Role of Public Programs and a Natural Barrier in Relative Valuation of Households' Storm-inflicted Health Outcomes under Optimal Private Defensive Strategies: Evidence from the Coastal Areas of Bangladesh

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Evidence from the Coastal Areas of Bangladesh

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Abstract
This paper introduces a theoretical model that allows the estimation of a household's valuation of health risks from major storms. An endogenous risk framework is developed in which the household can employ *ex-ante* self-protection and *ex-post* mitigating activities and treatments strategies to protect against storm-inflicted health problems. Combined with a health production function, our theoretical model reveals possible estimation methods to derive households' marginal willingness to pay to reduce health risks due to an increase in public programs and the greater storm protection role of mangroves. Results show that these marginal willingness-to-pay measures can be derived without the expected utility terms since they are a function of only prices and technological parameters. Our empirical analysis of coastal households of Bangladesh impacted by 2007 Cyclone Sidr confirms the possible influence of mangroves in reducing storm-inflicted injuries or illness. The probability of a household experiencing adverse health impacts from a major storm is higher if it has access to *ex-post* public disaster relief programs. However, there is no conclusive evidence of whether the likelihood of facing health impacts is higher if a household is located behind an embankment. Demographic characteristics such as age, number of females and number of children have considerable influence on the likelihood of a household facing storm-inflicted health impacts but not on medical expenditures for storm-inflicted injuries. To reduce damaging health outcomes from a major storm, results reveal that the households are willing to pay the highest amount for greater storm protection from mangroves followed by embankments and disaster relief programs.

Key words: Self-protection; mitigating activities and treatments; storm-inflicted health outcomes; mangroves; Cyclone Sidr; Bangladesh.

JEL Classifications: D81, H31, I12, Q54.

1. Introduction

Coastal areas with high population densities and widespread poverty are experiencing significant health risks as a result of frequent and severe storm events (IPCC, 2007; World Bank, 2010). Government support to reduce health risks of such vulnerable coastal population usually come in the form of *ex-ante* (i.e. before the natural disaster) publicly constructed protective barriers or embankments and *ex-post* (i.e. after the natural disaster) public disaster relief and rehabilitation programs. Besides public programs, the presence of a natural barrier, such as a mangrove forest, can also play possible storm protection role with respect to saving lives. However, a poor coastal household's decision to engage in private defensive strategies to insulate themselves against storm-inflicted health risks might also be influenced by their expectation of receiving public protection programs and their location relative to the coast and the mangroves. The purpose of the following paper is to propose a theoretical model that allows estimation of a poor coastal household's valuation of reducing storm-inflicted health risks in an environment where the household can pursue private defensive strategies given the presence of public programs and a natural barrier.

Since private defensive strategies adopted by coastal households could reduce the probability and severity of storm-inflicted health problems, the storm surge risk becomes endogenous. The endogenous risk framework, first introduced by Ehrlich and Becker (1972), assumes risks can be reduced either privately or collectively through *self-protection* activities, which could reduce the likelihood of an undesired state, and through *self-insurance* activities, which could reduce the severity of the consequences if the undesired state is realized. For poor households in coastal areas of a developing country, such actions may take specific forms (Table 1). Examples of self-protection include converting a mud-built house to a brick-built house, raising the height of the homestead, planting trees around the house, and moving the house behind an embankment. These activities help reduce the risk that a household may face adverse health effects from a major coastal storm. The household can also pursue self-insurance in terms of a set of mitigating activities and treatments in order to reduce the severity or magnitude of storm-inflicted injuries or diseases. These actions include taking medications and visiting a hospital or a doctor for medical treatment for illness or injuries (see Table 1). Hence, a household basically has two choices to protect its health from a storm event: the first choice is the set of *ex-ante* self-protection activities *before* the storm event, and the second choice is the set of *ex-post* mitigating activities and treatments in terms of self-insurance *after* the storm event.

However, studies reveal that individuals have the tendency not to insure or protect themselves against natural disaster risks and outcomes 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). Consequently, such help from outside sources might partially or fully crowd out private storm protection actions. In the disaster insurance literature, this tendency of a household to under-insure because of anticipated government or private charity support is called the 'charity hazard' (Lewis and Nickerson, 1989; Browne and Hoyt, 2000; Raschky and Weck-Hannemann, 2007). It is possible that a similar crowding out effect might occur if a poor coastal household partially or fully reduces its private defensive actions because it expects increased government spending on disaster relief and rehabilitation programs after storms occur.

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

Considering the possible influence of public programs and mangroves on private defensive strategies, we explore the possibility of measuring the household's marginal willingness-to-pay to protect its members' health from a major storm if the household has better access to public programs and lives near to a mangrove forest. In order to examine these effects, we develop a theoretical model combining a household health production function with an endogenous risk framework that includes *ex-ante* self-protection to reduce the probability of storm-inflicted health impacts and the level of *ex-post* mitigating activities and treatments for each health outcome given any exposure to a storm. In addition, our model incorporates the possible influence of government disaster relief and rehabilitation programs and of natural storm barriers, such as mangroves, on private actions.

The novel contribution of our paper is to suggest a theoretical model under an endogenous risk framework with the possibility of testing it empirically through a case study to estimate a household's valuation of reducing its health risks from major storms. Results from our model show that a household's valuation of reducing storm-inflicted health risks can be represented by the household's marginal willingness to pay for an improvement in its access to public programs or for an improvement in its access to storm protection services of mangroves. A household can experience greater storm protection services from a mangrove forest if it moves in close to the forest or if there is expansion of the forest area. Following Bresnahan and Dickie (1995), results further reveal that these marginal willingness-to-pay estimates can be derived without the expected utility terms since they are a function of only prices and technological parameters.

Our empirical analysis of coastal households of Bangladesh impacted by the 2007 Cyclone Sidr confirms the possible influence of mangroves in reducing storm-inflicted injuries or illness. Results show that the probability of a household experiencing more health-risks from a major storm is higher if the household has access to public disaster relief programs. However, the likelihood of household facing lower adverse health outcomes as a result of its location behind an embankment (a form of *ex-ante* public programs) is inconclusive. Demographic characteristics such as age, number of females, and number of children have considerable influence on the likelihood of a household facing storm-inflicted health risks but not on medical expenditures to storm-inflicted injuries. To reduce storm-inflicted health risks, results reveal that the households are willing to pay the highest for greater storm protection role of mangroves followed by *ex-ante* embankments and *ex-post* disaster relief programs.

This paper makes a methodological contribution to the literature concerning the possible storm protection role of a mangrove forest with respect to reducing illness and injury. Our theoretical model differs from the damage function approach adopted by Badola and Hussein (2005), Barbier (2007), and Das and Vincent (2009) by introducing the household health production function within an endogenous risk framework. In addition, our model considers other factors such as private defensive strategies and public programs that might also contribute towards reduction of storm-inflicted health risks. Preliminary empirical findings from the study confirm the positive influence of mangroves in reducing health-related risks from a major storm.

The rest of the paper is organized as follows. Section 2 describes the theoretical model and the predictions derived from it. Section 3 explains the possible empirical model. Section 4 suggests future directions for the empirical research. Section 5 concludes.

2. The Health Production Model of Defensive Behavior

Assume that a representative rural household located along the coastal area is exposed to an environmental risk in the form of a future cyclone-induced storm surge that could inflict various health problems. This environmental risk is endogenous because a household can take private defensive strategies to reduce its health-related risks from such major storms. Once a household is exposed to a major storm, we can define the health-related risks in terms of two characteristics: (1) the range of possible adverse health consequences, and (2) the probability distribution across health consequences. In this paper, we measure the adverse consequences in units that reflect the health consequences to people as a result of the storm surge event, such as the number of lost workdays and monetary losses for medication and visits to a hospital or a doctor for medical treatments. To keep the exposition simple, we assume that there is one adverse storm event and *n* states of nature. In a unified household model, the different states of nature reflect different health outcomes where $n = 1, \ldots, N$ reflects states of health that are ranked in descending level of health with 1 being the 'best health' state and *N* being the 'worst health' state. Since we are interested in the household's defensive actions when it is fully exposed to a storm surge event, we do not consider non-storm states.

Regarding defensive behavior, a household can employ a set of self-protection activities, Z_{ij}^{k} with $k = k_1, k_2, \ldots, k_K$, that can decrease the probability of experiencing any health problems as the result of a major storm. In addition, the household can also employ a set of self-insurance activities in terms of mitigations and treatments, T_{ij}^{t} with $t = t_1, t_2, ..., t_t$, that can reduce the severity of ex-post health problems once it is fully exposed to a storm event. For simplicity, the model does not consider the loss of life (risk of death) by assuming strict separability between mortality and morbidity.[1]

Let us assume that a household chooses to incur private defensive expenditures to deal with any future storm-inflicted health-related risk. The household thinks that prior planning for these investments in terms of self-protection and self-insurance would be beneficial if it is fully exposed to a major storm event in the future. Considering these assumptions, a representative household i located in village j maximizes a utility function with the standard properties,

$$U_{ij}^{n} = U_{ij}^{n}(X_{ij}, H_{ij}^{n}; \psi_{ij}) \qquad \forall\, n = 1, \ldots, N \tag{1}$$

where X_{ij} is consumption expenditure, H_{ij}^{n} is the health outcome for the household in state n, and ψ_{ij} signifies the exogenous socio-economic characteristics of the household and its location that may also affect utility. The model is structured as if the household maximizes a single state-dependent utility function subject to a set of constraints that determine the household's health production function and its full income budget.

The probability of facing adverse health impacts for a household that is fully exposed to a major storm can be represented as

$$\begin{aligned} &Q_{ij}^{n}(.) = Q_{ij}^{n}\left(Z_{ij}^{k}; G_{ij}, M_{ij}, C_{ij}\right) \\ &\forall n = 1, \ldots, N \text{ and } \forall\, k = k_1, k_2, \ldots, k_k \end{aligned} \tag{2}$$

where Z_{ij}^{k} is the set of k ex-ante self-protection activities that decrease the probability of facing health-related risks;[2] G_{ij} is the household's access to *ex-ante* public protective programs such as publicly constructed embankments or dams that reduce the probability of the household incurs flood damages; M_{ij} is a vector of characteristics capturing the role of mangroves as natural storm protection barriers, such as the area of the nearby mangrove forest, distance between the

[1] A strict separability condition between mortality and morbidity is applied based on three (3) reasons: first, it is better to avoid double counting morbidity benefits, which is usually estimated through willingness-to-pay (WTP) and cost-of-illness methods; second, it is difficult for the respondents to comprehend and provide judgments if both morbidity and mortality outcomes were put in the same survey; and, last, it is generally thought that morbidity effects are of second order importance (Krupnick, 2007).

[2] 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.

mangrove forest and the household, directional location of the household related to the coast and the mangroves, etc., and, lastly, C_{ij} is a vector of characteristics defining the major storm event, such as storm surge height and wind velocity at household location, direction and distance of the cyclone path from the household location, etc.

Considering that a household faces n health outcomes once it is fully exposed to a major storm event, its health production function can be defined as

$$H_{ij}^{n} = H_{ij}^{n}\left(T_{ij}^{t}; R_{ij}\right) \qquad \forall\, n = 1, \ldots, N \text{ and } \forall t = t_1, t_2, \ldots, t_t \tag{3}$$

where T_{ij}^{t} is the same set of t self-insurance activities that can reduce the severity of any storm-inflicted injury or disease; and R_{ij} is the household's access to public post-disaster relief and rehabilitation programs, some of which include health care for treating injuries and illness. It is expected that health outcomes will improve if the household undertakes self-insurance and enjoys accessibility to public post-disaster programs. That is, $\frac{\partial H_{ij}^{n}}{\partial T_{ij}^{t}} > 0$ and, $\frac{\partial H_{ij}^{n}}{\partial R_{ij}} > 0$.

If exposed to a storm event, a household incurs a minimum cost combination of medical care, lost wages, and consumption. This realized cost for a household that is fully exposed to a storm and facing adverse health impacts can be stated as

$$L_{ij}^{n} = L_{ij}^{n}\left(T_{ij}^{t}; R_{ij}\right) \qquad \forall n = 1, \ldots, N \text{ and } \forall t = t_1, t_2, \ldots, t_t \tag{4}$$

where the realized cost, L_{ij}^{n}, depends on the self-insurance activities ,T_{ij}^{t} with $t = t_1, t_2, \ldots, t_t$, and a household's access to government post-disaster relief and rehabilitation programs against a storm event, R_{ij}. It is expected that the cost is less if a household invests in self-insurance activities and has access to public protection programs. That is, $\frac{\partial L_{ij}}{\partial T_{ij}^{t}} < 0$; $\frac{\partial L_{ij}}{\partial R_{ij}} < 0$.

The household chooses the levels of self-protection, Z_{ij}^{k}, and self-insurance, T_{ij}^{t}, by maximizing its utility given the following full income constraint:

$$\begin{aligned} &I_{ij} = X_{ij} + P_{z}^{k'} \cdot Z_{ij}^{k} + P_{T}^{t'} \cdot T_{ij}^{t} + L_{ij}^{n}\left(T_{ij}^{t}; R_{ij}\right) \\ &\forall n = 1, \ldots, N;\ \forall k = k_1, \ldots, k_k;\ \text{and, } \forall t = t_1, \ldots, t_t \end{aligned} \tag{5}$$

Conceptually, the household income, I_{ij}, is equal to the non-labor income and wage income. We assume $P_X = 1$ where X_{ij} is a numeraire good which is normalized to a price of 1; $P_z^{k'}$ is the vector of prices of each k self-protection activity, where $k = k_1, \ldots, k_k$; and $P_T^{t'}$ is the vector of prices of each self-insurance activity, where $t = t_1, \ldots, t_t$.

Taking into account expressions (1)-(5), a household's maximization problem is[3]

$$\underset{Z^k, T^t}{Max}\ EU = \sum_{n=1}^{N} \left[Q^n \left(Z^k; G, M, C \right) \cdot U^n \left(X, H^n \left(T^t; R \right); \psi \right) \right]$$

Subject to, (6)

$$I = X + P_Z^{k'} \cdot Z^k + P_T^{t'} \cdot T^t + L^n \left(T^t; R \right)$$

where, $n = 1, ..., N$ states of nature; $k = k_1, ..., k_k$ self-protection activities; and $t = t_1, ..., t_t$ self-insurance activities.

Expression (6) shows that a household maximizes its expected utility subject to the full income constraint considering only the health outcomes when it is fully exposed to a damaging storm.

Substituting the income constraint and re-arranging terms, the household maximization problem (6) becomes

$$\underset{Z^k, T^t}{Max}\ EU = \sum_{n} \left[Q^n (Z^k; M, G, C) \cdot U^n \left(I - P_z^{k'} \cdot Z^k - P_T^{t'} \cdot T^t - L^n \left(T^t; R \right), H^n \left(T^t; R \right); \psi \right) \right] \qquad (7)$$

Expression (7) says that the expected utility to be maximized is the sum of utilities under n states of health of a household that is exposed to a severe storm event weighted by their respective probabilities.

The first order condition with respect to the level of ex-ante self-protection, Z^k, leads to

$$\frac{\partial EU}{\partial Z^k}: \quad \underbrace{\sum_n \frac{\partial Q^n}{\partial Z^k} \cdot U^n(.)}_{\text{Expected marginal benefits of self-protection}} = \underbrace{P_z^{k'} \cdot \sum Q^n \cdot \frac{\partial U^n(.)}{\partial I}}_{\text{Expected marginal costs of self-protection}} \qquad (8)$$

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

Expression (8) reveals that a household will take self-protection actions until the probability of weighted expected marginal benefits of each self-protection activity equals its expected marginal costs. By re-arranging terms, expression (8) can be further re-written as

$$\frac{\partial EU}{\partial Z^k}: \quad \left(\frac{1}{\lambda}\right)\cdot \underbrace{\sum_n \frac{\partial Q^n}{\partial Z^k}\cdot U^n(.)}_{\text{Expected marginal benefits of self-protection}} = \underbrace{P_z^{k'}}_{\text{Unit cost of self-protection activities}} \tag{8.1}$$

for all $k = k_1, \ldots, k_k$ self-protection activities and where $\lambda = \sum_n Q^n(.)\cdot\frac{\partial U^n}{\partial I}$ is the expected marginal utility of income. Expression (8.1) implies that at the optimum, the unit cost of self-protection, $P_z^{k'}$, is equal to the expected marginal benefits of self-protection multiplied by the expected marginal utility of household income.

Next, the first order condition with respect to the level of self-insurance, T^t, leads to

$$\frac{\partial EU}{\partial T^t}: \quad \underbrace{\sum_n Q^n\cdot\frac{\partial U^n}{\partial H^n}\cdot\frac{\partial H^n}{\partial T^t} - \sum_n Q^n\cdot\frac{\partial L^n}{\partial T^t}\cdot\frac{\partial U^n}{\partial I}}_{\text{Expected marginal benefits of self-insurance}} = \underbrace{P_T^{t'}\cdot\sum_n Q^n\cdot\frac{\partial U^n(.)}{\partial I}}_{\text{Expected marginal costs of self-insurance}} \tag{9}$$

Expression (9) reveals that a household will pursue self-insurance until the expected marginal benefits of each self-insurance activity equals its expected marginal costs. By re-arranging terms, expression (9) can be further re-written as

$$\frac{\partial EU}{\partial T^k}: \quad \left(\frac{1}{\lambda}\right)\cdot \underbrace{\sum_n Q^n\cdot\frac{\partial U^n}{\partial H^n}\frac{\partial H^n}{\partial T^t} - \sum_n Q^n\cdot\frac{\partial L^n}{\partial T^t}\cdot\frac{\partial U^n}{\partial I}}_{\text{Expected marginal benefits of self-insurance}} = \underbrace{P_T^{k'}}_{\text{Unit cost of self-insurance activities}} \tag{9.1}$$

for all $t = t_1, \ldots, t_t$ self-insurance activities and where $\lambda = \sum_n Q^n(.)\cdot\frac{\partial U^n}{\partial I}$ is the expected marginal utility of income. Expression (9.1) implies that at the optimum, the unit cost of self-insurance protection, $P_T^{t'}$, is equal to the expected marginal benefits of self-insurance multiplied by the expected marginal utility of household income.

2.1 Willingness-To-Pay

We derive the household's marginal willingness-to-pay (WTP) measure for risk reductions based on positive changes from three different sources: (1) improvement in household's access to storm protection services of mangroves, M , in terms of increase in area of the forest or decrease in the distance between the mangrove forest and the household; (2) improvement in household's access to *ex-ante* public storm protection programs, G , which can be achieved if the government allocate more resources on embankments or dams; and (3) improvement in household's access to public post-disaster relief and rehabilitation programs, R , through guaranteed access or more availability of such public programs.

A household can derive value for a decrease in the probability of facing storm-inflicted health problems resulting from an exogenous increase in the storm protection services of mangroves. This value can also be regarded as the marginal willingness-to-pay (WTP) of a household for reduction in the likelihood that it faces health-related impacts from a storm through its improved access to mangroves. The storm protection role of mangroves can be captured by the change in area of the nearby forest, change in the distance between the mangrove forest and household, or change in the directional location of the household related to the coast and the mangroves. The marginal WTP for a change in M is solved by first totally differentiating the objective function expressed in (7), setting it equal to zero, substituting for the first-order conditions from (8) and (9), and letting $dG = dR = dC = 0$. By following these sequential steps, the resulting WTP expression becomes

$$-\frac{\partial I}{\partial M} = \frac{1}{\lambda} \cdot \left[\sum_n \frac{\partial Q^n}{\partial M} \cdot U^n \right] \qquad (10)$$

Similarly, the marginal willingness to pay for an increase in public protective spending, G , can be derived by solving the objective function (7) with respect to G , setting it equal to zero, substituting for the first-order conditions from (8) and (9) and considering $dM = dR = dC = 0$.

$$-\frac{\partial I}{\partial G} = \frac{1}{\lambda} \cdot \left[\sum_n \frac{\partial Q^n}{\partial G} \cdot U^n \right] \qquad (11)$$

Lastly, the marginal willingness to pay for an improvement in a household's access to public sponsored health facilities, R, once a damaging storm surge has occurred is

$$-\frac{\partial I}{\partial R}=\frac{1}{\lambda}\cdot\left[-\sum_{n}Q^{n}\cdot\frac{\partial L^{n}}{\partial R}\cdot\frac{\partial U^{n}}{\partial I}+\sum_{n}Q^{n}\cdot\frac{\partial U^{n}}{\partial H^{n}}\cdot\frac{\partial H^{n}}{\partial R}\right] \qquad (12)$$

Expression (12) is derived after substituting for the first-order conditions from (3.8) and (3.9) and letting $dM=dG=dC=0$.

Under equations (10)-(12), the household's marginal willingness-to-pay (MWTP) expressions include unobservable expected marginal utility terms, which complicate empirical estimation. Assuming a spanning set of protection activities and employing rank condition of the matrix, Bresnahan and Dickie (1995) showed that marginal WTP estimates without expected utility terms can be derived in an exogenous risk framework where a household has access to multiple private protection activities. Later, Nastis and Crocker (2007) extended the technique to an endogenous risk framework to estimate parents' valuation of their own and their children's health for a reduction in the ambient level of health risks. In the next section, we show how this same approach can be applied in order to derive the marginal WTP measures considering expressions (7) to (12) of our theoretical model.

2.2 Rank Condition

Following equations (10) and (11), the marginal willingness-to-pay measures contain a total of N unknown utility terms, U^{n}, for $n=1,2,\ldots,N$ health outcomes. However, in expression (3.12), the marginal willingness-to-pay contains a total of $2N$ unknown expected marginal utility ratios of $\frac{\partial U^{n}}{\partial I}$ and $\frac{\partial U^{n}}{\partial H^{n}}$. Our goal is to derive marginal WTP measures that are freed from these unknown utility or ratios of expected marginal utility terms so that it is possible to test our endogenous risk model empirically.

In order to achieve this goal, we start with the expected utility maximization problem as stated under expression (7). For self-protection activities, Z^{k}, there are k first-order conditions following expression (7). As shown in expression (8.1), these k first-order conditions can be considered as a system of k equations in N unknowns since there are N unknown utility terms, U^n. In matrix form, they can be stated as

$$\Theta_Z \cdot \Lambda_1 = P_Z^k \qquad (13)$$

where $P_Z^k = \left(P_Z^{k_1}, P_Z^{k_2}, \mathrm{K}, P_Z^{k_k}\right)$, Λ_1 is the matrix containing the unknown utility terms, and Θ_Z is another matrix comprising the marginal products of Z^k.[4]

A unique solution exists for the first-order conditions of k self-protection activities if and only if the rank of the matrix Θ_Z is $R\left[\Theta_Z\right] = N$, which requires that $k \geq N$.[5] Then, the unknown utility terms can be recovered as,

$$\Lambda = \left[\Theta_Z^{-1}\right]' \cdot P_z^k \qquad (14)$$

Conversely, for self-insurance activities, the t first-order conditions can be expressed as t equations in $2N$ unknowns since there are N unknown marginal expected utility terms, $\frac{\partial U^n}{\partial I}$, and N unknown marginal expected utility terms, $\frac{\partial U^n}{\partial H^n}$.

Following Bresnahan and Dickie (1995) again, the first-order conditions for self-insurance, T^t, can be stated as

$$\Theta_T \cdot \Lambda_2 = P_T^t \qquad (15)$$

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[4] The full derivation of expression (13) is shown in Appendix 1.

[5] This condition is suggested by Bresnahan and Dickie (1995) in their paper regarding the influence of household activities that offer protection against health hazards where risk is treated as exogenous. Nastis and Crocker (2007) adopted the same condition under their endogenous risk framework in estimating parent's valuation of their own and their children's health. According to Bresnahan and Dickie (1995), the rank condition requires that the number of nonlinearly related health protection actions to reduce health risks equals the number of health outcomes. If the requirement holds, then the choices from the spanning set of protective actions suffice to reveal preferences. Considering this perspective, Bresnahan and Dickie (1995) further suggest that the pervasiveness of markets or of substitution opportunities, rather than features of the technology like separability, determine whether willingness to pay is observed independently of preferences. Using the same condition but under a different setup, Nastis and Crocker (2007) added that the effectiveness of each protection activity exhibits a strictly decreasing marginal product with respect to the intensity of use of the activity. For example, intensity may be the temperature at which a meal is cooked. Higher temperatures kill more harmful food bacteria but at a decreasing rate.

where $P_T^t = \left(P_T^{t_1}, P_T^{t_2}, \ldots, P_T^{t_t}\right)$, Λ_2 is the matrix containing the expected marginal utility terms, and Θ_T is another matrix comprising the marginal products of T^t with respect to health outcomes, H^n, and the realized costs, L^n, associated with the health outcomes.

Again, a unique solution exists for the first-order conditions of t self-insurance activities if and only if the rank of the matrix Θ_T is $R\left[\Theta_T\right] = 2N$, which requires that $t \geq 2N$.[6] Then, the unknown expected marginal utility terms can be recovered as

$$\Lambda_2 = \left[\Theta_T^{-1}\right]' \cdot P_T^t \qquad (16)$$

Using (13)-(16), ex-ante marginal willingness to pay expressions (10)-(12) can be expressed as

$$\begin{aligned} -\frac{\partial I}{\partial M} &= \Theta_M \cdot \Lambda_1 \\ -\frac{\partial I}{\partial G} &= \Theta_G \cdot \Lambda_1 \\ -\frac{\partial I}{\partial R} &= \Theta_R \cdot \Lambda_2 \end{aligned} \qquad (17)$$

where Θ_M is the matrix of marginal products of the storm protection role of mangroves, M, Θ_R is a matrix of the marginal products of a household's access to ex-post public health facilities as a form of disaster relief, R, and Θ_G is a matrix containing the marginal products of ex-ante public protective programs, G.

Substituting for Λ_1 and Λ_2 in expressions under equation (17) can recover the marginal WTPs without the utility terms and the expected marginal utility ratios:

$$-\frac{\partial I}{\partial M} = \Theta_M \cdot \left[\Theta_{Z^k}^{-1}\right]' \cdot P_z^k \qquad (18)$$

$$-\frac{\partial I}{\partial G} = \Theta_G \cdot \left[\Theta_{Z^k}^{-1}\right]' \cdot P_Z^k \qquad (19)$$

$$-\frac{\partial I}{\partial R} = \Theta_R \cdot \left[\Theta_{T^t}^{-1}\right]' \cdot P_T^t \qquad (20)$$

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[6] *Ibid.*

For the above expressions (18-20) to hold, a separability assumption developed by Quiggin (1992; 2002) is not necessary to obtain the results, nor are the sufficient conditions listed in Corollary 1 suggested by Shogren and Crocker (1991).[7] In addition, expressions (18)-(20) show ex-ante marginal WTPs as a function of prices and technological parameters only, i.e., they are independent of preferences.

Equation (18) says that the ex-ante marginal willingness-to-pay for an increase in the storm protection role of mangroves, M, for household health depends on the term Θ_M, which is the vector of parameters capturing the ability of the mangroves to reduce the probability of facing health-related risks, Q^n, for a major storm in n states of health, multiplied by another term $\left[\Theta_{Z^k}^{-1}\right]' \cdot P_Z^k$, which is the marginal change in self-protection expenditures. The latter term is based on the multiplication between the vector of parameters capturing the influence of k self-protection activities on the probability of facing health-related risks $\left(\sum_{n=1}^{N} \frac{\partial Q^n}{\partial Z^k}\right)$ for a damaging storm event in all possible states of nature, and the price of each self-protection activity, P_{ij}^k, where $P_z^k = P_z^{k_1}, P_z^{k_2}, \ldots, P_z^{k_k}$.

Therefore, equation (18) shows that the ex-ante marginal willingness-to-pay for an increase in the storm protection role of mangroves, M, requires information about the prices and technological parameters based on the role of self-protection, Z^k. It does not require information on the influence of self-protection, Z^k, on household preferences, U^n.

Likewise, equation (19) shows that the ex-ante marginal willingness-to-pay for an improvement in household access to ex-ante government protective spending, G, depends on the term Θ_G, which is the vector of parameters demonstrating the influence of ex-ante public programs G in

[7] The separability assumption derived by Quiggin (1992, 2002) shows that smoothness of risk reduction technologies, as implied by $k \geq N$ and $T \geq 2N$ in this model, is the sufficient condition for the separation of risk attitudes from willingness-to-pay for ambient risk reduction. Condition (c) of Corollary 1 of Shogren and Crocker (1991, p.8) states that, "utility terms will not appear in ex ante willingness to pay expressions for endogenous risk changes if and only if states are discrete, ex post severity is independent of ex ante self-protection, and a unique self-protection activity exists that exerts no cross-partial effects across states."

reducing the probability of a household facing health-related problems Q^n in all possible states of nature, multiplied by $\left[\Theta_{Z^k}^{-1}\right]' \cdot P_Z^k$, which is the marginal change in self-protection expenditures.

Equation (20) reveals that the ex-ante marginal willingness-to-pay for an improvement in household access to public health facilities , R, depends on the term Θ_R, which is the vector of parameters representing the role of public health facilities R in reducing household realized cost L^n and improving health outcome H^n , multiplied by another term $\left[\Theta_{T^t}^{-1}\right]' \cdot P_T^t$, which is the marginal change in self-insurance expenditures.

Hence, given the model assumptions, equations (18)-(20) reveal the following results.

RESULT 1: For the storm protection role of mangroves, estimation of WTP requires information (1) on the prices or total expenditures of self-protection activities; (2) on the technological parameters that capture the role of self-protection activities in reducing the probability of facing storm-inflicted health risks; and (3) on technological parameters that reveal the storm protection role of mangroves in influencing the probability of a household facing health-related risks from a major storm event.

RESULT 2: For ex-ante public programs, estimation of WTP requires information (1) on the prices or total expenditures of self-protection activities; (2) on the technological parameters that capture the role of self-protection activities in reducing the probability of facing storm-inflicted health risks; and (3) on technological parameters that reveal the influence of ex-ante public programs in reducing the probability of a household facing any storm-related health problems.

RESULT 3: For public health facilities, estimation of WTP requires information (1) on the prices or total expenditures of self-insurance activities; (2) on the technological parameters that capture the role of public sponsored health facilities in reducing the realized health-related costs; and (3) on technological parameters that shows the possible influence of public sponsored health facilities in improving the health outcomes for a household exposed to a major storm.

In all the results, the WTPs can be expressed independently of preferences.

3. Empirical Analysis

We assumed in our theoretical model that health protection activities indirectly contribute to health outcomes by reducing the severity and probability of sickness and injury. Following the econometric specification suggested by Just and Pope (1978), it is possible to perform regression estimations based on the linear representations of the key variables. [8]

The linear representation of the probability of facing health problems, Q^n, as a result of being exposed to a damaging storm depends on the household's total self-protection expenditure, $P_Z^k \cdot Z^k$, on the vector of characteristics capturing the storm protection role of mangroves, M, on the ex-ante public programs, G, on the vector of characteristics representing a severe storm event, C, and on the socio-economic characteristics and the location of the household, ψ. If the state-dependent probabilities are mapped to the unit interval, then the linear representation can be represented as

$$Q^{n^*} = \delta_1 + \delta_2^{'} \cdot \left(P_Z^k \cdot Z^k\right) + \delta_3 \cdot M + \delta_4 \cdot G + \delta_5 \cdot C + \delta_6 \cdot \psi + \varepsilon \qquad (21)$$

In order to estimate the state-dependent realized cost, L^n, associated with any kind of health-related risk, a reduced form linear specification is suggested following Saha et al. (1997). This reduced form linear representation of the realized costs depends on the total self-insurance expenditure, $P_T^t \cdot T^t$, and on the socio-economic characteristics and the location of the household, ψ.

$$L^{n^*} = \beta_1 + \beta_2^{'} \cdot \left(P_T^t \cdot T^t\right) + \beta_3 \cdot \psi + \eta \qquad (22)$$

where $\eta \equiv \varepsilon - B \cdot e$ is the heteroscadastic error term with $\varepsilon\left(0,1\right)$, $e:\ \left(\mu,1\right)$, and

[8] By considering risk rather than health outcomes, Just and Pope (1978) demonstrated that econometric estimates based on common specifications are uninformative with respect to risk since risk is not a direct input in the production function as it only indirectly affects output. In the paper, they showed that common specifications invalidate a number of postulates one would expect to hold for a production function with risk as an input. Considering this finding, they instead proposed a specification where some function of the inputs perturbs the effects of the disturbance term. The function along with the disturbance term appears additively in the production function. Nastis and Crocker (2007) suggested the same econometric specification to derive reduced-form linear equations of the main variables influencing the outcomes. Detail of the exposition can be found under Appendix 2.

$$B = \varphi_1 + \varphi_2 \cdot R \tag{22.1}$$

The heteroscadastic error term, η, depends on the gains of the health costs in terms of benefits, B, received from access to public sponsored health facilities, R. The qualitative effect of exogenous change in access to public health facilities is represented by φ_2.

Lastly, the linear representation of the state-dependent reduced-form health technology of the household health depends on the self-protection expenditure, $P_T^t \cdot T^t$, on the access to public sponsored health facilities, R, and on the socio-economic characteristics and location of the household, ψ.

$$H^{n^*} = \gamma_1 + \gamma_2' \cdot \left(P_T^t \cdot T^t \right) + \gamma_3 \cdot R + \gamma_4 \cdot \psi + \omega \tag{23}$$

All the reduced-form equations (21)-(23) follow from the econometric specification suggested by Just and Pope (1978) and later applied by Saha et al. (1997) and Nastis and Crocker (2007).

3.1 Estimation strategies

For this paper, equations (21) to (23) are applied empirically to a case study of private defensive expenditure allocation to reduce storm-inflicted health risks from thirty-five (35) villages comprising 500 households in southwest coastal areas of Bangladesh. These areas were struck by a severe storm, known as Cyclone Sidr, on 15 November 2007. The case study area is divided into two categories. The first category is defined as the protected areas that are located behind the mangrove forest and in a clockwise direction from the track of Cyclone Sidr. The second category is defined as the non-protected areas that are not located behind the mangrove forest and are either in a clockwise or counter-clockwise direction from the track of the storm.

To accommodate limitations of the available data from the household survey, some empirical modifications are applied following the reduced form equations (21) through (23). The probability of facing adverse health outcomes as a result of the storm, Q^n, corresponds to the survey question that asks the respondent whether he or she thinks someone in the household is sick or injured because of Cyclone Sidr.[9] That is, equation (21) can be estimated using either probit or logit estimation. Realized costs, L^n, represented by equations (22) and (22.1) can be identified based on medical expenditures and days lost associated with injury inflicted by storm surges from Cyclone Sidr. This can be employed based on either simple ordinary least squares (OLS) estimation or Tobit estimation. The latter estimation can be considered if the realized cost data turn out to be censored in nature. Lastly, household health status, H^n, under equation (23) is linked to the survey questions regarding whether any member of the household has faced health issues such as injury, diarrhea, typhoid or severe fever, jaundice, malaria, pneumonia, skin disease, etc., as a result of being exposed to Cyclone Sidr. Again, probit or logit estimation can be applied for each health outcome.

Putting together the reduced form equations and estimating them is both consistent and efficient. The identification requirements are met since there are more regressors than dependent variables and there is at least one regressor that is not included in the other regression equations. Measures of the household's marginal willingness-to-pay for an improvement in health can be derived from these estimates. From equation (18), the household's marginal willingness-to-pay for risk reduction in health as a result of an increase in the storm protection role of mangroves is equivalent to

$$\begin{aligned} -\frac{\partial I}{\partial M} &= \Theta_M \cdot \left[\Theta_{Z^k}^{-1}\right]' \cdot P_Z^k \\ &= \delta_3 \cdot \delta_2 \cdot P_Z^k \end{aligned} \tag{24}$$

From equation (19), the household's marginal willingness-to-pay for risk reduction in health as a result of an increase in access to publicly constructed embankments is equivalent to

$$\begin{aligned} -\frac{\partial I}{\partial G} &= \Theta_G \cdot \left[\Theta_{Z^k}^{-1}\right]' \cdot P_Z^k \\ &= \delta_4 \cdot \delta_2 \cdot P_Z^k \end{aligned} \tag{25}$$

[9] The ideal situation would have been to get subjective probability data from each respondent of the household by directly asking question based on a contingent valuation method (CVM). But as the household survey was conducted with the revealed preference method, gathering subjective probability data on the household's health status as a result of the household's exposure to a damaging future storm event cannot be inferred.

Last, from equation (20), the household's marginal willingness-to-pay for risk reduction in health as a result of an increase in access to public post-disaster relief and rehabilitation programs is equal to

$$\begin{aligned} -\frac{\partial I}{\partial R} &= \Theta_R \cdot \left[\Theta_{T^t}^{-1}\right] \cdot P_T^t \\ &= \begin{bmatrix} \varphi_2 & \gamma_3 \end{bmatrix} \cdot \begin{bmatrix} \beta_2 \\ \gamma_2 \end{bmatrix} \cdot P_T^t \end{aligned} \tag{26}$$

4. Case Study Area and the Survey

4.1 Study Area

Meteorologists and researchers consider Cyclone Sidr, which made landfall on the south-western coastal areas of Bangladesh on 15th November 2007 to be the most severe storm event to strike Bangladesh recently. It had a diameter of nearly 1000 km and sustained wind speed up to 240 km per hour accompanied by a maximum tidal surge height of 5.2 meters (or around 17 feet) in some affected areas (GOB, 2008). Although early warning systems contributed to successful evacuation of the coastal people which resulted in fewer human casualties, there was extensive damage to houses, live-stock, crops, and trees. In addition to the government-assisted early warning systems installed under the cyclone-preparedness program (CPP), one of the most significant factors to contribute to reduced loss of life and property in coastal areas was the Sundarban, the world's largest mangrove forest (UNESCO and WCMC, 2008; Iftekhar and Saenger, 2008). [10]

Based on the location of Sundarban mangrove forest and the track of the Cyclone Sidr, we adopted the following procedure to designate and demarcate the study area: First, we selected an area located on the southwest coast of Bangladesh that falls under the high cyclone risk zone.[11] Applying Geographic Information Systems (GIS), we followed the track of the Cyclone Sidr and the position of the Sundarban mangrove forest in order to identify the areas that would be

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

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

suitable for the analysis (see Figure1). Using GIS, we identified both the protected (P) and the non-protected (NP) coastal areas. We define as "protected" (P) any area that is located behind the Sundarban mangrove forest and is located in a clockwise direction from Cyclone Sidr. Conversely, we define as "non-protected" (NP) any area that is not located behind the Sundarban mangrove forest and is in either a clockwise or counter-clockwise direction from Cyclone Sidr. We then applied 'random area sampling' to select the unions that fall under protected (P) and non-protected (NP) areas.[12] The unions were chosen based on their location at an equal distance on either side along the track of Cyclone Sidr.

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

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

[12] 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.

4.2 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, males comprised 84.1% of the respondents, whereas, for non-protected areas, they accounted for 71.8%. The average age of the respondents was around 42 to 43 years old. 52.1% of the respondents in the protected areas had completed primary school education, while it was 45.5% in the non-protected areas. Less than 30% had secondary school education in both areas. The average household size was five members in the protected areas, and six in the non-protected areas, which is approximately the national average household size in Bangladesh. Nearly all the respondents (more than 90%) had been living in the same village since birth.

Day labor is the most common occupation (36%) among households in the protected areas, and agriculture (40%) in non-protected areas. Business activities come second as an occupation in both case study areas representing 13-16% of the respondents. In both areas, most of the households own the houses they live in. Regarding the structure of the house, most house walls are made of wood while the roofs are made of tin or corrugated iron sheet. More than 20 percent of the houses in non-protected areas are two storied; whereas, in the protected areas, less than 10 percent of the total houses are two storied. Less than 50 percent of the households in both study areas made any changes to their dwellings to reduce exposure to storm surge-inflicted damages although more than half believe that their houses face some storm damage risk due to their location at low elevations. Less than one third of the households have access to electricity while access to a cell phone use is close to 50%. In protected areas, most households obtain drinking water from ponds, canals, rivers, and preserved rain water, and in the non-protected areas, households rely on tube-wells, ponds, canals, and rivers.

The average annual household income in the protected area was US $816 and US $858 in the non-protected area. However, the average market value of assets (excluding house, land and pond) was nearly double for households in the non-protected areas (US $4,609) compared to households in the protected areas (US $2,802). The majority of the households that sustained damages from Cyclone Sidr have an average yearly income above US $1,450. In the survey, self-protection expenditures were designated and measured by adding the approximate amount that a household invested to pursue each self-protection action. This information was based on a follow-up question to those households who responded affirmatively to the earlier question regarding whether they had pursued any self-protection actions to avoid Cyclone Sidr-inflicted damages to their property. The average amount spent on self-protection in the protected area was US $1,825 per household; whereas, in the non-protected areas it was US $768 per household.

On the other hand, we could not directly determine the level of self-insurance expenditures due to data limitations. Instead, in the survey, self-insurance expenditures are proxied by taking into account the medical expenditures associated with the Cyclone Sidr-inflicted health damages and the approximate nominal value of the remittances received by households in order to deal with storm-inflicted property damages.[13] Based on the results from our survey, the average expenditure on self-insurance in the protected area was US $93 per household, and in the non-protected area, US $407 per household. However, not all the households surveyed engaged in self-protection and self-insurance. Our data reveals that among the households, only 22% participated in self-protection and 23% households in self-insurance.

4.3 Health Data

Table 3 summarizes households' health-related problems as a result of Cyclone Sidr. Out of 500 households, total responses for the entire study area are: 241 injuries, 242 cases of diarrhea, 235 of typhoid, 194 of jaundice, 181 of malaria, 184 of pneumonia, 175 of skin disease, and 144 of other diseases.

Results show that households from the non-protected area are more vulnerable to storm-inflicted adverse health outcomes than households from the protected area. In addition, the average amount of money spent on medication for most Cyclone Sidr inflicted diseases is higher for the households from the non-protected area. In general, findings from descriptive statistics suggest that households that are located in the non-protected area are more exposed to adverse health

[13] Since studies by Yang and Choi (2007) and Clarke and Wallsten (2003) provide empirical evidence that remittances can be a vital source of income for people whose other forms of livelihood may have been destroyed by the natural disasters, we assume that both medical expenditures and the remittance received to deal with storm damages can be used as proxies for self-insurance.

outcomes from major storms. Alternatively, this indicates the possible natural storm protection role of mangroves in reducing morbidity.

5. Estimation Results

5.1 Probability of facing Adverse Health Impacts

Table 4 shows the summary statistics based on the means and standard deviations of the explanatory variables that are used for the regression analyses. Results of the regression estimates are based on the full sample of the household survey. Table 5 shows the probit estimation of the reduced form equation (18), which represents the probability of facing adverse health outcomes as a result of a household being exposed to a major storm event. The table reports four regression specifications starting with a basic model (regression 1), which include as explanatory variables damages inflicted by Cyclone Sidr, pre-Cyclone Sidr household income, distance from the coast, asset holdings based on ownership of homestead, cropland, and pond area, and other socio-economic characteristics. For the other regression specifications, additional controls are progressively added starting with mangroves characteristics (regression 2), then, public programs (regression 3), and finally, the storm characteristics of Cyclone Sidr (regression 4).

The probit estimation is based on the survey question where the respondents were asked whether someone in the household had become sick or injured due to Cyclone Sidr. Although there are 479 categorical responses to the status of health question, the total number of observations is small with only 107 households invested in self-protection. However, in spite of the small number of observations due to lack of data points, the overall goodness-of-fit test based on the likelihood ratio (LR) stat shows that the model is significant at the 5% level for all regression specifications.

The estimation results suggest that a household that spends more on self-protection expenditures are also likely to face more health problems. Although not highly significant, this conflicting result might indicate that either there is inefficiency associated with the way the households reallocated their resources for self-protection or they are simply unlucky by falling directly into the path of Cyclone Sidr. Regarding the influence of income, the log and the square log of post-

Cyclone Sidr income bear the negative and positive signs respectively, though they are not statistically significant under all regression specifications. This result might indicate that the probability of a household member becoming sick or injured from a major storm event has a U-shaped relationship with income, initially decreasing, but then increasing. That is, both the low-income and high-income households are more vulnerable to storm-inflicted health-related risks compared to the middle-income households.

For low-income households, their vulnerability to storm-inflicted adverse health outcomes is exacerbated by various factors such as low wealth and income; lack of access to resources to cope with or adapt to natural disasters; settlement in desirable but more dangerous sites near coasts and floodplains that are frequently exposed to storm and flood events; lack of access to information and knowledge; poor housing quality; entitlement failure; resource dependency; low levels of community organization; lack of access to political power and representation; and beliefs and customs (Blaikie et al., 1994; Adger, 1999; Davis and Hall, 1999; Cutter et al., 2000; Rashid, 2000; Adger et al. 2003; McMichael, 2003; Few, 2007). For high-income households, it is possible that they might become more vulnerable if their living conditions significantly differ between pre- and post-disaster periods, which might make their self-protection strategies to protect their health against major storms difficult to implement compared to a middle-income household. In fact, some empirical studies reveal that non-poor individuals can be more vulnerable if they face large consumption changes as a result of their exposure to adverse shocks through economic crises and natural disasters (Glewwe and Hall, 1998; Dercon and Krishanan, 2000; Christiaensen and Subbarao, 2005; Dercon, 2005). However, studies also show that these richer individuals do not suddenly become poor since they can rely on their large asset holdings and higher income to address such adverse shocks (Dercon and Krishanan, 2000; Christiaensen and Subbarao, 2005).

Among other socio-economic characteristics, probability of experiencing adverse health outcomes due to a storm event is more likely to be high for households having more female members and children. This result is also well documented in contemporary literature which shows that female members and children are more at risk to disasters in addition to the ageing population of the community (Blaike et al., 1994; Fordham, 1998; Bourque et al., 2006).

However, the influence of the number of children on households facing health-related risks as a result of a major storm is not statistically significant under all regression specifications. Although not significant, results also reveal that the probability of facing storm-inflicted adverse health impacts is U-shaped in age of the head of a household. This result is not surprising considering the existing literature which shows that elderly individuals are more vulnerable to natural disasters (Phifer et al., 1988; Balikie et al., 1994; Hajat et al., 2005; Bourque et al., 2006).

With regard to the role of mangroves, households that fall into the non-protected area are more likely to become sick or injured as a result of a major storm event. This finding reaffirms results from Das and Vincent (2009) where they applied damage function approach on secondary data of 1999 Super Cyclone in Orissa, India to show possible influence of mangroves on saving lives. The coefficient of distance between the mangrove forest and the union where the household's village is located remains positive and significant throughout all regression specifications. This again suggests that close proximity to a natural storm protection barrier may reduce the probability of facing storm-inflicted health problems. However, results from our study also show a household located to the south and southwest direction relative to the coast and the mangrove forest are likely to face more health-related risks compared to a household that is oriented differently. Since directional location relative to the Sundarban mangrove forest may determine how well the household is protected by this natural barrier, a household that faces in less favorable direction may be compelled to take more self-protection actions. This might reduce its vulnerability of facing more health related risks from a major storm.

Whether or not a household is protected by an embankment appears to have no statistically significant impact on whether it is less likely to face adverse health outcomes from major storms. Regarding storm characteristics, households that fall into counter-clockwise direction of the Cyclone Sidr are more likely to experience storm-inflicted health problems. However, regression 4 shows that none of the other storm characteristic variables are strongly significant in the model. Since one cannot predict the track of a future storm event irrespective of a household's location and hence its potential impacts on health of the household members, these results should be taken with caution.

5.2 Realized Medical Expenses from Storm-inflicted Adverse Health Outcomes

Based on expressions (22)-(22.1), Table 6 reports the simple ordinary-least-squares (OLS) estimation on the realized medical costs for a household as a result of Cyclone Sidr. Considering the highly skewed distributions of the data, the explanatory variables such as self-insurance expenditures and amount of total assets holding for the households were all transformed into logarithmic form. Starting with the initial model comprising socio-economic characteristics of the household, regression results show that the households who spend more on self-insurance are also the ones with higher medical expenditures. Considering the definition and types of self-insurance of the theoretical model, i.e. mitigation activities and treatments, this result confirms that medical expenditures are an important determinant of households' choice for self-insurance in order to reduce the severity of its health consequences when exposed to a major storm event. This variable remains positive and highly significant when ex-post public programs are progressively added to the initial model.

Since self-insurance actions take place once a disaster occurs, we include a household's income after the Cyclone Sidr event for our regression analysis. This seems logical considering that a household's income can vary significantly between what it was *before* and *after* a major storm event. For instance, while a household's pre-cyclone income might have come from subsistence agriculture, its post-cyclone income might come from day labor because the agriculture crops have been destroyed as a result of the cyclone. Our results show that there is low correlation either between the log of pre-income and log of post-income or between the square log of pre-income and the square log of post-income. These correlation outcomes along with the t-tests confirm the difference between the sources of income before and after the Cyclone Sidr event.

Regarding the influence of income, results show that the medical expenditure as a result of storm-inflicted health problems has an inverted U-shaped relationship with post-Cyclone Sidr income, initially increasing, but then declining (see Figure 2). Both the log and square log of post-Cyclone Sidr income remain highly significant bearing positive and negative signs respectively. This result might imply that middle-income households spend more on and allocate more for medical expenditures compared to low-and high-income households. This result suggests that because the middle-income households do not have the same access to public sponsored health facilities as the poor (who are the primary recipients of aid) after a storm event, they invest more on medical expenditures. However, even though the middle-income households do take these financial steps in order to respond to a storm event, they are unlike high-income households that often own expensive storm-resistant homes or have medical insurance for any storm-related health problems. This finding from the household survey is consistent with what Kellenberg and Mobarak (2008) discovered in the relationship between aggregate income and disaster damages at country level using a country-year panel data set. Their results reveal existence of a non-monotonic Kuznets inverted U-relationship where they argue that such a non-linear relationship between aggregate incomes and disaster damages, where the risks first increases with income before they decrease, is a possibility if we consider behavioral changes among individual at the micro level in response to their increasing income. For example, these behavioral changes can be in terms of residents' choice to locate in desirable but more dangerous sites near coasts and floodplains which are frequently exposed to storm and flood events.

Among other socio-economic controls, the medical expenditure is high for younger heads of the households as well as for more female members' households though these relationships are not significant under both regression specifications. Interestingly, results also show that households with more children incur lower realized medical costs. This counterintuitive result might be partly explained by a relatively richer household's choice to increase its production of child services through child quality by increasing its resource investment in existing children compared to a lower-income household (Becker and Lewis, 1973; De Tray, 1974; Willis, 1987; Becker, 1991).

Regarding ex-post public programs, results reveal that households with access to public post-disaster rehabilitation programs spend less on medical expenditures. Although not statistically significant, this result might imply that access to ex-post public disaster rehabilitation programs act as substitutes for private medical expenditures (Rask & Rask, 2000). However, households' access to public disaster relief program turns out to have complementary relationship with private medical expenditures. [14]

[14] Regression specification error test (RESET) suggests that there is no omitted variable bias after inclusion of these ex-post public programs.

5.3 Probit Model for Experiencing Storm-inflicted Injury

Table 7 reports the probit model for experiencing storm-inflicted injury considering equation (23). Contrary to the previous findings, estimation results reveal that households who spend more on self-insurance expenditures are more likely to face a storm-inflicted injury. This result confirms that storm-inflicted injury is an important determinant for a household to allocate a significant portion in self-insurance in terms of ex-post mitigation activities and treatments. Regarding influence of income, the log and square log of post-Cyclone Sidr income reveal negative and positive signs respectively though they are not statistically significant in all regression specifications. Like the previous analysis on the probit estimation on health-risks, the probability of a household member with a storm-inflicted injury has a U-shaped relationship with income, initially declining, but then increasing. This might suggest that the low-income and high-income households are more vulnerable to an injury as a result of a major storm event compared to the middle-income households.

In the first regression specification without inclusion of the public programs, regression estimates show that coefficient of ownership of homestead, cropland, and pond area – a form of assets holding – is positive and significant at 5% level. However, when the public programs variables such as access to relief and rehabilitation programs are added to the model, the coefficient becomes statistically insignificant. Among other socio-economic variables, results show that the probability of a household experiencing storm-inflicted injury has a U-shaped relationship with age, with the relationship between injury and age initially declining, but then increasing. Although not significant, this result implies that an older head of a household is more likely to suffer health problems from major storms compared to a younger head of a household. In other words, the likelihood of suffering from storm-inflicted injury increases with age. Results also reveal that the likelihood of facing injuries due to a storm event is higher for households having fewer female and child inhabitants though these findings are not significant in both regression specifications.

Regarding public programs, households that received government assistance through public disaster relief programs are more likely the ones who faced injuries due to a major storm. This finding is logically consistent with the fact that the government usually targets those households that are deemed most vulnerable to natural disasters. In addition, results also show that the probability of a household experiencing storm-inflicted injury is more likely to decrease if it has access to public sponsored rehabilitation programs. Since access to these programs indirectly affects the well-being of a household's consumption smoothing behavior through the provision of construction materials for housing and seeds, fertilizers, and fingerlings for farming, it is possible that such programs are targeted for those households that had incurred significant storm-inflicted property damages but were physically more able to recuperate those damages through their productive activities.

5.4 Marginal Willingness-to-pay

Following expressions (24)-(26), Table 8 reveals marginal willingness-to-pays (MWTPs) for reduction in health-related risks. These MWTPs are generated through changes in three key variables: (i) households' living in close proximity to mangroves; (ii) households' access to publicly constructed embankments; and (iii) households' access to public post-disaster relief and rehabilitation programs.

To calculate MWTPs, values of the marginal effects that are suggested in expressions (24) to (26), are obtained based on econometric estimations of (21) to (23). These values are then multiplied with the average nominal value of households' self-protection and self-insurance expenditures in order to derive MWTPs per household. Results reveal that a household MWTP is highest for a greater storm protection role of mangroves, which is equivalent to Taka 3,372.23 or US $ 48.87. For the entire study area, approximate values of the MWTPs could be computed by multiplying the MWTP per household with the entire population in the study area which is around 3.69 million at the time of the survey.

Since the descriptive analyses of the study shows that storm-inflicted health-related problems are lower in the mangrove protected areas, it is not surprising to find the higher marginal willingness to pay value for reducing storm-inflicted health-related risks due to greater storm protection role of mangroves. This finding suggests that households reveal possible storm protection role of mangroves based on their previous encounters with major storms and hence they are willing to pay more for better storm protection services from mangroves. For public programs, we argue that households prefer access to publicly constructed embankments over ex-post disaster relief programs because they put more weight on reducing the likelihood rather than the severity to storm-inflicted health-related problems.

6. Conclusion and Policy Recommendations

Recent climate change reports reveal that while severity of cyclones caused by climate change is happening on a global scale, coastal areas with high population density and abject poverty might experience more health-related impacts in terms of increasing mortality and morbidity due to future cyclone and storm surge events. Facing such adverse health outcomes from major storms, a household might be forced to allocate its resources in private storm protection activities despite its limited capacity and access to public storm protective programs and a possible natural storm protection barrier such as the mangrove forest.

Regarding private storm protection actions, the study focuses on two types of actions: (1) self-protection, a form of prevention, where the households' private investments are made to reduce the likelihood (probability or risk) that a household will face adverse health impacts from a major storm; and (2) self-insurance, a form of adaptation, where households' private expenditures in terms of mitigation activities and treatments are used to reduce the adverse impacts, or severity, of any such health outcomes if they occur. However, existing literature reveals that the level of private storm protection investment might differ among households because of the expectation of public protective programs, and location of the household relative to the coast and natural coastal barriers. Considering these factors, the main objective of this paper is to see whether private response to reduce health impacts from future cyclone-induced storm surges is significantly lower in areas where households have greater access to public programs and live in close proximity to mangroves. Findings from this study have policy implications regarding how disaster relief and rehabilitation aid should be allocated more efficiently to best serve the affected households.

To fulfill the research objective, this paper demonstrates a theoretical model that combines household health production function with an endogenous risk framework where households choose self-protection and self-insurance to reduce the likelihood as well as the severity of its storm-inflicted adverse health outcomes. Given certain assumptions, results from the model reveal possible estimation methods to derive households' ex-ante marginal willingness to pay for reducing health risks due to an increase in public programs and the greater storm protection role of mangroves. One of the novel contributions of the paper in the health and the endogenous risk literature is to show that these marginal willingness-to-pay measures can be derived without the expected utility terms, i.e., they are function of only prices and technological parameters. As a result, the theoretical model can be tested empirically tested to measure the marginal willingness-to-pay estimates using household survey data. By introducing this method which is different from the damage function approach taken by Badola and Hussein (2005), Barbier (2007), and Das and Vincent (2009), this paper also contributes to literature about the storm protection role of mangroves in order to determine whether mangrove forests provide protection to lives that are at risk from severe and damaging storm events.

For the empirical analysis, the household survey data is based on a case study comprising 500 households among 35 villages in the southwest coastal areas of Bangladesh focusing on the aftermath of Cyclone Sidr, which made landfall on November 15, 2007. The case study area is divided into two categories. The first category is defined as the protected areas that are located behind the mangrove forest but fall into clockwise direction from the track of the Cyclone Sidr. The second category is defined as the non-protected areas that are not located behind the mangrove forest and fall either clockwise or counterclockwise direction from the track of the Cyclone Sidr.

Descriptive statistics and empirical results on the full sample of the case study area reveal: (i) households that spend more on self-protection are also likely to face more health related problems. This confounding result might indicate that either there is inefficiency regarding the ways the households reallocate their resources for self-protection or they are simply unlucky by falling directly into the path of Cyclone Sidr; (ii) there is a U-shaped relationship between the probability of a household member facing storm-inflicted health problems and its income. This might imply that the low-income and higher-income households are more vulnerable to storm-inflicted health risks compared to the middle-income households; (iii) results confirm the possible influence of mangroves in reducing storm-inflicted injuries and diseases; (iv) medical expenditures due to storm-inflicted health problems are an important determinant of households' choice for self-insurance; (v) there is an inverted U-shaped relationship between the post-Cyclone Sidr income and medical expenditures due to storm-inflicted health problems. This finding might suggests that once a household member is exposed to a storm-inflicted health problem, the middle-income households invests more in medical expenses compared to low-income and higher-income households; (vi) for publicly constructed embankments, results show inconclusive evidence about whether the probability of experiencing more health-risks from a major storm is lower for those households that live inside the embankment; (vii) for ex-post public programs, households that received government assistance through public disaster relief programs are more likely to incur storm-inflicted injuries. This finding is logically consistent with the fact that the government usually targets those households that are deemed most vulnerable to natural disasters; and (viii) demographic characterizes such as respondent's age, number of females and children have considerable influence on the likelihood of a household facing storm-inflicted health risks but not on medical expenditures to storm-inflicted injuries.

Regarding marginal willingness to pay measures for reducing health risks, results reveal that households are willing to pay the highest for greater storm protection role of mangroves. This is followed by households' marginal willingness to pay for ex-ante public programs such as access to embankments and ex-post public programs such as access to public sponsored disaster relief programs. These results are not surprising considering the descriptive analyses of the study which show that storm-inflicted health-related problems are lower in the mangrove protected areas. It seems from the marginal willingness to pay estimates, households acknowledge this fact and hence they are willing to pay more for better storm protection services from mangroves. For public programs, we argue that households prefer access to ex-ante embankments over ex-post disaster relief programs because they put more weight on reducing the likelihood rather than the severity to storm-inflicted health-related problems.

Based on the households' preference for more ex-ante storm protection measures, such as publicly constructed embankments and the presence of a natural barrier, this paper suggests that the government should collaborate with the local stakeholders in order to come up with an efficient tree plantation program along the coast by classifying trees other than mangroves that can play a significant storm protection role in saving lives and reducing storm-inflicted health-related problems. Since a post Tsunami analysis in Sri Lanka by Feagin et al. (2009) reveals that plantation of mangroves around the vulnerable coastline in inappropriate environmental settings might reduce long-term ecological sustainability in the targeted coastal areas, it is appropriate for the government to take all the factors into account before implementing such project. Moreover, the government should also consider the combination of having both mangroves and embankments in order to protect the latter from breaches as a result of a major storm event. Such a program might have the capacity to save more lives and reduce other storm-inflicted health-related risks. However, considering the uncertainties surrounding the extent of the storm protection role of mangroves from tidal waves that are too extreme in magnitude (Montgomery, 2006; Braatz et al., 2007; Forbes and Broadhead, 2007; Alongi, 2008; Cochard et al., 2008) and the government's own capacity to protect the coastal communities from intense storm events (World Bank, 2010), it is justifiable for the government to encourage more collective and individual participation in private storm protection actions.

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Appendix 1

Under endogenous storm surge risk model to reduce health damages through private activities, the first order conditions that are shown in matrix form in equation (12), can be derived by the following steps:
First order condition in equation (8.1) with respect to level of self-protection activities Z_{ij}^{k} is

$$\frac{\partial EU}{\partial Z_{ij}^{k}}: \qquad \frac{1}{\lambda}\cdot\left[\sum_{n}\frac{\partial Q_{ij}^{n}}{\partial Z_{ij}^{k}}\cdot U_{ij}^{n}(.)\right]=P_{z}^{k}$$

for all $k=k_1,k_2,\ldots,k_k$ self-protection activities and where $\lambda=\sum_{n}Q_{ij}^{n}\left(.\right)\cdot\frac{\partial U_{ij}^{n}}{\partial I}$ is the expected marginal utility of income.

Rearranging terms, the first order condition of (8.1) can be written in matrix form as

$$\begin{bmatrix} \frac{\partial Q_{ij}^{1}}{\partial Z_{ij}^{k_1}} & \cdots & \frac{\partial Q_{ij}^{N}}{\partial Z_{ij}^{k_1}} \\ \frac{\partial Q_{ij}^{1}}{\partial Z_{ij}^{k_2}} & \cdots & \frac{\partial Q_{ij}^{N}}{\partial Z_{ij}^{k_2}} \\ \vdots & \cdots & \vdots \\ \frac{\partial Q_{ij}^{1}}{\partial Z_{ij}^{k_k}} & \cdots & \frac{\partial Q_{ij}^{N}}{\partial Z_{ij}^{k_k}} \end{bmatrix} \cdot \begin{bmatrix} \frac{1}{\lambda}\cdot U_{ij}^{1} \\ \vdots \\ \vdots \\ \frac{1}{\lambda}\cdot U_{ij}^{N} \end{bmatrix} = \begin{bmatrix} P_{z}^{k_1} \\ \vdots \\ \vdots \\ P_{z}^{k_k} \end{bmatrix} \tag{A.1.1}$$

The vectors can be written as

$$\Theta_Z\cdot\Lambda=P_{z}^{k} \tag{A.1.2}$$

where Θ_Z is the vector of parameters that can be empirically estimated; Λ_1 is the vector of variables that includes the utility terms including the marginal utility of income λ; and, $P_{z}^{k}=\left(P_{Z}^{k_1},\ldots,P_{Z}^{k_k}\right)$ is the price of each self-protection activity for a system of k equations.

Expression (A.1.2) contains a total of N unknown utility terms based on $n=1,\ldots,N$ states of health. Applying established results from linear algebra, a unique solution exists for the first-order conditions if and only if the rank of the matrix Θ_Z is $R\left[\Theta_Z\right]=N$, which requires that $k\geq N$. Then the unknown utility terms can be expressed as

$$\Lambda_1=\left[\Theta_Z^{-1}\right]'\cdot P_{Z}^{k} \tag{A.1.3}$$

Now, the first order condition in equation (9.1) with respect to level of self-protection activities T_{ij}^{t} is

$$\frac{\partial EU}{\partial T_{ij}^{t}}: \qquad \frac{1}{\lambda}\cdot\left[-\sum_{n}Q_{ij}^{n}\cdot\frac{\partial L_{ij}^{n}}{\partial T_{ij}^{t}}\cdot\frac{\partial U_{ij}^{n}}{\partial I}+\sum_{n}Q_{ij}^{n}\cdot\frac{\partial U_{ij}^{n}}{\partial H_{ij}^{n}}\cdot\frac{\partial H_{ij}^{n}}{\partial T_{ij}^{t}}\right]=P_{T}^{t}$$

for all $t=t_1,t_2,\ldots,t_t$ self-insurance activities and where $\lambda=\sum_{n}Q_{ij}^{n}\left(.\right)\cdot\frac{\partial U_{ij}^{n}}{\partial I}$ is the expected marginal utility of income.

Rearranging terms, the first order condition of (9.1) can be written in matrix form as

$$-\begin{bmatrix} \frac{\partial L_{ij}^{1}}{\partial T_{ij}^{t_1}} & \cdots & \frac{\partial L_{ij}^{N}}{\partial T_{ij}^{t_1}} \\ \frac{\partial L_{ij}^{1}}{\partial T_{ij}^{t_2}} & \cdots & \frac{\partial L_{ij}^{N}}{\partial T_{ij}^{t_2}} \\ \vdots & \cdots & \vdots \\ \frac{\partial L_{ij}^{1}}{\partial T_{ij}^{t_t}} & \cdots & \frac{\partial L_{ij}^{N}}{\partial T_{ij}^{t_t}} \end{bmatrix} \cdot \begin{bmatrix} \frac{Q_{ij}^{1} \cdot \frac{\partial U_{ij}^{1}}{\partial I}}{\lambda} \\ \vdots \\ \frac{Q_{ij}^{N} \cdot \frac{\partial U_{ij}^{N}}{\partial I}}{\lambda} \end{bmatrix} + \begin{bmatrix} \frac{\partial H_{ij}^{1}}{\partial T_{ij}^{t_1}} & \cdots & \frac{\partial H_{ij}^{N}}{\partial T_{ij}^{t_1}} \\ \frac{\partial H_{ij}^{1}}{\partial T_{ij}^{t_2}} & \cdots & \frac{\partial H_{ij}^{N}}{\partial T_{ij}^{t_2}} \\ \vdots & \cdots & \vdots \\ \frac{\partial H_{ij}^{1}}{\partial T_{ij}^{t_t}} & \cdots & \frac{\partial H_{ij}^{N}}{\partial T_{ij}^{t_t}} \end{bmatrix} \cdot \begin{bmatrix} \frac{Q_{ij}^{1} \cdot \frac{\partial U_{ij}^{1}}{\partial H_{ij}^{1}}}{\lambda} \\ \vdots \\ \frac{Q_{ij}^{N} \cdot \frac{\partial U_{ij}^{N}}{\partial H_{ij}^{N}}}{\lambda} \end{bmatrix} = \begin{bmatrix} P_{T}^{t_1} \\ \vdots \\ \vdots \\ P_{t}^{t_t} \end{bmatrix} \qquad \text{(A.1.4)}$$

The vectors can be written as

$$\theta_T^1 \cdot \Psi_1 + \theta_T^2 \cdot \Psi_2 = P_T^t \qquad \text{(A.1.5)}$$

where θ_T^τ , $\tau = 1, 2$ is the vector of parameters that can be empirically estimated and Ψ_v , $v = 1, 2$ is the vector of variables that includes the utility terms including the marginal utility of income λ ; and, $P_T^t = \left(P_T^{t_1}, \ldots, P_T^{t_t} \right)$ is the price of each self-insurance activity. This system of t equations can be further written as

$$\begin{bmatrix} \theta_T^1 & \theta_T^2 \end{bmatrix} \cdot \begin{bmatrix} \Psi_1 \\ \Psi_2 \end{bmatrix} = P_T^t \qquad \text{(A.1.6)}$$

More precisely,

$$\Theta_T \cdot \Lambda_2 = P_T^t \qquad \text{(A.1.7)}$$

Expression (A.1.7) contains a total of $2N$ unknown utility terms based on $n = 1, \ldots, N$ states of health. Using well-known results from linear algebra, a unique solution exists for the first-order conditions if and only if the rank of the matrix Θ_T is $R\left[\Theta_T\right] = 2N$, which requires that $k \geq 2N$. Then the unknown utility terms can be expressed as

$$\Lambda_2 = \left[\Theta_T^{-1} \right]' \cdot P_T^t \qquad \text{(A.1.8)}$$

To derive ex ante marginal willingness to pay measures for an increase in storm protection role of mangroves to reduce the probability and the severity of the health loss is the marginal change of income that holds expected utility constant. This can be found by totally differentiating the objective function (7) with respect to M_{ij}, setting it equal to zero, substituting for the first order conditions from equations (8) and (9) with respect to Z_{ij}^k and T_{ij}^t, and letting $dG_{ij} = dR_{ij} = dC_{ij} = 0$.

$$-\frac{\partial I_{ij}}{\partial M_{ij}} = \frac{1}{\lambda} \cdot \left[\sum_n \frac{\partial Q_{ij}^n}{\partial M_{ij}} \cdot U_{ij}^n \right]$$

This can be further written as,

$$-\frac{\partial I}{\partial M_{ij}} = \begin{bmatrix} \frac{\partial Q_{ij}^{1}}{\partial M_{ij}} & \mathrm{L} & \frac{\partial Q_{ij}^{n}}{\partial M_{ij}} \end{bmatrix} \cdot \begin{bmatrix} \frac{U_{ij}^{1}}{\lambda} \\ \mathrm{M} \\ \frac{U_{ij}^{n}}{\lambda} \end{bmatrix} \tag{A.1.9}$$

which can be further reduced to

$$-\frac{\partial I}{\partial M} = \Theta_{M} \cdot \Lambda_{1}$$

$$\Rightarrow -\frac{\partial I}{\partial M} = \Theta_{M} \cdot \left[\Theta_{Z}^{-1}\right]' \cdot P_{Z}^{k} \tag{A.1.10}$$

Similarly, for ex ante public protective programs, the ex-ante marginal willingness to pay can be derived by totally differentiating the objective function (7) with respect to G_{ij}, setting it equal to zero, substituting for the first order conditions from equations (8) and (9) with respect to Z_{ij}^{k} and T_{ij}^{t}, and letting $dM_{ij} = dR_{ij} = dC_{ij} = 0$.

$$-\frac{\partial I_{ij}}{\partial G_{ij}} = \frac{1}{\lambda} \cdot \left[\sum_{n} \frac{\partial Q_{ij}^{n}}{\partial G_{ij}} \cdot U_{ij}^{n} \right]$$

This can be written as

$$-\frac{\partial I}{\partial G_{ij}} = \begin{bmatrix} \frac{\partial Q_{ij}^{1}}{\partial G_{ij}} & \mathrm{L} & \frac{\partial Q_{ij}^{N}}{\partial G_{ij}} \end{bmatrix} \cdot \begin{bmatrix} \frac{U_{ij}^{1}}{\lambda} \\ \mathrm{M} \\ \frac{U_{ij}^{N}}{\lambda} \end{bmatrix} \tag{A.1.11}$$

which can be further reduced to

$$\begin{aligned} -\frac{\partial I}{\partial G} &= \Theta_{G} \cdot \Lambda_{1} \\ \Rightarrow -\frac{\partial I}{\partial G} &= \Theta_{G} \cdot \left[\Theta_{Z}^{-1}\right]' \cdot P_{Z}^{k} \end{aligned} \tag{A.1.12}$$

Lastly, for ex post public assisted disaster relief and rehabilitation programs, the ex-ante marginal willingness to pay can be derived by totally differentiating the objective function (7) with respect to R_{ij}, setting it equal to zero, substituting for the first order conditions from equations (8) and (9) with respect to Z_{ij}^{k} and T_{ij}^{t}, and letting $dM_{ij} = dG_{ij} = dC_{ij} = 0$.

$$-\frac{\partial I_{ij}}{\partial R_{ij}}=\frac{1}{\lambda}\cdot\left[-\sum_{n}Q_{ij}^{n}\cdot\frac{\partial L_{ij}^{n}}{\partial R_{ij}}\cdot\frac{\partial U_{ij}^{n}}{\partial I_{ij}}+\sum_{n}Q_{ij}^{n}\cdot\frac{\partial U_{ij}^{n}}{\partial H_{ij}^{n}}\cdot\frac{\partial H_{ij}^{n}}{\partial R_{ij}}\right]$$

This can be written as

$$-\frac{\partial I}{\partial R}=\begin{bmatrix}\frac{\partial H^{1}}{\partial R} & \cdots & \frac{\partial H^{N}}{\partial R}\end{bmatrix}\cdot\begin{bmatrix}\frac{Q^{1}\cdot\frac{\partial U^{1}}{\partial H^{1}}}{\lambda}\\ \vdots\\ \frac{Q^{N}\cdot\frac{\partial U^{N}}{\partial H^{N}}}{\lambda}\end{bmatrix}-\begin{bmatrix}\frac{\partial L^{1}}{\partial R} & \cdots & \frac{\partial L^{N}}{\partial R}\end{bmatrix}\cdot\begin{bmatrix}\frac{Q^{1}\cdot\frac{\partial U^{1}}{\partial I}}{\lambda}\\ \vdots\\ \frac{Q^{N}\cdot\frac{\partial U^{N}}{\partial I}}{\lambda}\end{bmatrix} \tag{A.1.13}$$

which can be further reduced to

$$-\frac{\partial I}{\partial R}=\theta_{R}^{1}\cdot\Psi_{1}+\theta_{R}^{2}\cdot\Psi_{2}$$

$$\Rightarrow-\frac{\partial I}{\partial R}=\begin{bmatrix}\theta_{R}^{1} & \theta_{R}^{2}\end{bmatrix}\cdot\begin{bmatrix}\Psi_{1}\\ \Psi_{2}\end{bmatrix}$$

$$\Rightarrow-\frac{\partial I}{\partial R}=\Theta_{R}\cdot\Lambda_{2} \tag{A.1.14}$$

$$\Rightarrow-\frac{\partial I}{\partial R}=\Theta_{R}\cdot\left[\Theta_{T}^{-1}\right]'\cdot P_{T}^{t}$$

Appendix 2

Just and Pope (1978) were first to suggest the idea that formulations of stochastic production functions are very restrictive for cases where risk is an important input. They showed in their paper that common specifications invalidate number of postulates one would expect to hold for a production function with risk as an input. Thus, econometric estimates based on these common specifications turn out to be uninformative with respect to risk. Because, risk is not a direct input in the production function; hence, it indirectly affects the output. Based on these assumptions, Just and Pope (1978) proposed an econometric specification where some function of the input, say $g\left(X\right)$, perturbs the effects of the disturbance term, say ε. They consider the newly defined term to appear additively in the production function, say y.

$$\begin{gathered}y=f\left(X\right)+g\left(X\right)\cdot\varepsilon\\ \text{where, }E\left(\varepsilon\right)=0,\ Var\left(\varepsilon\right)=\sigma_{\varepsilon}^{2}\end{gathered} \tag{A.2.1}$$

Just and Pope (1978) suggested that any special case for which $f\left(X\right)$ satisfies the standard requirements for a production function and $g\left(X\right)$ to be linearly homogenous should hold for the above specification.

Extending to observation t, equation (A.2.1) can be shown as

$$
\begin{aligned}
& y_t = f\left(V_t,\alpha\right) + g\left(V_t,\beta\right)\cdot\varepsilon_t \\
& \text{where,} \\
& \ln f\left(V_t,\alpha\right) \equiv v_t^{'}\cdot\alpha \\
& \ln \text{g}\left(V_t,\alpha\right) \equiv v_t^{'}\cdot\beta \\
& V_t = V\left(X_t\right) \\
& E\left(\varepsilon_t\right)=0;\ E\left(\varepsilon_t^2\right)=1;\ E\left(\varepsilon_t\varepsilon_\tau\right)=0\ \text{ for } t\neq\tau
\end{aligned}
\tag{A.2.2}
$$

Taking logs, equation (A.2.2) becomes

$$\ln y_t = \ln f\left(V_t,\alpha\right) + \ln\left[1+\varepsilon_t\cdot\frac{g\left(Z_t,\alpha\right)}{f\left(Z_t,\beta\right)}\right] \tag{A.2.3}$$

According to Just and Pope (1978), this function can be consistently estimated using maximum likelihood.

For the endogenous health risk model, activities of health protection adopted by the household (i.e. risk in Just and Pope, 1978) indirectly contribute to health outcomes (i.e. output in Just and Pope, 1978) by reducing the likelihood and the severity of a bad health outcome as a result of a damaging storm surge event.

Following some previous applications of Just and Pope (1978) technique (Saha et al.1997; Nastis & Crocker, 2007), the linear representation of the state dependent realized cost function L^n in equation (3.22) can be estimated as

$$L^n = \beta_1 + \beta_2^{'}\cdot\left(P_T^t\cdot T^t\right) + \beta_3\cdot\psi + \eta \tag{A.2.4}$$

where $\eta \equiv \varepsilon - B\cdot e$, is the heteroscadastic error term with $\varepsilon\left(0,1\right)$, and $e:\ \left(\mu,1\right)$.
Also,

$$B = \varphi_1 + \varphi_2\cdot R \tag{A.2.5}$$

The coefficient $\beta_2^{'}$ is the effect of the self-insurance expenditures in terms of medical expenditures and treatment costs, lost working days, etc., on the realized costs L^n , and the coefficient β_3 is the effect of socio-economic status and location of the household on its health costs. Heteroscadastic error term η depends on the gains in health costs in terms of benefits, B , received from a household's access to public disaster relief and rehabilitation programs, . R . The qualitative effect of exogenous change in access to public disaster relief and rehabilitation programs is represented by φ_2 .

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Figures

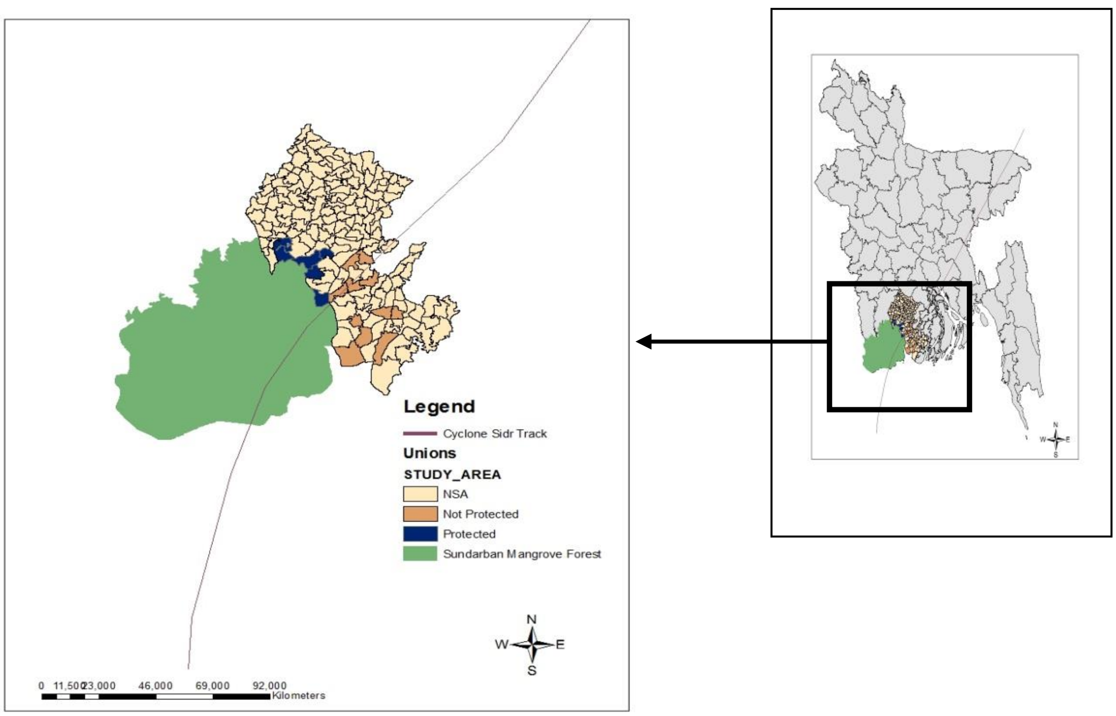

Figure 1: The Study Area – The Protected and Non-Protected Areas

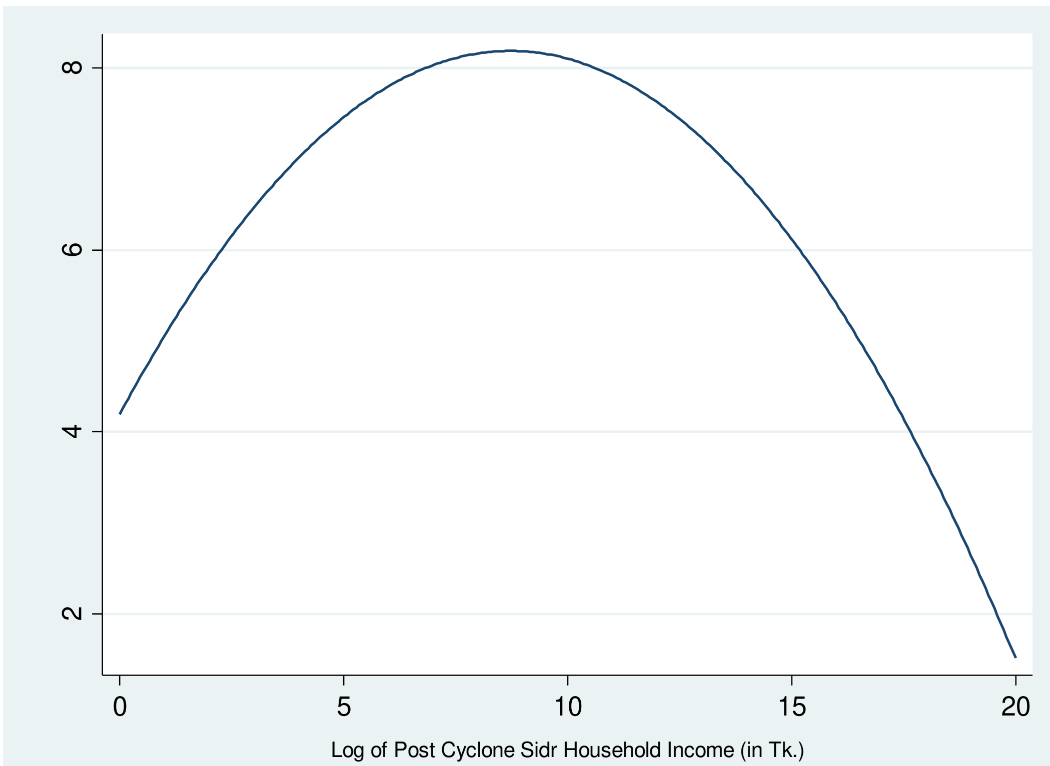

Figure 2: Inverted U-shaped Kuznets Curve between Medical Expenditures and Household Income

Table 1: Self-protection and self-insurance actions in reducing health-related risks and impacts from major storms in coastal areas of Bangladesh

Examples of private self-protection affecting the probability of facing health impacts from major storms	*Examples of private self-insurance in terms of mitigation activities and treatments to reduce exposure to adverse health effects from major storms*
▪ Converting mud built house to brick built house ▪ Raising height of the homestead ▪ Moving house inside embankment ▪ Planting trees around the house	▪ Purchasing medications ▪ Visiting a doctor or hospital ▪ Taking time off from work to recuperate from injuries

Source: Reconnaissance Survey, November 2008

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

Household Characteristics		Value	
		Protected	**Non-protected**
Respondent average age (mean)		42.89	41.69
Respondent gender (%)	Male	84.09	71.79
	Female	15.91	28.21
Literacy rate of Respondent (%)	Illiterate	7.83	8.36
	Primary School	52.07	45.45
	High School	26.73	27.27
Respondent Occupation (%)	Farmer	24.09	39.78
	Fisherman	6.82	7.17
	Trader	15.91	13.26
	Service	6.36	6.45
	Wage worker	35.91	11.93
Respondent is head of household (%)		81.36	63.08
Respondent living in the village since birth (%)		91.82	90.68
Average number of family members (Min-Max)		4.97 (1-11)	5.66 (0-25)
Average number of adults (Min-Max)		3.68 (1-10)	4.43 (1-15)
Average number of children (Min-Max)		1.89 (1-7)	1.72 (1-10)
Average number of males at work (Min-Max)		1.33 (1-4)	1.55 (1-7)
Type of wall used for dwelling at present (%)	Katcha/ Earthen	18.26	5.02
	Tin/ C.I. Sheet	21.46	46.58
	Pacca (brick)	9.13	11.42
	Wood	37.44	42.92
	Jhupri/ Chon	10.50	17.35
Type of roof used for dwelling at present (%)	Katcha/ Earthen	0.46	1.07
	Tin/ C.I. Sheet	73.97	80.71
	Pacca (brick)	2.28	1.79
	Wood	4.57	2.50
	Jhupri/ Chon	18.72	13.93
Nature of house in past (%)	Same	52.51	74.29
Floors of house at present (%)	Ground floor	90.91	78.85
	Up to first floor	9.09	21.15
Tenure of residence (%)	Rented	3.67	3.94
	Owned	89.45	92.11
Elevation status of the house (%)	High land	6.82	5.00
	Mid land	37.27	41.07
	Low land	55.91	53.93
Size of homestead (Mean in hectare)		0.13 ha	0.14 ha
Type of latrine (%)	Sanitary	7.73	21.94
	Ring/slab	83.18	64.03
	Katcha	9.55	12.95
Source of drinking water – multiple responses (%)	Deep Tube well	0.45	26.43
	Tube well	12.27	33.57
	Pond/ River	67.73	31.79
	Rain water	48.64	15.36
	Filtered Pond	24.09	11.79
Percentage with electricity connection		21.46	31.79
Percentage with access to cell phone		48.18	45.16
Average household income (US $ /year)		815.47	857.19
Average per capita income (US $ /year)		167.00	200.50
Main source of energy- multiple responses (%)	Wood/ Coal	93.52	98.55
	Twigs/ Leafs	83.80	61.82

Table 3: Summary Statistics of Households' Health-related Problems due to Cyclone Sidr

Type of disease	Study area	No. of responses			Average number of days suffering	Average amount spent in medication (in Tk.)
		Yes	No	Total		
Injury	Protected	66	37	103	125.8	5944.44
	Non-protected	72	69	141	75.61	8848.59
	Entire area	**138**	**106**	**244**	**99.23**	**7483.21**
Diarrhea	Protected	28	70	98	10.54	1583.33
	Non-protected	29	115	144	8.17	1710.71
	Entire area	**57**	**185**	**242**	**9.33**	**1648.18**
Typhoid	Protected	67	19	86	24.55	1209.70
	Non-protected	89	60	149	25.82	2345.45
	Entire area	**156**	**79**	**235**	**25.28**	**1854.52**
Jaundice	Protected	9	56	65	40.00	2537.50
	Non-protected	10	119	129	53.50	3232.00
	Entire area	**19**	**175**	**194**	**47.94**	**2923.33**
Malaria	Protected	1	60	61	-	-
	Non-protected	2	118	120	11.00	2250.00
	Entire area	**3**	**178**	**181**	**11.00**	**2250.00**
Pneumonia	Protected	14	50	64	71.08	3423.08
	Non-protected	7	113	120	44.25	2768.75
	Entire area	**21**	**163**	**184**	**60.35**	**3173.81**
Skin Disease	Protected	16	42	58	136.79	1200.00
	Non-protected	20	97	117	138.55	6552.50
	Entire area	**36**	**139**	**175**	**137.82**	**4348.53**
Others	Protected	12	42	54	214.36	10808.33
	Non-protected	11	79	90	233.90	13510.00
	Entire area	**23**	**121**	**144**	**223.67**	**12036.36**

Table 4: Summary statistics of the Key variables used for Regression Analysis

Variable	Definition	No. of obs.	Mean	Standard Deviation
Dependent Variables				
HEALTH	If any household member is facing Cyclone Sidr-inflicted health-risks (=1, 0 otherwise)	479	0.616	0.487
L(HEALTHCOST)	Medical expenditures on Cyclone Sidr-inflicted health losses (in Tk.)	304	7.836	1.39
INJURY	If any household member is facing Cyclone Sidr-inflicted injury (=1, 0 otherwise)	244	0.566	0.497
Independent Variables				
L(EXPSP)	Log of self-protection expenditures (in Tk.)	84	7.967	1.67
L(EXPSI)	Log of self-insurance expenditures (in Tk.)	297	8.084	1.69
L(PREINC)	Log of Pre-Cyclone Sidr HH Income (in Tk.)	449	11.569	1.079
L(PREINC2)	Square of the log of Pre-Cyclone Sidr HH Income (in Tk.)	449	135.02	25.28
L(POSTINC)	Log of Post-Cyclone Sidr HH Income (in Tk.)	489	10.648	1.262
L(POSTINC2)	Square log of Post-Cyclone Sidr HH Income (in Tk.)	489	114.96	24.44
AREA	Area of homestead, crop land, and the pond (in decimal)	500	142.6	24.441
EMB	If household is protected by the embankment (=1, 0 otherwise)	497	0.6097	0.4883
AGE	Age of the respondent (in years)	497	42.221	13.252
MFRATIO	Male/ Female ratio of the household	498	1.248	0.7933
CHILD	Number of children in the household	500	1.26	1.1896
MDIST	Distance between the union and the mangrove forest (in km.)	500	7.536	7.981
MDIR	If household is located to the south or the southwest direction relative to the coast and the Sundarban mangrove forest (=1, 0 otherwise)	500	0.548	0.498
LGRELIEF	Log of ex-post government sponsored disaster relief received (in Tk.)	446	8.285	1.076
LGREHABN	Log of ex-post government sponsored disaster rehabilitation received (in Tk.)	268	8.648	1.62
SURGEHT	Approximate average Cyclone Sidr induced Storm surge height (in meter)	500	3.982	0.7085
STORMEXP	If household falls into counter-clockwise direction from Cyclone Sidr (=1, 0 otherwise)	500	0.42	0.4941
STORMDIS	Directional Distance between Household and the Track for the Cyclone Sidr (in km)	500	15.839	10.124

Table 5: Probit Model for Experiencing Storm-inflicted Health Problems

Variables	Parsimonious Model		Add the Mangroves Characteristics		Add the Ex-Ante Public Programs		Add the Storm Surge Characteristics	
	Coeff.	Marginal Effect	Coeff.	Marginal Effect	Coeff.	Marginal Effect	Coeff.	Marginal Effect
CONSTANT	15.561 (0.72)		22.517 (0.94)		24.569 (1.02)		20.941 (0.86)	
EXPSP	2.26e-06 (1.79)**	6.84 e-07	3.74 e-06 (2.42)***	1.03 e-07	3.74 e-06 (2.38)***	1.00 e-06	3.82 e-06 (2.41)***	1.02 e-06
L(PREINC)	-2.392 (-0.66)	-0.7226	-3.453 (-0.86)*	-0.9467	-3.685 (-0.92)	-0.9905	-3.078 (-0.75)	-0.8197
L(PREINC2)	0.0919 (0.59)	0.0278	0.1297 (0.77)	0.0356	0.1405 (0.83)	0.0378	0.1151 (0.66)	0.0306
AREA	-0.0002 (-0.42)	-0.00006	0.00006 (0.11)	0.00001	-0.00005 (-0.09)	-0.00001	-0.00007 (-0.13)	-0.00002
DCOAST	0.0128 (1.70)**	0.0039	0.0168 (1.12)	0.0046	0.0044 (0.26)	0.0012	0.0083 (0.42)	0.0022
AGE	-0.0056 (-0.08)	-0.0017	-0.0153 (-0.21)	-0.0042	-0.0089 (-0.12)	-0.0024	-0.0045 (-0.06)	-0.0012
AGE2	0.00004 (0.05)	0.00001	0.0001 (0.15)	0.00003	0.00009 (0.12)	0.00002	0.00005 (0.06)	0.00001
MFRATIO	-0.5653 (-2.24)**	-0.1708	-0.8541 (-2.68)***	-0.2342	-0.9161 (-2.84)***	-02462	-0.8809 (-2.63)***	-0.2346
CHILD	0.2498 (1.62)*	0.0755	0.2609 (1.66)**	0.0715	0.2570 (1.62)*	0.0691	0.2615 (1.58)*	0.0696
PROTECTED			-1.181 (-1.51)*	-0.3239	-1402 (-1.74)**	-0.3769	-0.8947 (-0.73)	-0.2383
MDIST			0.0519 (1.11)	0.0142	0.0588 (1.23)	0.0158	0.06551 (1.27)*	0.0174
MDIR			1.532 (2.42)***	0.4202	1.816 (2.70)***	0.4880	1.845 (2.71)***	0.4913
EMB					-0.8380 (-1.55)*	-0.2253	-0.8975 (-1.01)	-0.2390
SURGEHT							-0.1015 (-0.19)	-0.0270
STORMEXP							0.6597 (0.59)	0.1757
STORMDIS							-0.0212 (-0.76)	-0.0057
LOG LIKE.	-46.664		-42.276		-40.953		-40.626	
LR Chi2 (df)	18.76** (9)		27.54** (12)		29.33**(13)		29.99** (16)	
OBS.	87		87		86		86	

a. Dependent variable is the dummy variable regarding whether any household member is facing Cyclone Sidr-inflicted health impacts.

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

Table 6: OLS for Medical Expenditures as a result of Storm-inflicted Health problems

Variable	Parsimonious model		Add the Ex-post public programs	
	Coefficient	Standard Error	Coefficient	Standard Error
CONSTANT	-1.837 (-1.31)*	1.398	-0.9767 (-0.62)	1.573
L(EXPSI)	0.7849 (30.24)***	0.0259	0.8048 (22.12)***	0.0364
L(POSTINC)	0.9168 (3.45)***	0.2658	0.5452 (1.87)**	0.2912
L(POSTINC2)	-0.0525 (-3.85)***	0.0137	-0.0319 (-2.06)**	0.015
L(AREA)	-0.0001 (-0.77)	0.0002	-0.0003 (-0.85)	0.0003
AGE	-0.0119 (-0.70)	0.0169	-7.291 (-0.14)	0.0217
AGE SQUARED	0.00009 (0.50)	0.0002	-0.0058 (-0.27)	0.0002
MFRATIO	0.0389 (0.72)	0.0539	-672 e-06 (-0.03)	0.0768
CHILD	-0.0223 (-0.67)	0.0331	-0.0265 (-0.68)	0.039
LGRELIEF			0.0853 (1.63)*	0.052
LGREHABN			-0.0166 (-0.48)	0.034
R^2	0.7791		0.7935	
Adj. R^2	0.7726		0.7788	
$F\ (df_1,df_2)^b$	119.47*** (8,271)		54.17*** (10, 141)	
OBS.	280		152	
RESET, $F\ (df_1,df_2)^c$	35.20*** (3,268)		23.33*** (3, 138)	
Shapiro-Wilk W Test, p-value [d]	0.000		0.000	

a. Dependent variable is the log of medical expenditures for Cyclone Sidr-inflicted health losses; t-tests are shown in parentheses beneath coefficient estimates.
b. Significant at 5% level.
c. Regression specification error test for omitted variables. The F-values of the RESET tests for both model specifications confirm that there is 'no' omitted variable in the model.
d. Testing for normality of residuals. The p-value is based on the assumptions that the distribution is normal. Since the p-values are very small, we reject that the residuals are normally distributed.

Table 7: Probit Model for Experiencing Storm-inflicted Injury [a]

Variable	Parsimonious model		Add the Ex-post public programs	
	Coefficient	Marginal Effect	Coefficient	Marginal Effect
CONSTANT	-0.1962 (-0.07)		-3.450 (-0.91)	
L(EXPSI)	0.17783 (3.07)***	0.0692 (3.07)***	0.2035 (2.05)**	0.0777 (2.05)**
L(POSTINC)	-0.1081 (-0.20)	-0.0421 (-0.20)	0.5727 (0.85)	0.2187 (0.85)
L(POSTINC2)	0.0009 (0.03)	0.0003 (0.03)	-0.0353 (-0.98)	-0.0135 (-0.98)
AREA	0.0012 (2.27)**	0.0005 (2.28)**	0.0007 (0.89)	0.0003 (0.89)
AGE	-0.0026 (-0.07)	-0.001 (-0.07)	-0.0274 (-0.50)	-0.0105 (-0.50)
AGE2	3.69 e-06 (0.01)	1.44 e-06 (0.01)	0.0003 (0.47)	0.0001 (0.47)
MFRATIO	-0.0381 (-0.33)	-0.0148 (-0.33)	0.1424 (0.69)	0.0544 (0.69)
CHILD	0.0179 (0.26)	0.007 (0.26)	-0.1567 (-1.55)*	-0.0598 (-1.55)*
LGRELIEF			0.3846 (2.90)***	0.1469 (2.90)***
LGREHABN			-0.2959 (-3.31)***	-0.1130 (-3.30)***
LOG-LIKE.	-148.419		-72.945	
LR CHI2 (df)	19.17** (8)		20.52** (10)	
Prob.> Chi2 (χ^2)	0.014		0.0247	
Pseudo R^2	0.0607		0.1233	
OBS.	232		124	

a. Dependent variable is the dummy variable regarding whether any household member is facing Cyclone Sidr inflicted injury
b. Z-tests are shown in parentheses beneath coefficient estimates. Significance levels: ***1%, **5%, *10%

Table 8: Marginal Willingness-to-Pay for reduction in Health-related Risks

MWTP for risk reduction in health as a result of …	MWTP expression in the model	MWTP per household	Total WTP for the entire study area (in million)
an increase in households' exposure to greater storm protection role of mangroves	$-\frac{\partial I_{ij}}{\partial M_{ij}}$	Taka 3372.23 or US $ 48.87	Taka 12,443.38 or US $ 180.33 million
an increase in households' access to publicly constructed embankments	$-\frac{\partial I_{ij}}{\partial G_{ij}}$	Taka 2520.88 or US $ 36	Taka 9302.05 or US $ 132.84 million
an increase in households' access to public post-disaster relief and rehabilitation programs	$-\frac{\partial I_{ij}}{\partial R_{ij}}$	Taka 249.72 or US $ 3.62	Taka 921.47 or US $ 13.35 million

Notes on information used to derive MWTPs:

[a] Marginal effects of δ_2, δ_3, δ_4, φ_2, β_2, γ_2, γ_3, are used based on results of the regression estimations from Tables 5,7, and 8. These marginal effects are considered following expressions (24)-(26) to perform an empirical analysis of the theoretical model.

[b] Average self-protection expenditures = Tk. 94,549 and Average self-insurance expenditures = Tk. 18,776.07

[c] Total population in the study area (in 2008) = 3.69 million

[d] 1 US $ = Tk. 69 at the time of the survey (in 2008)