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 combines household production with an endogenous risk framework in order to understand how ex-ante private spending by coastal households against ex-post storm-inflicted damages would evolve given the public programs and the presence of a mangrove forest. The theoretical model confirms the influence of public protection programs and the mangrove forest on private defensive expenditures based on whether the public programs serve as a possible stochastic substitute or a stochastic complement to the mangroves. The model is later applied empirically to a case study based on survey data from 35 villages comprising 500 households in the southwest coastal areas of Bangladesh affected by Cyclone Sidr in November 2007. Preliminary empirical results reveal the influence of public protective programs and the mangroves on a household's storm protection choices. However, results also show that other controls seem to have a considerable influence and add a degree of complexity to the relationship.

Key words: Self-protection; Self-insurance; Storm-inflicted damages; Mangroves; Bangladesh

JEL Classifications: D81, Q51, Q54.

1. Introduction

According to reports, climate changes may significantly increase the intensity of severe cyclones and associated storm surge events in future because of sea level rise and increases in sea surface temperatures (IPCC, 2005, 2007; UNDP, 2007; Dasgupta *et al.,* 2009). As a result, households in the coastal areas would be more vulnerable to cyclone and storm surge induced damages to life and property. Considering the higher risks entailed in facing extensive cyclone and storm surge related damages, households that have had previous encounters with damaging cyclones might invest their time and money in different ex-ante private defensive strategies in order to insulate themselves against storm surge risk. When households take private action to reduce the probability and severity of storm-inflicted damages, the storm surge risk becomes endogenous. Under incomplete market insurance, the term for private investments that reduce the probability of endogenous environmental storm surge risks is "self-protection" while the term for expenditures that reduce the magnitude of the environmental risk if it is realized is "self-insurance".[1] However, a household's access to government-assisted cyclone preparedness and disaster management programs as well as its access to a natural storm protection barrier such as a mangrove forest could hinder incentives to increase private storm protection activities to reduce the storm surge damage risk. Thus, the level of ex-ante private investment that a household might allocate for protection against storm-inflicted damages might differ from one household to another depending on risk perception, expectation of public protection programs, and the location of the household relative to the coast and the mangroves. Taking into account the above factors, this paper sets out to investigate how ex-ante private spending by coastal households to self-protect and self-insure against ex-post storm surge damages would evolve given the level of government protection spending and the presence of a natural storm protection barrier.

Recent reports on climate change reveal that while the severity of cyclones due to climate change is increasing on a global scale, coastal areas marked by high population density and abject poverty might experience more damage as a result of cyclone and storm surge events (IPCC, 2005, 2007; UNDP, 2007; Dasgupta *et al.,* 2009).[2] For example, one of the most affected areas is the coastal population of Bangladesh due to its unique geographic and geomorphologic characteristics causing it to frequently face severe storm events (IPCC, 2007; Murty and El-Sabh, 1992; Ali, 1996, 1999; Karim and Mimura, 2008).[3] Conditional upon experiencing adverse storm events in the future, we can divide a representative household's preference for ex-ante private expenditures in this type of unfavorable environment into two parts: (1) Household *ex-ante self protection expenditures* on actions that decrease the probability of incurring ex-post property damages as a result of a future storm event. This includes converting a mud-built house to brick-built house, raising the height of the homestead, moving the house inside the embankment, and taking refuge in a neighbor's house; (2) Household *ex-ante self-insurance expenditures* on actions that relieve the impact of storm surge damage risk to property once it has occurred.[4] This includes opportunities for households to diversify post-disaster income, options to increase borrowing through different formal and informal sources, and possibilities to receive private transfer through remittances and charities (see Table 1).[5]

[1] Ehrlich and Becker (1972) defined two basic technologies of endogenous risk: self-protection and self-insurance. Self-protection reduces the probability of an undesired state whereas self-insurance reduces the severity of consequences if the state is realized. Both self-protection and self-insurance mechanisms to reduce risks can be extended to natural disaster losses from floods, earthquakes, cyclones, etc.

[2] Raw data on natural disaster deaths between 1960 and 2007 prepared by the Center for Research on the Epidemiology of Disasters (CRED, 2008) also reveal that meteorological disaster related deaths as a result of cyclones and storm surges are mainly concentrated in the tropics. 91% of the deaths occurred in Asia alone.

[3] By severe cyclone and storm surges, the study refers to Category 5 and 6 Cyclones, which are known as Severe Cyclone with core hurricane intensity (SCHI) and Super Cyclone (SC) respectively. Based on the Bangladesh Meteorological Department (BMD) definition, the maximum wind speed is greater than 118 km/h for SCHI whereas it is greater than 220 km/h for SC storms (ADRC, 2005). Under the Saffir-Simpson hurricane scale, which the National Weather Service in the USA uses to categorize hurricane intensity, the storms would come under Category 3 and Category 4 if we take into account the expected damages as a result of cyclone-induced wind speed and storm surge (NWS, 2006).

[4] It may seem that the household can take actions prior to as well as subsequent to the occurrence of the storm surge event. Yet it has to formulate strategies and allocate investment before the event occurrence.

[5] Skoufias (2001) has given a detailed exposition of the different coping strategies adopted by households from low- and middle-income countries to protect themselves against natural disaster risks.

However, human behavioral studies show that one of the main inhibiting factors when it comes to humans investing in natural disaster risk reduction strategies is their inadequate concern about impending natural disasters (O'Connor *et al.*, 2002; Brechin, 2003; Nisbet and Myers, 2007; Norgaard, 2009), where they put a future natural disaster risk to be low on the probability scale but high on the consequence scale (Kahneman & Tversky, 1979; Magat *et al.*, 1987; Camerer and Kunreuther, 1989; Kahneman *et al.,* 2001). In addition, studies that have considered the inclination of individuals for public or private storm protection actions reveal that individuals have the tendency to not 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; Kunreuther and Pauly, 2006). Hence, public protection programs might partially or fully crowd out private storm protection actions.[6] This behavioral pattern of under-insurance because of anticipated government support is termed the 'charity hazard' in disaster insurance literature (Browne and Hoyt, 2000; Lewis and Nickerson, 1989; Raschky and Weck-Hannemann, 2007).[7] Moreover, government intervention might be lower in areas that are presumed to cope better because of their close proximity to a possible natural storm protection barrier such as a mangrove forest. As a result, the crowding out effect in these areas is bound to be lower. Thus, households living close to a mangrove forest would commit more resources for ex-ante private spending against storm surge damage if they expect to receive fewer public goods due to lower government intervention.

With regard to the storm protection role of mangroves, available scientific evidence suggests that the ability of mangrove forests to attenuate wave energy against severe cyclone-induced storm surges strongly depends on forest density, diameter of stems and roots, forest floor slope, bathymetry, the spectral characteristics (height, period, etc.) of the incidence of waves, and the tidal stage at which the waves enter the forest (Mazda *et al.,* 1997, 2006; Massel *et al.,* 1999; Quartel *et al.,* 2007). Basing themselves on types of mangroves species, Brinkman *et al.* (1997) and Mazda *et al.* (2006) have found that waves could be reduced in energy by 50 percent if a mangrove forest is within 100 to 150 meters. However, despite scientific literature lending credence to a mangrove's role as a wave barrier against storm surges, there is considerable debate on whether they play a significant role in protecting life and property against the increasing severity of cyclones and associated storm surges.[8] Offering a partial explanation on differences in the actual storm protection role played by mangroves, eco-hydrology studies have shown that mangroves are less likely to stop a tsunami wave higher than 6 meters, which also implies that they may not be that effective in protecting life and property against tsunami-type storm surges (Wolanski, 2007; Cochard *et al.,* 2008; Yanagisawa *et al.,* 2009). Moreover, according to these same reports, wave attenuation by mangroves is qualitatively different for large, infrequent disturbances such as tsunamis, hurricanes/typhoons, tidal bores, etc., as opposed

[6] 'Partial' or 'full' crowding effect refers to a household's decision to partially or fully reduce their investment in self-protection and self-insurance because they expect increased government spending on disaster relief and rehabilitation programs against future storm-inflicted damages.

[7] The charity hazard defines an individual's tendency not to insure or take any other mitigation measures as a result of the reliance on expected financial assistance from either federal relief programs or donations by other individuals.

[8] According to most studies, coastal areas with dense mangrove forests suffered less damage to life and property compared to areas where mangroves were either completely destroyed or had been converted to other land uses (Badola & Hussein, 2005; Das & Vincent, 2009; Danielson *et al.,* 2005; Kathiresan and Rajendran, 2005; UNEP, 2005; Barbier, 2007). There is also a handful of studies that question the actual storm protection role played by mangroves (Alongi, 2008; Chatenoux and Peduzzi, 2007; Kerr and Baird, 2007).

to small, frequent disturbances such as tropical storms, coastal floods, and tidal waves (Alongi, 2008).
Taking into consideration the role played by the degree of government intervention, the moral hazard, and the presence of mangrove forest on ex-ante private investment associated with storm-surge damages, this paper addresses the following research questions: (1) Does the expectation of public-assisted disaster relief and rehabilitation programs as a result of the increasing intensity of future severe cyclone-induced storm surge events result in less self-protection and self-insurance by coastal households?; and, (2) Does living in close proximity to mangroves lead to less self-protection and self-insurance by coastal households against damages from cyclone-induced storm surge events?

To find answers to the research questions, the paper introduces a theoretical model combining the household production function with an endogenous risk framework where households choose the level of ex-ante private spending against ex-post cyclone induced storm surge damage risk.[9] Estimating the empirical model, the paper focuses on a study of the private defensive expenditure allocation decisions from thirty five (35) villages comprising 500 households in the southwest coastal areas of Bangladesh which suffered a severe cyclone induced storm surge event in November 2007.

This paper contributes to the literature in the following areas: (1) on endogenous risk literature, it is the first to introduce a two-choice variables model, i.e. self-protection and self-insurance, for a risk-averse household. Using Kuhn-Tucker conditions, this paper identifies four types of households' behavioral responses to reduce the likelihood and severity of facing monetary losses or damages to property from a major storm event. Consequently, the model is able to show the 'corner' solutions that might arise because of a household's inability to afford private storm protection; (2) on the expectation of public good literature, comparative static analyses from the model reveal that ex-ante public programs are complements to self-protection expenditures but substitutes to self-insurance; whereas, ex-post public programs are substitutes to self-protection but complements to self-insurance. Therefore, these findings suggest possible 'full' or 'partial' crowding out as well as crowding in effects on household's self-protection and self-insurance; (3) on the literature on the role of mangroves as a natural storm protection barrier, this paper is the first to introduce an endogenous risk framework model in order to understand the possible influence of mangroves on private storm protection strategies. Moreover, the study is also the first to conduct an empirical investigation about possible influence of mangroves on private storm protection strategies with household survey data.[10]

The rest of the paper is as follows. Section 2 explains the household model of ex-ante private investment while Section 3 describes the process of data collection and offers a brief description of the study area. In Section 4 discusses the empirical and econometric estimations. Section 5

[9] Researchers use the household production function framework extensively in environmental studies to infer an individual's values for health risk changes as a result of some environmental 'bad' (Agee & Crocker, 1996; Berger *et al.,* 1987; Bresnahan *et al.,* 1987; Harrington & Portney, 1987; Shogren & Crocker, 1992; Freeman, 2003).
[10] Using damage function approach on secondary data of 1999 Super Cyclone in Orissa, Das and Vincent (2009) show possible storm protection role of mangroves in saving lives and property.

reports the results and Section 6 analyzes them. Section 7 outlines conclusions and policy recommendations.

2. The Household Model of Ex-Ante Private Investment

Let us suppose that a rural household living along a coastal area is exposed to a severe cyclone-induced storm surge which would inflict property loss. We can describe this environmental storm surge risk in terms of two characteristics: (1) the range of possible adverse consequences, and (2) the probability distribution across consequences. In this paper, we measure the adverse effects in units that reflect the consequences, such as monetary losses to property in terms of the number of damaged houses, trees, livestock and poultry, and agricultural crops. To keep the exposition simple, we assume that there is one possible adverse cyclone-induced storm surge event and two possible states of nature: state 1, the household faces damages to property; and state 2, the household experiences no damages to property.

Since we are interested in households' storm protection actions when they are fully exposed to a storm surge event, the household model does not consider non-storm states. In addition, the model does not bring any dynamic perspective to the problem, because evidence shows storms are frequent events (IPCC, 2005, 2007). Fig. 1 illustrates the probability tree that depicts how the sequence of events that takes place when a household is fully exposed to a storm surge.

Under a simple discrete formulation, Fig. 1 shows that the starting point of the probability tree is the adverse storm event, which is exogenous. At this point, each household faces two states of nature: state 1, the probability of experiencing property damages, which is notated $\pi(.)$; and state 2, the probability of experiencing no damages to property, which is notated $1-\pi(.)$. We assume that a household's ex-ante private spending can influence its probability of experiencing property damage through self-protection and a reduction in the severity of damages 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 household i located in village j is[11]

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

where Z_{ij} is the level of ex-ante self-protection expenditures to pursue actions to decrease the probability of facing ex-post property damages;[12] G_{ij} is the household's access to ex-ante public protection programs (e.g. access to knowledge through disaster preparedness programs as well as access to embankments or dams that reduce the probability of flooding due to cyclone-induced

[11]Indexing by village *j* helps to identify villages that are located behind a natural storm protection barrier such as the mangrove and the ones that are not. Hence, index j represents a household's location along the coast based on two types of possible storm-affected areas: (1) areas that are protected by mangroves from a future storm event, and (2) areas that are not protected by mangroves from a future storm event, i.e., households in villages that are exposed to the coast.

[12] The model assumes that there are no interdependencies of self-protection among households. That is, private self-protection actions of a household will have no positive or negative externality impact on other households. This suggests that there is no way a household can transfer the consequences of its self-protection actions to others.

storm surges);[13] 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 ex-ante self-insurance expenditures to pursue actions to reduce the severity of ex-post property damage,[14] and R_{ij} is the household's access to ex-post public sponsored disaster relief and rehabilitation programs. We expect the property losses to decrease if the household invests in ex-ante self-insurance expenditures and enjoys accessibility to public-assistance programs designed specifically to reduce the severity of the event. That is, $\frac{\partial L_{ij}}{\partial A_{ij}} < 0;\ \frac{\partial L_{ij}}{\partial R_{ij}} < 0.$

The household is assumed to maximize a *Von Neumann-Morgenstern utility index* over wealth. Considering the two possible states of nature, let $U_{ij}^{L}(.) \equiv U_{ij}(W_1)$ denote the household utility when the household faces storm-inflicted monetary losses to property (state 1) 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 ex-ante 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-inflicted monetary losses or damages to property (state 2) 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 a bad event (i.e. full exposure to a major storm), we suggest that a household faces more disutility when it experiences storm-inflicted monetary losses or damages to property. 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 self-protection (Z_{ij}) and self-insurance (A_{ij}) expenditures. Given these assumptions, the *Von Neumann-Morgenstern utility functions* under the two states of nature are

$$\begin{aligned} U_{ij}^{L} &\equiv U_{ij}(W_1) \equiv U_{ij}\left(I_{ij} - Z_{ij} - A_{ij} - L_{ij}(A_{ij}, R_{ij})\right) \\ U_{ij}^{NL} &\equiv U_{ij}(W_2) \equiv U_{ij}\left(I_{ij} - Z_{ij} - A_{ij}\right) \end{aligned} \tag{3}$$

[13] The word 'public' implies national and local governments being in the service of the village *j*. We use this word interchangeably with government throughout the paper.

[14] As in the case of self-protection, we assume that there is no interdependence of self-insurance among households. That is, if a household adopts self-insurance, then the decision or action has no bearing on other households in terms of any positive or negative externality.

Considering expressions (1.1)-(1.3), the household maximization problem is[15]

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

$$\Rightarrow \left[\pi\left(Z;G,M,C\right)\cdot U^{SE}(W_1)+(1-\pi(Z;G,M,C))\cdot U^{NSE}(W_2)\right] \quad (4)$$

Expression (4) says that the expected utility is maximized at 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 ex-ante self-insurance and self-protection lead to

$$\frac{\partial EU}{\partial A}: \quad \underbrace{-\pi(.)\cdot U^{'}(W_1)\left[1+\frac{\partial L}{\partial A}\right]}_{\text{Expected marginal benefit of self-insurance}} = \underbrace{U^{'}(W_2)\cdot\left[(1-\pi(.))\right]}_{\text{Expected marginal cost of self-insurance}} \quad (5)$$

$$\frac{\partial EU}{\partial Z}: \quad \underbrace{-\frac{\partial \pi(.)}{\partial Z}\cdot\left[U(W_1)-U(W_2)\right]}_{\text{Expected marginal benefit of self-protection}} = \underbrace{\left[\pi(.)\cdot U^{'}(W_1)+(1-\pi(.))\cdot U^{'}(W_2)\right]}_{\text{Expected marginal cost of self-protection}} \quad (6)$$

where $U^{'}(W_1)$ and $U^{'}(W_2)$ are the marginal utilities of income with respect to self-insurance and self-protection respectively.

Expression (5) reveals that a household could employ ex-ante 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, is equal to its expected marginal costs. Expression (6) reveals that a household could employ ex-ante self-protection up to the point where the expected marginal benefits of self-protection, as defined by the decreased chance of the bad state weighted by the utility difference between the two states, equal to its expected marginal costs.

For the household to obtain the optimal level of self-protection and self-insurance expenditures, the second order sufficient conditions (SOSC) require,

$$(a).\ \left|H_{zz}\right|<0;\ \left|H_{AA}\right|<0$$

$$(b).\ \left|H\right| = \begin{vmatrix} H_{ZZ} & H_{ZA} \\ H_{AZ} & H_{AA} \end{vmatrix} = H_{ZZ}\cdot H_{AA} - H_{AZ}^2 > 0 \quad (7)$$

where $\left|H\right|$ is the Hessian determinant of the problem.

Following expression (7), the second order conditions require

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

$$H_{AA} = \frac{d^2 EU}{dA_{ij}^2}$$

$$= -\pi(.) \cdot \left[U_{AA}(W_1) \cdot \left(1 + \frac{\partial L_{ij}}{\partial A_{ij}} \right)^2 + U_A(W_1) \cdot \frac{\partial^2 L_{ij}}{\partial A_{ij}^2} \right] \leq 0 \tag{8}$$

$$H_{ZZ} = \frac{d^2 EU}{dZ_{ij}^2} = \left[\begin{array}{c} \frac{\partial^2 \pi_{ij}(.)}{\partial Z_{ij}^2} \cdot \{U(W_1) - U(W_2)\} - 2 \cdot \frac{\partial \pi_{ij}(.)}{\partial Z_{ij}} \cdot \{U^{'}(W_1) - U^{'}(W_2)\} \\ + \{\pi_{ij}(.) \cdot U^{"}(W_1) + (1 - \pi_{ij}(.)) \cdot U^{"}(W_2)\} \end{array} \right] \leq 0 \tag{9}$$

$$H_{AZ} = H_{ZA} = \frac{d^2 EU}{dA_{ij} dZ_{ij}}$$

$$\Rightarrow \frac{\partial \pi}{\partial Z} \cdot \left[-U^{'}(W_1) \cdot \left(1 + \frac{\partial L}{\partial A} \right) + U^{'}(W_2) \right] \tag{10}$$

$$+ \pi(.) \cdot U^{"}(W_1) \cdot \left(1 + \frac{\partial L}{\partial A} \right) + (1 - \pi(.)) \cdot U^{"}(W_2) \quad \leq 0 \text{ or, } \geq 0$$

where $U^{"}(W_1)$ and $U^{"}(W_2)$ are the second derivatives of utility with respect to income under self-insurance and self-protection.

In order to ensure the sign of the own-partials for self-protection and self-insurance is negative $(H_{ZZ} < 0;\ H_{AA} < 0)$, expressions (8) and (9) lead to the following conditions:

Condition 1. The probability of facing ex-post storm inflicted property damages, $\pi_{ij}(.)$, is strictly quasi-convex with respect to ex-ante self-protection expenditure, Z_{ij}: $\frac{\partial \pi(.)}{\partial Z} < 0; \frac{\partial^2 \pi(.)}{\partial Z^2} > 0.$

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 2. 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 3. $$\left[\begin{array}{l} \frac{\partial^2 \pi(.)}{\partial Z^2} \cdot \{U(W_1) - U(W_2)\} \\ \qquad + \{\pi(.) \cdot U^{"}(W_1) + (1 - \pi(.)) \cdot U^{"}(W_2)\} \end{array} \right] > \left[-2 \cdot \frac{\partial \pi(.)}{\partial Z} \cdot \{U^{'}(W_1) - U^{'}(W_2)\} \right]$$

However, expression (10) reveals that the sign of second order cross partials of self-protection and self-insurance expenditures $\left(\text{i.e. } H_{ZA} \text{ and } H_{AZ}\right)$ 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-partials plays a significant role on the comparative static results.

2.1 Household Behavioral Responses to Storm Protection

Considering the nature of the problem, we can expect four (4) types of behavioral responses from the households to reduce the likelihood and severity of facing monetary losses or damages to property as a result of major storms. The four types are: (a) both self-protection and self-insurance, i.e. the interior solution; (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, i.e. doing nothing.

Taking into account the type (d) behavioral response, there might be a possibility that a household is forced to forgo investing in private storm-protection because of its inability to afford such protection. In order to identify this kind of household, we start with the assumption that there is a minimum subsistence level of consumption of the composite good X that a household must consume in order to survive.[16] Otherwise, the household incurs some lower bound of utility, say $\bar{U}$, from facing death, irrespective of whether it experiences a future storm event.[17] This can be expressed based on the following condition,[18]

$$\begin{aligned} &\text{For } X < X^0 \\ &\Rightarrow\ U^L(.) = U^{NL}(.) = \bar{U} \\ &\Rightarrow\ \text{disutility for the household in terms of facing death} \\ &\quad\ \text{if the consumption of composite good falls below subsistence level} \end{aligned} \qquad (11)$$

where X^0 is the subsistence level of consumption of the composite good.

We also assume that limits on the marginal utilities for the households from the composite good X tend to move towards infinity if consumption of the composite good move towards the subsistence level.[19] That is,

[16] An alternative way of specifying the subsistence constraint is to employ the Stone-Geary utility function. The Stone-Geary function describes consumers as first purchasing subsistence quantities of each good and then dividing the remaining expenditure among the goods in fixed proportions. It gives rise to the linear expenditure system (LES) where the expenditure on each good is linear in all prices and in income.

[17] This lower bound of utility for a household facing death might lead to zero or even negative value $\left(\bar{U} < -\infty\right)$ since the Von Neumann-Morgenstern utility function can be defined over a cardinal scale based on the property that it is unique up to positive linear transformations (Silberberg, 2001).

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

[19] Condition (1.11) can also be expressed as one of the Inada type conditions (Inada, 1963) which is $\lim_{X \to X^0} \frac{\partial U}{\partial X} = \infty$.

For $X \to X^0$ from above

$$\Rightarrow \frac{\partial U^L}{\partial X} = U_X^L \to \infty \text{ or, } \frac{\partial U^{NL}}{\partial X} = U_X^{NL} \to \infty \tag{12}$$

$\Rightarrow$ limits on utility for the household tends to move towards infinity

if the consumption of composite good moves towards subsistence level

If we assume that each household is rational and makes an optimal investment decision based on marginal analysis, expressions (11)-(12) force the households to buy at least the subsistence level of the composite good X . Fig. 2 illustrates how the total utility of a household transforms under this particular situation. But to identify the group of households who do not pursue self-protection and self-insurance $(\text{i.e. } Z = 0 \text{ and } A = 0)$ since they can afford only subsistence levels of consumption, we need to set up the household maximization problem by introducing the Kuhn-Tucker conditions with a non-linear programming approach.

Given the expressions (1)-(3) and (11)-(12), the household optimization framework with non-negative inequality constraints is,[20]

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

subject to

$$\begin{aligned} & X + Z + A + L(A;R) \le I \quad \text{(income constraint)} \\ & X \ge X^0 \quad \text{(composite good consumption constraint)} \\ & Z \ge 0 \\ & A \ge 0 \end{aligned} \tag{13}$$

Given the problem, the Lagrangian function is,

$$\begin{aligned} \mathfrak{L}(Z,A,X,\lambda,\mu) = & \left[\pi(Z;G,M,C)\cdot U^L(X) + \left(1-\pi(Z;G,M,C)\right)\cdot U^{NL}(X)\right] \\ & + \lambda\cdot\left[I - X - Z - A - L(A;R)\right] + \mu\cdot\left[X - X^0\right] \end{aligned} \tag{14}$$

The first-order Kuhn-Tucker conditions are

$$\begin{aligned} Z: \quad & \frac{\partial \mathfrak{L}}{\partial Z} = \frac{\partial \pi}{\partial Z}\left(U^{SE} - U^{NSE}\right) - \lambda \le 0 \\ & Z \cdot \frac{\partial \mathfrak{L}}{\partial Z} = 0 \\ & Z \ge 0 \end{aligned} \tag{15}$$

[20] Regarding the maximization problem, there is a distinction between the expected utility stated in equation (4) and the expected utility stated in equation (13). In equation (4), we substituted for X (i.e. the composite good) considering the income constraint. Thus, the choice variables for equation (1.4) are Z and A. But for the maximization problem with constraints in equation (13), 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.

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

$$A \cdot \frac{\partial \mathfrak{L}}{\partial A} = 0 \tag{16}$$

$$A \geq 0$$

$$X: \quad \frac{\partial \mathfrak{L}}{\partial X} = \pi \cdot \frac{\partial U^{SE}}{\partial X} + (1-\pi) \cdot \frac{\partial U^{NSE}}{\partial X} - \lambda \leq 0$$

$$X \cdot \frac{\partial \mathfrak{L}}{\partial X} = 0 \tag{17}$$

$$X \geq 0$$

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

$$\lambda \cdot \frac{\partial \mathfrak{L}}{\partial \lambda} = 0 \tag{18}$$

$$\lambda \geq 0$$

$$\mu: \quad \frac{\partial \mathfrak{L}}{\partial \mu} = X - X^0 \geq 0$$

$$\mu \cdot \frac{\partial \mathfrak{L}}{\partial \mu} = 0 \tag{19}$$

$$\mu \geq 0$$

Starting with expression (19), the composite good consumption constraint $\left(= X \geq X^0\right)$ is non-binding since expressions (11) and (12) ensures that a rational household will always prefer to consume the composite good at least at the subsistence level. This implies $\mu = 0$ and $\frac{\partial \mathfrak{L}}{\partial \mu} \geq 0$ for the non-binding composite good consumption constraint to hold. But $X \geq X^0$ also suggests that $X > 0$ and from expression (17) we have,

$$\frac{\partial \mathfrak{L}}{\partial X} = 0$$

$$\Rightarrow \underbrace{\pi(.) \cdot U_X^L + \left(1 - \pi(.)\right) \cdot U_X^{NL}}_{\substack{\text{Expected marginal benefit from consuming good X} \\ \text{in both the bad state (adverse event) and the good state} \\ \text{(non-adverse event) of nature weighted by their} \\ \text{respective probabilities}}} = \underbrace{\lambda}_{\substack{\text{Shadow price of the composite good X} \\ \text{or the marginal imputed cost (opportunity cost)} \\ \text{of consuming the composite good or the expected} \\ \text{marginal utility of income}}} \tag{20}$$

Expression (20) 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.

Considering a household will exhaust its budget, which is equivalent to say $\lambda > 0$ and $\frac{\partial \mathfrak{L}}{\partial \lambda} = 0$ from expression (18), 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. $X \geq X^0$.

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

From (15), if $Z > 0$, then the first order condition with respect to Z is an unconstrained maximum of the Lagrangian.

$$\frac{\partial \mathfrak{L}}{\partial Z} = 0$$
$$\Rightarrow \frac{\partial \pi}{\partial Z} \cdot \left(U^{SE} - U^{NSE} \right) - \lambda = 0 \qquad (21)$$
$$\Rightarrow \underbrace{\frac{\partial \pi}{\partial Z} \cdot \left(U^{SE} - U^{NSE} \right)}_{\substack{\text{Expected marginal benefit} \\ \text{of self-protection}}} = \underbrace{\lambda}_{\substack{\text{Shadow price of self-protection} \\ \text{or, the marginal imputed cost} \\ \text{(opportunity cost) of self-protection}}}$$

Expression (21) 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 (16), if $A > 0$, then,

$$\frac{\partial \mathfrak{L}}{\partial A} = 0$$
$$\Rightarrow \left[-\left(1 + \frac{\partial L}{\partial A} \right) \right] \cdot \lambda = 0 \qquad (22)$$

Since $\lambda > 0$, we can infer from expression (22)

$$\left[-\left(1 + \frac{\partial L}{\partial A} \right) \right] = 0$$

By re-arranging terms,

$$\underbrace{-\frac{\partial L}{\partial A}}_{\substack{\text{Marginal benefit of self-insurance} \\ \text{(monetary loss or damages to property averted)}}} = \underbrace{1}_{\text{Marginal cost of self-insurance since } P_{self-insurance} = \$1} \qquad (22.1)$$

Expression (22.1) 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 (21) and (22.1) ensure that an interior solution exists for a household that where it allocates resources both for self-protection and self-insurance.

2.1.2 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 (16),

$$\frac{\partial \mathfrak{L}}{\partial A}\leq 0 \quad \Rightarrow \left[-\left(1+\frac{\partial L}{\partial A}\right)\right]\cdot\lambda\leq 0 \tag{23}$$

But since $\lambda>0$,

$$\begin{aligned}&\left[-\left(1+\frac{\partial L}{\partial A}\right)\right]\leq 0\\ \Rightarrow\quad &\underbrace{-\frac{\partial L}{\partial A}}_{\text{Marginal benefit of self-insurance}}\leq\underbrace{1}_{\text{Marginal cost of self-insurance}}\end{aligned} \tag{23.1}$$

Thus, expression (23.1) 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 (21) should hold to ensure that a household has positive allocation for self-protection$(Z>0)$. Hence, given conditions (21) and (23.1) under certain assumptions, we can express the self-protection only corner solution$\left(Z>0;\ A=0;\ \text{and } X\geq X^{0}\right)$.

2.1.3 Type (c): Self-insurance only corner solution

In the case of self-insurance only corner solution, it follows from expression (15) that we should have,

$$\begin{aligned}&\frac{\partial \mathfrak{L}}{\partial Z}\leq 0\\ &\Rightarrow\underbrace{\frac{\partial \pi}{\partial Z}\cdot\left(U^{SE}-U^{NSE}\right)}_{\substack{\text{Expected marginal benefit}\\ \text{of self-protection}}}\leq\underbrace{\lambda}_{\substack{\text{Shadow price or the marginal imputed cost}\\ \text{(the opprtunity cost) of self-protection or, simply}\\ \text{the expected marginal utility of income}}}\end{aligned} \tag{24}$$

where expression (24) 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 (22.1) and (24) hold to ensure we can express the self-insurance only corner solution $\left(Z=0;\ A>0;\ \text{and}\ X \geq X^{0}\right)$.

2.1.4 Type (d): No self-protection and self-insurance

For no self-protection and no self-insurance case, we argue that the conditions such as (23.1) and (24) 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.

Based on (11)-(22), the four types of household behavioral responses to private storm protection are summarized in Table 2.

2.2 Comparative Analysis under Self-protection and Self-insurance

It might be possible that 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 access to mangroves. Irrespective of income and asset holdings, a household faced with the prospect of public programs and living in close proximity to mangroves is likely to invest less in self-protection and self-insurance. This paper explores now the influence of these postulates over a household's self-protection and self-insurance.

However, comparative analyses results reveal 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 signs of the relationships between a household's private defensive strategies and its access to mangroves remain ambiguous without the additional restrictions. These additional conditions are discussed in detail in Appendix A.

Given the model assumptions along with the additional restrictions, results from the comparative statics reveal the following propositions.

PROPOSITION 1: For a risk-averse household, ex-ante government protection spending G leads to crowding-in (i.e. complements) of ex-ante self-protection Z, i.e. $\frac{\partial Z}{\partial G}>0$ but crowding-out (i.e. substitutes) of ex-ante self-insurance A, i.e. $\frac{\partial A}{\partial G}<0$.

Proof and results from Proposition 1 depends on Condition 4 and Condition 5 (see Appendix A). Condition 4 suggests that self-protection and self-insurance are stochastic substitutes and Condition 5 implies that more ex-ante government programs can accentuate the influence of self-protection 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. One way to explain Condition 5 is that the positive influence of the dissemination of knowledge through public-led disaster preparedness educational programs increases the households' choice for private storm protection actions. However, a household's decision to adopt more private storm protection actions might be negatively affected if it is located behind an embankment. For

Condition 4, an alternative explanation might be a household's inability to go beyond certain level of self-protection and then allocating the rest of its storm protection budget for self-insurance, although this is not how Hiebert (1983) and Archer et al. (2006) defined 'stochastic substitutes' and 'stochastic complements.' Since it is possible to propose alternative economic interpretations for Condition 4 and Condition 5, the direction of the sign for an increase of ex-ante government spending on the optimum levels of self-protection and self-insurance is an empirical question.

PROPOSITION 2: For a risk-neutral household, ex-ante self-protection Z goes down (i.e., becomes a substitute) but ex-ante self-insurance A goes up (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 $\frac{\partial A}{\partial R} > 0$. However, for a risk-averse household, it is not possible to determine the direction of the influence of ex-post public disaster relief and rehabilitation programs on ex-ante self-protection and self-insurance.

Proofs and results of Proposition 2 suggest the possibility of observing the 'full' or 'partial' crowding out effect of household's self-protection but a 'full' or 'partial' crowding in effect of self-insurance if it experiences an increase in access to ex-post public-assistance disaster relief and rehabilitation programs. However, findings of Proposition 2 depend on Condition 4 as well as Condition 6 (Appendix A). Condition 6 proposes that access to more ex-post public disaster relief and rehabilitation programs can accentuate the effect of self-insurance to reduce storm-inflicted monetary loss or damages to property. If there is lack of trust among the households on government programs once a disaster strike, a household might be forced to invest more in self-insurance compared to self-protection taking into account its limited storm protection budget. However, such an ad hoc interpretation cannot be justified considering the theoretical setup of our model. Therefore, the crowding in effect argument based on the sign of $\frac{\partial A}{\partial R}$ remains ambiguous. Empirical evidence might be the only way to provide answers on possible direction of the sign for an increase of ex-post public programs on the optimum levels of self-protection and self-insurance.

PROPOSITION 3: For a risk-averse household, we expect exposure to the storm protection services of mangrove forests M to increase the household's ex-ante self-protection Z, i.e., $\frac{\partial Z}{\partial M} > 0$, but to decrease ex-ante self- insurance A, i.e. $\frac{\partial A}{\partial M} < 0$.

That is, exposure to storm protection services by mangroves acts as a complement to self-protection but as a substitute to self-insurance.

Proof and results of Proposition 3 rely on Condition 4 and Condition 7 (Appendix A). Condition 7 states that more storm protection from the mangroves would accentuate the influence of self-protection in reducing the probability of facing storm-inflicted damages to property. One possible explanation for Condition 7 is that the households protected by the mangroves might have lower expectation of receiving ex-post public-assistance programs since they are presumed to cope better from major storms. Hence, the mangroves protected households would 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 protect their properties from frequent storms. Again, such an ad hoc interpretation cannot be justified considering the theoretical setup of our model. Therefore, the direction of the sign for $\frac{\partial Z}{\partial M}$ remains ambiguous. However, the negative relationship between storm protection role of mangroves and self-insurance among the protected households is more reasonable.

Table 3 summarizes the comparative statics results with the accompanying conditions. Proofs of all the above propositions are shown in Appendix A.

2.2.1 Policy Implications

Since this paper identifies four behavioral patterns a household might follow to reduce the likelihood and severity of facing monetary losses or damages to property, it is imperative for the government to develop policies that take into account these patterns as well as the types of indigenously developed private storm protection practices. In addition, as the theoretical model also reveals possible 'corner' solutions of the households that cannot allocate a separate budget for storm protection, government should ensure that its disaster preparedness and management activities are more pro-poor and prioritized on the basis of need. Hence, it is vital for the government to come up with policies for proper identification of the households with systematic documentation of their socio-economic and demographic characteristics.

With results from the propositions of our theoretical model showing possible influence of public protection programs and the mangrove forest on private storm protection expenditures, government should consider the prospect of strengthening the joint public-private partnerships in storm protection strategies involving the coastal communities. Although some of the findings, such as the crowding in effects, beg more precise economic interpretations in order to understand the channels through which the existing public programs and the mangroves can influence private storm protection strategies, it will be unreasonable if the policymakers completely ignore these possible relationships.

Moreover, considering the increasing frequency and severity of storm events, it might be increasingly difficult to support enough public initiatives by the government to properly protect the coastal communities (IPCC, 2007; The World Bank, 2010). Even completely relying on mangroves for protection against major storms may not be effective if the households are exposed to more severe storms such as the tsunamis, typhoons, and tidal bores (Alongi, 2008; Wolanski, 2007; Cochard et al., 2008). Taking these factors into account, the government should further strengthen the joint public-partnership collaboration with the coastal households in order to protect them from major storms. It should encourage more collective and individual participation in ex-ante private storm protection measures. For example, government can develop a program that ensures collaboration among its engineers and the coastal communities to come up with low cost storm-resistant housing. In order to minimize costs and facilitate recovery, this program should allow for existing indigenous design and construction methods of housing which are based on the households' past experiences with cyclones and storm surge events.[21] Policies can also geared towards correct plantation of trees besides mangroves along the coast as observations from Bangladesh coastal households reveal that dense plantation of coconuts, beetle nuts, and banana trees around the house can provide some form of protection from strong winds and surges (Islam, 1981; Paul and Routray, 2010). Any policy measures that help diversify post-storm household income would also enhance the ability of households to cope with disasters. Since informal risk sharing mechanisms through social bonding and social safety-nets play a significant role in short term survival and long-term livelihood security from major storms in rural low-income communities such as Bangladesh (Paul and Routray, 2010), government can work with non-governmental organizations and local communities to foster this kind of institutional setup. Government can develop program for effective monitoring of the impact of aid and design corrective measures to avoid development of relief dependency among households exposed to major storms.

3. Study Area, Sampling and the Data

3.1 Study Area

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.[22] 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.[23] 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 was the Sundarban mangrove forest.[24] Studies have estimated that the Cyclone severely affected approximately 30,000 acres of forest resources while it partially affected another 80,000 acres of forest amounting to total forest damages worth US $145 million due to its impact on the southeastern part of the Sundarban

[21] Examples of localized housing constructions methods that are observed in Bangladesh coastal households to protect against major storms are: (1) semi-flat roofed houses with separable tin sheets or small thatched roof houses made from rice straw and materials collected from nearby forests. The frame of these houses are made from hard bamboo which can be dismantled and used as a raft during storm surge; (2) square-shaped houses with more than one roof with less space in the upper floor to keep valuables and take shelters during storms; (3) use of guy ropes tied to bamboo poles and trees to support four sides of the house in low surge locations in order to prevent it from blowing or washing away during a storm surge; (4) gentle sloping of the house roof towards south-east to allow the strong wind during storms to flow over the house so it can withstand less severe wind forces, etc. These observations are well-documented in government and international development organizational reports (GOB, 2008) as well as in Paul and Routray (2010), Parvin et al. (2008), and Vasta (2004).

[22] Based on sustained wind speed, Cyclone Sidr is considered to be a category 4 storm under the Saffir-Simpson Hurricane scale but it is a Category 6 super cyclone under the Bangladesh Meteorological Department (BMD) cyclone categorization scale.

[23] A total of 3,406 people perished during Cyclone Sidr with about one thousand declared missing and over half a million sustaining physical injuries. According to a report by the World Bank and the Government of Bangladesh (GOB), the Cyclone affected around 2.3 million households to some degree and about one million very seriously. It estimates total damages and loses at US $1.7 billion (GOB, 2008).

[24] The other significant factor contributing to fewer human casualties is the landfall of Cyclone Sidr during low tide, which resulted in surge waves of relatively lower height (GOB, 2008).

(GOB, 2008).[25] But faced with the prospect of increasingly more severe tropical cyclones due to climate change, it is of paramount importance to know whether the current capacity of the forest would provide an effective safeguard to households against future storm-inflicted damages.[26]

Considering Cyclone Sidr, the study analyzes ex-ante private spending for purposes of self-protection and self-insurance by the coastal households of Bangladesh in order to protect themselves against ex-post storm damages given the level of government protection programs and the presence of a natural storm protection barrier, the Sundarban mangrove forest.[27] Given their differential access to public protection programs, the study gave us an ideal opportunity to find differences in private defensive strategies adopted by households from the affected areas. We have divided the study area into two taking into consideration the research questions:[28]

(1) Areas that are located behind the Sundarban mangrove forest and in a clock-wise direction from Cyclone Sidr;
(2) Areas that are not located behind the Sundarban mangrove forest and are placed either in a clock-wise or counter-clockwise direction from Cyclone Sidr.

In the case of the latter, there is no natural storm protection barrier to rely upon. Therefore, they have to rely on other forms of protection through either public or private actions. We adopted the following procedure in order to demarcate the study area:

Step 1: We first selected the areas located on the southwest coast of Bangladesh for the case study because they fall under the high cyclone risk zone;[29] **Step 2:** Applying 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.3); **Step 3:** Using GIS, we

[25] Located along the southwest coast of Bangladesh, the Sundarban mangrove forest is considered to be the world's largest mangrove forest spanning 2,316 square miles or around 6,000 square km (Das and Siddiqi, 1989). It is also a world natural heritage site (UNESCO, 2009; WCMC, 2009).

[26] This could easily have happened if Cyclone Sidr had had its landfall during high rather than low tide. In addition to the threat of exposure to frequent cyclones and storm surges, the forest is also currently facing other environmental hazards such as salinity due to a rise in sea level and river erosion (Ali, 1996; Rahman *et al.*, 2008). Although prohibited by law because the forest is administratively under government control as a protected area, studies have estimated that there are about 3.5 million coastal people depending directly or indirectly on forest resources such as timber, grass, honey/ wax, fish, shrimp fry, etc., for their livelihood (Hoq, 2007).

[27] This case study is well suited to answer the research questions in several respects. Firstly, we conducted the household survey within a year from the most recent economically damaging severe cyclone induced storm surge event experienced by the coastal households. This allowed us to get information on key variables from the affected households based on both records and recollections of the event. Secondly, the storm surge event had not only affected households that were exposed to the coast, that is, those without a natural storm protection barrier, but also households that were located behind the Sundarban mangrove forest, which is a natural storm protection barrier. Given their differential access to public protection programs, this gave us an ideal opportunity to study the differences in private defensive strategies adopted by households from the two affected areas.

[28] Research questions are: (1) Does the expectation of public-assisted disaster relief and rehabilitation programs as a result of the increasing intensity of future severe cyclone induced storm surge events result in less self-protection and self-insurance by coastal households?; and, (2) Does living in close proximity to mangroves lead to less self-protection and self-insurance by coastal households against damages from cyclone-induced storm surge events?

[29] 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). Like the areas on the southwest coast, the entire Sundarban Mangrove forest area also comes under the high risk zone. We do not provide in this study the map illustrating the location of the mangrove forest vis-à-vis the high cyclone risk zone but it is available from the authors upon request.

identified both the protected (P) and the non-protected (NP) coastal areas (see Fig. 3).[30] We define as protected coastal areas (P) any area that is located behind the Sundarban mangrove forest and is located in a clockwise direction from Cyclone Sidr. Conversely, we define non-protected areas (NP) as any area that is not located behind the Sundarban mangrove forest and is in either a clockwise or counter-clockwise direction from Cyclone Sidr; **Step 4:** We then applied **'**random area sampling' to select the unions that fall under protected (P) and non-protected (NP) areas.[31] While selecting the unions, we maintained an equal distance to the right and left from the track of Cyclone Sidr.

3.2 Sampling Strategy

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. We selected around 500 households 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 a percentage-wise rural-urban composition and the type of dwellings using the Bangladesh Population Census Data.

We conducted personal interviews with the head of the household using trained enumerators speaking the local language under the supervision of the researcher. We pre-tested the questionnaires in October 2008. We carried out the final survey from the 1st to the 15th of November, 2008. The survey gathered information on household involvement in ex-ante private averting activities along with expenditures against ex-post Cyclone Sidr-inflicted damages. It also collected information on important demographic and socio-economic characteristics of the households. We collected secondary data, especially meteorological information on Cyclone Sidr and geophysical information on the Sundarban mangrove forest, from various sources.[32]

3.3 Household Characteristics in the Study Area

Table 4 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, the percentage of male respondents is 84.09 percent whereas, for non-protected areas, it is 71.79 percent. The average age of the respondents is around 42-43 years. 52.07 percent of the respondents had completed primary school (class 1-5) level education in the protected areas while it was 45.45 percent in the non-protected areas. Less than 30 percent had completed high school in both areas. The average household size is five in the protected areas and six in the non-protected areas. Both household sizes in the sample cohere therefore with the national household average of Bangladesh. Results show that most of the respondents (more than 90 percent) have been living in the same village since birth.

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[30] GIS stands for Geographic Information Systems.

[31] 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.

[32] We summarize both primary and secondary sources of data in Table B.1 under Appendix B.

Regarding occupation, most of the household members earn their livelihood from day labor (36 percent) in the protected areas and from agriculture (40 percent) in non-protected areas[33]. Business activities come second in both the case study areas representing 13-16 percent of the respondents. In both study 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. Interestingly, 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 50 percent believe that their houses face some storm surge-inflicted damage risk due to their location at low elevations. In the study area, less than one third of the households have access to electricity while access to a cell phone is close to 50 percent in both areas. Sources of drinking water vary between the two study areas. In the protected area, households mainly drink from ponds/canals, rivers, and preserved rain water. In the non-protected areas, on the other hand, households rely on tube-wells, ponds/canals, rivers, and deep tube-wells.

The average annual household income showed similarities in the two study areas despite differences in the respondents' main occupations. The average annual household income in the protected area was US $816 while it was approximately US $858 in the non-protected area. However, the average market value of assets (excluding house, land and pond) turned out to be higher for households in the non-protected area at approximately US $4609 compared to households in the protected area for which it was around US $2802. [34]

With respect to the degree of exposure to Cyclone Sidr, the study found that the majority of the households which faced Cyclone Sidr-inflicted damages in the two case study areas have yearly income above Taka one lakh (or less than US $1450). Results also show that the higher income households in both areas to spend a significant portion on ex-ante averting activities as opposed to the low-income households. This might indicate that the higher-income households are willing to allocate more for self-protection and self-insurance since they expect to incur more storm-inflicted monetary losses to property. Hence, richer households are more vulnerable to storm-inflicted property damages compared to the low-income households. In terms of Cyclone Sidr-inflicted total damages, we found damages to households in the non-protected area (at around Tk. 10,000 or US $145) to be higher than for those households located in the protected area. Interestingly, the results also reveal that households located in the protected area have spent more on ex-ante self-protection but less on self-insurance compared to households in the non-protected area.[35] But total damages as a result of Cyclone Sidr are high in the non-protected area. These outcomes might imply that households in the non-protected area allocate more for ex-ante self-insurance since their expectation of facing future cyclone-inflicted damages are higher than for those households in the protected area.

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[33] Salinity intrusion in agricultural land could be one of the main reasons behind people switching from agriculture to wage labor in the protected areas. Since the protected area is also close to the only port along the southwest coast and its adjacent industrial area, most of the households either directly or indirectly earn their livelihood through day labor.

[34] Source: Bangladesh Bureau of Statistics (BBS); http://www.bbs.gov.bd/na_wing/gdp_08.pdf

[35] Average amount spent on self-protection in the protected area is Tk. 125909.80 (US $ 1824.78) per household; whereas, in the non-protected area it is Tk. 52963 (US $ 767.58) per household. Regarding self-insurance, the average in the protected area is Tk. 6446.09 (US $ 93.42) and in the non-protected area, it is Tk. 28114.75 (US $ 407.46) per household. For conversion, exchange rate is US $ 1 = Tk. 69.

3.4 Influence of Household Income, Land Ownership, Consumption, and Public Programs

Based on the household survey, we find basically four (4) types of behavioral responses from the households to reduce the likelihood and severity of facing monetary losses or damages to property as a result of Cyclone Sidr, a major storm.[36] The four types are: (a) both self-protection and self-insurance; (b) self-protection only; (c) self-insurance only; and (d) no self-protection and self-insurance. Table 5 shows the breakdown of each household type by study area, i.e. protected and non-protected areas. Among the households, only 8.87% applied both self-protection and self-insurance. Surprisingly, household response to both self-protection and self-insurance is higher in the protected area. Non-response to both self-protection and self-insurance is also lower in the same area. However, self-insurance only corner solution tends to be higher among households from the non-protected area. If we look into the average household income and average land for the entire study area, we find that both the average income and the average land area are the lowest for the households with no self-protection and self-insurance. Moreover, these households also possess the lowest average weekly rice and meat consumption compared to the other types of households. Table 6 summarizes the results. While looking at the entire study area, these findings might indicate that income, ownership of land, and the consumption level of a household might influence its choice for self-protection and self-insurance.

On the issue of accessibility to public protection programs, 82 percent of the households in the non-protected area live inside the embankment while only 35 percent of the households from the protected area live inside the embankment. Similarly, 62 percent of households in the non-protected area live close to a cyclone shelter. This accessibility is at 44 percent in the case of households in the protected area. Thus, households from the non-protected area have more access to public programs compared to households from the protected area. Regarding ex-post public programs in terms of access to disaster relief and rehabilitation, households from both areas have equal access to relief, although households from the protected area have better access to rehabilitation programs. Table 7 summarizes the findings. In relation to Table 5, we can state that access to ex-ante public programs like an embankment and a cyclone shelter can act as a deterrent to take up self-protection and self-insurance strategies. Since households from the non-protected area have better access to ex-ante public programs, they might be more disinclined to allocate resources for private storm protection actions. As reflected in Table 5, this behavioral pattern is evident from households that are located in the non-protected area although the same argument cannot be made when we consider the possible role of ex-post public disaster relief and rehabilitation programs on private storm protection.

4. Empirical Analysis and Econometric Specification

This section discusses how the theoretical model introduced in Chapter 1 is used to answer the research questions. As discussed in Section 2.2, all three PROPOSITIONS require some empirical evidence in order to establish the possible direction of the sign for the effect of an increase in the influences of public programs and mangrove forests on the optimum levels of a

[36] Basically, our household survey data identifies four types of households' behavioral responses to private storm protection strategies. Since it is difficult to define what is meant by the subsistence level of consumption of the composite good, the paper assumes that all households fulfill the idea that they consume at least at the subsistence level of the composite good in order to survive, i.e. consuming at $X \geq X^0$, which is consistent with the theoretical model.

household's private storm protections in terms of self-protection and self-insurance. Without empirical evidence, it is difficult to justify the conditions 4-7 (for more details, see Appendix 1), which drive the results of the PROPOSITIONS. Hence, it is important to test the theoretical model empirically in order to establish issues such as the possible "crowding in" effect on private storm protection investments.

Therefore, in order to position the empirical study vis-à-vis the research questions and the three PROPOSITIONS, the research hypotheses are presented as follows:

> **H_1**: Expected storm-inflicted damage is an important determinant of household investment in ex-ante private defensive strategies in terms of self-protection and self-insurance;
>
> **H_2**: The presence of public disaster relief and rehabilitation programs leads to households investing less in self-protection and more in self-insurance activities against expected storm-inflicted damages;
>
> **H_3**: Households living in close proximity to mangroves invest more in self-protection and less in self-insurance.

Hypotheses **H_2** and **H_3** are formed by following PROPOSITIONS 2 and 3 as discussed in Chapter 1. However, PROPOSITION 1 considering the role of ex-ante government protection spending on self-protection and self-insurance cannot be incorporated due to lack of credible data from the household survey. Hypothesis **H_1** is suggested to find whether households that place a higher value on ex-ante private storm protection actions are also the ones with higher expected storm-inflicted damages. That is, whether the expectation of facing future storm-inflicted damages would encourage households to employ more private defensive strategies ex-ante.

To test hypotheses H_2 and H_3, the paper then estimates how the value that a household places on ex-ante private protection changes as a result of an increase in access to ex-ante public protective spending, $\left(\frac{\partial Z}{\partial G}, \frac{\partial A}{\partial G}\right)$; an increase in exposure to mangrove forests, $\left(\frac{\partial Z}{\partial M}, \frac{\partial A}{\partial M}\right)$; and an increase in access to ex-post government-sponsored relief and rehabilitation programs, $\left(\frac{\partial Z}{\partial R}, \frac{\partial A}{\partial R}\right)$. These econometric estimations are able not only to test the research hypotheses, but also to empirically examine Propositions 1-3 as discussed in Chapter 1. In addition, they allow testing the reduced form equations empirically in order to test the possible comparative statics results as reported in Table 3.

The econometric specifications are determined based on two issues: (1) when households' self-protection and self-insurance choices are treated as separate decisions; and (2) when households' self-protection and self-insurance choices are treated as joint decisions. However, considering the nature of the household survey data, the two-step Heckman model using the full information maximum likelihood method as well as the two-part model are performed when households' private protection choices are treated as two-separate decisions. On the other hand, the seemingly unrelated bivariate probit model and the recursive simultaneous probit model are performed when households' private storm protection choices are jointly determined.

4.1 Econometric Specification under Separability assumption for Storm Protection Choices

Based on the first order conditions under expressions (5) and (6), we can translate the household's optimal choices into a binary decision (0,1) of whether to undertake any ex-ante averting strategies against a storm-inflicted damage risk in the future.[37]

Let us assume that d_{ij}^{Z} is an indicator of the binary decision to participate in ex-ante self-protection Z_{ij} and d_{ij}^{A} is the other indicator of the binary decision to participate in ex-ante self-insurance A_{ij}. Furthermore, let us assume that each household is rational and makes an optimal investment decision based on marginal analysis. Then, following equations (5) and (6), a household's choice is determined by

For self-protection Z_{ij}:

$$d_{ij}^{Z}=1 \quad \text{if} \quad \left[-\pi \cdot \frac{\partial Q_{ij}(.)}{\partial Z_{ij}} \cdot \left(U(W_1) - U(W_2) \right) \geq \pi \cdot \left(Q_{ij}(.) \cdot U^{'}(W_1) + (1-Q_{ij}(.)) \cdot U^{'}(W_2) \right) \right]$$

$$d_{ij}^{Z}=0 \quad \text{otherwise}$$

For self-insurance A_{ij}:

$$d_{ij}^{A}=1 \quad \text{if} \quad \left[-\pi \cdot Q_{ij}(.) \cdot U^{'}(W_1) \cdot \left(1 + \frac{\partial L_{ij}(.)}{\partial A_{ij}} \right) \geq \pi \cdot U^{'}(W_2) \cdot \left(1 - Q_{ij}(.) \right) \right]$$

$$d_{ij}^{A}=0 \quad \text{otherwise}$$

(25)

The above expression implies that households will only participate in ex-ante averting strategies if the expected marginal benefits of undertaking private defensive strategies (i.e., Z_{ij} and A_{ij}) are no less than the expected marginal costs of undertaking the strategies. Otherwise, it will not participate in any ex-ante averting strategies. We can specify expression (25) also as the probability models that are convenient for empirical estimations.

Based on these simplified assumptions, the participation decision of a household will differ with its access to ex-ante government protective programs G_{ij}, exposure to mangrove forest M_{ij}, access to ex-post public sponsored relief and rehabilitation programs R_{ij}, as well as its socio-economic characteristics, ψ_{ij}. Because characteristics of a severe cyclone-induced storm surge event can affect the effectiveness of a household's ex-ante averting choices, storm characteristics C_{ij} will also then influence the decision to participate.

[37] It is possible to find a similar binary response assumption to investigate household optimal choices in applied empirical studies by Agee and Crocker (1996) and Barbier (2007).

From the utility maximizing problem in expression (4), if the household does decide to undertake ex-ante averting strategies, then we can specify the linear representations of the reduced form equations for optimal self-protection Z_{ij}^{*} and optimal self-insurance A_{ij}^{*} as

$$Z_{ij}^{*} = \beta_0 + \beta_1 \cdot G_{ij} + \beta_2 \cdot M_{ij} + \beta_3 \cdot R_{ij} + \beta_5 \cdot C_{ij} + \beta_6 \cdot \psi_{ij} + \varepsilon_{ij}$$
$$A_{ij}^{*} = \zeta_0 + \zeta_1 \cdot G_{ij} + \zeta_2 \cdot M_{ij} + \zeta_3 \cdot R_{ij} + \zeta_5 \cdot C_{ij} + \zeta_6 \cdot \psi_{ij} + \mu_{ij} \quad (26)$$

In expressions (25)-(26), we show the exact econometric specifications for self-protection and self-insurance in Appendix C. [38]

Since not all households in the sample participate in self-protection or self-insurance activities, the main data issue arises when ex-ante averting expenditures are missing for households who do not participate in any ex-ante averting activities.[39] If the first order conditions are not satisfied, it is natural to expect households to be less willing to participate in any ex-ante averting activities, i.e., self-protection or self-insurance, or both. Hence, there will be sample selection bias if we apply the OLS regression analysis because it may not be possible to make inferences about the determinants of the ex-ante level of private spending for the entire coastal population. To avoid this sample selection bias and taking into account the household responses to self-protection and self-insurance measures, there is a possibility that a household may not be able to allocate resources for private storm protection due to reasons other than its inability to afford that protection. [40] For example, evidence reveals that factors such as risk perception (Kahneman and Tversky, 1979; Magat et al., 1987; Camerer and Kunreuther, 1989; Kahneman et al., 2001) and higher expectation of receiving public protection programs (Lewis and Nickerson, 1989; Browne and Hoyt, 1990; Raschky and Weck-Hannemann, 2007) might influence how people want to allocate investment for protection from natural disasters. Hence, we consider that the Heckman model (Heckman, 1979) is most appropriate for our limited dependent variable problem since we believe that zero outcomes in our model, i.e. the 'corner solutions' based on the four possible behavioral patterns of a household's storm protection strategies, are not an actual choice of zero.

Another option is to test for the dependency between the error terms of the participation and the outcome equations. If the errors are dependent based on the LR test, 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

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[38] For simplicity, we assume the demand functions for ex-ante averting strategies to be linear.

[39] As Table 4 indicates, only 107 households incurred self-protection expenditures whereas 297 households incurred self-insurance expenditures.

[40] In the household survey questionnaire, the relevant questions regarding self-protection and self-insurance were as follows.

(1) For participation in self-protection, the question was, "have you taken any private self-protection measures to avoid or avert damages (losses) to property before occurrence of a severe cyclone event?" For those who answered 'yes' to this question, the follow-up question (for outcome) was, "what are the types of private self-protection measures you or your household have taken? What is the approximate amount spent to pursue each self-protection measure to reduce cyclone-induced storm surge damages?"

(2) For participation in self-insurance, the question was, "did your household take any private self-insurance measures to reduce the damage (loss) to property after occurrence of a severe cyclone?" Those who answered 'yes,' were then asked about the type of self-insurance measures taken to reduce the severity of severe cyclone-inflicted property damages.

Yu, 1996; Puhani, 2000; Madden, 2008). However, considering the collinearity issue associated with the inverse mills ratio and other regressors under the Heckman two-step method, the paper reports estimation results both from the full information maximum likelihood (FIML) estimator and the two-part model.[41] Hence, we can use the results for comparison purposes.

4.1.1 Estimation Results

The regression results reported in this paper are based on the full sample of the household survey. Table 8 shows the summary statistics based on the means and standard deviations of the explanatory variables that are used for the regression analyses. Table 9 presents the result of the full information maximum likelihood (FIML) of the full sample selection model for self-protection. It has two parts: (1) results from the selection equation with the marginal effects of the regressors on the probability of participation in self-protection; and, (2) results from the outcome equation conditional on participation with the marginal effects of the regressors on the expected value of the level of self-protection expenditures. Table 9 reports four regression specifications under the selection equation starting with the parsimonious model (column 1 and 2) comprising Cyclone Sidr inflicted damages, Pre-Cyclone Sidr income, distance from the coast, and the socio-economic characteristics. To get reasonably stable estimates under the exclusion restrictions, the parsimonious specification of the selection equation also considers additional variables like whether the household is located inside the embankment and asset holdings based on ownership of homestead, cropland, and pond area. For the next regression specification, additional controls are progressively added starting with the storm protection role of mangroves characteristics (column 3 and 4). Then, the public programs are added with this specification (column 5 and 6). The last regression specification includes the characteristics of Cyclone Sidr (column 7 and 8) - the most recent severe cyclone event of November 2007 which affected the southwest coastal areas of Bangladesh including the Sundarban mangrove forest.

Under FIML, regression results from the selection equation support the hypotheses that storm-inflicted damage is an important determinant of households' participation in ex-ante self-protection. This variable is positive and highly significant in all regression specifications. Although not highly significant, the log and square log of a household's pre-Cyclone Sidr income reveal positive and negative signs respectively under all specifications. This might suggest that the probability of a household participating in ex-ante self-protection activities has an inverse 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 low- and high-income household. This could happen if the middle-income households perceive existing public disaster relief and rehabilitation programs to give preference to low-income households on the basis that they are the most vulnerable as well as without the means (unlike rich households) to reduce the likelihood of being affected by future storm-inflicted damages. Conversely, the coefficient of ownership of homestead, cropland, and pond area--a form of assets holding--remains positive and significant throughout. This might indicate that the richer households rely on their asset holdings rather than on income when making choices regarding self-protection.

[41] Both 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.

Among other socio-economic characteristics, results show that a household is more likely to participate in self-protection if it has a fewer number of children and has less access to credit compared to other households. With regard to the role of mangroves, households that fall into the protected area are more likely to participate in self-protection though this turns out to be insignificant when other controls like public programs and storm characteristics are progressively added to the model. However, directional location of the household relative to the coast and the mangroves play a key role in household participation in self-protection. Under the most elaborate regression specification that introduces all the controls, results show that the households located to the south and southwest directions relative to the coast and the Sundarban mangrove forest are less likely to participate in self-protection compared to other households. Since the Sundarban mangrove forest is situated along the southwest coast of Bangladesh, it seems the households that are located other than the south or southwest directions relative to the forest perceive the expected threat from storm-inflicted damages. Hence, they are willing to take more self-protection actions.

Furthermore, results show that the distance between the mangrove forest and the union where the household's village is located bears the negative sign and is significant under all specifications. This might imply that the likelihood of a household participating in self-protection actions goes down if it is located further away from the mangroves. This high private response from the households living close to the mangrove forest could happen if they expect to receive fewer public goods when a damaging storm event takes place. Because of their close proximity to a natural storm protection barrier, these households might feel rather insecure as they are presumed to cope better against a damaging storm event compared to other households. Among the public programs, public disaster relief leads to households participating less in self-protection activities. But the presence of public disaster rehabilitation leads to more participation in self-protection though it is significant only at the regression specification under the public programs. When it comes to storm surge characteristics, the directional distance between the household and the track of the Cyclone Sidr have positive influence on households participating in self-protection. However, results also show that the households that fall into counter-clockwise direction from Cyclone Sidr are less likely to participate in self-protection. But this result should not be taken much seriously since one cannot predict the track of a future storm event irrespective of a household's location and hence its influence on household's self-protection actions.

The results of the outcome equation conditional on participation as reported under Table 10 under four regression specifications also confirm the hypothesis that storm-inflicted damage is an important determinant of a household's choice of the level investment in self-protection. The coefficient remained significant and changed little in magnitude as we added other controls progressively such as regressors capturing the socio-economic characteristics of the household and the storm protection role of mangroves, access to public disaster relief and rehabilitation programs, and the characteristics of the severe cyclone-induced storm surge. Interestingly, the log and square log of pre-Cyclone Sidr income remain strongly significant in all regression specifications bearing negative and positive signs respectively. That is, conditional on participation, a household's level of self-protection expenditures exhibit a U-shaped relationship with income, initially declining, but then increasing. This might imply that once a household decides to participate, low- and high-income households allocate more for self-protection compared to middle-income households. That is, a low-income household, because of its low income, smaller asset holdings, and lack of access to public programs, is forced to allocate more for self-protection to reduce the probability of being affected by storm-inflicted damages. Otherwise, it might be impossible for the low-income household to reduce the severity of the damages once the storm event has taken place. However, for a richer household conditional on its decision to participate in self-protection, allocating a significant portion for self-protection might be associated more with affordability rather than with the ability to reduce the severity of storm-inflicted damages once the storm event has occurred. Among other socio-economic variables, results show that a household invests more in self-protection if it does not plan to migrate in the future, has access to credit but is not a member of any village-level organization, and it's house is located on a low elevated land. Regarding the role of mangroves and public programs, none of the variables seems to have a strong influence on household level of self-protection spending.[42] This same outcome also applies when we consider the role of the storm surge characteristics on self-protection investment.[43]

Table 11 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. However, it is possible to partially determine the amount of self-insurance expenditures by the household if we take into account the medical expenditures associated with the Cyclone Sidr-inflicted health damages and the approximate nominal value of the remittances received to deal with storm damages. We assume that both medical expenditures and the remittance received to deal with storm damages can be used as proxies for self-insurance, as both the actions are costly for the household in terms of transferring funds from good to bad states of nature.[44] Both the actions are costly in the sense that they become sunk costs in dealing with the severity of storm-surge-inflicted damages where the opportunity costs of using the funds for alternative purposes could be significant especially for the poorer households. Nevertheless, the simplified assumption in determining ex-ante self-insurance expenditures comes with a caveat: the possibility of having no way to identify the linkage between the household participation decision and, conditional on participation, a household's choice regarding the level of self-insurance. Hence, we perform a separate Probit estimation on the probability of a household pursuing self-insurance actions and a separate Tobit estimation to deal with the censored nature

[42] Under FIML, the dummy variable representing the directional location of the household relative to the coast and the mangroves is not included in the outcome specification since it is used under 'exclusion restriction' to determine the selection equation.

[43] Under FIML, the likelihood ratio test (LR test) for correlation between the error terms of the two equations $(\rho = 0)$ for all specifications except the parsimonious one suggests strong evidence against the null since the value of the LR statistics are large with p-values smaller than 10%. That is, we reject the null or accept the dependence between the error terms. Thus, the LR test supports the application of the Heckman two-step method using the limited information maximum likelihood estimation (LIML) instead of the two part model. However, considering the issue of collinearity associated with the inverse mills ratio and other regressors, the two-part model is also applied as an alternative regression specification against the results derived from FIML. Compared to FIML, results from the two-part model reveal the same results except for the mangroves variables where none of them has any influence on household's choice and the level of self-protection spending. Results from the two-part model can be available from the authors upon request.

[44] During disasters or emergencies, remittances can be a vital source of income for people whose other forms of livelihood may have been destroyed either by conflict or due to natural disaster. According to the Overseas Development Institute, aid actors who are considering better ways of supporting people in emergency responses increasingly recognize this as important (Savage, 2007). However, there is an opportunity cost regarding the use of remittances in dealing with disasters as they could have been allocated for more productive other alternatives.

of the sum of the self-insurance proxy variables (i.e., medical expenditures and remittances).[45] In addition, we included a household's income before the Cyclone Sidr event and a household's income after the Cyclone Sidr event. By defining the former as pre-Cyclone Sidr income or pre-income and the latter as post-Cyclone Sidr income or post-income, we try to capture their influence on the household level of self-insurance since a household's income can vary significantly between what it was *before* the cyclone and *after* if the household has the option to diversify its post-disaster income which might be different from its pre-disaster income source.[46] For instance, while a household's pre-cyclone income (i.e., pre-income) might have come from subsistence agriculture, its post-cyclone income (i.e., post-income) might come from day labor because the agriculture crops have been destroyed as a result of the Cyclone.

Similar to self-protection, regression results of the Probit estimation in Table 11 (columns 2-5) reveal that self-insurance is also an important private defensive strategy against storm-inflicted damages. However, the coefficients of both public disaster relief and rehabilitation programs are positive and highly significant. This implies that the probability of a household participating in self-insurance increases if the household has more access to public disaster relief and rehabilitation programs, which is contrary to the results found under self-protection. Among the mangrove variables, the coefficient of the binary variable representing whether a household comes within the mangrove-protected area has a negative sign and is statistically significant. This implies that households from the protected area are less likely to invest in self-insurance. But the variable is dropped under the final regression specification when we add the storm surge characteristics controls progressively to the model. In addition, households that are located close to the mangroves are more likely to participate in self-insurance. Directional location of the household relative to the coast and the mangroves has no influence of a household's participation in self-insurance based on any of the regression specifications.

Among the socio-economic controls, a household is more likely to participate in self-insurance if it has access to credit and has more children whereas it is less likely to participate if it is a member of a village-level organization which ensures access to some form of social capital. Interestingly, households are also more likely to participate in self-insurance if it is located further away from the coast. However, although the log and square log of pre-disaster income indicate the existence of an inverted U-shaped relationship, they do not have a significant influence on the probability of self-insurance. In addition, the log and square log of post-disaster income show no significant relationship to the likelihood of a household participating in self-insurance. This might imply that other factors rather than income play a major role on household level self-protection participation.

Table 11 also shows the censored Tobit model results for estimating the level of ex-ante self-insurance expenditures of the households, starting with the parsimonious model (column 6) and

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[45] Given the assumptions, the Tobit estimation on the level of self-insurance allows censoring to be placed at zero without any loss of generality since there is no negative self-insurance value. Also, we assume that households not responding to the amount allocated for self-insurance have zero self-insurance expenditures. Therefore, we can infer these simplified assumptions as a way to deal with the missing values.

[46] Regarding the relationship between pre-Cyclone Sidr and post-Cyclone Sidr income, 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 results along with the t-tests confirm the difference between the sources of income before and after the Cyclone Sidr event. .

then gradually adding the mangroves characteristics, the public programs, and the storm surge characteristics (columns 7-9). The results confirm that storm-inflicted damage is an important factor in household level self-insurance investment. Under all specifications, the coefficient of the nominal value of storm-inflicted property damages remains positive and highly significant. When it comes to income, 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, conditional on participation, a household's self-insurance expenditures exhibit a significant U-shaped relationship with post- Cyclone Sidr income, initially declining, but then increasing. This might imply that low- and high-income households allocate more for self-insurance compared to middle-income households. Among the socio-economic variables, 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, the results show that households also invest more in self-insurance if they have more children. Results further show that households allocate more for self-insurance if they live inside the embankment but their houses are located on a land with lower elevation. Interestingly, households also invest more on self-insurance if they are located further away from the coast though this turns out to be insignificant when we add storm characteristics in the model. Regarding mangroves, households that come within the mangrove protected area invest less in self-insurance. This finding supports the hypothesis that close proximity to mangroves causes households to allocate less for self-insurance. That is, in such cases, mangroves act as a substitute for self-insurance. Regarding the distance, households that are located close to the mangroves invest more in self-insurance. However, the directional location relative to the coast and the mangroves has no influence on investment in self-insurance. Access to public disaster relief and rehabilitation programs has no influence on household level self-insurance spending as well. None of the storm characteristic variables is strongly significant.

4.1.2 Discussion

The empirical results on the full sample of the case study area reveal that: (i) storm-inflicted damage is an important determinant of households' participation in ex-ante self-protection and self-insurance; (ii) With respect to the first issue of crowding out, presence of public disaster relief and rehabilitation programs leads to households being willing to invest more in self-insurance but less in self-protection. This might imply lack of trust among people on government programs once a disaster strikes; (iii) With respect to the second issue of the effect of living near mangrove forest, results show households protected by mangroves are less likely to participate in self-insurance. This could indicate that households in non-protected areas have higher expectations of facing future storm-inflicted damages than households in the mangrove protected areas; (iv) Income and size of assets have a strong influence on a household's choice of self-protection and self-insurance; (v) middle income households are more likely to participate in self-protection and self-insurance compared to low-income and-rich households. This is probably because middle-income households perceive that they are more likely to lose from storm-inflicted damages since they are neither in a position like the low-income households, where there is nothing to lose; nor are they in the position of richer households who can rely on their assets and access to loans to cope better against storm-inflicted damages. However, results also show that besides location of households relative to mangrove barriers, other socio-economic, demographic, and geo-physical factors seem to have considerable influence and add a degree of complexity to the relationships.

Considering the key results, (i) obviously supports hypothesis $\mathbf{H_1}$; whereas, (ii)-(iv) partially support hypotheses $\mathbf{H_2}$ and $\mathbf{H_3}$. Regarding null hypothesis $\mathbf{H_2}$, estimation results reveal that it can be rejected on the ground that access to pubic disaster relief and rehabilitation programs, which are ex-post public programs, increases household level of self-insurance spending. However, when we consider the influence of public disaster relief programs in reducing the probability of a household participating in self-protection activities, the null hypothesis cannot be rejected. Hence, it is not conclusive from these two contradictory findings. Yet, they support PROPOSITION 2 under a 'risk neutral' household since both access to relief and rehabilitation programs have positive influence on the households' choice for self-insurance activities $\left(\text{i.e. } \frac{\partial A_{ij}}{\partial R_{ij}} > 0\right)$ while the public disaster relief has negative influence on the households' choice for self-protection actions $\left(\text{i.e. } \frac{\partial Z_{ij}}{\partial R_{ij}} < 0\right)$.

Estimation results also lead to inconclusive conclusion regarding whether to accept or reject null hypothesis $\mathbf{H_3}$. Taking into account the key findings, households that fall into the protected area are less likely to participate in self-insurance activities; thus, supporting the null hypothesis. However, the same households are also more likely to participate in self-protection though the coefficient becomes insignificant when we add additional controls such as the public programs and storm characteristics to the regression model. But, this anomaly lends support to PROPOSOITION 3 where it suggests that exposure to storm protection services of mangroves acts as a complement to self-protection $\left(\text{i.e. } \frac{\partial Z_{ij}}{\partial M_{ij}} > 0\right)$ but as a substitute to self-insurance $\left(\text{i.e. } \frac{\partial A_{ij}}{\partial M_{ij}} < 0\right)$. Nevertheless, both hypothesis $\mathbf{H_3}$ and PROPOSITION 3 cannot be well supported when we consider other characteristics such as the nearest distance between mangrove forest and household location or the directional location of the household relative to the coast and the mangroves.

PROPOSITION 1 considering the role of ex-ante government protection spending on self-protection and self-insurance cannot be fully tested due to lack of credible data.

4.2 Econometric Specification for Joint Assumption on Private Strom Protection Choices

Considering the two private storm protection strategies of self-protection and self-insurance, there is a possibility that these variables along with their predictors and coefficients are linked together by some common, not measurable, factor. Taking this factor into account, an alternative econometric specification of joint estimation of self-protection and self-insurance choices using a bivariate probit model can be suggested. The bivariate nature of the model involving two binary equations replicates the seemingly unrelated regression estimation (SURE) form as suggested by

Zellner (1962). Hence, this econometric specification can also be stated as seemingly unrelated bivariate probit model. In the next section, the paper discusses about it in details followed by the estimation results and the discussion based on the econometric specification.

4.2.1 Estimation results

Table 12 shows the result of the joint estimation of the two private storm protection strategies using a bivariate probit model which replicates the seemingly unrelated regression (SUR) form. With two probit equation estimations which are jointly determined, Table 12 reports the four regression specifications starting with the parsimonious model (discussed in the previous section) under both self-protection and self-insurance. The parameters are estimated by maximizing the log-likelihood function of the bivariate probit model using non-linear optimization method. The Lagrange multiplier test to see whether $\rho = 0$ so that the probit models can be estimated separately shows that the null is rejected at 5% level for the first two model specifications. However, there is small evidence against the null at 5% level for the last two model specifications although the null can be rejected at 10% level when the storm characteristics are progressively added to the model (for the full model specification).

Compared to the results when self-protection and self-insurance choices are treated as separate rather than joint decisions (in section 4.1.1), most of the results from the previous analysis hold when the joint estimation of the seemingly bivariate probit model is performed. In all regression specifications as reported in Table 12, the results support for the hypothesis that storm-inflicted damage is an important determinant of household's choice for self-protection and self-insurance. For both private storm protection strategies, this variable is positive and significant in all regression specifications although it is highly significant for the probability of a household participating in self-protection activities. Regarding the influence of income, results show that the likelihood of a household participating in self-protection has an inverse U-shaped relationship with pre-Cyclone Sidr income, initially increasing, but then declining. However the log and the square log of a household's pre-Cyclone Sidr income are not highly significant for all regression specifications. A similar inverse U-shaped relationship between the likelihood of a household participating in self-insurance and the post-Cyclone Sidr income is found but the signs of the coefficients are not significant. 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 for self-insurance. Like the earlier result under separate estimations, this might imply that the richer households rely on their asset holdings rather than on income when making their choices about self-protection and self-insurance. Interestingly, the seemingly bivariate estimation also shows that a household is more likely to pursue self-protection and self-insurance if it is located further away from coast. This result might reflect that the poorer households, who are less likely to participate in self-protection and self-insurance, are also the ones that are located along the coast because the average land price in that area tend to be lower as a result of its high exposure to storm surge risk.

Among other socio-economic characteristics, results show that if the head of the household is young, then he or she is more likely to participate in self-protection; whereas, if the head of the household is older, he or she is more likely to participate in self-insurance although the results are not statistically significant. Regarding the influence of education, if the respondent heads of the households are more literate, then the likelihood of them participating in self-protection is high but the likelihood of them participating in self-insurance is low compared to the respondent heads of the households who are illiterate. Results also show that a household is more likely to participate in self-protection if it has less access to credit, has a fewer number of children, and has more female members. On the other hand, a household is more likely to participate in self-insurance if it has more access to credit, has more children, and has electricity but no phone connection. Table 12 summarizes the results.

With regard to the role of mangroves, households that fall into the non-protected area are more likely to participate in self-insurance. Although not significant, similar conclusions can be drawn for the likelihood in participating in self-protection when other controls like public programs and storm characteristics are progressively added to the model. Unlike distance from the coast, distance between the mangrove forest and the union where the household's village is located bears the negative sign for both self-protection and self-insurance although it becomes insignificant for self-insurance when the storm characteristics are considered. However, the directional location of the household relative to the coast and the mangroves bears the expected sign but significant only for the probability of a household participating in self-protection. The negative sign of the coefficient implies that a household not protected by mangroves from a storm event are more likely to participate in self-protection and self-insurance because they perceive the expected threat from storm-inflicted damage is higher compared to a household that is protected by mangroves. Among the public programs, the coefficients for both public disaster relief and rehabilitation programs are positive and highly significant for self-insurance. However, only public rehabilitation programs have positive influence on self-protection though it is significant only at the regression specification under the public programs. Interestingly, households that are located inside the embankment are less likely to participate in self-protection and self-insurance but the signs of the coefficient are statistically insignificant. For storm characteristics, households that faced higher storm surge are more likely to participate in self-protection but less in self-insurance. However, results also show that a household is less likely to participate in self-protection if it falls into counter-clockwise direction from Cyclone Sidr or if it is located further away from the track of the Cyclone Sidr. As stated previously, these results should not be taken much seriously since one cannot predict the track of a future storm event irrespective of a household's location and hence its influence on household's private storm protection actions.

Table 13 shows the marginal effects of the four types of joint probabilities in terms of a household's choice for self-protection and self-insurance. Results from joint probabilities again confirm the importance of storm-inflicted damage on household's participation in self-protection and self-insurance. However, income does not seem to have an influence on the joint probabilities. Interestingly, households that have more asset holdings are more likely to participate in both self-protection and self-insurance. The opposite picture of a household participating in no self-protection and self-insurance is true if it has less asset holdings. Regarding the influence of mangroves, households that fall into non-protected area are more likely to participate in both self-protection and self-insurance but less likely to participate in private storm protection activities if it falls into the mangrove protected area. However, a household is also likely to participate in both self-protection and self-insurance if the distance between the mangrove forest and the household's village is smaller. For the public programs, access to both public disaster relief and rehabilitation programs increases the likelihood that a household will participate in both self-protection and self-insurance activities. But access to relief seems to have no significant influence on the probability that a household not participating in any storm protection actions. Although not significant, result also reveals that a household is more likely to participate in both storm protection actions if it is located outside the embankment.

4.2.2 Discussion

Regarding the hypotheses tests and the propositions, key results from the seemingly unrelated bivariate probit model on the full sample of the case study area lead to same conclusions like in the previous analysis (in section 4.1.2) when self-protection and self-insurance choices are treated as separate rather than joint decisions. That is, the key results support hypothesis H_1 but partially support hypotheses H_2 and H_3. In addition, they also support PROPOSITION 2 and PROPOSITION 3. Like in the previous analysis, PROPOSITION 1 considering the role of ex-ante government protection spending on self-protection and self-insurance cannot be fully tested due to lack of credible data.

4.3 Future Directions

Besides the possible relationship between the error terms of two equations representing self-protection and self-insurance, it is also likely that there could be an endogeneity problem since the alternative risk management actions taken by the household are unlikely to be independent. That is, the choice of self-protection is unlikely to be independent of the choice of self-insurance and vice-versa. Hence, there could be the issue of simultaneity bias as a result of the possible interaction between the two endogenous variables within a system of the two equations. However, the issue of having few data points for the self-protection and self-insurance outcomes causes the joint estimation based on simultaneous equations estimation model to be performed only for the participation equations but not for the outcome equations. In addition, following Amemiya (1981) and Madalla (1983), the econometric model based on the simultaneous bivariate probit model for the two participation equations will not be logically consistent.[47]

Hence, taking into account the data issue, the sequential nature of the problem, and the joint determination of self-protection and self-insurance, it seems the best way to deal with all these issues if a *two-step simultaneous-heckman* type model involving the four equations, i.e. the two-participation equations and the two-outcome equations of self-protection and self-insurance, can be performed. Furthermore, in order to fully test the research questions and conduct future sensitivity analysis, the paper suggests additional explorations on the functional forms. Since simple linear representations of the reduced-form demand equations are considered in this paper, testing for the correct choice of the functional form for the demand equations of self-protection and self-insurance expenditures might lead to better estimation results.

[47] The only way the logical consistency of the model can be achieved if one of the participation equations is without the endogenous variable (i.e. the left-hand-side variable) in the other. Following the same argument, we can also infer that a bivariate probit model in which each left-hand-side variable appears on the right-hand-side of the other equation is not 'identified.' We can force the computer program to produce values just by specifying the bivariate probit model as if it were not simultaneous. But, the values will be meaningless.

7. Conclusion

This paper demonstrates an empirical application of a theoretical model in order to understand how ex-ante private defensive strategies by coastal households evolve against ex-post storm-inflicted damages given the level of government protective spending and the presence of a natural storm protection barrier.

Results from the theoretical model reveal four types of households' behavioral responses to reduce the likelihood and severity of facing monetary losses or damages to property from a major storm event. The four types are: (a) both self-protection and self-insurance, i.e. the interior solution; (b) self-protection only, i.e. the corner solution; (c) self-insurance only, i.e. the corner solution; and (d) no self-protection and self-insurance, i.e. doing nothing. Moreover, the results confirm the influence of public protective programs and the mangrove forest on private defensive expenditures based on whether the public programs serve as possible substitute or complement to the storm protection provided by mangroves. The comparative statics of the model reveal that *ex-ante* public programs are complements to self-protection expenditures but substitutes to self-insurance whereas *ex-post* public programs are substitutes to self-protection but complements to self-insurance. Consequently, we might observe 'full' or 'partial' crowding out effect on household's self-protection and self-insurance activities given the presence of mangroves.

Descriptive statistics and empirical results on the full sample of the case study area reveal: (i) storm-inflicted damage is an important determinant of households' participation in ex-ante self-protection and self-insurance; (ii) With respect to the first issue of crowding out, presence of public disaster relief and rehabilitation programs leads to households being willing to invest more in self-insurance but less in self-protection. This might imply lack of trust among people on government programs once a disaster strikes; (iii) With respect to the second issue of the effect of living near mangrove forest, results show households protected by mangroves are less likely to participate in self-insurance. This could indicate that households in non-protected areas have higher expectations of facing future storm-inflicted damages than households in the mangrove protected areas; (iv) Income and size of assets have a strong influence on a household's choice of self-protection and self-insurance; (v) middle income households are more likely to participate in self-protection and self-insurance compared to low-income and-rich households. This is probably because middle-income households perceive that they are more likely to lose from storm-inflicted damages since they are neither in a position like the low-income households, where there is nothing to lose; nor are they in the position of richer households who can rely on their assets and access to loans to cope better against storm-inflicted damages. However, results also show that besides location of households relative to mangrove barriers, other socio-economic, demographic, and geo-physical factors seem to have considerable influence and add a degree of complexity to the relationships.

Since the extent of the storm protection role of mangroves to protect lives and property against large, infrequent, and long-period waves such as the tsunamis, hurricanes/ typhoons, tidal bores etc., is uncertain (Alongi, 2008; Wolanski, 2007; Cochard *et al.*, 2008), and it is possible that the government might not be able to continue its support for public programs due to increased frequency in the occurrence of storms (The World Bank, 2010) - the government should focus its programs in both mangroves protected and non-mangroves protected areas and encourage more collective and individual participation in ex-ante private storm protection measures against future storm-inflicted damages. One option is to subsidize housing construction costs so households can convert mud house to brick-built houses. Any policy measures that help diversify post-storm household income would also enhance the ability of households to cope with disasters.

In addition, the government should refrain from undertaking costly programs such as the planting of mangroves around the vulnerable coastline in inappropriate environmental settings, which might reduce long-term ecological sustainability in the area as revealed in post tsunami analysis in Sri Lanka (Fegin *et al.*, 2009). Instead, it should promote sensible coastal development and disaster preparation programs through individual and collective participation. These programs should enhance the long-term capacity of people to cope and adapt themselves against future storm-inflicted damages. 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.

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Appendix A

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 (5) and (6) and the implicit function theorem, the comparative static effects of a decrease in G on the optimal levels of self-protection Z yields,

$$\frac{\partial Z^*}{\partial G} = \frac{\begin{vmatrix} -\frac{\partial F^1}{\partial G} & H_{ZA} \\ -\frac{\partial F^2}{\partial G} & H_{AA} \end{vmatrix}}{|H|} \tag{A.1.1}$$

$$\Rightarrow \frac{\begin{vmatrix} -\frac{\partial EMB_Z}{\partial G} & H_{ZA} \\ -\frac{\partial EMB_A}{\partial G} & H_{AA} \end{vmatrix}}{|H|} = \frac{\overbrace{H_{AA} \cdot \left(-\frac{\partial EMB_Z}{\partial G}\right)}^{\text{direct effect}} + \overbrace{H_{AZ} \cdot \left(\frac{\partial EMB_A}{\partial G}\right)}^{\text{indirect effect}}}{|H|}$$

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 (5); $F^2 \equiv EMB_A$ is the first order condition with respect to self-insurance, i.e. the expected marginal benefits of self-insurance based on expression (6); 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 (A.1.1), 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,

$$\frac{\partial A^*}{\partial G} = \frac{\begin{vmatrix} H_{ZZ} & -\frac{\partial F^1}{\partial G} \\ H_{AZ} & -\frac{\partial F^2}{\partial G} \end{vmatrix}}{|H|} \quad \text{(A.1.2)}$$

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

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 (5); $F^2 \equiv EMB_A$ is the first order condition with respect to self-insurance, i.e. the expected marginal benefits of self-insurance based on expression (6); 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 (A.1.2), 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 (A.1.1) and (A.1.2) 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 (A.1.1) leads to

$$\frac{\partial Z}{\partial G} = \frac{\overbrace{H_{AA}}^{'-'} \cdot \begin{bmatrix} -\overbrace{\frac{\partial^2 \pi(.)}{\partial G \partial Z}}^{'?'} \cdot \overbrace{\left(U(W_1) - U(W_2)\right)}^{'-'} \\ +\overbrace{\frac{\partial \pi}{\partial G}}^{'-'} \cdot \overbrace{\left(U'(W_1) - U'(W_2)\right)}^{'+'} \end{bmatrix} + \overbrace{H_{ZA}}^{'?'} \cdot \begin{bmatrix} -\overbrace{\frac{\partial \pi(.)}{\partial G}}^{'-'} \cdot \overbrace{U'(W_1)}^{'+'} \cdot \overbrace{\left(1 + \frac{\partial L}{\partial A}\right)}^{'-'} \\ +\overbrace{U'(W_2)}^{'+'} \cdot \overbrace{\frac{\partial Q(.)}{\partial G}}^{'-'} \end{bmatrix}}{|H|} \quad \text{(A.1.3)}$$

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 (A.1.2) yields

$$\frac{\partial A}{\partial G} = \frac{\overbrace{H_{ZZ}}^{'-'} \cdot \begin{bmatrix} \overbrace{\frac{\partial \pi(.)}{\partial G}}^{'-'} \cdot \overbrace{U'(W_1)}^{'+'} \cdot \overbrace{\left(1 + \frac{\partial L}{\partial A}\right)}^{'-'} \\ -\overbrace{U'(W_2)}^{'+'} \cdot \overbrace{\frac{\partial \pi(.)}{\partial G}}^{'-'} \end{bmatrix} + \overbrace{H_{AZ}}^{'?'} \cdot \begin{bmatrix} \overbrace{\frac{\partial^2 \pi(.)}{\partial G \partial Z}}^{'?'} \cdot \overbrace{\left(U(W_1) - U(W_2)\right)}^{'-'} \\ +\overbrace{\frac{\partial \pi}{\partial G}}^{'-'} \cdot \overbrace{\left(U'(W_1) - U'(W_2)\right)}^{'+'} \end{bmatrix}}{|H|} \quad \text{(A.1.4)}$$

It is not possible to sign expression (A.1.3) and (A.1.4) unambiguously. They can only be signed if the following conditions hold,

Condition 4. $H_{AZ} = H_{ZA} < 0$. That is, assuming self-protection and self-insurance to be stochastic substitutes.[48] This implies that the marginal utility of ex-ante self-protection, Z, decreases if more ex-ante self-insurance, A, a ctivities are taken by the household and vice-versa.

Condition 5. $\frac{\partial^2 \pi(.)}{\partial G \partial Z} < 0$. 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 (4) and (5) are met, it is possible to sign - expressions (A.1.1) and (A.1.2) accordingly.

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

$$\frac{\partial A}{\partial G} = \frac{\overbrace{H_{zz}}^{"-"} \cdot \overbrace{\text{2nd bracketed term}}^{"+"} + \overbrace{H_{AZ}}^{"-"} \cdot \overbrace{\text{4th bracketed term}}^{"+"}}{|H|} = \frac{"-" + "-"}{|H|} < 0 \quad \text{(A.1.5)}$$

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[48] 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.

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

$$\frac{\partial Z^*}{\partial R} = \frac{\begin{vmatrix} -\frac{\partial F^1}{\partial R} & H_{ZA} \\ -\frac{\partial F^2}{\partial R} & H_{AA} \end{vmatrix}}{|H|}$$

$$\Rightarrow \frac{\begin{vmatrix} -\frac{\partial EMB_Z}{\partial R} & H_{ZA} \\ -\frac{\partial EMB_A}{\partial R} & H_{AA} \end{vmatrix}}{|H|} = \frac{\overbrace{H_{AA} \cdot \left(-\frac{\partial EMB_Z}{\partial R}\right)}^{\text{direct effect}} + \overbrace{H_{AZ} \cdot \left(\frac{\partial EMB_A}{\partial R}\right)}^{\text{indirect effect}}}{|H|} \tag{A.1.6}$$

$$\frac{\partial A^*}{\partial R} = \frac{\begin{vmatrix} H_{ZZ} & -\frac{\partial F^1}{\partial R} \\ H_{AZ} & -\frac{\partial F^2}{\partial R} \end{vmatrix}}{|H|}$$

$$\Rightarrow \frac{\begin{vmatrix} H_{ZZ} & -\frac{\partial EMB_Z}{\partial R} \\ H_{AZ} & -\frac{\partial EMB_A}{\partial R} \end{vmatrix}}{|H|} = \frac{\overbrace{H_{ZZ} \cdot \left(-\frac{\partial EMB_A}{\partial R}\right)}^{\text{direct effect}} + \overbrace{H_{AZ} \cdot \left(\frac{\partial EMB_Z}{\partial R}\right)}^{\text{indirect effect}}}{|H|} \tag{A.1.7}$$

Expressions (A.1.6)-(A.1.7) 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 (A.1.6) and (A.1.7) lead to,

$$\frac{\partial Z}{\partial R}=\frac{\overset{'-'}{H_{AA}}\cdot\left[\overbrace{\frac{\partial\pi(.)}{\partial Z}}^{'-'}\cdot\overbrace{U^{'}(W_1)}^{'+'}\cdot\overbrace{\frac{\partial L(.)}{\partial R}}^{'-'}-\overbrace{\pi}^{'+'}\cdot\overbrace{U^{''}(W_1)}^{'-'}\cdot\overbrace{\frac{\partial L}{\partial R}}^{'-'}\right]+\overset{'?'}{H_{ZA}}\cdot\left[\begin{array}{l}-\overbrace{\pi(.)}^{'+'}\cdot\overbrace{U^{'}(W_1)}^{'+'}\cdot\overbrace{\frac{\partial^2 L(.)}{\partial R\partial A}}^{"?"}\\+\overbrace{\pi(.)}^{'+'}\cdot\overbrace{\left(1+\frac{\partial L(.)}{\partial A}\right)}^{'-'}\cdot\overbrace{U^{''}(W_1)}^{"-"}\cdot\overbrace{\frac{\partial L}{\partial R}}^{"-"}\end{array}\right]}{|H|} \tag{A.1.8}$$

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,

$$\frac{\partial A}{\partial R}=\frac{\overset{'-'}{H_{ZZ}}\cdot\left[\begin{array}{l}\overbrace{\pi(.)}^{'+'}\cdot\overbrace{U^{'}(W_1)}^{'+'}\cdot\overbrace{\frac{\partial^2 L(.)}{\partial R\partial A}}^{"?"}\\+\overbrace{\pi(.)}^{'+'}\overbrace{\left(1+\frac{\partial L(.)}{\partial A}\right)}^{'-'}\cdot\overbrace{U^{''}(W_1)}^{"-"}\cdot\overbrace{\frac{\partial L(.)}{\partial R}}^{"-"}\end{array}\right]+\overset{'?'}{H_{AZ}}\cdot\left[-\overbrace{\frac{\partial\pi(.)}{\partial Z}}^{'-'}\cdot\overbrace{\frac{\partial L(.)}{\partial R}}^{'-'}\cdot\overbrace{U^{'}(W_1)}^{'+'}+\overbrace{\pi(.)}^{'+'}\cdot\overbrace{U^{''}(W_1)}^{'-'}\cdot\overbrace{\frac{\partial L}{\partial R}}^{'-'}\right]}{|H|} \tag{A.1.9}$$

It is not possible to sign expression (A.1.9) 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

$$\frac{\partial Z}{\partial R}=\frac{\overbrace{-\pi\cdot\frac{\partial^2 L}{\partial A^2}}^{'-'}\cdot\overbrace{\frac{\partial\pi}{\partial Z}\cdot\left(\frac{\partial L}{\partial R}\right)}^{'+'}-\overbrace{\left(-\frac{\partial\pi}{\partial Z}\cdot\frac{\partial L}{\partial A}\right)}^{'-'}\cdot\overbrace{\left(\pi\cdot\frac{\partial^2 L}{\partial R\partial A}\right)}^{'?'}}{|H|} \tag{A.1.10}$$

$$\frac{\partial A}{\partial R}=\frac{\overbrace{-\frac{\partial^2\pi}{\partial Z^2}\cdot L(.)\cdot}^{'-'}\overbrace{\pi\cdot\frac{\partial^2 L}{\partial R\partial A}}^{'?'}-\overbrace{\left(-\frac{\partial\pi}{\partial Z}\cdot\frac{\partial L}{\partial A}\right)}^{'-'}\cdot\overbrace{\frac{\partial L}{\partial R}\cdot\frac{\partial\pi}{\partial Z}}^{'+'}}{|H|} \tag{A.1.11}$$

Under the risk neutral case, it is possible to sign both (A.1.10) and (A.1.11) if the following condition holds:

Condition 6. $\frac{\partial^2 L(.)}{\partial R \partial A} < 0$. 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 (6) along with the other conditions hold, then it is possible to sign expression (A.1.10) and (A.1.11) indicating the following relationship

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

$$\frac{\partial A}{\partial R} = \frac{\overbrace{H_{ZZ}}^{'-'} \cdot \overbrace{\text{2nd bracketed term}}^{"-"} - \overbrace{H_{AZ}}^{"-"} \cdot \overbrace{\text{4th bracketed term}}^{"+"}}{|H|} = \frac{"+" \; - \; "-"}{"+"} > 0 \qquad \text{(A.1.12)}$$

Expression (A.1.12) 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

$$\frac{\partial Z}{\partial M} = \frac{\begin{vmatrix} -\frac{\partial EMB_Z}{\partial M} & H_{ZA} \\ -\frac{\partial EMB_A}{\partial M} & H_{AA} \end{vmatrix}}{|H|} = \frac{H_{AA} \cdot \left(-\frac{\partial EMB_A}{\partial M}\right) + H_{ZA} \cdot \left(\frac{\partial EMB_A}{\partial M}\right)}{|H|}$$

$$= \frac{\overset{'-'}{H_{AA}} \cdot \left[\begin{array}{l} -\overbrace{\frac{\partial^2 \pi(.)}{\partial M \, \partial Z}}^{'?'} \cdot \overbrace{\left(U(W_1) - U(W_2)\right)}^{'-'} \\ + \overbrace{\frac{\partial \pi}{\partial M}}^{'-'} \cdot \overbrace{\left(U'(W_1) - U'(W_2)\right)}^{'+'} \end{array}\right] + \overset{'?'}{H_{ZA}} \cdot \left[\begin{array}{l} -\overbrace{\frac{\partial \pi(.)}{\partial M}}^{'-'} \cdot \overbrace{U'(W_1)}^{'+'} \cdot \overbrace{\left(1 + \frac{\partial L}{\partial A}\right)}^{'-'} \\ + \overbrace{U'(W_2)}^{'+'} \cdot \overbrace{\frac{\partial \pi(.)}{\partial M}}^{'-'} \end{array}\right]}{|H|} \qquad \text{(A.1.13)}$$

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

$$\frac{\partial A}{\partial M} = \frac{\begin{vmatrix} H_{ZZ} & -\frac{\partial EMB_Z}{\partial M} \\ H_{AZ} & -\frac{\partial EMB_A}{\partial M} \end{vmatrix}}{|H|} = \frac{H_{ZZ} \cdot \left(-\frac{\partial EMB_A}{\partial M} \right) + H_{AZ} \cdot \left(\frac{\partial EMB_Z}{\partial M} \right)}{|H|}$$

$$\frac{\overset{'-'}{H_{ZZ}} \cdot \begin{bmatrix} \overbrace{\frac{\partial \pi(.)}{\partial M}}^{'-'} \cdot \overbrace{U'(W_1)}^{'+'} \cdot \overbrace{\left(1 + \frac{\partial L}{\partial A}\right)}^{'-'} \\ -\overbrace{U'(W_2)}^{'+'} \cdot \overbrace{\frac{\partial \pi(.)}{\partial M}}^{'-'} \end{bmatrix} + \overset{'?'}{H_{AZ}} \cdot \begin{bmatrix} \overbrace{\frac{\partial^2 \pi(.)}{\partial M \, \partial Z}}^{'?'} \cdot \overbrace{\left(U(W_1) - U(W_2)\right)}^{'-'} \\ -\overset{'-'}{\frac{\partial \pi}{\partial M}} \cdot \overbrace{\left(U'(W_1) - U'(W_2)\right)}^{'+'} \end{bmatrix}}{|H|} \qquad (A.1.14)$$

As before, it is not possible to sign expression (A.1.13) and (A.1.14) 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 7. $\frac{\partial^2 \pi(.)}{\partial M \partial Z} < 0$. 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 (A.1.13) and (A.1.14) show

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

$$\frac{\partial A}{\partial M} = \frac{\overbrace{H_{zz}}^{"-"} \cdot \overbrace{\text{2nd bracketed term}}^{"+"} + \overbrace{H_{AZ}}^{"-"} \cdot \overbrace{\text{4th bracketed term}}^{"+"}}{|H|} = \frac{"-" \;+\; "-"}{|H|} < 0 \qquad (A.1.15)$$

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 .

Appendix B
Table B.1: Sources of Data

Sl. No.	Data Head	Description	Sources
1.	Damages (losses) due to Cyclone Sidr	Property damages in selected villages	Disaster Management Bureau (DMB); Household Survey
2.	Meteorological information	Track of Cyclone Sidr; wind velocity at different observation points; radius of cyclone eye at selected observation points; projected sea elevation (tidal surge) at different coastal areas	Bangladesh Meteorological Department (BMD); Institute of Water Modeling (IWM)
3.	Geo-physical information	Area of mangrove; location of embankments; distances of the selected unions (villages) from the coastline; from Sundarban mangrove forest; from the track of Cyclone Sidr.	Digitized maps from LGED, CEGIS; Household Survey
4.	Socio-economic information	Total population; age; education years; occupation; Cyclone Sidr pre - and post - income level; asset information; male-female ratio; children, etc.	Census data (Bangladesh Bureau of Statistics, BBS); Household survey
5.	Ex-ante private defensive strategies/ expenditures	Risk mitigating and risk coping information based on participation (binary response) and conditional on participation, expenses incurred.	Household survey

Appendix C

Combining equations (2.2)-(2.3), it is possible to express the participation and outcome choices for ex-ante self-insurance, A, by the following econometric specification,

(i) Participation equation for self-insurance:

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

(A.2.1)

(ii) Outcome equation Level of ex ante self-insurance expenditures, *A*,

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

Expression (A.2.1) 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-insurance and the level of self-insurance expenditures equation conditional on participation.

Similar econometric specification can be set for ex-ante self-protection expenditures, Z_{ij}.

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Figures

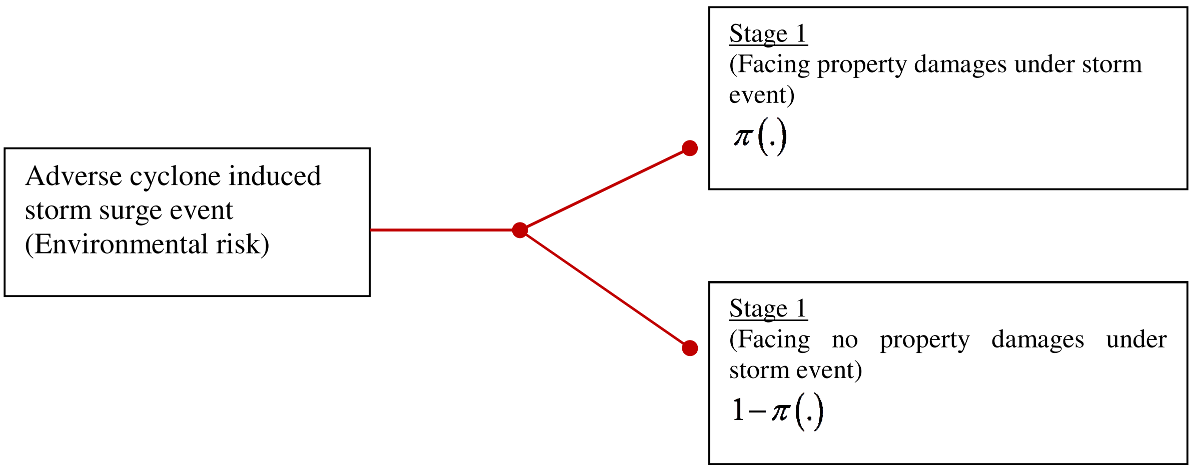

Figure 1: Probability Tree of a Sequence of Events

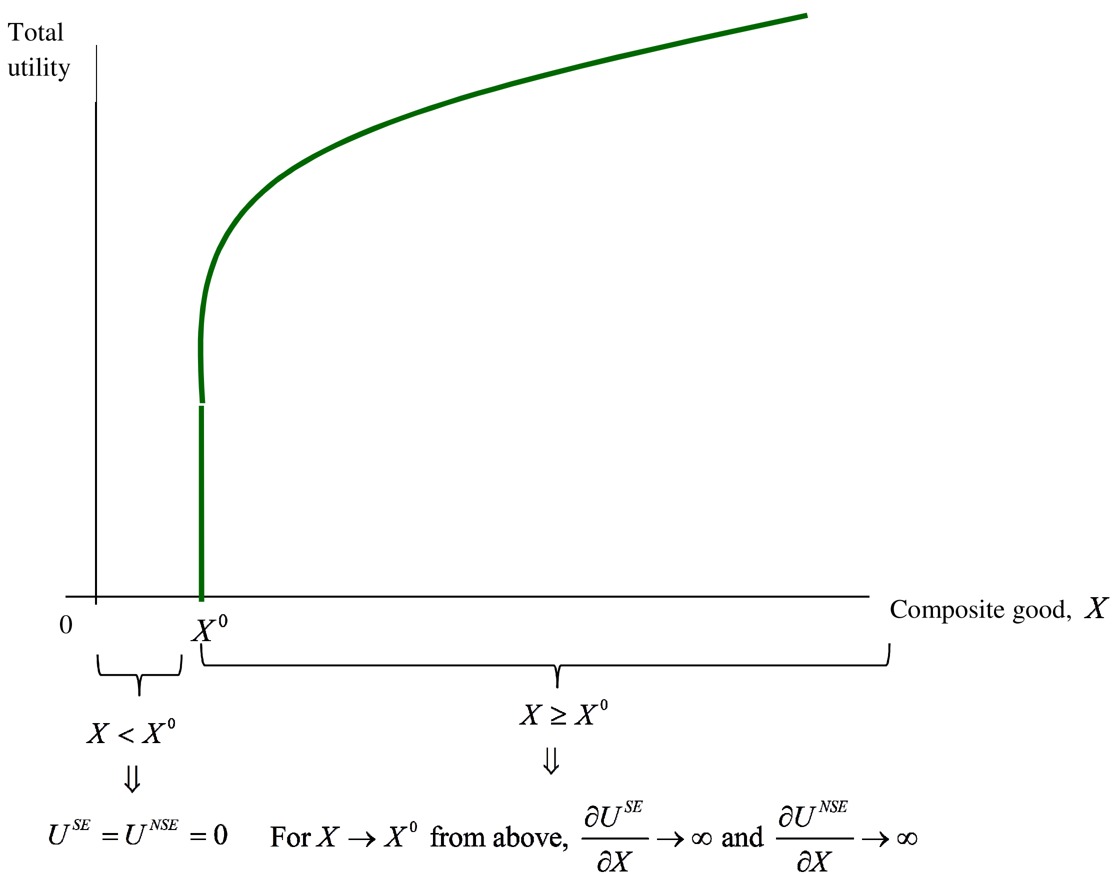

Figure 2: Shape of the Total Utility for the Composite Good under Certain Assumptions (Holding Other Variables Constant)

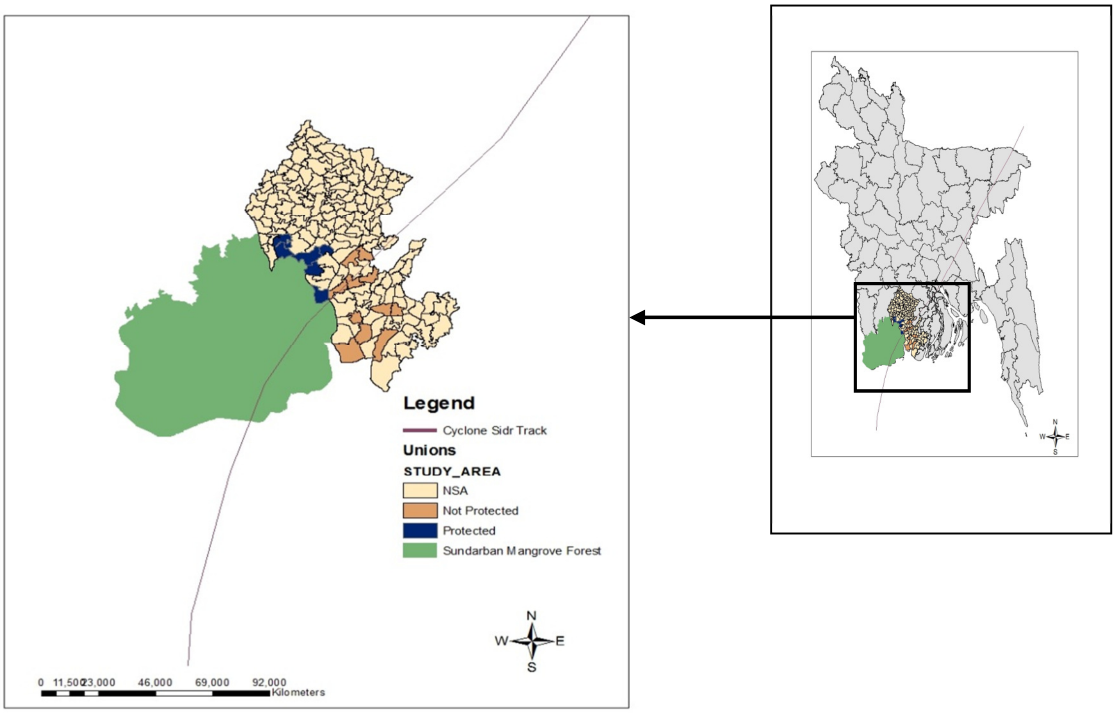

Figure 3: The Study Area – The Protected and Non-Protected Areas

Tables

Table 1: Self-protection and Self-insurance based on Bangladesh Coastal Households

Examples of Private Self-protection affecting probability	*Examples of Private Self-insurance affecting ex post monetary loss or damage to property*
▪ Converting mud built house to brick built house ▪ Raising height of the homestead ▪ Moving house inside embankment ▪ Planting trees around the house	▪ Opportunities to diversify post disaster income ▪ Options for increased borrowing from both formal and informal sources ▪ Setting aside private transfers through remittances and charities[49]. ▪ Access to social capital

Source: Reconnaissance Survey, summer 2008

Table 2: Household behavioral responses to private storm protection strategies under non-binding constraint $X \geq X^0$ using the Kuhn-Tucker conditions

Case	Outcome	Interpretation
1	$Z > 0; A > 0$	Both self-protection and self-insurance
2	$Z > 0; A = 0$	Self-protection only corner solution
3	$Z = 0; A > 0$	Self-insurance only corner solution
4	$Z = 0; A = 0$	No self-protection and no self-insurance

[49] Setting aside private transfers exclusively for self-insurance could be considered as a type of opportunity cost where the fund could be utilized for highest valued alternative like investing on productive activities with income earning potential for the future.

Table 3: Comparative Static Results of the Household Model of Ex-ante Private Investment

Ex-ante self-protection (Z_{ij})		
	Conditional Result	**Requirements for Signing Conditional Result**
Access to ex- ante public protection spending	$\frac{dZ_{ij}}{dG_{ij}} > 0$	1. $H_{AZ} = H_{ZA} < 0$ 2. $\frac{\partial^2 \pi_{ij}(.)}{\partial G_{ij} \partial Z_{ij}} < 0$
Exposure to mangrove forest	$\frac{dZ_{ij}}{dM_{ij}} > 0$	1. $H_{AZ} = H_{ZA} < 0$ 2. $\frac{\partial^2 \pi_{ij}(.)}{\partial M_{ij} \partial Z_{ij}} < 0$
Access to ex-post relief and rehabilitation programs	$\frac{dZ_{ij}}{dR_{ij}} < 0$ (Holds only for risk neutral households)	$\frac{\partial^2 L_{ij}(A_{ij}, R_{ij})}{\partial R_{ij} \partial A_{ij}} < 0$
Ex- ante self-insurance (A_{ij})		
Access to ex- ante public protection spending	$\frac{dA_{ij}}{dG_{ij}} < 0$	1. $H_{AZ} = H_{ZA} < 0$ 2. $\frac{\partial^2 \pi_{ij}(.)}{\partial G_{ij} \partial Z_{ij}} < 0$
Exposure to mangrove forest	$\frac{dA_{ij}}{dM_{ij}} < 0$	1. $H_{AZ} = H_{ZA} < 0$ 2. $\frac{\partial^2 \pi_{ij}(.)}{\partial M_{ij} \partial Z_{ij}} < 0$
Access to ex-post relief and rehabilitation programs	$\frac{dA_{ij}}{dR_{ij}} > 0$ (Holds only for risk neutral households)	$\frac{\partial^2 L_{ij}(A_{ij}, R_{ij})}{\partial R_{ij} \partial A_{ij}} < 0$

Table 4: 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
Average per capita income (US $ /year)	Wood/ Coal	167.00	200.50
Main source of energy- multiple responses (%)	Twigs/ Leafs	93.52	98.55
		83.80	61.82

Table 5: Household Type based on Self-protection and Self-insurance*

Type	Non-protected area	Protected area	Total
Both self-protection and self-insurance	10 (3.57)	34 (15.74)	44 (8.87)
Only self-protection	36 (12.86)	28 (12.96)	64 (12.90)
Only self-insurance	44 (15.71)	25 (11.57)	69 (13.91)
No self-protection and self-insurance	190 (67.86)	129 (59.72)	319 (64.31)
Total	280 (100.00)	216 (100.00)	496 (100.00)

*Based on frequencies by study area; percentage are expressed in parentheses.

Table 6: Income, Landownership, and Meat Consumption by Storm Protection Strategies

Household type	Mean yearly household income (in Tk.)	Mean land ownership (in decimals)	Mean rice consumption (in grams/ week)	Mean meat consumption (in grams/ week)
Both self-protection and self-insurance	81,569.09	198.64	19118.2	3875.0
Only self-protection	69,746.16	165.64	19546.1	3627.5
Only self-insurance	70,089.70	149.22	18930.2	13270.9
No self-protection and self-insurance	69,330.43	129.89	17163.74	3499.22
No. of observations	**487**	**496**	**312**	**104**

Table 7: Accessibility to Public Goods in the Study Area

Sl. No.	Variable Name	Protected Area (obs.)	Non-protected Area (obs.)
1.	House located inside embankment (%)	34.56 (217)	81.43 (280)
2.	Cyclone shelter close to house (%)	44.19 (215)	61.73 (277)
3.	Planning to migrate in future (%)	50.91 (220)	18.25 (274)
4.	Access to relief (%)	90.00	88.53
5.	Access to rehabilitation (%)	64.68	46.35

Table 8: 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 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 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
EMB	If household is protected by the embankment (=1, 0 otherwise)	497	0.6097	0.4883
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
EDUC2	If head of the household has primary level education (=1,0 otherwise)	492	0.4837	0.5002
EDUC3	If head of the household has secondary and higher level education (=1,0 otherwise)	492	0.3963	0.4896
EDUC4	If head of the household has tertiary level education (=1,0 otherwise)	492	0.0386	0.1929
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
HELEV	If household falls into low elevation area (=1, 0 otherwise)	500	0.474	0.499
MIGRATION	If planning to migrate in the future (=1, 0 otherwise)	494	0.328	0.469
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
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 9: 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	Parsimonious Model (1)		Add the Mangroves Characteristics (2)		Add the Public Programs (3)		Add the Storm Surge Characteristics (4)	
CONSTANT	-13.663 (-1.74)**		-14.097 (-1.83)**		-14.755 (-1.85)**		-12.979 (-1.57)*	
L(DAMAGE)	0.1826 (2.58)**	0.0497	0.2094 (2.89)***	0.0559	0.2289 (3.05)***	0.0592	0.1994 (2.64)***	0.0501
L(PREINC)	1.896 (1.44)*	0.5166	1.978 (1.54)*	0.5279	2.081 (1.56)*	0.5378	1.821 (1.32)*	0.4577
L(PREINC2)	-0.0783 (-1.40)*	-0.0213	-0.0815 (-1.50)*	-0.0217	-0.0857 (-1.52)*	-0.0222	-0.0756 (-1.29)*	-0.019
AREA	0.0006 (2.02)**	0.0002	0.0006 (2.20)**	0.0002	0.0006 (1.99)**	0.0001	0.0006 (1.99)**	0.0001
EMB	-0.2407 (-1.20)	-0.0669	0.0072 (0.03)	0.0019	-0.074 (-0.34)	-0.0193	0.003 (0.01)	0.0009
DCOAST	0.0037 (0.73)	0.0009	0.0014 (0.18)	0.0004	0.0059 (0.70)	0.0015	0.004 (0.39)	0.001
AGE	-0.003 (-0.54)	-0.0008	-0.0052 (-0.91)	-0.0014	-0.0071 (-1.18)	-0.0018	-0.0072 (-1.17)	-0.0018
EDUYR	-0.0001 (-0.00)	-0.0000	0.0032 (0.15)	0.0009	0.0029 (0.13)	0.0008	0.0078 (0.35)	0.0019
CREDIT	-0.2423 (-1.57)*	-0.0670	-0.2852 (-1.80)**	-0.0776	-0.3381 (-2.06)**	-0.0893	-0.3598 (-2.13)**	-0.0926
MEMBER	0.1997 (1.03)	0.0571	0.1563 (0.77)	0.0434	0.1957 (0.94)	0.0533	0.1696 (0.79)	0.0446
MFRATIO	-0.1056 (-1.08)	-0.0288	-0.0712 (-0.77)	-0.019	-0.0993 (-1.03)	-0.0257	-0.1046 (-1.04)	-0.0263
CHILD	-0.1533 (-2.20)**	-0.0418	-0.1596 (-2.35)***	-0.0426	-0.1869 (-2.59)***	-0.0483	-0.1726 (-2.29)**	-0.0434
HELEV	-0.2348 (-1.55)*	-0.0649	-0.1836 (-1.17)	-0.0496	-0.1174 (-0.72)	-0.0306	-0.1243 (-0.70)	-0.0315
MIGRATION	0.0354 (0.22)	0.0097	-0.1366 (-0.78)	-0.0357	-0.1629 (-0.91)	-0.041	-0.0901 (-0.50)	-0.0223
PROTECTED			0.4528 (1.38)*	0.1233	0.3401 (1.00)	0.0892	-0.5282 (-1.08)	-0.1294
MDIST			-0.0359 (-1.54)*	-0.0096	-0.0331 (-1.32)*	-0.0086	-0.0515 (-1.99)**	-0.0129
MDIR			-0.5557 (-1.83)**	-0.1467	-0.5431 (-1.69)**	-0.1394	-0.6303 (-1.99)**	-0.1571
ARELEIF					-0.4066 (-1.57)*	-0.1206	-0.4285 (-1.60)*	-0.1251
AREHABN					0.3209 (1.83)**	0.0817	0.200 (1.09)	0.0498
SURGEHT							0.1346 (0.66)	0.0338
STORMEXP							-0.7349 (-1.92)**	-0.1721
STORMDIS							0.0369 (3.59)***	0.009

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

Table 10: 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)								
Variable	(1)		(2)		(3)		(4)	
	Coeff.	Marginal Effect	Coeff.	Marginal Effect	Coeff.	Marginal Effect	Coeff.	Marginal Effect
CONSTANT	4067115 (2.34)***		4794661 (2.67)***		4312178 (2.18)**		4149218 (2.13)**	
L(DAMAGE)	30375.84 (2.01)**	35373.84	20413.19 (1.36)*	34548.74	19330.95 (1.17)	35700.36	23051.4 (1.47)*	37416.27
L(PREINC)	-794574 (-2.87)***	-742672	-890241.7 (-3.06)***	-756754.6	-795128 (-2.45)***	-646310	-791386.3 (-2.48)***	-660161
L(PREINC2)	36136.13 (3.07)***	33994.05	12382.16 (3.26)***	34900.26	36245.51 (2.59)***	30112.2	36095.18 (2.62)***	30645.3
DCOAST	1026.43 (1.47)*	1126.74	-171.67 (-0.16)	-73.887	-447.15 (-0.40)	-24.02	421.52 (0.28)	710.35
AGE	194.27 (0.22)	111.82	227.66 (0.25)	-126.297	183.45 (0.20)	-326.35	178.87 (0.19)	-341.92
EDUYR	-2547.85 (-0.70)	-2550.49	-4456.52 (-1.16)	-4239.11	-3371.29 (-0.86)	-3161.68	-3685.97 (-0.89)	-3124.84
CREDIT	27417.17 (1.08)	20806.91	38296.32 (1.36)*	19114.88	44058.46 (1.51)*	19976.86	47357.16 (1.60)*	21547.73
MEMBER	-28705.4 (-0.80)	-23292.17	-50413.29 (-1.34)*	-39939.71	-55887 (-1.40)*	-42015.55	-58546 (-1.44)*	-46420.68
HELEV	41068.91 (1.56)*	34660.33	60192.17 (2.19)**	47827.14	55844.58 (1.97)**	47461.57	59179.57 (2.03)**	50238.34
MIGRATION	-52084.4 (-1.90)**	-51116.93	-59235.29 (-2.03)**	-68490.02	-64872.5 (-2.12)**	-76579.11	-67954.4 (-2.13)**	-74460.54
PROTECTED			56091.53 (0.98)	86509.78	51561.84 (0.91)	75814.84	91481.35 (1.02)	53317.56
MDIST			1146.33 (0.41)	-1280.69	1039.39 (0.37)	-1328.33	2025.18 (0.64)	-1687.79
ARELEIF					-39011.6 (-0.78)	-67286.54	-26547.72 (-0.51)	-56534.65
AREHABN					10128.37 (0.34)	33133.27	13455.5 (0.44)	27888.5
SURGEHT							10078.43 (0.32)	19774.91
STORMEXP							48699.64 (0.62)	-4706.39
STORMDIS							-2255.29 (-0.96)	403.43
RHO	-0.3237 (-0.729)		-0.6890 (-3.23)***		-0.7193 (-3.55)***		-0.7253 (-3.83)***	
LAMBDA	-34849.81 (-0.672)		-85649.17 (-2.06)**		-90230.95 (-2.17)**		-90482.61 (-2.34)***	
LOG LIKE.	-1321.69		-1314.92		-1265.04		-1257.75	
LR test $(\rho = 0)$	0.34		2.95		3.53		4.14	
LR test $(\text{prob.}>\chi^2)$	0.5627		0.0861		0.0602		0.0419	
OBS.	440		409		401		401	
CENSORED OBS.	349		322		317		317	

[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 except for the parsimonious specification. 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 11: Probit and Tobit Model for Ex-ante Self-insurance

Variable	Probit Model [a]				Tobit Model [b]			
	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
	Coeff.	Coeff.	Coeff.	Coeff.	Coeff.	Coeff.	Coeff.	Coeff.
CONSTANT	-20.232 (-2.20)**	-18.965 (-2.08)**	-16.327 (-2.09)**	-16.526 (-1.99)**	612998.3 (2.46)***	690832.8 (2.82)***	678984.1 (2.76)***	731619.6 (2.95)***
L(DAMAGE)	0.1398 (1.99)**	0.1369 (1.92)**	0.14138 (1.82)**	0.1397 (1.76)**	10669.91 (3.24)***	10673.66 (3.28)***	10590.39 (3.23)***	10319.91 (3.14)***
L(PREINC)	2.731 (1.79)**	2.469 (1.63)*	1.6794 (1.33)*	1.91 (1.41)*	-25888.4 (-0.68)	-40030.17 (-1.07)	-41837.2 (-1.12)	-39852.5 (-1.07)
L(PREINC2)	-0.1247 (-1.90)**	-0.1138 (-1.75)**	-0.0772 (-1.41)*	-0.0868 (-1.48)*	1006.05 (0.62)	1624.31 (1.03)	1725.31 (1.09)	1643.2 (1.04)
L(POSTINC)	0.5016 (0.98)	0.5667 (1.06)	0.5069 (0.95)	0.4912 (0.91)	-150744.1 (-6.70)***	-149547.7 (-6.74)***	-147146.4 (-6.66)***	-148766.2 (-6.73)***
L(POSTINC2)	-0.0233 (-0.89)	-0.0257 (-0.94)	-0.0205 (-0.75)	-0.0184 (-0.66)	8323.07 (7.21)***	8227.56 (7.21)***	8105.01 (7.13)***	8212.67 (7.21)***
AREA	0.0002 (0.66)	0.0001 (0.27)	0.0002 (0.72)	0.0002 (0.69)	14.721 (0.98)	8.051 (0.54)	8.072 (0.54)	7.569 (0.50)
EMB	-0.0318 (-0.18)	-0.0435 (-0.23)	-0.0888 (-0.44)	0.1556 (0.62)	16093.32 (1.92)**	12919.25 (1.49)*	15121.77 (1.73)**	22820.19 (2.15)**
DCOAST	0.0131 (2.48)***	0.0234 (2.78)***	0.0306 (3.37)***	0.0212 (1.79)**	177.38 (0.75)	1000.08 (2.71)***	876.53 (2.34)***	473.88 (0.98)
AGE	0.0031 (0.57)	0.0035 (0.64)	0.0017 (0.29)	0.0036 (0.59)	450.122 (1.75)**	438.97 (1.71)**	459.76 (1.76)**	490.97 (1.87)**
CREDIT	0.2105 (1.37)*	0.2868 (1.80)**	0.2310 (1.36)*	0.2066 (1.20)	1279.78 (1.27)	1609.52 (1.60)*	1701.53 (1.70)**	1712.26 (1.71)**
MEMBER	-0.5215 (-2.45)***	-0.6915 (-3.04)***	-0.7968 (-3.35)***	-0.7943 (-3.29)***	2481.86 (0.34)	6445.94 (0.89)	7449.46 (1.02)	6677.12 (0.91)
MFRATIO	-0.0184 (-0.19)	-0.0334 (-0.34)	-0.0097 (-0.09)	0.0142 (0.13)	-341.48 (-0.04)	-6831.21 (-0.71)	-6997.62 (-0.72)	-6354.23 (-0.66)
CHILD	0.0809 (1.31)*	0.0923 (1.44)*	0.1177 (1.77)**	0.1106 (1.65)**	13923.38 (4.72)***	14583.74 (4.96)***	14533.4 (4.90)***	14230.2 (4.77)***
HELEV	-0.1270 (-0.82)	0.0158 (0.10)	-0.0276 (-0.16)	-0.0765 (-0.41)	8164.98 (1.14)	14218.15 (1.95)**	11773.88 (1.60)*	8552.28 (1.07)
MIGRATION	-0.1444 (-0.90)	-0.1019 (-0.57)	-0.1489 (-0.77)	-0.0697 (-0.35)	-8316.17 (-1.11)	-2.532 (-0.00)	1009.49 (0.12)	2948.37 (0.35)
PROTECTED		-0.7821 (-2.39)***	-0.9930 (-2.78)***	-0.3837 (-0.76)		-57607.3 (-3.76)***	-52450.72 (-3.37)***	-45216.88 (-2.08)**
MDIST		-0.047 (-1.85)**	-0.0448 (-1.66)**	-0.0329 (-1.15)		-2306.24 (-2.00)**	-2196.22 (-1.90)**	-2124.96 (-1.75)**
MDIR		0.0214 (0.06)	-0.1192 (-0.32)	0.0043 (0.01)		1558.41 (0.10)	2023.8 (0.13)	5313.77 (0.33)
ARELEIF			1.0548 (2.26)**	1.076 (2.25)**			16397.71 (1.32)*	14891 (1.20)
AREHABN			0.8792 (4.94)***	0.9467 (5.18)***			-8713.12 (-1.13)	-7441.48 (-0.94)
SURGEHT				-0.4035 (-1.93)**				-11886.2 (-1.33)*
STORMEXP				0.2689 (0.76)				-6104.79 (-0.41)
STORMDIS				-0.0031 (-0.30)				137.07 (0.32)
Log Like.	-198.36	-192.72	-172.82	-170.74	-3216.79	-3208.20	-3179.27	-3178.24
LR Chi2	43.60	54.87	90.23	94.38	109.27	126.45	128.58	130.64
OBS.	399	399	391	391	402	402	394	394

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

Variables	Parsimonious Model		Add the Mangroves Characteristics		Add the Public Programs		Add the Storm Surge Characteristics	
	SPROT	SINSUR	SPROT	SINSUR	SPROT	SINSUR	SPROT	SINSUR
CONSTANT	-15.031 (-1.94)**	-5.655 (-2.17)**	-15.693 (-1.98)**	-5.457 (-2.02)**	-15.005 (-1.78)**	-7.641 (-2.68)***	-12.433 (-1.48)*	-6.792 (-2.27)**
L(DAMAGE)	0.1576 (2.23)**	0.0916 (1.42)*	0.1877 (2.55)***	0.0904 (1.38)*	0.2117 (2.75)***	0.1193 (1.63)*	0.1788 (2.30)**	0.1206 (1.62)*
L(PREINC)	2.008 (1.56)*		2.173 (1.66)**		2.0633 (1.47)*		1.509 (1.08)	
L(PREINC2)	-0.0808 (-1.49)*		-0.0876 (-1.59)*		-0.0833 (-1.41)*		-0.0599 (-1.02)	
L(POSTINC)		0.6255 (1.24)		0.6018 (1.15)		0.5815 (1.09)		0.5663 (1.06)
L(POSTINC2)		-0.0319 (-1.24)		-0.0308 (-1.16)		-0.0261 (-0.97)		-0.024 (-0.88)
AREA	0.0006 (2.15)**	0.0005 (1.58)*	0.0005 (1.76)**	0.0004 (1.20)	0.0005 (1.72)**	0.0005 (1.52)*	0.0005 (1.75)**	0.0005 (1.54)*
DCOAST	0.0079 (1.95)**	0.0141 (3.26)***	0.0078 (1.01)	0.0251 (3.26)***	0.0102 (1.19)	0.0329 (3.72)***	0.0141 (1.37)*	0.0263 (2.41)***
AGE	-0.0013 (-0.24)	0.0038 (0.71)	-0.0019 (-0.34)	0.0043 (0.80)	-0.0038 (-0.65)	0.0015 (0.25)	-0.0049 (-0.81)	0.0026 (0.45)
EDUC2	0.3502 (1.09)	-0.0635 (-0.23)	0.3923 (1.18)	0.0635 (0.23)	0.4007 (1.17)	-0.0426 (-0.14)	0.2099 (0.59)	-0.0125 (-0.04)
EDUC3	0.5139 (1.56)*	-0.2823 (-0.98)	0.5639 (1.65)**	-0.1639 (-0.56)	0.5186 (1.47)*	-0.2523 (-0.79)	0.4028 (1.10)	-0.2277 (-0.71)
EDUC4	0.3624 (0.79)	-0.8539 (-1.74)**	0.2781 (0.58)	-0.729 (-1.45)*	0.3318 (0.69)	-0.8072 (-1.50)*	0.1706 (0.34)	-0.7804 (-1.45)*
CREDIT	-0.2074 (-1.40)*	0.2281 (1.53)*	-0.2758 (-1.80)**	0.2677 (1.75)**	-0.3408 (-2.12)**	0.1763 (1.06)	-0.3408 (-2.08)**	0.1633 (0.98)
MFRATIO	-0.1223 (-1.26)*	-0.0095 (-0.10)	-0.1041 (-1.06)	-0.0199 (-0.21)	-0.1295 (-1.26)*	0.0121 (0.12)	-0.1387 (-1.30)*	0.0347 (0.33)
CHILD	-0.1306 (-1.92)**	0.0647 (1.08)	-0.1448 (-2.06)**	0.0745 (1.21)	-0.1668 (-2.23)**	0.1041 (1.60)*	-0.1449 (-1.86)**	0.096 (1.46)*
ELEC	-0.1188 (-0.68)	0.3653 (2.15)**	-0.0354 (-0.19)	0.4023 (2.28)**	-0.0007 (-0.00)	0.4334 (2.29)**	0.046 (0.24)	0.4116 (2.17)**
PHONE	-0.3025 (-1.91)**	-0.1296 (-0.83)	-0.3186 (-1.98)**	-0.1705 (-1.08)	-0.371 (-2.22)**	-0.3328 (-1.95)**	-0.3218 (-1.83)**	-0.317 (-1.83)**
PROTECTED			0.1004 (0.32)	-0.6848 (-2.24)**	-0.184 (-0.06)	-0.9241 (-2.76)***	-1.009 (-2.05)	-0.3473 (-0.71)
MDIST			-0.0549 (-2.24)**	-0.0449 (-1.89)**	-0.0458 (-1.79)**	-0.0399 (-1.56)*	-0.0654 (-1.86)**	-0.0301 (-1.10)
MDIR			-0.6115 (-1.86)**	-0.1068 (-0.33)	-0.4999 (-1.44)*	-0.2096 (-0.59)	-0.6575 (-1.86)**	-0.1121 (-0.30)
EMB					-0.1828 (-0.91)	-0.1606 (-0.82)	-0.2152 (-0.83)	0.0409 (0.16)
ARELEIF					-0.3842 (-1.54)*	1.155 (2.52)***	-0.3201 (-1.23)	1.1295 (2.44)***
AREHABN					0.3488 (1.99)**	0.9372 (5.21)***	0.1821 (0.98)	1.0031 (5.43)***
SURGEHT							0.3529 (1.77)**	-0.3214 (-1.67)**

Variables	Parsimonious Model		Add the Mangroves Characteristics		Add the Public Programs		Add the Storm Surge Characteristics	
	SPROT	SINSUR	SPROT	SINSUR	SPROT	SINSUR	SPROT	SINSUR
STORMEXP							-0.7256 (-1.93)**	0.2782 (0.81)
STORMDIS							0.0394 (3.69)***	-0.0058 (-0.56)
LOG LIKE.	-402.674		-392.885		-356.163		-347.814	
Wald [b] (χ^2)	55.91 (28)		71.67 (34)		105.88(40)		119.52 (46)	
OBS.	404		404		394		394	
LR test [c] $(\rho = 0)$	$\chi^2(1)$ = 5.240**		$\chi^2(1)$ =4.532**		$\chi^2(1)$ =2.541*		$\chi^2(1)$ = 3.289*	

a. Dependent variables are the probability of households participating in self-protection and the probability of households participating in self-insurance activities. Z-tests are shown in parentheses beneath coefficient estimates.

b. To test for linear restrictions on the coefficients, the Wald test with asymptotic chi-squared distribution is performed for all four model specifications. Results confirm that all the regressors are jointly statistically significant at 1% level.

c. The likelihood ratio (LR) test is performed to check the null hypothesis that there is exists no contemporaneous correlation $(\rho = 0)$ between the errors of the two probit equations. For the first two model specifications, we reject the null at 5% and 10% levels. However, we fail to reject the null at 5% level for the last two model specifications although the null is rejected at 10% level for the last specification.

Significant levels: ***1%, **5%, *10%.

Table 13: Marginal Effects of Joint Probabilities of Self-protection and Self-insurance using the Seemingly Unrelated Bivariate Probit [a]

Variable	Joint probabilities			
	P_{11} (Both self-protection and self-insurance)	P_{10} (Only self-protection)	P_{01} (Only self-insurance)	P_{00} (No self-protection and self-insurance)
L(DAMAGE)	0.0188 (2.52)***	0.0276 (1.75)**	0.0142 (0.87)	-0.0605 (-2.64)***
L(PREINC)	0.0963 (1.07)	0.2949 (1.09)	-0.0963 (-1.07)	-0.2949 (-1.09)
L(PREINC2)	-0.0038 (-1.01)	-0.0117 (-1.02)	0.0038 (1.01)	0.0117 (1.02)
L(POSTINC)	0.0347 (1.04)	-0.0347 (-1.04)	0.1200 (1.05)	-0.1200 (-1.05)
L(POSTINC2)	-0.0015 (-0.87)	0.0014 (0.87)	-0.0051 (-0.88)	0.0051 (0.88)
AREA	0.00007 (2.08)**	0.00007 (1.20)	0.00008 (1.04)	-0.00021 (-2.19)**
DCOAST	0.0025 (2.37)***	0.0012 (0.55)	0.0047 (1.96)**	-0.0083 (-2.59)
AGE	-0.0002 (-0.27)	-0.0011 (-0.93)	0.0009 (0.68)	0.0004 (0.22)
EDUC2	0.0127 (0.41)	0.0421 (0.59)	-0.0161 (-0.24)	-0.0387 (-0.39)
EDUC3	0.0109 (0.34)	0.0972 (1.23)	-0.0719 (-1.10)	-0.0362 (-0.35)
EDUC4	-0.0326 (-1.31)*	0.0799 (0.59)	-0.1162 (-2.62)***	0.0688 (0.47)
CREDIT	-0.0114 (-0.72)	-0.0789 (-2.28)**	0.0556 (1.61)*	0.0348 (0.69)
MFRATIO	-0.0067 (-0.69)	-0.0292 (-1.38)*	0.0162 (0.71)	0.0198 (0.62)
CHILD	-0.0034 (-0.50)	-0.0342 (-2.22)**	0.0296 (2.04)**	0.0079 (0.37)
ELEC	0.0301 (1.37)*	-0.018 (-0.49)	0.0909 (1.91)**	-0.1030 (-1.69)**
PHONE	-0.0401 (-2.31)***	-0.0431 (-1.25)	-0.0462 (-1.24)	0.1293 (2.49)***
PROTECTED	-0.0816 (-1.80)**	-0.1648 (-1.88)**	-0.0114 (-0.11)	0.2578 (1.91)**
MDIST	-0.006 (-2.24)**	-0.0109 (-2.01)**	-0.0022 (-0.37)	0.0192 (2.33)***
MDIR	-0.0482 (-1.40)*	-0.1198 (-1.73)**	0.0177 (0.23)	0.1504 (1.40)*
EMB	-0.0113 (-0.46)	-0.0458 (-0.84)	0.0224 (0.42)	0.0346 (0.45)
ARELEIF	0.0423 (2.51)***	-0.1349 (-1.71)**	0.1522 (5.42)***	-0.0596 (-0.71)
AREHABN	0.0698 (3.58)***	-0.0229 (-0.62)	0.1908 (5.07)***	-0.2376 (-4.50)***
SURGEHT	0.0029 (0.16)	0.0887 (2.24)**	-0.0907 (-2.16)**	-0.0009 (-0.01)
STORMEXP	-0.0287 (-0.96)	-0.1478 (-2.28)**	0.1063 (1.32)*	0.0702 (0.67)
STORMDIS	0.0022 (2.05)**	0.0081 (3.72)***	-0.0037 (-1.67)**	-0.0065 (-2.05)**

a. Joint probabilities are reported based on the final regression specification including the storm characteristics. Z-tests are shown in parentheses. Significant levels: ***1%, **5%, *10%.