)**	0.2576 (0.75)
STORMDIS							0.0386 (3.61)***	-0.0044 (-0.43)
LOG LIKE. (OBS)	-401.978 (402)		-392.845 (402)		-355.536 (392)		-345.119 (392)	
Wald χ^2 (df)	52.89 (26)		67.86 (32)		102.95(38)		116.71 (44)	
LR test $(\rho = 0)$	$\chi^2(1)$ = 4.607**		$\chi^2(1)$ =4.128**		$\chi^2(1)$ =2.273*		$\chi^2(1)$ = 2.971*	

[a] Dependent variables are the probability of households participating jointly in self-protection and self-insurance activities. Z-tests are shown in parentheses beneath coefficient estimates. Significant levels: ***1%, **5%, *10%.

[1] We assume that the self-protection or self-insurance actions of the household have no positive or negative externality impact on other households. This suggests that the household cannot transfer the consequences of its self-protection or self-insurance actions to others.

[2] For ease of exposition, we omit the household index i and the village index j in the following steps.

[3] Hiebert (1983) introduced the terms 'stochastic substitutes' and 'stochastic complements' to define the relationships between technological inputs to reduce risks of a competitive firm facing production uncertainty. Archer *et al.* (2006) later applied the same terms to sign their comparative static results under the endogenous risk framework to study a parent's child care choices among alternative childcare technologies when the child could be exposed to some environmental hazard.

[4] Although the Sundarban may have offered protection to many coastal communities, Cyclone Sidr also severely affected approximately 30,000 acres of forest resources while partially affected another 80,000 acres in the southeast Sundarban, thus causing estimated forest damages of US $ 145 million (GOB, 2008).

[5] We selected the area based on the Saffir-Simpson tropical storm intensity scale developed by the UN Office for the Coordination of Human Affairs (OCHA). Areas on the southwest coast and the entire Sundarban mangrove forest fall under the high risk zone. The map illustrating this division is available from the authors upon request.

[6] The term 'union' refers to the lowest administrative unit in the rural areas of Bangladesh. Administratively, Bangladesh has 6 divisions, 64 zilas, 508 upazilas and 4466 unions (Source: *Statistical Pocketbook of Bangladesh*, 2009). Under the Village Chaukidari Act of 1870, villages were grouped into unions to provide for a system of watches and wards in each village.

[7] Besides performing full information maximum likelihood (FIML) method on our full sample following the Heckman model, we also performed separate regressions for the two-part model. Since most of the results remain unchanged under the two-part model compared to the Heckman model, we decided to report the most significant and robust specification results using FIML in Table 4.

[8] To test H_1, we use actual damages inflicted by Cyclone Sidr as a proxy for expected damages, as our survey occurred in the year following the storm. Although our survey was able to recover households' estimates of self-protection actions and expenditures that they undertook before the storm and their self-insurance measures immediately after the storm, it proved too difficult in such an ex-post survey to obtain the households' estimates of their expected damages from Cyclone Sidr.

[9] The likelihood ratio test (LR test) for the correlation between the error terms of the two equations for all regressions except the basic regression 1 suggests that the Heckman two-step method is preferred to the two-part model. However, taking into account the possible collinearity between the inverse Mills ratio and other regressors, we also considered the two-part model as an alternative regression specification. Results from the two-part model are similar, except that none of the mangroves variables are statistically significant. The regressions from the two-part model are available from the authors upon request.

[10] Using the damage function approach and secondary data from the 1999 Super Cyclone in Orissa, Das and Vincent (2009) show the possible storm protection role of mangroves in saving lives and property. Barbier (2007) employs an expected damage function approach to estimate the value of mangroves in protecting against coastal storms across provinces in Thailand over 1996-2004.

[11] There is a distinction between the expected utility stated in equation (3) and the expected utility stated in equation (A.1). In equation (3), we substituted for X (i.e. the composite good) considering the income constraint. Thus, the choice variables for equation (4) are Z and A. But for the maximization problem with constraints in equation (A.1), we do not perform any substitution since we are interested in the Kuhn-Tucker conditions in order to explain the household behavioral responses to private storm protection strategies (i.e. the four types). Thus, for this case, the choice variables are Z, A, and X.

[12] Hiebert (1983) introduced the terms 'stochastic substitutes' and 'stochastic complements' to define the relationships between technological inputs to reduce risks of a competitive firm facing production uncertainty. Archer *et al.* (2006) later applied the same terms to sign their comparative static results under the endogenous risk framework to study a parent's child care choices among alternative childcare technologies when the child could be exposed to some environmental hazard.