WORKING PAPER

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

No. 54 - 10

Sakib Mahmud
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SANDEE
South Asian Network for Development and Environmental Economics

November 2010

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Sakib Mahmud
Edward B. Barbier

Department of Economics and Finance
University of Wyoming (UW),USA

November 2010

South Asian Network for Development and Environmental Economics (SANDEE)
PO Box 8975, EPC 1056
Kathmandu, Nepal

SANDEE Working Paper No. 54 - 10

Published by the South Asian Network for Development and Environmental Economics (SANDEE)
PO Box 8975, EPC 1056, Kathmandu, Nepal.
Telephone: 977-1-5003222 Fax: 977-1-5003299

SANDEE research reports are the output of research projects supported by the South Asian Network for Development and Environmental Economics. The reports have been peer reviewed and edited. A summary of the findings of SANDEE reports are also available as SANDEE Policy Briefs.

National Library of Nepal Catalogue Service:

Sakib Mahmud, and Edward B. Barbier
Are Private Defensive Expenditures against Storm Damages Affected by Public Programs and Natural Barriers? Evidence from the Coastal Areas of Bangladesh
(SANDEE Working Papers, ISSN 1893-1891; 2010- WP 54)

ISBN: 978 - 9937 - 8376 - 3 - 7

Key words:

1. Self-protection
2. Self-insurance
3. Cyclone damages
4. Mangroves
5. Bangladesh

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SANDEE is financially supported by International Development Research Center (IDRC), The Ford Foundation, Swedish International Development Cooperation Agency (SIDA), the World Bank and the Norwegian Agency for Development Cooperation (NORAD). The opinions expressed in this paper are the author's and do not necessarily represent those of SANDEE's donors.

The Working Paper series is based on research funded by SANDEE and supported with technical assistance from network members, SANDEE staff and advisors.

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Comments should be sent to Sakib Mahmud, Department of Economics and Finance
University of Wyoming (UW), USA Email: sakib_1822@yahoo.com

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Abstract

This paper introduces a theoretical model combining household production with an endogenous risk framework in order to understand how ex-ante private spending by coastal households would evolve against ex-post cyclone induced storm surge damage risk given the level of government protective spending 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 depending on whether the public programs serve as a possible stochastic substitute or a stochastic complement to the storm protection provided by the mangroves. We applied the model to a case study based on survey data from 35 villages comprising 500 households in the southwest coastal areas of Bangladesh affected by the most recent severe cyclone of November 2007. Empirical results on the full sample reveal that: (i) the presence of public disaster relief and rehabilitation programs leads to households being willing to invest more in self-insurance but less in self-protection; (ii) households protected by mangroves are more likely to participate in self-protection but less in self-insurance; (iii) the income and size of assets have a strong influence on a household's choice of self-protection but not on self-insurance; and, (iv) middle income households are more likely to participate in self-protection and self-insurance compared to low-income and-rich households; but, once the households decide to participate in private defensive strategies, resources based on their capabilities to implement the defensive strategies.

Key words: Self-protection; Self-insurance; Cyclone damages; Mangroves; Bangladesh

JEL Classifications: D81, Q51, Q54.

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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1. Introduction

According to reports, climate change 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. Faced with the possibility of extensive cyclone and storm surge related damages associated with such a scenario, 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 markets for 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 also 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] 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

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[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 percent of the deaths occurred in Asia alone.

house to a 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.[3] This includes opportunities for households to diversify post-disaster income, options to increase borrowing through different formal and informal sources, and the possibility of receiving private transfers through remittances and charities (see Table 2).[4]

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 for impending natural disasters (O'Connor *et al.*, 2002; Brechin, 2003; Nisbet and Myers, 2007; Norgaard, 2009), which leads a future natural disaster risk to remain low on the probability scale but high on the consequence scale (Kahneman and Tversky, 1979; Magat *et al.,* 1987; Camerer and Kunreuther, 1989; Kahneman *et al.,* 2001). In addition, access to public-assisted programs that can either reduce the magnitude of losses to life and property (for e.g., government-funded cyclone shelters, relief, and rehabilitation programs) or reduce the probability of flooding (for e.g., government and international donor-funded coastal embankments) in case of a storm event might induce the coastal households to shirk their own responsibility for risk mitigation which would be reflected in a reduction in ex-ante self-protection and self-insurance activities. Yet, if people regard access to government disaster-assistance programs as a premium-free insurance against natural disasters, it leads to a special kind of moral hazard for the state: that is, while it may suspect that a household's decision to refrain from self-protection and self-insurance arises from the belief that the government cannot infer their motives and/or will bail them out in the event of a disaster, it cannot, on moral grounds, curtail or deny a household's right to a public good in the form of disaster assistance on that basis. This situation of low private response as a result of expected public-assisted programs might lead to either a partial or full crowding out effect.[5] 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.

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

3 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.

4 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.

5 '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.

the level of ex-ante private spending against ex-post cyclone induced storm surge damage risk.[6] Estimating the empirical model, the paper focuses on a study of the private defensive expenditure allocation decisions from 35 villages comprising 500 households in the southwest coastal areas of Bangladesh which suffered a severe cyclone induced storm surge event in November 2007.

The rest of the paper is as follows. Section 2 discusses the background to the study and the relevant literature. Section 3 explains the household model of ex-ante private investment while Section 4 describes the process of data collection and offers a brief description of the study area. In Section 5 we discuss the empirical and econometric estimations. Section 6 analyzes the results while we outline our conclusions and policy recommendations in Section 7.

2. Background

The coastal region of Bangladesh is subject to disastrous cyclones every year due to the unique geographic and geomorphologic characteristics of the coast making it prone to severe cyclone and associated storm surge events (IPCC, 2005, 2007; Murty and El-Sabh, 1992; Ali, 1996, 1999; Karim and Mimura, 2008).[7] Although according to historical data Bangladesh witnessed only about 1 percent of the world's total tropical storms between 1877 and 1995, it experienced the highest number of storm-inflicted casualties during the same period where 53 percent of the world's total tropical storms that claimed 5,000 or more lives took place in Bangladesh (Ali, 1996; GOB, 2008). The high storm-inflicted human casualties are the result of both the high population density and the poor socio-economic conditions along the Bangladesh coast.

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 in recent times.[8] 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.[9] 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

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6 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' (Berger *et al.*, 1987; Bresnahan *et al.*, 1997; Harrington & Portney, 1987; Shogren & Crocker, 1992; Freeman, 2003).

7 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).

8 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.

9 A total of 3406 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).

mangrove forest.[10] 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 (GOB, 2008).[11] 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.[12]

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.[13] 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 to small, frequent disturbances such as tropical storms, coastal floods, and tidal waves (Alongi, 2008).

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. This behavioral pattern of under-insurance because of anticipated government support is termed

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[10] 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).

[11] Located along the southwest coast of Bangladesh, the Sundarban mangrove forest is considered to be the world's largest mangrove forest spanning 2316 square miles or around 6000 square km (Das and Siddiqi, 1989; Rahman, 2003). It is also a world natural heritage site (UNESCO, 2009; WCMC, 2009).

[12] 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).

[13] 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 (Das and 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).

the 'charity hazard' in disaster insurance literature (Browne and Hoyt, 2000; Lewis and Nickerson, 1989; Raschky and Weck-Hannemann, 2007).[14] Studies also reveal that an individual's disregard for insuring oneself against damages to life and property in the case of natural disaster events could be the outcome of a tendency to treat natural disaster risks as having a low probability but high consequences (Magat *et al.*, 1987; Camerer and Kunreuther, 1989; Kunreuther, 1996; Kahneman *et al.*, 2001).[15] Moreover, government intervention might be lower in areas that have dense mangrove forests because of the storm protection role of mangroves. Thus, it is reasonable to expect the crowding-out effect in these areas to be lower. This also means that households living close to a mangrove forest would invest more in ex-ante averting activities against storm-inflicted damages because they have low expectations of public goods due to lower government intervention. The following sections of the paper will focus on these issues.

3. The Household Model of Ex-ante Private investment

Let us suppose that a rural household living along the coastal area is exposed to an environmental risk in the form of 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 consequences in units that reflect the consequences to people as a result of the storm surge event, such as monetary losses 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 storm surge event occurs with the household facing damages to property;
State 2: the storm surge event occurs with the household experiencing no damages to property.

The household model does not consider states under no storm surge event because under no storm surge a household maintaining the same status-quo becomes a sure event with the probability being one while its likelihood of facing any property losses becomes a non-existent event with the probability being zero. In addition, the model does not bring any dynamic perspective to the problem assuming that the storm event is more frequent rather than a rare event. Fig. 1 illustrates the probability tree that depicts how the sequence of events takes place, where experiencing 'damages to property' is the final outcome.

Under a simple discrete formulation, Fig. 1 shows that the starting point of the probability tree is the adverse storm event, where occurrence of the exogenous storm event is assigned probability θ. Conditional on occurrence of the exogenous storm event θ, each household faces two states of nature: the probability of experiencing property damages conditional on the storm event, $\pi(.) \mid \theta$ (State 1); and the probability of experiencing no damages to property conditional on the storm event, $1-\pi(.) \mid \theta$ (State 2). We assume that a household's ex-ante private spending

14 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.

15 However, Kahn (2005) and Smith *et al.* (2006) suggest that some private responses are inevitable when a large share of private and public capital supporting peoples' livelihoods are at stake irrespective of the possibility of the crowding out effect

can influence the probability of experiencing property damage due to a future storm event through self-protection and a reduction in the severity of the storm-inflicted damages in its aftermath 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.

Let us assume that a household chooses to incur ex-ante self-insurance expenditures against a future storm event if and only if it thinks that prior investment would be beneficial in such a scenario. Then, each household *i* located in village *j* maximizes a utility function with the standard properties

$$U_{ij} = U_{ij}\ (X_{ij},\ S_{ij},\ \psi_{ij}) \qquad (1)$$

where X_{ij} is consumption expenditure, S_{ij} is a random variable representing exposure to an economically damaging storm surge event, and ψ_{ij} is the exogenous socio-economic characteristics of the household and its location that may also affect utility.[16]

Let us represent the probability of facing damages to property conditional on the storm event as

$$\pi_{ij}\,(.)\,|\,\theta \equiv \pi_{ij}\,(Z_{ij},\ G_{ij}\ ;\ M_{ij}\ ,\ C_{ij})\ \ |\,\theta \qquad (2)$$

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 conditional on the future storm surge event;[17] G_{ij} is the household's access to ex-ante public protection programs against the storm event (e.g., construction of embankments or dams to reduce the probability of flooding due to cyclone-induced storm surge);[18] 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 event, where we define the characteristics as storm surge height and wind velocity at household location, direction and distance of the cyclone path from the household location, etc.

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

$$L_{ij} = L_{ij}\ (\ S_{ij}\ ;\ A_{ij}\ ,\ R_{ij}\ ) \qquad (3)$$

where S_{ij} is a random variable representing a household's exposure to an economically damaging storm surge event, A_{ij} is the level of ex-ante self-insurance expenditures to pursue actions to reduce the severity of ex-post property damage as a result of a future cyclone-induced storm surge event,[19] and R_{ij} is the household's access to ex-post public sponsored disaster relief and

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16 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.

17 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.

18 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.

19 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.

rehabilitation programs. We expect the property losses to go up if the household is more exposed to a cyclone-induced storm surge event. On the other hand, the damage is less if the household invests in ex-ante self-insurance expenditures and enjoys accessibility to public-assisted programs designed specifically to reduce the severity of the event.
That is,

$$\frac{\partial L_{ij}}{\partial S_{ij}} > 0; \ \frac{\partial L_{ij}}{\partial A_{ij}} < 0; \ \frac{\partial L_{ij}}{\partial R_{ij}} < 0.$$

Rather than treating S_{ij} as a continuous random event, we assume, for the sake of simplicity, that the probability of facing property damages conditional on the storm event can be transformed into a zero-one event with probability concentrated at $S_{ij} = 1$ for 'full exposure' and $S_{ij} = 0$ for 'no exposure' conditions. Based on this simplified assumption, S_{ij} becomes a random event which is discrete in nature. Hence, the probability of the degree of exposure to damages conditional on the storm event (State 1) becomes concentrated at $S_{ij} = 1$ and the probability of facing no damages conditional on the storm event (State 2) turns out be concentrated at $S_{ij} = 0$. That is,

Under 'Full Exposure' condition (With $S_{ij} = 1$), (4)
State 1 (Facing damages to property with the storm event): $\pi_{ij}\ (Z_{ij,}\ G_{ij};\ M_{ij},\ C_{ij}) \mid \theta$
Under 'No Exposure' condition (With $S_{ij} = 0$),
State 2 (Zero damages to property with the storm event): $\pi_{ij}\ (Z_{ij,}\ G_{ij};\ M_{ij},\ C_{ij}) \mid \theta$

where $\pi_{ij}\ (Z_{ij,}\ G_{ij};\ M_{ij},\ C_{ij})$ is the probability of the 'full exposure' condition of facing damages to property as a result of the storm surge event.

Substituting the zero-one condition of expression (4) in the ex-post monetary loss or damages to property expression (3) leads to

$$L_{ij} = L_{ij}\,(1;\ A_{ij,}\ R_{ij}) = L_{ij}\,(A_{ij},\ R_{ij}),\ \text{when}\ S_{ij} = 1 \qquad (5)$$
$$L_{ij} = L_{ij}\,(0;\ A_{ij,}\ R_{ij}) = 0,\ \text{when}\ S_{ij} = 0$$

Expression (5) implies that the household faces two situations: (i) property loss which is equivalent to $L_{ij} = L_{ij}\,(A_{ij,}\ R_{ij})$ if it is fully exposed to a future cyclone-induced storm surge event ($S_{ij} = 1$); (ii) no property loss $L_{ij} = 0$ if it is not exposed to a future storm surge event ($S_{ij} = 0$). Thus, based on the exposure condition, a household faces the prospect of having either monetary losses or no monetary losses to property as a result of the storm surge event.

The household chooses the level of ex-ante self-protection expenditures Z_{ij} and self-insurance expenditures A_{ij} by maximizing its utility given the following full income constraint

$$I_{ij} = X_{ij} + A_{ij} + Z_{ij} + L_{ij}\,(S_{ij};\ A_{ij},\ R_{ij}) \qquad (6)$$

Considering expressions (1)-(6), substituting the income constraint (6) and re-arranging terms, the household maximization problem becomes

$$\underset{Z_{ij},A_{ij}}{Max}\,E(U) = \theta\cdot\begin{bmatrix}\pi_{ij}(Z_{ij},G_{ij},M_{ij},C_{ij})\cdot U_{ij}((I_{ij}-A_{ij}-Z_{ij}-L_{ij}(A_{ij},G_{ij}),S_{ij}=1;\psi_{ij})\\ +(1-\pi_{ij}(Z_{ij},G_{ij},M_{ij},C_{ij}))\cdot U_{ij}((I_{ij}-A_{ij}-Z_{ij},S_{ij}=0;\psi_{ij})\end{bmatrix}$$

$$\Rightarrow\theta\cdot\begin{bmatrix}\pi_{ij}\left(Z_{ij},G_{ij},M_{ij},C_{ij}\right)\cdot U_{ij}(W_1)\\ +(1-\pi_{ij}(Z_{ij},G_{ij},M_{ij},C_{ij}))\cdot U_{ij}(W_2)\end{bmatrix} \qquad (7)$$

where $W_1 \equiv ((I_{ij} - A_{ij} - Z_{ij} - L_{ij}(.)), S_{ij} = 1; \psi_{ij}) A_{ij} W_1 \equiv ((I_{ij} - A_{ij} - Z_{ij} - L_{ij}(.)), S_{ij} = 1; \psi_{ij})$ is the net wealth considering property loss under full exposure condition ($S_{ij} = 1$), and $W_2 \equiv ((I_{ij} - A_{ij} - Z_{ij}), S_{ij} = 0; \psi_{ij})$ is the net wealth with no property loss under no exposure condition ($S_{ij} = 0$).

Expression (8) says that the expected utility to be maximized is the sum of utilities of being exposed and not exposed to a severe cyclone-induced storm surge event weighted by their respective probabilities. The first-order conditions with respect to the level of ex-ante self-insurance (A_{ij}) and ex-ante self-protection (Z_{ij})lead to

$$\frac{\partial EU}{\partial A_{ij}}: \quad \underbrace{-\theta \cdot \pi_{ij}(.) \cdot U'(W_1)\left[1 + \frac{\partial L_{ij}}{\partial A_{ij}}\right]}_{\text{Expected marginal benefit of self-insurance}} = \underbrace{\theta \cdot U'(W_2) \cdot \left[(1 - \pi_{ij}(.))\right]}_{\text{Expected marginal cost of self-insurance}} \tag{8}$$

$$\frac{\partial EU}{\partial Z_{ij}}: \quad \underbrace{-\theta \cdot \frac{\partial \pi_{ij}(.)}{\partial Z_{ij}} \cdot \left[U(W_1) - U(W_2)\right]}_{\text{Expected marginal benefit of self-protection}} = \underbrace{\theta \cdot \left[\pi(.) \cdot U'(W_1) + (1 - \pi(.)) \cdot U'(W_2)\right]}_{\text{Expected marginal cost of self-protection}} \tag{9}$$

where $U'(W_1)$ and $U'(W_2)$ are the marginal utilities of income with respect to self-insurance and self-protection when $S_{ij} = 0$ and $S_{ij} = 1$ respectively.

Expression (8) reveals that a household could employ ex-ante private spending 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 the expected marginal costs of self-insurance. Expression (9) reveals that a household could employ ex-ante private spending to protect itself against a storm surge 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 states just about balance the expected marginal costs of self-protection.

3.1 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 damages 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. We explore now the influence of these postulates over a household's self-protection and self-insurance.

Given the model assumptions along with additional restrictions, results from the comparative statics reveal the following propositions. We provide proofs of the following propositions in Appendix 1.

PROPOSITION 1: For a risk-averse household, ex-ante government protection spending G_{ij} is a complement to ex-ante self-protection Z_{ij}, i.e., $\frac{\partial Z_{ij}}{\partial G_{ij}} > 0$ but a substitute to ex-ante self-insurance A_{ij}, i.e., $\frac{\partial A_{ij}}{\partial G_{ij}} < 0$.

PROPOSITION 2: For a risk-neutral household, ex-ante self-protection Z_{ij} goes down (i.e., becomes a substitute) but ex-ante self-insurance A_{ij} goes up (i.e., becomes a complement) if households have more access to ex-post public-assisted disaster relief and rehabilitation programs R_{ij}, i.e., $\frac{\partial Z_{ij}}{\partial R_{ij}} < 0$ and $\frac{\partial A_{ij}}{\partial R_{ij}} > 0$ 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.

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

That is, exposure to storm protection services by mangroves acts as a complement to self-protection but as a substitute to self-insurance. Table 1 summarizes the comparative statics results with the accompanying conditions.

In terms of policy implications, for a risk-averse household, Proposition 1 shows the possibility of 'full' or 'partial' crowding in for self-protection but crowding out for self-insurance in the case of an increase in ex-ante government spending. On the other hand, assuming a household to be risk-neutral, Proposition 2 reveals the possibility of observing the 'full' or 'partial' crowding out effect on households' self-protection but a 'full' or 'partial' crowding in effect on their self-insurance activities in case of an increase in ex-post public-assisted disaster relief and rehabilitation programs. Lastly, Proposition 3 suggests that households which live in close proximity to mangroves and are risk averse are more likely to invest in self-protection but less in self-insurance.

3.2 Ex-ante Willingness to Pay

Given certain restrictions, we find that the directional results from Proposition 1-3 provide the necessary tool to derive the marginal willingness to pay (MWTP) for a household as a result of its increased access to public protection programs and mangroves in order to reduce storm-inflicted damage risks.

In our household model for ex-ante private investment, two of the key assumptions are: (1) self-protection, Z_{ij}, can only influence the probability of facing property damages, π_{ij}, and (2) self-insurance, A_{ij}, can only influence the ex-post monetary loss to property, L_{ij}. That is, both self-protection and self-insurance separately affect the two final outcomes when a household is exposed to a future severe cyclone induced storm surge event. Assuming the sufficient conditions (a) and (b) listed in Corollary 1 of Shogren and Crocker (1991), the ex-ante willingness to pay expressions under this model show that it is possible to remove the utility terms irrespective of state independence or state dependence.[20] Consequently, the model does not suffer from any 'joint production technology' problem (Dickie, 2003; Freeman, 2003). In fact, Freeman (2003) suggested that the averting behavior model cannot be applied due to the jointness of the implicit production technology which arises if the averting activities jointly produce reductions in the probability of a bad state and the magnitude of the bad event once it is realized.

[20] Condition (a) and (b) of Corollary 1 of Shogren and Crocker (1991) states that, *"utility terms will not appear in ex-ante willingness to pay expressions for endogenous risk changes if and only if at least one of the following conditions is true: (a) A two-state world exists where ex-ante self-protection affects only ex-ante probability; (b) A two-state world exists where ex-ante self-protection affects only ex-post severity, and the marginal utilities between states are equal"* (1991, p.8).

Given the assumptions, the value to the household of an increase in ex-ante public protective spending (G_{ij}) to reduce the probability of facing damages to property is the marginal change in income that holds the expected utility constant. We could find this by first totally differentiating Equation (7) and setting it equal to zero and then by applying the first order conditions using expressions (8)-(9) and letting $dR_{ij} = dC_{ij} = 0$ but $dM_{ij} \neq 0$.

$$\begin{aligned} \frac{dI_{ij}}{dG_{ij}} &= -\frac{\dfrac{\partial \pi_{ij}(.)}{\partial G_{ij}}}{\dfrac{\partial \pi_{ij}(.)}{\partial Z_{ij}}} - \frac{\dfrac{\partial \pi_{ij}(.)}{\partial M_{ij}}}{\dfrac{\partial \pi_{ij}(.)}{\partial Z_{ij}}} \cdot \frac{dM_{ij}}{dG_{ij}} \\ &= \underbrace{\frac{\partial Z_{ij}}{\partial G_{ij}}}_{\substack{\text{direct effect on} \\ \text{self-protection}}} + \underbrace{\frac{\partial Z_{ij}}{\partial M_{ij}} \cdot \frac{dM_{ij}}{dG_{ij}}}_{\substack{\text{indirect effect on} \\ \text{self-protection}}} \end{aligned} \tag{10}$$

Expression (10) shows that a household's marginal willingness to pay for a small increase in ex-ante government protective measures depends on two parts. The first part represents the direct effect of ex-ante government programs on self-protection based on the ratio of the marginal productivities of self-protection Z_{ij} and ex-ante public spending G_{ij} in reducing the probability of storm surge damages to property $\pi_{ij}(.)$. The second part is the indirect effect on self-protection represented by the multiplication of two terms: (1) the ratio of marginal productivities of self-protection Z_{ij} and the storm protection role of mangroves M_{ij} in reducing the probability of storm surge damages to property $\pi_{ij}(.)$; and (2) the influence of ex-ante public spending G_{ij} on the storm surge protection role of mangroves M_{ij}.

Similarly, MWTP for an increase in the storm protection role of mangroves M_{ij} holding the expected utility constant also depends on the relationship among self-protection, government spending, and the storm protection role of mangroves. Totally differentiating equation (7) and setting it equal to zero, substituting the first order conditions under expressions (8)-(9), and allowing $dG_{ij} \neq 0$ but $dR_{ij} = dC_{ij} = 0$ leads to

$$\begin{aligned} \frac{dI_{ij}}{dM_{ij}} &= -\frac{\dfrac{\partial \pi_{ij}(.)}{\partial M_{ij}}}{\dfrac{\partial \pi_{ij}(.)}{\partial Z_{ij}}} - \frac{\dfrac{\partial \pi_{ij}(.)}{\partial G_{ij}}}{\dfrac{\partial \pi_{ij}(.)}{\partial Z_{ij}}} \cdot \frac{dG_{ij}}{dM_{ij}} \\ &= \underbrace{\frac{\partial Z_{ij}}{\partial M_{ij}}}_{\substack{\text{direct effect of mangroves} \\ \text{on self-protection}}} + \underbrace{\frac{\partial Z_{ij}}{\partial G_{ij}} \cdot \frac{dG_{ij}}{dM_{ij}}}_{\substack{\text{indirect effect of mangroves} \\ \text{on self-protection}}} \end{aligned} \tag{11}$$

Again expression (11) shows that the marginal willingness to pay for an increase in the storm protection role of mangroves M_{ij} depends on two parts. The first part is the direct effect of mangroves on self-protection represented by the marginal rate of technical substitution between the storm protection role of mangroves M_{ij} and self-protection Z_{ij} in reducing the probability of experiencing storm-inflicted damages to property $\pi_{ij}(.)$. In addition, the MWTP depends also on the indirect effect of mangroves on self-protection comprising the multiplication of two terms: (1) the rate of technical substitution between ex-ante public spending G_{ij} and self-protection Z_{ij} in reducing the probability of storm-inflicted damages π_{ij}; and, (2) the term representing the influence of the storm protection role of mangroves M_{ij} on ex-ante public spending G_{ij}.

We can find the value of an increase in household access to ex-post government storm-risk-reducing strategies like relief and rehabilitation programs R_{ij} by totally differentiating equation (7), setting it equal to zero, substituting the first order condition from expression (8), and letting $dG_{ij} = dM_{ij} = 0$

$$\frac{dI_{ij}}{dR_{ij}} = -\frac{\dfrac{\partial L_{ij}(A_{ij}, R_{ij})}{\partial R_{ij}}}{\dfrac{\partial L_{ij}(A_{ij}, R_{ij})}{\partial A_{ij}}} = \frac{\partial A_{ij}}{\partial R_{ij}} \qquad (12)$$

Expression (12) reveals that a household's marginal willingness to pay (MWTP) for a small increase in ex-post government risk-reducing programs like disaster relief and rehabilitation programs is the ratio of the marginal productivities of ex-ante self-insurance A_{ij} and a household's access to government relief and rehabilitation programs R_{ij} in reducing monetary loss to property L_{ij}. This is the same as the marginal rate of technical substitution (MRTS) between A_{ij} and R_{ij} in reducing L_{ij}.

4. Study Area, Sampling and the Data

4.1 Study Area

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.[21] 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:[22]

(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:

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[21] 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.

[22] 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?

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 (see Figure 2);[23]

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 Figure 3 and Figure 4);

Step 3: Using GIS, we identified both the protected (P) and the non-protected (NP) coastal areas (see Figure 4).[24] 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.[25] While selecting the unions, we maintained an equal distance to the right and left from the track of Cyclone Sidr.

4.2 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 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.[26]

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23 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- -vis the high cyclone risk zone but it is available from the authors upon request.

24 GIS stands for Geographic Information Systems.

25 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.

26 We summarize both primary and secondary sources of data in Table 2.A under Appendix 1.

4.3 Household Characteristics in the Study Area

Table 2 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 84.1 percent whereas, for non-protected areas, it is 71.8 percent. The average age of the respondents is around 42-43 years. 52.1 percent of the respondents had completed primary school (class 1-5) level education in the protected areas while it was 45.5 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.

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.[27] 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 sheets. 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. The average annual per capita income is about US $187 in the study areas, which is substantially lower in comparison with the national average of US $599 for the same period.[28]

With respect to the degree of exposure to Cyclone Sidr, we found that the majority of the households which faced Cyclone Sidr-inflicted damages in the two case study areas have yearly income below Tk. 100,000 (or less than US $1450). We also found low-income households in both areas to spend a significant portion on ex-ante averting activities as opposed to high-income households. This might indicate the influence of socio-economic variables on household choice of ex-ante private actions. 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. Table 3 shows the mean comparison results for the two groups based on past and current yearly income, total damages, and ex-ante averting expenditures for self-protection and self-insurance. Interestingly, the results 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. 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.

On the issue of accessibility to public protection programs, we found 82 percent of the households in the non-protected area to 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. We have summarized the results in Table 4.

5. Empirical Analysis and Econometric Specification

This section discusses how we have used the theoretical model to answer the research questions. In order to position the empirical study vis- -vis the research questions, we present the research hypotheses below:

H_1: Expected storm-inflicted damage is an important determinant of households investing in ex-ante private defensive strategies in terms of self-protection and self-insurance activities;

H_2: The presence of public disaster relief and rehabilitation programs leads to households investing less in self-protection and self-insurance activities against expected storm-inflicted damages;

H_3: Households living in close proximity to mangroves invest less in self-protection and self-insurance activities against expected storm-inflicted damages.

In order to test hypothesis H_1 using empirical data, the paper first estimates whether households that place a higher value on ex-ante private defensive strategies by participating in self-protection and self-insurance are also the ones that are more likely to be exposed to 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 averting behavior (i.e., self-protection and self-insurance) changes as a result of an increase in access to ex-ante public protective spending $\left(\frac{\partial Z_{ij}}{\partial G_{ij}}, \frac{\partial A_{ij}}{\partial G_{ij}}\right)$ an increase in exposure to mangrove forests ; $\left(\frac{\partial Z_{ij}}{\partial M_{ij}}, \frac{\partial A_{ij}}{\partial M_{ij}}\right)$; and an increase in access to ex-post government-sponsored relief and rehabilitation programs $\left(\frac{\partial Z_{ij}}{\partial R_{ij}}, \frac{\partial A_{ij}}{\partial R_{ij}}\right)$. hese econometric estimations are not only able to test the research hypotheses but to empirically examine Propositions 1-3.

In addition, the paper also attempts to test the marginal willingness to pay (WTP) propositions (10)-(12) indirectly since direct measurement of the WTPs are not feasible. Expressions (10)-(12) reveal that to empirically estimate the MWTPs, it is imperative to find: (1) marginal effects of

G_{ij} and M_{ij} on ex-ante self-protection Z_{ij}; (2) marginal effect of R_{ij} on ex-ante self-insurance A_{ij}; and, (3) possible sign and direction of the relationship between G_{ij} and M_{ij}. Using the theoretical model, it is possible to derive reduced-form demand equations for ex-ante averting strategies of self-protection Z_{ij} and self-insurance A_{ij} in order to discover the marginal effects among the key variables. In addition, it is possible to test the reduced form equations empirically in order to test the possible comparative statics results (see Table 1). Based on the first order conditions under expressions (8) and (9), 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.[29]

Let us assume that d^{Z}_{ij} is an indicator of the binary decision to participate in ex-ante self-protection Z_{ij} and d^{A}_{ij} 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 (8) and (9), a household's choice is determined by

$$\begin{aligned}
&\text{For self-protection } Z_{ij}:\\
&d_{ij}^{Z}=1 \quad \text{if } \left[-\pi\cdot\frac{\partial Q_{ij}(.)}{\partial Z_{ij}}\cdot\left(U(W_1)-U(W_2)\right)\geq\pi\cdot\left(Q_{ij}(.)\cdot U'(W_1)+(1-Q_{ij}(.))\cdot U'(W_2)\right)\right]\\
&d_{ij}^{Z}=0 \quad \text{otherwise}\\
&\text{For self-insurance } A_{ij}:\\
&d_{ij}^{A}=1 \quad \text{if } \left[-\pi\cdot Q_{ij}(.)\cdot U'(W_1)\cdot\left(1+\frac{\partial L_{ij}(.)}{\partial A_{ij}}\right)\geq\pi\cdot U'(W_2)\cdot\left(1-Q_{ij}(.)\right)\right]\\
&d_{ij}^{A}=0 \quad \text{otherwise}
\end{aligned} \tag{13}$$

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 (13) 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.

From the utility maximizing problem in expression (7), 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 G^{*}_{ij} and optimal self-insurance A^{*}_{ij} as

$$\begin{aligned}
Z_{ij}^{*}&=\beta_0+\beta_1\cdot G_{ij}+\beta_2\cdot M_{ij}+\beta_3\cdot R_{ij}+\beta_5\cdot C_{ij}+\beta_6\cdot\psi_{ij}+\varepsilon_{ij}\\
A_{ij}^{*}&=\zeta_0+\zeta_1\cdot G_{ij}+\zeta_2\cdot M_{ij}+\zeta_3\cdot R_{ij}+\zeta_5\cdot C_{ij}+\zeta_6\cdot\psi_{ij}+\mu_{ij}
\end{aligned} \tag{14}$$

29 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).

In expressions (13)-(14), we show the exact econometric specifications for self-protection and self-insurance in Appendix 3 based on the two 'hurdles' (i.e., hurdles based on participation and outcome choices).[30]

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.[31] 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, we take the recorded 'zero self-protection' or 'self-insurance expenditures' from the household survey as a discrete choice which does not arise either from infrequency of investment or a corner solution.[32] Hence, it is reasonable to assume that the first hurdle dominance applies for this study. Consequently, if the model assumes dependence between the disturbance terms in the participation and the outcome equations, then we can apply either full information maximum likelihood (FIML) or the limited information maximum likelihood (LIML) using the Heckman two-step method (Heckman, 1979). On the other hand, if the model does not assume any dependency between the error terms, then we could suggest a two-part model (Cragg, 1971; Manning *et al.*, 1981; Jones, 1989; Leung and Yu, 1996; Puhani, 2000; Madden, 2008).[33] 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. Hence, we can use the results for comparison purposes.

6. Results and Discussion

For the preliminary analysis, we base the regression results reported in this paper on the full sample of the household survey. Table 5 shows the summary statistics based on the means and standard deviations of the explanatory variables that are used for the regression analyses. Table 6 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

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

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

32 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.

33 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.

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 6 reports four regression specifications starting with the parsimonious model comprising Cyclone Sidr inflicted damages, Pre-Cyclone Sidr income, and distance from the coast. 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, we progressively add additional controls starting with the socio-economic and the storm protection role of mangroves characteristics. The addition of public programs follows this specification. The last regression specification includes the characteristics of Cyclone Sidr—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. Furthermore, the log and square log of a household's pre-Cyclone Sidr income remains significant with 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.

Among the socio-economic characteristics, results show that a household is more likely to participate in self-protection if it has a fewer number of children, has memberships in different village level organizations indicative of a social network, 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 plays 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 north, northeast and northwest directions relative to the coast and the Sundarban mangrove forest are more likely to participate in self-protection compared to other households. Distance between the mangrove forest and the union where the household's village is located bears the negative sign but is insignificant under all specifications. 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 10% level. When it comes to storm surge characteristics, surge height and the directional distance between the household and the track of the Cyclone Sidr both have positive influences on households participating in self-protection.

The results of the outcome equation conditional on participation 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. This might imply that 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 the socio-economic variables, results show that a household invests more in self-protection if it does not plan to migrate in the future and has access to credit but is not a member of any village-level organization. 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.[34] This same outcome also applies when we consider the role of the storm surge characteristics on self-protection investment.

Under FIML, the likelihood ratio test (LR test) for correlation between the error terms of the two equations *(P = 0)* for all specifications suggests little evidence against the null since the value of the LR statistics are small with p-values greater than 10%. That is, we fail to reject the null or the independence between the error terms in all cases. Thus, the LR test supports the application of the two-part model instead of the Heckman two-step method using the limited information maximum likelihood estimation (LIML). Moreover, considering the issue of collinearity associated with the inverse mills ratio and other regressors, the paper reports results from the two-part model which we can use as an alternative regression specification against the results derived from FIML. Table 7 reports the two-part model for ex-ante self-protection in the selection equation (using the Probit estimation) followed by the estimation on the outcome equation (using the OLS estimation on the sub-sample of positive observations under the selection equation). The Probit estimation on the participation equation reveals similar results to the FIML estimation regarding the test of hypotheses. That is, the probability of participation in self-protection is highly influenced by the future storm-inflicted damages. Like the results from FIML, a household's income and asset holdings in terms of land ownership strongly influence the probability of participation. However, results also show that households located outside the embankment are more likely to participate in self-protection. Among the socio-economic characteristics, households that have less access to credit and have fewer children are more likely to participate in self-protection. Regarding the role of mangroves, again the directional location of the household relative to the coast and the mangroves play an influential role on a household's choice for self-protection.

[34] Under FIML, all the characteristics capturing the storm protection role of mangroves cannot be added to the outcome specification since inclusion of the dummy variables representing the directional location of the household relative to the coast and the mangroves lead to 'no convergence.'

Among the public programs, the probability of participation in self-protection is high among households who have less access to public disaster relief programs. But it is low with regard to a household's access to rehabilitation programs although the coefficient becomes insignificant when we add storm characteristics to the model. Among the storm characteristics variables, height of the storm surge and the directional location of the household vis- -vis the track of the cyclone can influence a household's participation in self-protection activities.

Estimation results from the second part of the model (OLS estimation on the sub-sample of positive observations) support the hypothesis that storm-inflicted damages play a key role on the household-level self-protection spending. Household income seems to have a strong influence on self-protection. Signs of the coefficients on the log and square log of income again support the presence of a U-shape relationship with self-protection expenditures implying that the low-and high-income households allocate more for self-protection compared to the middle-income households although not all coefficients are significant. The presence of public disaster-relief programs is significant and bears the same negative sign although the coefficient for public disaster-rehabilitation programs is not significant. However, the role of mangroves as a storm-protection service has no influence on the self-protection spending.[35] Among the socio-economic variables, the level of self-protection is less if the household is planning to relocate in the future to a better location.

Tables 8 and 9 show 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.[36] 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 of the sum of the self-insurance proxy variables (i.e., medical expenditures and remittances).[37] In addition, we included

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[35] To compare the results with FIML, we drop dummy variables 1-7 representing the directional location of the household relative to the coast and the mangrove forest from the outcome equation of the two part model.

[36] 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.

[37] 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.

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.[38] 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 8 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 to the southeast, east, and northeast direction relative to the coast and the mangroves are more likely to participate in self-insurance.

Among the socio-economic controls, a household is more likely to participate in self-insurance if it has 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 at a higher elevation. 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 9 shows the censored Tobit model results for estimating the level of ex-ante self-insurance expenditures of the households. 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

[38] 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. .

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. Households that come within the mangrove protected area and are located further away from the mangroves invest less in self-insurance. These findings support 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 directional location relative to the coast and the mangroves, households that are located in easterly and southwesterly directions invest more in self-insurance. However, the results show that access to public disaster relief and rehabilitation programs have no influence on household level self-insurance spending. None of the storm characteristic variables is strongly significant.[39]

Furthermore, in order to fully test the research questions and conduct future sensitivity analysis, we need to conduct further explorations on the functional forms and the econometric specifications of the model. For future research, the study suggests looking at issues such as: (1) testing for the correct choice of the functional form for the reduced-form demand equations of self-protection and self-insurance expenditures. In this paper, we consider simple linear representations of the reduced-form demand equations; (2) testing for seemingly unrelated regressions (SUR) models. A need for this can arise if the reduced form demand equations of self-protection and self-insurance have the same dependent and independent variables where different coefficients are linked together by some common, not measurable, factor. But there could be no efficiency gains over OLS if the contemporaneous correlation across errors equals zero and there is less correlation between explanatory variables across equations; and, (3) testing for simultaneity or endogeneity bias. This could arise if there is interaction between the endogenous variables, self-protection and self-insurance, within the system of their reduced form equations. For example, a possible endogeneity issue can arise if the amount of ex-ante private protective spending that the households incur in order to cope with expected storm-inflicted damages influences ex-ante public investment in embankments.

7. Conclusion and Policy Recommendations

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 show that a representative household's marginal willingness to pay for an increase in ex-ante public storm protection programs depends on two effects: (1) the

[39] An interesting extension to the current work would be to test the inverted U-relationship of self-protection and self-insurance expenditures with income by considering the corner solutions where households *do not* invest in private protection, not because they choose to but rather because they cannot afford to. This argument would be of interest to the relatively poor population. Regarding marginal willingness to pay, preliminary results from the case study reveals that it is possible to trace the marginal effects of public programs and the mangrove forest on the households' ex-ante private defensive behavior based on self-protection and self-insurance. However, the analysis requires the sign and the direction of the relationship between public programs and the mangrove forest in order to obtain the ex-ante marginal willingness to pay for public protective spending and for a possible natural storm protection barrier. Further analysis might establish this linkage to determine ex-ante marginal willingness to pay for the above programs based on the available data.

direct effect of the public programs on a household's ex-ante self-protection spending; and (2) the indirect effect of the programs on self-protection expenditures through a household's location relative to the coast and the mangrove forest. We obtain a similar result when we consider the benefit to the household of an increase in its proximity to the mangrove forest. Both results confirm the influence of public protection programs and the mangrove forest on private defensive expenditures based on whether the public programs serve as a possible substitute or complement to the storm protection provided by mangroves. In addition, the results further show that the benefit to the household from an increase in ex-post public relief and rehabilitation programs depends on the ratio of the marginal productivities of self-insurance and a household's access to these public programs. However, the comparative statics on how changes in public programs and exposure to mangroves influence a household's ex-ante private averting strategies with regard to self-protection and self-insurance 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. Hence, 'full' or 'partial' crowding out effects might occur through a replacement of a household's self-protection and self-insurance activities given the presence of the mangrove forest.

To estimate the model empirically, the paper then focuses on a case study of the private defensive expenditure allocation decisions of 500 households from 35 villages on the southwest coastal areas of Bangladesh struck by a severe cyclone-induced storm surge event in November 2007. Empirical results from the case study reveal the influence of public protective programs and the mangroves on a household's storm protection choices. However, results also show that the location of the household vis- -vis the mangrove barrier, other socio-economic, demographic, and geo-physical factors seem to have a considerable influence and add a degree of complexity to the relationship. 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 government should focus its programs in areas that encourage more collective and individual participation in ex-ante private storm protection against future storm-inflicted damages. 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 (Feagin *et al.,* 2009). Instead, it should promote sensible coastal development and disaster preparation programs through individual and collective participation that enhance the capacity of social-ecological systems 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.

8. Acknowledgements

We gratefully acknowledge the financial support from the South Asian Network for Development and Environmental Economics (SANDEE) to conduct the household survey. We wish to thank Professor Enamul Haque and other SANDEE resource persons for their useful suggestions and valuable comments at different stages of my work. We wish to express our gratitude to the Disaster Management Bureau (DMB), the Institute of Water Modeling (IWM), the Bangladesh Meteorological Department (BMD), and the Center for Environment and Geographic Information

Services (CEGIS) of Bangladesh for providing secondary data at different stages of my research. We would like to thank the Economic Research Group (ERG) of Bangladesh for providing me institutional support while conducting the household survey. We would also like to thank the team of interviewers in Bangladesh who collected household data as part of this research. The usual disclaimers apply.

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LIST OF TABLES

Table 1: Comparative Static Results of the Household Model of Ex-ante Private Investment

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

Table 2: Summary Statistics of Households in 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 3: Mean Comparison Tests of Two Groups Considering the Key Variables

Measures	Group Type	Obs.	Mean	Standard Deviation
Post-Cyclone Sidr income	Protected Non-protected Combined	212 277 489	59410.73 79044.27 70532.39	58453.12 84785.04 75085.42
Pre-Cyclone Sidr income	Protected Non-protected Combined	200 249 449	266511.20 172609.40 214436.50	868803.70 209371.00 601446.40
Total damages	Protected Non-protected Combined	218 275 493	91588.08 102013.60 97403.55	109468.20 170593.40 146695.10
Ex-ante self-protection expenditure	Protected Non-protected Combined	61 46 107	125909.80 52963.00 94549.53	160780.80 115838.60 147123.70
Ex-ante self-insurance expenditure	Protected Non-protected Combined	128 169 297	6446.09 28114.75 18776.07	12542.43 85224.33 65615.39

Table 4: Accessibility of Public Goods

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.	Reasons for future migration (%) Unemployment Floods Cyclone & storm surge Lack of opportunity Poverty	 41.96 37.50 73.21 73.21 39.29	 36.54 65.38 59.62 59.62 30.77
5.	Access to relief (%)	90.00	88.53
6.	Access to rehabilitation (%)	64.68	46.35

Table 5: Summary statistics of the Key variables

Sl. No.	Variable	Definition	No. of observations	Mean	Standard Deviation
1.	L(DAMAGE)	Log of the nominal value of Cyclone Sidr inflicted damages (in Tk.)	493	10.885	1.1381
2.	L(PREINC)	Log of Pre-Cyclone Sidr HH Income (in Tk.)	449	11.569	1.079
3.	L(PREINC2)	Square log of Pre-Cyclone Sidr HH Income (in Tk.)	449	135.02	25.28
4.	L(POSTINC)	Log of Post-Cyclone Sidr HH Income (in Tk.)	489	10.648	1.262
5.	L(POSTINC2)	Square log of Post-Cyclone Sidr HH Income (in Tk.)	489	114.96	24.44
6.	AREA	Area of homestead, crop land, and the pond (in decimal)	500	142.6	24.441
7.	EMB	If household is protected by the embankment (=1, 0 otherwise)	497	0.6097	0.4883
8.	DCOAST	Distance from the coast (in Km.)	500	44.10	18.248
9.	PROTECTED	If household falls into the mangrove protected area (=1, 0 otherwise)	500	0.44	0.497
10.	MDIST	Distance between the union and the mangrove forest (in km.)	500	7.536	7.981
11.	MDIR2-MDI-R7	Dummy variable regarding the directional location of the household relative to the coast and the mangrove forest (MDIR2 = 1 if Southeast, 0 otherwise; MDIR3= 1 if East, 0 otherwise; MDIR4= 1 if Northeast, 0 otherwise; MDIR5 = 1 if North, 0 otherwise; MDIR6=1 if West, 0 otherwise; and MDIR7=1 if Southwest, 0 otherwise.)	500	3.065	1.337
12.	ARELIEF	If household has access to relief (=1, 0 otherwise)	499	0.8938	0.3084
13.	AREHABN	If household has access to rehabilitation (=1, 0 otherwise)	492	0.5508	0.4979
14.	SURGEHT	Approximate average Cyclone Sidr induced Storm surge height (in meter)	500	3.982	0.7085
15.	STORMEXP	If household falls into counter-clockwise direction from Cyclone Sidr (=1, 0 otherwise)	500	0.42	0.4941
16.	STORMDIS	Directional Distance between Household and the Track for the Cyclone Sidr (in km)	500	15.839	10.124
17.	AGE	Age of the respondent (in years)	497	42.221	13.252
18.	EDUYR	Average years of respondent education	492	6.868	3.643
19.	CREDIT	If household has access to credit (=1, 0 otherwise)	492	0.5752	0.4948
20.	MEMBER	If household is a member of village level organizations (=1, 0 otherwise)	486	0.1934	0.3954
21.	MFRATIO	Male/ Female ratio of the household	498	1.248	0.7933
22.	CHILDREN	Number of children in the household	500	1.26	1.1896
23.	HELEV2-HELEV3	Dummy variable regarding the elevation of the house (HELEV1 =1 if high elevation, 0 otherwise; HELEV2 =1 if medium elevation, 0 otherwise; and HELEV3 = 1 if low elevation, 0 otherwise)	500	2.49	0.606
24.	MIGRATION	If planning to migrate in the future (=1, 0 otherwise)	494	0.328	0.469

[40] Regarding the direction of the mangrove forest from the household (union), there is no household that falls into the northwest direction from the mangrove forest. Therefore, this category is dropped for regression analysis under MDIR variable.

Table 6: Full information maximum likelihood (FIML) for Participation in Ex-ante Self-Protection

Variable	Parsimonious Model		Add the Mangroves and Socio-Economic Characteristics		Add the Public Programs		Add the Storm Surge Characteristics	
Selection Equation (dependent variable is the probability of households participating in ex-ante self-protection)								
CONSTANT	-16.393 (-2.24)**		-13.929 (-1.75)**		-14.985 (-1.79)**		-17.016 (-2.09)**	
L(DAMAGE)	0.1461 (2.20)**	0.0401	0.2086 (2.83)***	0.0541	0.229 (3.01)***	0.0578	0.1904 (2.49)***	0.0472
L(PREINC)	2.255 (1.83)**	0.6187	1.9174 (1.44)*	0.4969	2.103 (1.50)*	0.5311	1.568 (1.15)	0.3888
L(PREINC2)	-0.0912 (-1.76)**	-0.0250	-0.0797 (-1.41)*	-0.0206	-0.0877 (-1.47)*	-0.0221	-0.0657 (-1.13)	-0.0163
AREA	0.00057 (2.20)**	0.0002	0.0007 (2.46)***	0.0002	0.0007 (2.32)***	0.0002	0.0007 (2.23)**	0.0002
EMB	-0.1259 (-0.70)	-0.0349	-0.3283 (-1.16)	-0.0877	-0.3128 (-1.15)	-0.0813	-0.2855 (-0.89)	-0.0727
DCOAST	0.0037 (0.81)	0.001	-0.0069 (-0.52)	-0.0018	-0.0008 (-0.07)	-0.0002	-0.0064 (-0.37)	-0.0016
AGE			-0.0055 (-0.94)	-0.0014	-0.007 (-1.08)	-0.0017	-0.0073 (-1.17)	-0.0018
EDUYR			0.0018 (0.08)	0.0005	0.0029 (0.14)	0.0008	0.0139 (0.62)	0.0034
CREDIT			-0.3142 (-1.96)**	-0.0832	-0.3619 (-2.18)**	-0.0936	-0.3717 (-2.18)**	-0.0945
MEMBER			0.2792 (1.30)*	0.0778	0.3039 (1.39)*	0.0832	0.2117 (0.96)	0.0557
MFRATIO			-0.0681 (-0.68)	-0.0176	-0.1038 (-1.01)	-0.0262	-0.1069 (-1.05)	-0.0265
CHILD			-0.1586 (-2.18)**	-0.0411	-0.1820 (-2.39)***	-0.0459	-0.1804 (-2.22)**	-0.0448
MIGRATION			-0.1119 (-0.63)	-0.0285	-0.1459 (-0.80)	-0.0359	-0.1534 (-0.81)	-0.0371
PROTECTED			0.8032 (1.78)**	0.2155	0.5199 (1.14)	0.1343	Dropped	Dropped
MDIST			-0.0229 (-0.82)	-0.0059	-0.0159 (-0.56)	-0.004	-0.032 (-1.11)	-0.0078
MDIR2			0.7931 (1.52)*	0.2452	0.5497 (1.08)	0.1598	1.036 (1.83)**	0.3242
MDIR4			0.5477 (0.84)	0.1655	0.3516 (0.55)	0.0989	4.023 (2.86)***	0.9352

MDIR4			0.5477 (0.84)	0.1655	0.3516 (0.55)	0.0989	4.023 (2.86)***	0.9352
MDIR5			-0.2617 (-0.45)	-0.0609	-0.0207 (-0.04)	-0.0051	3.099 (2.91)***	0.8589
MDIR6			0.8058 (0.85)	0.2735	0.9882 (0.99)	0.3418	3.419 (2.95)***	0.8355
ARELEIF					-0.4518 (-1.71)**	-0.1333	-0.4674 (-1.72)**	-0.1366
AREHABN					0.2779 (1.54)*	0.0693	0.2157 (1.17)	0.0529
SURGEHT							0.6539 (2.16)**	0.1622
STORMDIR							1.076 (1.43)*	0.2909
STORMDIS							0.0744 (3.68)***	0.0185
Outcome Equation (dependent variable is the level of household ex-ante self-protection expenses (in Tk.) conditional on participation in self-protection activities)								
Variable	Coeff.	Marginal Effect	Coeff.	Marginal Effect	Coeff.	Marginal Effect	Coeff.	Marginal Effect
CONSTANT	2709939 (1.56)*		4070751 (2.40)***		3658025 (1.93)**		4432671 (2.12)**	
L(DAMAGE)	45167.46 (3.36)***	48621.98	30142.76 (2.04)**	37244.1	26922.96 (1.72)**	38892.87	25545.6 (1.61)*	39014.8
L(PREINC)	-578470 (-2.09)**	-525166.6	-786305.4 (-2.88)***	-721048.5	-690174 (-2.23)**	-580241.5	-814284 (-2.43)***	-703382.8
L(PREINC2)	26382.03 (2.26)**	24225.4	35749.09 (3.08)***	33037.82	31430.78 (2.37)***	26848.9	36618.4 (2.55)***	31967.9
DCOAST	972.81 (1.51)*	1060.04	-109.46 (-0.11)	-346.09	-442.38 (-0.41)	-489.10	-109.71 (-0.07)	-561.61
AGE			134.02 (0.15)	-53.577	149.97 (0.16)	-196.18	10.961 (0.01)	-505.9
EDUYR			-2209.98 (-0.59)	-2148.82	-1536.4 (-0.40)	-1380.44	-1955.19 (-0.45)	-968.04
CREDIT			28103.24 (1.08)	17455.38	41190.8 (1.47)*	22358.03	52236.51 (1.68)**	26064.6
MEMBER			-49576.15 (-1.33)*	-40200.06	-62993.8 (-1.59)*	-47336.3	-68505.5 (-1.68)**	-53674.4
MIGRATION			-55314.81 (-1.96)**	-59134.22	-57172.6 (-1.92)**	-64825.51	-64695.7 (-2.03)**	-75591.3
PROTECTED			60345.25 (1.09)	87408.08	48111.6 (0.86)	75146.24	57203.8 (0.64)	57203.8

MDIST			1246.03 (0.45)	466.74	1345.36 (0.49)	516.55	1584.7 (0.50)	-646.7
ARELEIF					-57763.8 (-1.20)	-80653.7	-50231.19 (-0.98)	-82262.8
AREHABN					18766.7 (0.66)	33319.3	23150.6 (0.76)	38429.9
SURGEHT							2697.88 (0.08)	48953.4
STORMDIR							17013.9 (0.22)	91501.4
STORMDIS							-1992.66 (-0.78)	3270.7
STORMDIS								
RHO								
LAMBDA								
LOG LIKELIHOOD								
LR test (p=0) LR test (prob.>X^2)								
OBS. CENSORED OBS								

Dependent variable is the probability of households participating in ex-ante self-protection activities. All models are estimated using the full information maximum likelihood (FIML) of the sample selection method. The LR stat to test independence between the error terms of the participation and outcome equations provide little evidence against the null. In addition, separate test shows higher collinearity between the inverse mills ratio and the other explanatory variables. Hence, FIML and the two-part model (restricted likelihood) are preferred over Heckman two-stage estimation for the sample selection model for ex-ante self-protection. Z-tests are shown in parentheses beneath coefficient estimates. Significance levels: ***1%, **5%, *10%.

Table 7: Two-part Model for Ex-ante Self-Protection

	Parsimonious Model		Add the Mangroves and Socio-Economic Characteristics		Add the Public Programs		Add the Storm Surge Characteristics	
Probit Equation (dependent variable is the probability of households participating in ex-ante self-protection)								
Variable	Coeff.	Marginal Effect	Coeff.	Marginal Effect	Coeff.	Marginal Effect	Coeff.	Marginal Effect
CONSTANT	-16.825 (-2.29)**		-13.528 (-1.70)**		-14.696 (-1.77)**		-17.516 (-2.11)**	
L(DAMAGE)	0.1405 (2.12)**	0.0387	0.2005 (2.71)***	0.0519	0.2252 (2.93)***	0.0568	0.19086 (2.46)***	0.0472
L(PREINC)	2.338 (1.89)**	0.6446	1.899 (1.43)*	0.4926	2.095 (1.50)*	0.5288	1.7151 (1.26)	0.4238
L(PREINC2)	-0.0946 (-1.81)**	-0.0261	-0.0791 (-1.41)*	-0.0205	-0.0874 (-1.48)*	-0.022	-0.07195 (-1.24)	-0.0178
AREA	0.00055 (2.07)**	0.0002	0.0007 (2.20)**	0.0002	0.0006 (2.06)**	0.0002	0.0006 (1.96)**	0.0002
EMB	-0.1579 (-0.92)	-0.0442	-0.4928 (-2.06)**	-0.1335	-0.5109 (-2.06)**	-0.1349	-0.5014 (-1.67)**	-0.1296
DCOAST	0.0038 (0.83)	0.001	-0.012 (-0.91)	-0.0031	-0.0062 (-0.45)	-0.0016	-0.0137 (-0.77)	-0.0034
AGE			-0.0043 (-0.74)	-0.0011	-0.0049 (-0.80)	-0.0012	-0.0053 (-0.86)	-0.0013
EDUYR			0.0045 (0.21)	0.0012	0.005 (0.23)	-0.0013	0.015 (0.67)	0.0037
CREDIT			-0.3275 (-2.03)**	-0.0868	-0.3746 (-2.25)**	-0.0968	-0.3867 (-2.26)**	-0.098
MEMBER			0.2606 (1.21)	0.0723	0.2845 (1.29)*	0.0774	0.2073 (0.93)	0.0543
MFRATIO			-0.0663 (-0.65)	-0.0172	-0.1007 (-0.95)	-0.0254	-0.1246 (-1.16)	-0.0308
CHILD			-0.1495 (-2.00)**	-0.0388	-0.1752 (-2.23)**	-0.0442	-0.1835 (-2.26)**	-0.0453
MIGRATION			-0.1217 (-0.69)	-0.0309	-0.1364 (-0.76)	-0.0337	-0.1139 (-0.61)	-0.0276
PROTECTED			0.9101 (1.96)**	0.2449	0.6407 (1.35)*	0.1661	Dropped	Dropped
MDIST			-0.0121 (-0.42)	-0.0031	-0.006 (-0.20)	-0.0015	-0.0301 (-0.97)	-0.0074

MDIR2			0.7902 (1.55)*	0.2444	0.6015 (1.15)	0.1768	1.3347 (2.35)***	0.4301
MDIR4			0.6174 (0.95)	0.1896	0.4317 (0.64)	0.1242	4.386 (2.85)***	0.9457
MDIR5			-0.3301 (-0.55)	-0.0746	-0.1848 (-0.31)	-0.0432	3.098 (2.64)***	0.8591
MDIR6			0.7477 (0.75)	0.2508	0.6105 (0.59)	0.1945	2.928 (2.38)***	0.8158
ARELEIF					-0.4210 (-1.58)*	-0.1231	-0.4168 (-1.52)*	-0.1196
AREHABN					0.2869 (1.59)*	0.0714	0.2158 (1.16)	0.0528
SURGEHT							0.6388 (1.94)**	0.1578
STORMDIR							1.0011 (1.18)	0.2689
STORMDIS							0.0786 (3.63)***	0.0194
Log Likelihood	-214.37		-184.40		-176.153		-169.374	
Pseudo R^2	0.0508		0.1361		0.1515		0.1842	
LR Chi2 (df.)	22.95 (6)		58.11 (23)		62.92 (25)		76.48 (27)	
OBS.	441		411		403		403	
Outcome Equation on the sub-sample (dependent variable is the level of household ex-ante self-protection expenses (in Tk.) on the subsample of the population that participates in self-protection activities)								
Variable	Parsimonious Model		Add the Mangroves and Socio-Economic Characteristics		Add the Public Programs		Add the Storm Surge Characteristics	
	Coeff.	Marginal Effect	Coeff.	Marginal Effect	Coeff.	Marginal Effect	Coeff.	Marginal Effect
CONSTANT	2901690 (1.90)**		4100696 (2.48)***		2863633 (1.55)*		2936859 (1.53)*	
L(DAMAGE)	47736.82 (3.95)***	47736.8	35520.91 (2.67)***	35520.9	39516.18 (2.86)***	39516.2	39146.87 (2.66)***	39146.9
L(PREINC)	-635757.1 (-2.47)***	-635757	-823434.8 (-3.00)***	-823434.8	-599123.5 (-1.92)**	-599123.5	-616253 (-1.90)**	-616253
L(PREINC2)	29239.79 (2.68)***	29239.8	37694.12 (3.24)***	37694.1	27757.84 (2.08)**	27757.8	28440.4 (2.04)**	28440.4
DCOAST	1390.51 (2.34)***	1390.5	96.713 (0.09)	96.7	-48.022 (-0.04)	-48.02	-124.37 (-0.08)	-124.37

AGE			241.345 (0.25)	241.35	215.928 (0.22)	215.9	283.05 (0.28)	283.05
EDUYR			-490.37 (-0.13)	-490.4	665.94 (0.17)	665.9	1160.14 (0.28)	1160.14
CREDIT			27680.48 (1.02)	27680.5	37688.56 (1.31)*	37688.6	37420.94 (1.26)	37420.9
MEMBER			-44295.53 (-1.14)	-44295.5	-48721.14 (-1.16)	-48721.1	-52686.57 (-1.19)	-52686.57
MIGRATION			-65733.72 (-2.17)**	-65733.7	-64489.91 (-2.02)**	-64489.9	-59913.91 (-1.78)**	-59913.91
PROTECTED			71645.87 (1.21)	71645.9	63388.46 (1.06)	63388.5	27847.18 (0.30)	37847.2
MDIST			789.59 (0.26)	789.6	1007.46 (0.33)	1007.5	475.23 (0.14)	475.23
ARELEIF					-90189.7 (-1.82)**	-90189.7	-83969.91 (-1.53)*	-83969.9
AREHABN					23944.33 (0.78)	23944.3	18170.76 (0.55)	18170.8
SURGEHT							11015.67 (0.32)	11015.7
STORMDIR							-33347.03 (-0.41)	-33347.03
STORMDIS							1149.46 (0.58)	1149.5
Adjusted R2	0.3805		0.4235		0.4364		0.4145	
F(n1,n2)	14.97 (4, 87)		6.81 (11, 76)		6 (13, 71)		4.72 (16, 68)	
Log Likelihood	-1201.45		-1143.34		-1102.91		-1102.69	
Prob. > F	0.0000		0.0000		0.0000		0.0000	
OBS.	92		88		85		85	

Under the two-part model, the first part is the Probit model and the dependent variable is the probability of households participating in ex-ante self-protection activities. The second part is ordinary least squares (OLS) on the sub-sample of the households who have positive investment in self-protection. For the Probit model, Z-tests are shown in parentheses beneath coefficient estimates; whereas, t-tests are shown in parentheses for OLS. Significance levels: ***1%, **5%, *10%.

Table 8: Bivariate Probit Model for Participation in Ex-ante Self-Insurance

Variable	Parsimonious Model		Add the Mangroves and Socio-Economic Characteristics		Add the Public Programs		Add the Storm Surge Characteristics	
	Coeff.	Marginal Effect	Coeff.	Marginal Effect	Coeff.	Marginal Effect	Coeff.	Marginal Effect
CONSTANT	-20.950 (-2.48)***		-17.978 (-1.97)**		-17.064 (-2.14)**		-16.529 (-1.97)**	
L(DAMAGE)	0.1780 (2.65)***	0.0521	0.13715 (1.90)**	0.0383	0.14136 (1.76)**	0.0367	0.124 (1.53)*	0.032
L(PREINC)	2.761 (1.97)**	0.8085	2.316 (1.53)*	0.6471	1.8164 (1.40)*	0.4706	1.885 (1.39)*	0.4872
L(PREINC2)	-0.125 (-2.07)**	-0.0365	-0.1085 (-1.66)**	-0.0303	-0.084 (-1.50)*	-0.0218	-0.0872 (-1.49)*	-0.0225
L(POSTINC)	0.5063 (1.05)	0.5033	0.5086 (0.94)	0.1421	0.3918 (0.73)	0.1015	0.3904 (0.70)	0.1009
L(POSTINC2)	-0.0248 (-1.00)	-0.0248	-0.0224 (-0.81)	-0.0063	-0.0135 (-0.49)	-0.0035	-0.0128 (-0.45)	-0.0033
AREA	0.0003 (1.04)	0.0000	0.0001 (0.36)	0.0000	0.0003 (0.89)	0.0001	0.0003 (0.80)	0.0000
EMB	-0.0965 (-0.58)	-0.0285	-0.1218 (-0.52)	-0.0344	-0.2104 (-0.83)	-0.0556	0.0389 (0.13)	0.01
DCOAST	0.0131 (2.71)***	0.0038	0.0289 (2.04)**	0.0081	0.0307 (2.07)**	0.0079	0.0071 (0.37)	0.0018
AGE			0.0026 (0.45)	0.0007	0.0017 (0.28)	0.0005	0.0027 (0.44)	0.0007
EDUYR			-0.0215 (-0.95)	-0.006	-0.0257 (-1.05)	-0.0067	-0.0257 (-1.04)	-0.0066
CREDIT			0.3318 (2.04)**	0.0907	0.2899 (1.66)**	0.0737	0.2684 (1.52)*	0.0682
MEMBER			-0.5969 (-2.54)***	-0.1424	-0.7511 (-3.01)***	-0.1567	-0.7626 (-3.03)***	-0.1581
MFRATIO			-0.0256 (-0.26)	-0.0071	-0.0039 (-0.04)	-0.001	0.0064 (0.06)	0.0017
CHILD			0.1006 (1.50)*	0.0281	0.1265 (1.82)**	0.0328	0.1381 (1.96)**	0.0357
HELEV2			-0.5215 (-1.59)*	-0.1371	-0.6683 (-1.84)**	-0.1587	-0.7243 (-1.96)**	-0.1702

HELEV3			-0.3243 (-1.00)	-0.0922	-0.5244 (-1.46)*	-0.1404	-0.6227 (-1.71)**	-0.1671
MIGRATION			-0.0567 (-0.31)	0.0157	-0.1055 (-0.53)	-0.0269	0.0026 (0.01)	0.0007
PROTECTED			-1.045 (-2.32)***	-0.2717	-1.394 (-2.89)***	-0.3313	Dropped	Dropped
MDIST			-0.0576 (-1.93)**	-0.0161	-0.0363 (-1.16)	-0.0094	-0.0388 (-1.20)	-0.01
MDIR2			0.7604 (1.13)	0.2465	0.820 (1.15)	0.2556	1.114 (1.49)*	0.36
MDIR3			0.5624 (0.77)	0.1851	0.831 (1.07)	0.2749	1.509 (1.36)*	0.529
MDIR4			0.5526 (0.69)	0.1767	0.7448 (0.88)	0.2341	2.244 (1.35)*	0.732
MDIR5			0.6410 (0.95)	0.2143	1.246 (1.73)**	0.4337	1.159 (0.91)	0.400
MDIR6			Dropped	Dropped	Dropped	Dropped	Dropped	Dropped
Variable	Coeff.	Marginal Effect	Coeff.	Marginal Effect	Coeff.	Marginal Effect	Coeff.	Marginal Effect
MDIR7			0.6523 (0.92)	0.1882	1.183 (1.55)*	0.3229	1.62 (1.50)*	0.443
ARELEIF					1.038 (2.19)*	0.1718	1.031 (2.16)**	0.1705
AREHABN					0.9787 (5.27)***	0.2414	0.9839 (5.23)***	0.2419
SURGEHT							-0.3971 (-1.11)	-0.1026
STORMDIR							0.7691 (0.90)	0.2102
STORMDIS							0.0165 (0.71)	0.0042
Log Likelihood	-215.72		-186.63		-164.95		-163.13	
Pseudo R^2	0.0708		0.1457		0.2372		0.2456	
LR Chi2 (df)	32.86 (8)		63.65 (24)		102.59 (26)		106.22 (28)	
OBS.	426		397		389		389	

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

Table 9: Censored Tobit Model for Ex-ante Self-Insurance

Variable	Parsimonious Model		Add the Mangroves and Socio-Economic Characteristics		Add the Public Programs		Add the Storm Surge Characteristics	
	Coeff.	Marginal Effect	Coeff.	Marginal Effect	Coeff.	Marginal Effect	Coeff.	Marginal Effect
CONSTANT	614800.6 (2.52)**		687954.6 (2.82)***		682264.6 (2.79)***		788753.4 (3.12)***	
L(DAMAGE)	10875.76 (3.36)***	4794.28	11056.44 (3.37)***	4903.52	10886.36 (3.31)***	4889.99	10290.34 (3.13)***	4619.81
L(PREINC)	-23991.52 (-0.64)	-10575.99	-41708.5 (-1.11)	-18497.69	-43616.93 (-1.16)	-19592.11	-43137.59 (-1.15)	-19366.47
L(PREINC2)	926.79 (0.58)	408.55	1685.32 (1.06)	747.44	1786.79 (1.12)	802.60	1763.46 (1.11)	791.69
L(POSTINC)	-142830.9 (-6.50)***	-62963.02	-148952 (-6.71)***	-66060.08	-146346.7 (-6.62)***	-65736.88	-150573.2 (-6.79)***	-67599.3
L(POSTINC2)	7997.30 (7.07)***	3525.39	8208.83 (7.19)***	3640.61	8069.31 (7.09)***	3624.62	8303.51 (7.28)***	3727.83
AREA	11.273 (0.79)	4.969	7.651 (0.51)	3.393	8.273 (0.55)	3.716	6.261 (0.41)	2.811
EMB	11494.28 (1.39)*	4979.53	11493.83 (1.12)	5009.38	12135.75 (1.17)	5357.6	21065.5 (1.81)**	9177.09
DCOAST	69.136 (0.31)	30.477	750.55 (1.20)	332.87	558.33 (0.88)	250.79	-281.77 (-0.35)	-126.50
AGE			422.81 (1.63)*	187.52	437.38 (1.66)**	196.46	465.66 (1.77)**	209.05
EDUYR			1565.11 (1.55)*	694.12	1626.18 (1.62)*	730.46	1708.99 (1.69)**	767.25
CREDIT			6244.86 (0.86)	2749.67	7431.53 (1.01)	3311.94	7263.58 (0.99)	3235.77
MEMBER			-6559.87 (-0.66)	-2828.64	-6323.24 (-0.63)	-2764.67	-7209.53 (-0.72)	-3137.84
MFRATIO			3953.25 (0.89)	1753.26	3342.89 (0.74)	1501.58	3361.53 (0.75)	1509.15
CHILD			14043.79 (4.68)***	6228.41	14131.1 (4.66)***	6347.49	14532.27 (4.81)***	6524.21
HELEV2			5002.21 (0.32)	2239.91	3217.64 (0.21)	1454.58	1300.92 (0.08)	585.56

HELEV3			18353.86 (1.20)	7992.72	14278.06 (0.92)	6314.45	11206.3 (0.72)	4969.34
MIGRATION			-437.1 (-0.05)	-193.64	389.51 (0.05)	175.14	3679.06 (0.43)	1667.49
PROTECTED			-57083.2 (-2.78)***	-24168.77	-48700.64 (-2.33)***	-21102.47	-108113.3 (-1.64)**	-45438.73
MDIST			-2193.51 (-1.62)**	-972.82	-2136.04 (-1.57)*	-959.48	-2353.73 (-1.70)**	-1056.7
MDIR2			7080.57 (0.29)	3236.67	10318.7 (0.42)	4847.12	25565.57 (0.99)	12788.6
MDIR3			15879.56 (0.59)	7737.35	16059.44 (0.59)	7924.94	59096.61 (1.43)*	35903.96
MDIR4			16318.43 (0.54)	7837.19	20901.45 (0.68)	10383.1	Dropped	Dropped
MDIR5			18229.54 (0.71)	8995.18	13942.58 (0.54)	6795.61	36779.67 (0.73)	20215.16
MDIR6			-10263.32 (-0.18)	-4219.38	-2818.5 (-0.05)	-1240.62	36227.26 (0.58)	20480.34
Variable	Coeff.	Marginal Effect	Coeff.	Marginal Effect	Coeff.	Marginal Effect	Coeff.	Marginal Effect
MDIR7			20217.13 (0.78)	9161.74	20660.18 (0.79)	9468.01	56519.39 (1.40)*	26812.41
ARELIEF					15201.63 (1.22)	6225.6	13257.25 (1.06)	5489.84
AREHABN					-8048.1 (-1.02)	-3633.6	-7985.78 (-1.01)	-3603.5
SURGEHT							-8726.13 (-0.60)	-3917.57
STORMDIR							-68176.39 (-1.48)*	-28015.26
STORMDIS							1193.24 (1.24)	535.7
Log Likelihood	-3433.021		-3207.32		-3178.62		-3176.60	
Pseudo R^2	0.0115		0.0196		0.02		0.0206	
Chi2 (df)	79.84 (8)		128.22 (25)		129.88 (27)		133.91 (29)	
OBS.	430		402		394		394	

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

LIST OF FIGURES

Figure 1: Probability Tree of a Sequence of Events

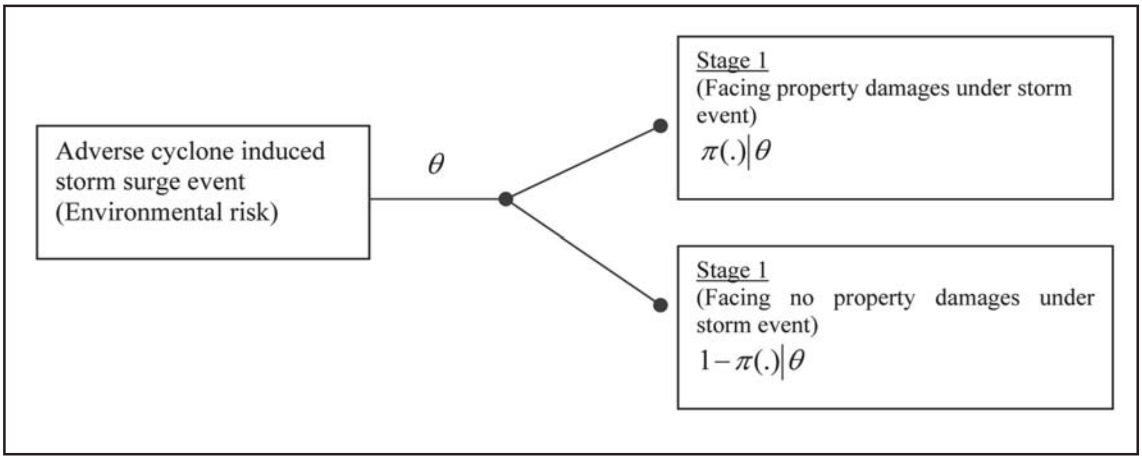


Figure 2: Exposure to High Cyclone Risk of Bangladesh Coastal and Sundarban Mangrove Areas

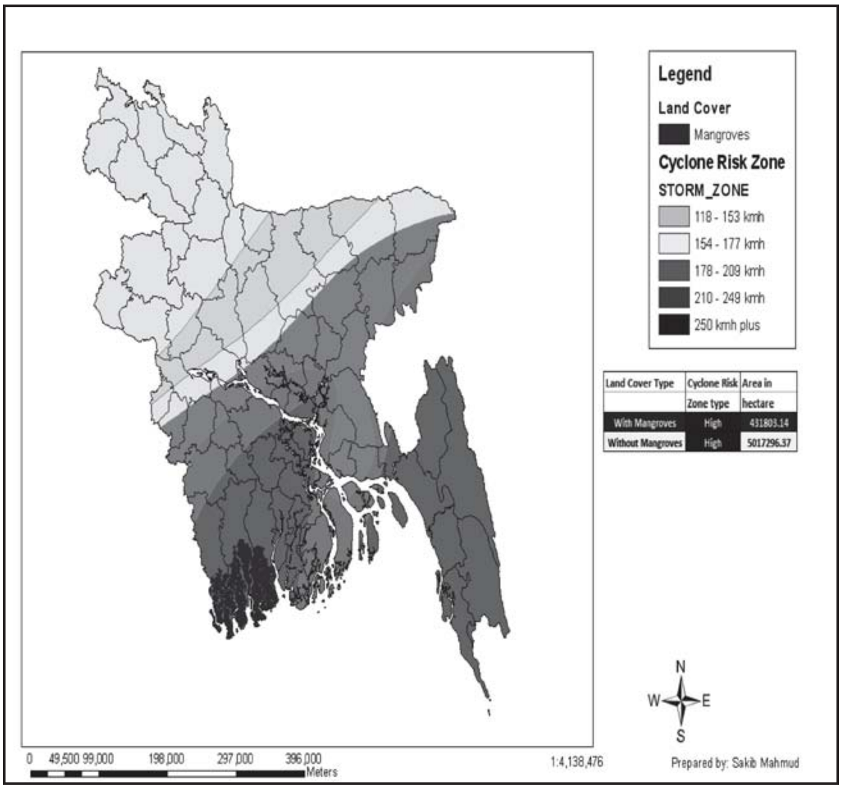


Figure 3: Track of Cyclone Sidr and Its Satellite Image Making Landfall on the South Western Coast of Bangladesh

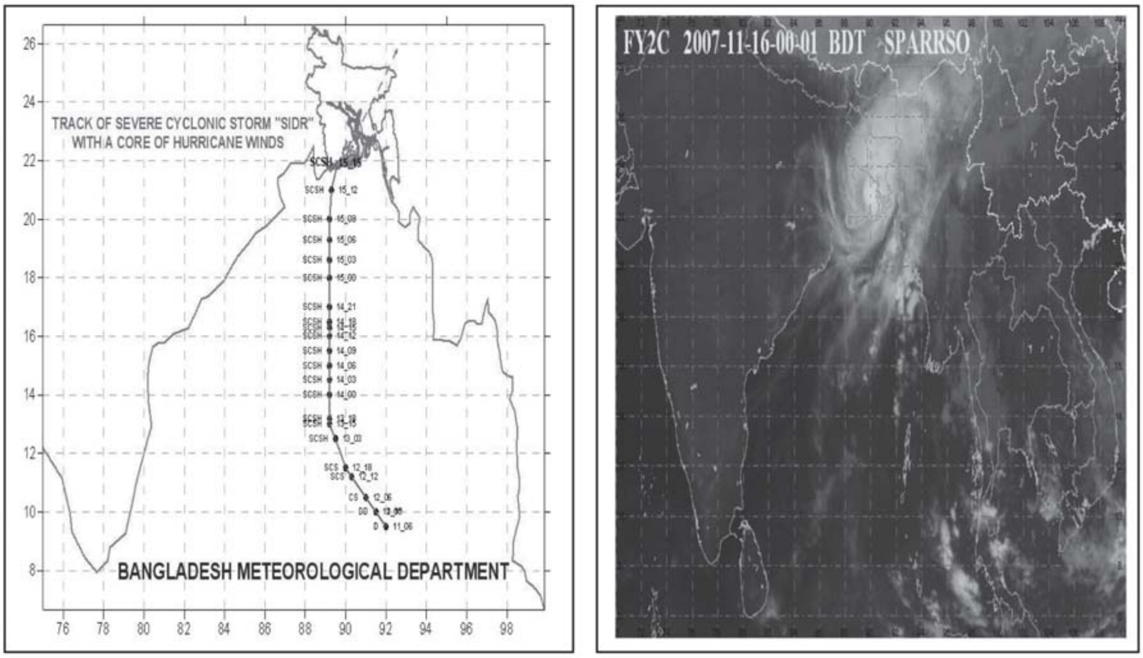
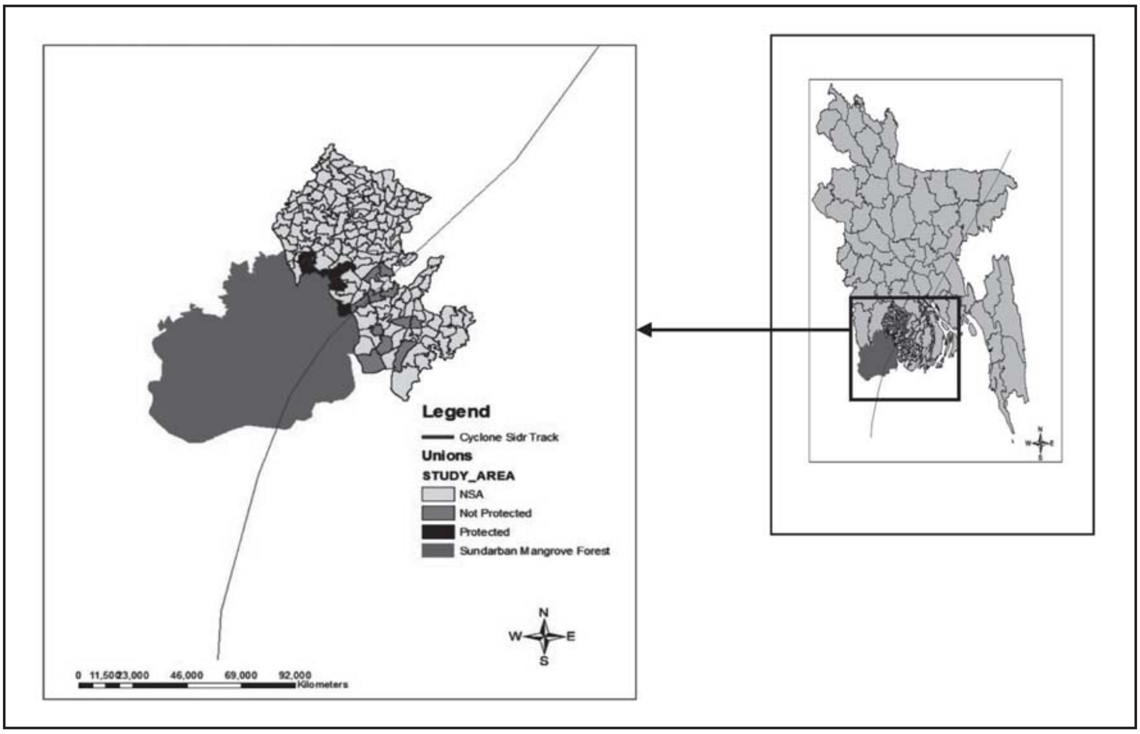


Figure 4: Enlarged Study Area: Mangrove Exposed and Non-Mangrove Exposed



APPENDICES

APPENDIX 1

Table 1A: 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 cyclone shelters; from 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.	Health-related information	Symptoms/ types of disease due to Cyclone Sidr; no. of days suffering; money spent for health care	Household survey
6.	Ex-ante averting activities	Risk mitigating and risk coping information based on participation (binary response)and conditional on participation, expenses incurred.	Household survey

APPENDIX 2

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 (8) and (9), the implicit function theorem, and assuming that the matrix H is the negative definite, the comparative static effects of a decrease in G_{ij} on the optimal levels of self-protection Z_{ij} and self-insurance A_{ij} yields

$$\frac{\partial Z^*}{\partial G} = \frac{\overbrace{H_{AA} \cdot \left(-\frac{\partial EMB_Z}{\partial G} \right)}^{\text{direct effect}} + \overbrace{H_{AZ} \cdot \left(\frac{\partial EMB_A}{\partial G} \right)}^{\text{indirect effect}}}{|H|} \qquad \textbf{(A.2.1)}$$

In expression (A.2.1), 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.

$$\frac{\partial A^*}{\partial G} = \frac{\overbrace{H_{ZZ} \cdot \left(-\frac{\partial EMB_A}{\partial G} \right)}^{\text{direct effect}} + \overbrace{H_{AZ} \cdot \left(\frac{\partial EMB_Z}{\partial G} \right)}^{\text{indirect effect}}}{|H|} \qquad \textbf{(A.2.2)}$$

In expression (A.2.2), 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.2.1) and (A.2.2) 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-insuranc$\left(\frac{\partial EMB_A}{\partial G} \right)$. 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.

Under it is the 'no restriction' condition, we can express the influence of ex-ante public protective spending G_{ij} on self-protection Z_{ij} as

$$\frac{\partial Z_{ij}}{\partial G_{ij}} = \frac{\begin{vmatrix} -\frac{\partial F^1}{\partial G_{ij}} & H_{ZA} \\ -\frac{\partial F^2}{\partial G_{ij}} & H_{AA} \end{vmatrix}}{|H|} = \frac{H_{AA} \cdot \left(-\frac{\partial F^1}{\partial G_{ij}} \right) + H_{ZA} \cdot \left(-\frac{\partial F^2}{\partial G_{ij}} \right)}{|H|}$$
$$= \frac{\overset{\text{'-'}}{H_{AA}} \cdot \left[\begin{array}{l} -\overbrace{\frac{\partial^2 \pi_{ij}(.)}{\partial G_{ij} \partial Z_{ij}}}^{\text{'?'}} \cdot \overbrace{\left(U(W_1) - U(W_2) \right)}^{\text{'-'}} \\ + \overbrace{\frac{\partial \pi_{ij}}{\partial G_{ij}}}^{\text{'-'}} \cdot \overbrace{\left(U'(W_1) - U'(W_2) \right)}^{\text{'+'}} \end{array} \right] + \overset{\text{'?'}}{H_{ZA}} \cdot \left[\begin{array}{l} -\overbrace{\frac{\partial \pi_{ij}(.)}{\partial G_{ij}}}^{\text{'-'}} \cdot \overbrace{U'(W_1)}^{\text{'+'}} \cdot \overbrace{\left(1 + \frac{\partial L_{ij}}{\partial A_{ij}} \right)}^{\text{'-'}} \\ + \overbrace{U'(W_2)}^{\text{'+'}} \cdot \overbrace{\frac{\partial Q_{ij}(.)}{\partial G_{ij}}}^{\text{'-'}} \end{array} \right]}{|H|} \qquad \textbf{(A.2.3)}$$

Similarly, we can state the influence of G_{ij} on ex-ante self-insurance A_{ij} as

$$\frac{\partial A_{ij}}{\partial G_{ij}} = \frac{\begin{vmatrix} H_{ZZ} & -\frac{\partial F^1}{\partial G_{ij}} \\ H_{AZ} & -\frac{\partial F^2}{\partial G_{ij}} \end{vmatrix}}{|H|} = \frac{H_{ZZ}\cdot\left(-\frac{\partial F^2}{\partial G_{ij}}\right) + H_{AZ}\cdot\left(\frac{\partial F^1}{\partial G_{ij}}\right)}{|H|}$$

$$= \frac{\overset{'-'}{H_{ZZ}}\cdot\left[\begin{array}{l}\overbrace{\frac{\partial \pi_{ij}(.)}{\partial G_{ij}}}^{'-'}\cdot\overbrace{U'(W_1)}^{'+'}\cdot\overbrace{\left(1+\frac{\partial L_{ij}}{\partial A_{ij}}\right)}^{'-'} \\ -\overbrace{U'(W_2)}^{'+'}\cdot\overbrace{\frac{\partial \pi_{ij}(.)}{\partial G_{ij}}}^{'-'}\end{array}\right] + \overset{'?'}{H_{AZ}}\cdot\left[\begin{array}{l}\overbrace{\frac{\partial^2 \pi_{ij}(.)}{\partial G_{ij}\partial Z_{ij}}}^{'?'}\cdot\overbrace{(U(W_1)-U(W_2))}^{'-'} \\ +\overbrace{\frac{\partial \pi_{ij}}{\partial G_{ij}}}^{'-'}\cdot\overbrace{(U'(W_1)-U'(W_2))}^{'+'}\end{array}\right]}{|H|} \quad \textbf{(A.2.4)}$$

It is not possible to sign expression (A.2.3) and (A.2.4) unambiguously. We can only sign them if the following conditions hold,

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

Condition 2. $\frac{\partial^2 \pi_{ij}(.)}{\partial G_{ij}\partial Z_{ij}} < 0$ .iis suggests that more ex-ante government protection activities G_{ij} can accentuate the influence of self-protection Z_{ij} in reducing the l probability of facing storm-inflicted damages to property.

Assuming conditions (1) and (2) are met, it is possible to sign - expressions (A.2.1) and (A.2.2) accordingly.

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

$$\frac{\partial A_{ij}}{\partial G_{ij}} = \frac{\overbrace{H_{zz}}^{"-"}\cdot\overbrace{\text{2nd bracketed term}}^{"+"}+\overbrace{H_{AZ}}^{"-"}\cdot\overbrace{\text{4th bracketed term}}^{"+"}}{|H|} = \frac{"-" + "-"}{|H|} < 0 \quad \textbf{(A.2.5)}$$

Therefore, under additional restrictions, comparative statics result show that ex-ante government protection spending G_{ij} is a complement to ex-ante self-protection Z_{ij} but is a substitute to ex-ante self- insurance A_{ij}.

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 we can determine the direction of the relationship only under certain restrictions. Comparative static results show

$$\frac{\partial Z^*}{\partial R} = \frac{\overbrace{H_{AA}\cdot\left(-\frac{\partial EMB_Z}{\partial R}\right)}^{\text{direct effect}}+\overbrace{H_{AZ}\cdot\left(\frac{\partial EMB_A}{\partial R}\right)}^{\text{indirect effect}}}{|H|} \quad \textbf{(A.2.6)}$$

$$\frac{\partial A^*}{\partial R} = \frac{\overbrace{H_{ZZ} \cdot \left(-\frac{\partial EMB_A}{\partial R} \right)}^{\text{direct effect}} + \overbrace{H_{AZ} \cdot \left(\frac{\partial EMB_Z}{\partial R} \right)}^{\text{indirect effect}}}{|H|} \tag{A.2.7}$$

Expressions (A.2.6)-(A.2.7) 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 $\left(\frac{\partial EMB_Z}{\partial G}\right)$ and self-insurance $\left(\frac{\partial EMB_A}{\partial G}\right)$. Conversely, the indirect effects depend on the cross partials (H_{Az} and H_{ZA}) 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_{ij} on the expected marginal benefits of self-protection $\left(EMB_Z = \frac{\partial EU}{\partial Z_{ij}} \right)$. However, if we assume the households to be risk neutral, then it is possible to establish the direction of the relationships by imposing the additional restriction.

Under the 'no restriction' condition, the influence of ex-post government risk-reducing programs R_{ij} on household self-protection Z_{ij} show

$$\frac{\partial Z_{ij}}{\partial R_{ij}} = \frac{\begin{vmatrix} -\frac{\partial F^1}{\partial R_{ij}} & H_{ZA} \\ -\frac{\partial F^2}{\partial R_{ij}} & H_{AA} \end{vmatrix}}{|H|} = \frac{H_{AA} \cdot \left(-\frac{\partial F^1}{\partial R} \right) + H_{ZA} \cdot \left(\frac{\partial F^2}{\partial R} \right)}{|H|} \tag{A.2.8}$$

$$= \frac{\overset{\text{'-'}}{H_{AA}} \cdot \left[\overbrace{\frac{\partial \pi_{ij}(.)}{\partial Z_{ij}}}^{\text{'-'}} \cdot \overbrace{U'(W_1)}^{\text{'+'}} \cdot \overbrace{\frac{\partial L_{ij}(.)}{\partial R_{ij}}}^{\text{'-'}} - \overbrace{\pi_{ij}}^{\text{'+'}} \cdot \overbrace{U''(W_1)}^{\text{'-'}} \cdot \overbrace{\frac{\partial L_{ij}}{\partial R_{ij}}}^{\text{'-'}} \right] + \overset{\text{'?'}}{H_{ZA}} \cdot \left[\begin{array}{l} - \overbrace{\pi_{ij}(.)}^{\text{'+'}} \cdot \overbrace{U'(W_1)}^{\text{'+'}} \cdot \overbrace{\frac{\partial^2 L_{ij}(.)}{\partial R_{ij} \partial A_{ij}}}^{\text{"?"}} \\ + \overset{\text{'+'}}{\pi_{ij}}(.) \cdot \overbrace{\left(1 + \frac{\partial L_{ij}(.)}{\partial A_{ij}} \right)}^{\text{'-'}} \cdot \overbrace{U''(W_1)}^{\text{"-"}} \cdot \overset{\text{"-"}}{\frac{\partial L_{ij}}{\partial R_{ij}}} \end{array} \right]}{|H|}$$

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

On ex-ante self-insurance A_{ij},

$$\frac{\partial A_{ij}}{\partial R_{ij}} = \frac{\begin{vmatrix} H_{ZZ} & -\frac{\partial F^1}{\partial R_{ij}} \\ H_{AZ} & -\frac{\partial F^2}{\partial R_{ij}} \end{vmatrix}}{|H|} = \frac{H_{ZZ} \cdot \left(-\frac{\partial F^2}{\partial R_{ij}} \right) + H_{AZ} \cdot \left(\frac{\partial F^1}{\partial R_{ij}} \right)}{|H|}$$

$$= \frac{\overset{'-'}{H_{ZZ}} \cdot \left[\begin{array}{l} \overbrace{\pi_{ij}(.)}^{'+'} \cdot \overbrace{U'(W_1)}^{'+'} \cdot \overbrace{\frac{\partial^2 L_{ij}(.)}{\partial R_{ij} \partial A_{ij}}}^{"?"} \\ + \overbrace{\pi_{ij}(.)}^{'+'} \overbrace{\left(1 + \frac{\partial L_{ij}(.)}{\partial A_{ij}} \right)}^{'-'} \cdot \overbrace{U''(W_1)}^{"-"} \cdot \overbrace{\frac{\partial L_{ij}(.)}{\partial R_{ij}}}^{"-"} \end{array} \right] + \overset{?}{H_{AZ}} \cdot \left[- \overbrace{\frac{\partial \pi_{ij}(.)}{\partial Z_{ij}}}^{'-'} \cdot \overbrace{\frac{\partial L_{ij}(.)}{\partial R_{ij}}}^{'-'} \cdot \overbrace{U'(W_1)}^{'+'} + \overset{'+'}{\pi}(.) \cdot \overset{'-'}{U''}(W_1) \cdot \overset{'-'}{\frac{\partial L_{ij}}{\partial R_{ij}}} \right]}{|H|} \quad \textbf{(A.2.9)}$$

It is not possible to sign expression (A.2.9) 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 $\left(\frac{\partial EMB_Z}{\partial R} = \frac{\partial F^1}{\partial R_{ij}} \right)$ under the indirect effect. Moreover, we need to impose an additional restriction to sign the term $\frac{\partial^2 L}{\partial R_{ij} \partial A_{ij}}$ and the cross partial H_{zA}. Assuming household to be risk neutral, comparative static results show

$$\frac{\partial Z}{\partial R} = \frac{H_{AA} \cdot \left(-\frac{\partial F^1}{\partial R} \right) + H_{ZA} \cdot \left(\frac{\partial F^2}{\partial R} \right)}{|H|}$$

$$= \frac{\overbrace{-\pi \cdot \frac{\partial^2 L}{\partial A^2}}^{'-'} \cdot \overbrace{\frac{\partial \pi}{\partial Z} \cdot \left(\frac{\partial L}{\partial R} \right)}^{'+'} - \overbrace{\left(-\frac{\partial \pi}{\partial Z} \cdot \frac{\partial L}{\partial A} \right)}^{'-'} \cdot \overbrace{\left(\pi \cdot \frac{\partial^2 L}{\partial R \partial A} \right)}^{'?'}}{|H|} \quad \textbf{(A.2.10)}$$

$$\frac{\partial A}{\partial R} = \frac{H_{ZZ} \cdot \left(-\frac{\partial F^2}{\partial R} \right) + H_{AZ} \cdot \left(\frac{\partial F^1}{\partial R} \right)}{|H|}$$

$$= \frac{\overbrace{-\frac{\partial^2 \pi}{\partial Z^2} \cdot L(.)}^{'-'} \cdot \overbrace{\pi \cdot \frac{\partial^2 L}{\partial R \partial A}}^{'?'} - \overbrace{\left(-\frac{\partial \pi}{\partial Z} \cdot \frac{\partial L}{\partial A} \right)}^{'-'} \cdot \overbrace{\frac{\partial L}{\partial R} \cdot \frac{\partial \pi}{\partial Z}}^{'+'}}{|H|} \quad \textbf{(A.2.11)}$$

Under the risk neutral case, it is possible to sign both (A.2.10) and (A.2.11) if the following condition holds:

Condition 3. A strict quasi-convex relationship exists between storm-inflicted property losses and ex-ante self-insurance expenditure $\frac{\partial L_{ij}}{\partial A_{ij}} < 0; \frac{\partial^2 L_{ij}}{\partial A_{ij}^2} > 0$. This means that property losses as a result of a storm surge event decreases at a declining rate if the household is ready to commit more self-insurance expenditure.

Condition 4. 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}, $\frac{\partial \pi_{ij}(.)}{\partial Z_{ij}} < 0; \frac{\partial^2 \pi_{ij}(.)}{\partial Z_{ij}^2} > 0.$

This implies that the probability of facing property losses as a result of a cyclone-induced storm surge event falls at a decreasing rate with more increases in household self-protection expenditure.

Condition 5. $\frac{\partial^2 L_{ij}(.)}{\partial R_{ij} \partial A_{ij}} < 0.$ Condition 5 states that more ex-post public-assisted disaster relief and rehabilitation programs R_{ij} accentuate the effect of self-insurance in reducing monetary loss or damages to property as a result of a severe storm event. If Conditions (3)-(5) hold, then it is possible to sign expression (A.2.10) and (A.2.11) indicating the following relationship

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

$$\frac{\partial A_{ij}}{\partial R_{ij}} = \frac{\overbrace{H_{ZZ}}^{\text{'–'}} \cdot \overbrace{\text{2nd bracketed term}}^{\text{"–"}} - \overbrace{H_{AZ}}^{\text{"–"}} \cdot \overbrace{\text{4th bracketed term}}^{\text{"+"}}}{|H|} = \frac{\text{"+"} - \text{"–"}}{\text{"+"}} > 0 \qquad \textbf{(A.2.12)}$$

Expression (A.2.12) shows that ex-ante self-protection Z_{ij} is expected to go down but ex-ante self-insurance A_{ij} is expected to go up if households have more access to ex-post government-assisted disaster relief and rehabilitation programs R_{ij}. 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_{ij} 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.

Under the 'no restriction' condition, it is possible to express the influence of mangrove forests M_{ij} on self-protection Z_{ij} as

$$\frac{\partial Z_{ij}}{\partial M_{ij}} = \frac{\begin{vmatrix} -\frac{\partial F^1}{\partial M_{ij}} & H_{ZA} \\ -\frac{\partial F^2}{\partial M_{ij}} & H_{AA} \end{vmatrix}}{|H|} = \frac{H_{AA} \cdot \left(-\frac{\partial F^1}{\partial M_{ij}}\right) + H_{ZA} \cdot \left(\frac{\partial F^2}{\partial M_{ij}}\right)}{|H|} \qquad \textbf{(A.2.13)}$$

$$= \frac{\overset{\text{'–'}}{H_{AA}} \cdot \left[\begin{array}{l} -\overbrace{\frac{\partial^2 \pi_{ij}(.)}{\partial M_{ij} \partial Z_{ij}}}^{\text{'?'}} \cdot \overbrace{\left(U(W_1) - U(W_2)\right)}^{\text{'–'}} \\ + \overbrace{\frac{\partial \pi_{ij}}{\partial M_{ij}}}^{\text{'–'}} \cdot \overbrace{\left(U'(W_1) - U'(W_2)\right)}^{\text{'+'}} \end{array}\right] + \overset{\text{'?'}}{H_{ZA}} \cdot \left[\begin{array}{l} -\overbrace{\frac{\partial \pi_{ij}(.)}{\partial M_{ij}}}^{\text{'–'}} \cdot \overbrace{U'(W_1)}^{\text{'+'}} \cdot \overbrace{\left(1 + \frac{\partial L_{ij}}{\partial A_{ij}}\right)}^{\text{'–'}} \\ + \overbrace{U'(W_2)}^{\text{'+'}} \cdot \overbrace{\frac{\partial \pi_{ij}(.)}{\partial M_{ij}}}^{\text{'–'}} \end{array}\right]}{|H|}$$

Similarly, it is possible to state the influence of M_{ij} on ex-ante self-insurance A_{ij} as

$$\frac{\partial A_{ij}}{\partial M_{ij}} = \frac{\begin{vmatrix} H_{ZZ} & -\frac{\partial F^1}{\partial M_{ij}} \\ H_{AZ} & -\frac{\partial F^2}{\partial M_{ij}} \end{vmatrix}}{|H|} = \frac{H_{ZZ} \cdot \left(-\frac{\partial F^2}{\partial M_{ij}}\right) + H_{AZ} \cdot \left(\frac{\partial F^1}{\partial M_{ij}}\right)}{|H|}$$

$$\frac{\overset{\text{'-'}}{H_{ZZ}} \cdot \begin{bmatrix} \overbrace{\frac{\partial \pi_{ij}(.)}{\partial M_{ij}}}^{\text{'-'}} \cdot \overbrace{U'(W_1)}^{\text{'+'}} \cdot \overbrace{\left(1 + \frac{\partial L_{ij}}{\partial A_{ij}}\right)}^{\text{'-'}} \\ -\overbrace{U'(W_2)}^{\text{'+'}} \cdot \overbrace{\frac{\partial \pi_{ij}(.)}{\partial M_{ij}}}^{\text{'-'}} \end{bmatrix} + \overset{\text{'?'}}{H_{AZ}} \cdot \begin{bmatrix} \overbrace{\frac{\partial^2 \pi_{ij}(.)}{\partial M_{ij} \partial Z_{ij}}}^{\text{'?'}} \cdot \overbrace{(U(W_1) - U(W_2))}^{\text{'-'}} \\ -\overbrace{\frac{\partial \pi_{ij}}{\partial M_{ij}}}^{\text{'-'}} \cdot \overbrace{(U'(W_1) - U'(W_2))}^{\text{'+'}} \end{bmatrix}}{|H|} \quad \textbf{(A.2.14)}$$

As before, it is not possible to sign expression (A.2.13) and (A.2.14) unambiguously unless we impose additional restrictions. It is possible to sign them using condition 6 (i.e.,$H_{AZ} = H_{ZA} < 0$) as well as by introducing the following restriction

Condition 6. $\frac{\partial^2 \pi_{ij}(.)}{\partial M_{ij} \partial Z_{ij}} < 0$. is condition states that more storm protection from mangroves M_{ij} accentuates the influence of self-protection Z_{ij} 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_{ij} decreases at an increasing rate for an increase in the household's exposure to the storm-protection services of mangrove forests M_{ij}.

Assuming it is possible to meet conditions (1) and (6), expressions (A.2.13) and (A.2.14) show

$$\frac{\partial Z_{ij}}{\partial M_{ij}} = \frac{\overbrace{H_{AA}}^{\text{"–"}} \cdot \overbrace{\text{2nd bracketed term}}^{\text{"–"}} + \overbrace{H_{ZA}}^{\text{"–"}} \cdot \overbrace{\text{4th bracketed term}}^{\text{"–"}}}{|H|} = \frac{\text{"+" + "+"}}{|H|} > 0$$

$$\frac{\partial A_{ij}}{\partial M_{ij}} = \frac{\overbrace{H_{zz}}^{\text{"–"}} \cdot \overbrace{\text{2nd bracketed term}}^{\text{"+"}} + \overbrace{H_{AZ}}^{\text{"–"}} \cdot \overbrace{\text{4th bracketed term}}^{\text{"+"}}}{|H|} = \frac{\text{"–" + "–"}}{|H|} < 0 \quad \textbf{(A.2.15)}$$

With additional restrictions, the comparative statics result now demonstrates that exposure to storm protection services of mangrove forests M_{ij} is a substitute for households' ex -ante self-protection behavior (Z_{ij}). However, it acts as a substitute for ex-ante self- insurance (A_{ij}).

APPENDIX 3

Combining equations (17)-(18), for ex-ante self-insurance, A_{ij}, it is possible to express the two 'hurdles' (i.e., hurdles based on participation and outcome choices) for ex-ante self-insurance A_{ij} by the following econometric specification,

(i) Participation equation (first hurdle) for self-insurance:

$$d_{ij}^{A^*} = X_{1ij}^{'} \cdot \zeta_{1k} + \mu_{ij} \qquad \text{where } X_{1ij}^{'} = \begin{bmatrix} 1 \\ G_{1ij} \\ M_{1ij} \\ R_{1ij} \\ C_{1ij} \\ \psi_{1ij} \end{bmatrix}, \quad k = 1, \ldots \ \ldots 6; \quad \mu_{ij} \sim N(0,1)$$

$$d_{ij}^{A} = 1 \quad \text{if } d_{ij}^{A^*} \geq 0$$
$$d_{ij}^{A} = 0 \quad \text{otherwise}$$

(ii) Outcome equation (second hurdle): Level of ex ante self-insurance expenditures, A_{ij}

$$A_{ij}^{*} = X_{2ij}^{'} \cdot \zeta_{2k} + \phi_{ij} \qquad \text{where } X_{2ij}^{'} = \begin{bmatrix} 1 \\ G_{2ij} \\ M_{2ij} \\ R_{2ij} \\ C_{2ij} \\ \psi_{2ij} \end{bmatrix}, \quad k = 1, \ldots \ \ldots 6; \quad \phi_{ij} \sim N(0,\sigma_{\phi}^{2}) \qquad \textbf{(A.3.1)}$$

$$A_{ij} = A_{ij}^{*} \quad \text{if } d_{ij}^{A} = 1$$
$$A_{ij} = 0 \quad \text{if } d_{ij}^{A} = 0$$

Expression (A.3.1) states that a separate set of factors as reflected under the vectors of explanatory variables X_{1ij} and X_{2ij} influence the household participation decision equation for self-insurance (first hurdle) and the level of self-insurance expenditures equation conditional on participation (second hurdle).

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

(i) Participation equation (first hurdle) for self-protection:

$$d_{ij}^{Z^*} = X_{3ij}^{'} \cdot \zeta_{1k} + \mu_{ij} \qquad \text{where } X_{3ij}^{'} = \begin{bmatrix} 1 \\ G_{3ij} \\ M_{3ij} \\ R_{3ij} \\ C_{3ij} \\ \psi_{3ij} \end{bmatrix}, \quad k = 1, \ldots \ \ldots 6; \quad \vartheta_{ij} \sim N(0,1)$$

$$d_{ij}^{Z} = 1 \quad \text{if } d_{ij}^{Z^*} \geq 0$$
$$d_{ij}^{Z} = 0 \quad \text{otherwise}$$

(ii) Outcome equation (second hurdle): Level of ex ante self-protection expenditures, Z_{ij}

$$Z_{ij}^{*} = X_{4ij}^{'} \cdot \zeta_{2k} + \phi_{ij} \quad \text{where } X_{4ij}^{'} = \begin{bmatrix} 1 \\ G_{4ij} \\ M_{4ij} \\ R_{4ij} \\ C_{4ij} \\ \psi_{4ij} \end{bmatrix}, \; k = 1, \dots \dots 6; \;\; \gamma_{ij} \sim N(0, \sigma_{\phi}^{2}) \qquad \textbf{(A.3.2)}$$

$$Z_{ij} = Z_{ij}^{*} \quad \text{if } d_{ij}^{Z} = 1$$

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

Expression (A.3.2) states that a separate set of factors as reflected under the vectors of explanatory variables X_{3ij} and X_{4ij} influence the household participation decision equation for self-protection (first hurdle) and the level of self-protection expenditures equation conditional on participation (second hurdle).

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Fax:977-1-5003299
E-mail: info@sandeeonline.org
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9789937837637