ADAPTATION TO NATURAL DISASTERS THROUGH THE AGRICULTURAL LAND RENTAL MARKET: EVIDENCE FROM BANGLADESH

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We examine the effects of natural disaster exposure on agricultural households who simultaneously make rent-in and rent-out decisions in the land rental market. Our econometric approach accounts for the effects of disaster exposure both on the adjustments in the quantity of operated land (i.e. extensive margin) and agricultural yield conditional on the land quantity adjustments (i.e. intensive margin), based on selectivity-corrected samples of rental market participants. Employing a household survey dataset from Bangladesh, we find that farmers were able to ameliorate their losses from exposure to disasters by optimizing their operational farm size through participation in the land rental market. These results are robust to alternative specifications. This suggests that the land rental market may be an effective instrument reducing disaster risk, and post-disaster policies should take into account this role more systematically. (JEL *Q24, Q54, D13, D64, Q15*).

Keywords: Bangladesh; Natural Disasters; Extensive and Intensive Margins; Land Rental Market.

I. INTRODUCTION

Agricultural households from low-income countries, where widespread poverty among rural households often limits their ability to invest in defensive measures especially when markets are incomplete or non-existent, are highly susceptible to exposure to climate-induced natural disasters such as floods and cyclones. Consequently, natural disasters often force rural households and farmers to adopt coping strategies such as cutting back on consumption of basic food and nutrients and selling of productive assets such as agricultural land (Duflo 2003; Jensen 2000).[1] Apart from selling agricultural land, the immediate response of many rural households is to seek off-farm work in either agricultural or non-agricultural employment (Banerjee 2007; Mueller and Quisumbing 2011). However, farmers might also have another coping mechanism, which is to adjust their operational farm size through participation in the land rental market (Banerjee 2010b; Ward and Shively 2011). Through

[1] For example, selling of arable land is among the coping strategies adopted by Bangladeshi farmers in response to disaster exposure (BBS 2010).

participation in the land rental market, some farmers facing exposure to disaster risks might choose to rent-in agricultural land, whereas others might rent-out land. These land rental transactions enable farmers to adjust their operational farm size, and thus indirectly, agricultural yield. To date, this potential mechanism of farmers using the land rental market as a source of indirect adaptation to natural disaster exposure has not yet been addressed in literature. Here, we investigate this potential role of the land rental market in ameliorating the agricultural yield effects of disaster exposure through a case study of Bangladesh.

Bangladesh is predominantly an agricultural country that experiences recurring damaging disaster events, such as floods and cyclones. During 2006-11, Bangladesh experienced aggregate losses of US$ 114 million from 11 floods and US$ 2,570 million from 15 cyclones (EM-DAT 2016). Most of these losses occur to agriculture, which employs around 44 percent of the labor force and accounts for 20 percent of gross domestic product (BBS 2010). Moreover, low average farm size and high incidence of rural poverty in Bangladesh necessitate the optimal management and utilization of the available land especially in response to a disaster.

We examine agricultural adaptation to natural disaster exposure via the land rental market using an econometric model of a farmer's rent-in and rent-out choices. For this purpose, we adapt the standard empirical model that accounts for both extensive margin, i.e. adjustments in the quantity of operated land, and intensive margin, i.e. agricultural yield conditional on the land quantity adjustment (e.g., Lee 1990; Moore, Gollehon, and Carey 1994; Pfeiffer and Lin 2012 and 2014). The extensive margin is estimated in a simultaneous equations model, in which the amounts of rent-in and rent-out land chosen by each farmer are censored by sample selection. The next stage employs the selectivity-corrected sample to estimate the intensive margin of the effects of natural disaster exposure on agricultural yield, conditional on the quantity adjustment in operated land. We then calculate total intensive and extensive margins, and the total marginal effects of natural disaster exposure on agricultural yield. Data comes from the Bangladesh Integrated Household Survey (BIHS) 2011-12, which is the most comprehensive source of household-level socioeconomic and agricultural data in Bangladesh (Ahmed 2013). This survey provides household-level information on exposure to natural disasters over the period 2006-11, which allows us to examine the effects of disaster exposure in inducing variations in agricultural yield (which indicates the direct effect of disaster exposure on agricultural yield) and land rental market transactions (which indicates the indirect effect of disaster on agricultural yield).

Existing literature focuses on the direct effects of natural disasters on agricultural yield (e.g., Deschenes and Greenstone 2007; Mendelsohn, Nordhaus, and Shaw 1994). We additionally examine the effects of disasters on land rental market transactions, which can be an important source of adaptation (Ward and Shively 2011).[2] In particular, we take into account the possibility that farmers might be able to mitigate or reduce the adverse effects of disaster on agricultural yield through land rental market transactions (Banerjee 2010b). The results of our analysis supports the latter effect. We find that Bangladeshi farmers exposed to a natural disaster have 0.25 percent higher agricultural yield, which consists of -1.18 percent intensive margin and 1.44 percent extensive margin. That is, while the exposure to a disaster results in a 1.18 percent direct decrease in yield, those adjusting their operational farm size were able to overcome that loss due to a 1.44 percent indirect increase in yield coming from the land rental market.

Our results have important implications for Bangladesh and other low-income countries in terms of the role of land management within a community for disaster risk reduction. In response to a natural disaster, if farmers in a rural community manage and utilize their land to increase their yields, this coping strategy has been found to ameliorate adverse impacts and might even compensate for the losses from disaster exposure (Sklenica *et al.* 2014; Deininger, Savastano, and Carletto 2012; Masterson 2007). In this paper, we show that access to a well-functioning land rental market might be a crucial part of the coping strategy that allows farmers to adjust their yields, and thus improving and facilitating the functioning of such markets in rural areas should be an important component of government post-disaster relief policies.

The content of the remainder of this paper is as follows. Section II discusses the background information on land rental market and disasters during 2006-11 in Bangladesh. Section III describes data and identification. Section IV specifies the empirical model. Section V reports and discusses empirical results. Finally, Section VI summarizes and concludes by discussing the key policy implications of the analysis.

[2] Ward and Shively (2011) appears to be the only previous study that considers the land rental market as a source of disaster adaptation, although their analysis does not consider the indirect effects of land rental transactions in response to a disaster on agricultural yield.

II. BACKGROUND

II.A Land Rental Market in Bangladesh

Our empirical analysis focuses on Bangladesh, which is predominantly an agricultural economy that experiences recurring floods and cyclones. Rural households in Bangladesh predominantly depend on agriculture for their livelihood and employment. Agriculture employs around 44 percent of the labor force in Bangladesh and contributes around 20 percent of its gross domestic product (BBS 2010). However, due to a high level of land fragmentation and increasing population, per-capita arable land declined from 0.174 ha in 1961 to 0.049 ha in 2013 (World Bank 2015), creating increased pressure on limited land resources to produce sufficient food and other commodities. Since Bangladesh has one of the lowest average farm sizes globally, estimated at 0.344 ha per rural household (BBS 2014), many farmers rely on the land rental market to better manage and utilize the available arable land.

Although rental arrangements do not change the land ownership structure, the presence of land rental market, mostly informal in Bangladesh like many other developing countries, is an effective way to redistribute the operating farm size among the farmers. Farmers often manage their agricultural plots to equalize the size distribution of the operating farms by either renting in additional land or renting out surplus land (Teklu and Lemi 2004; Rahman 2010). Typically, smallholders rent in land from larger farmers to increase their operational farm size. For example in 2008, 33.8 percent of rural households in Bangladesh rented at least a part of their total operated land, whereas 24.2 percent operated a combination of owned and rented lands. In addition, 9.6 percent of them operated only rented lands (BBS 2014).

Common land rental categories in Bangladesh are (i) share-cropping arrangements, and (ii) cash-renting at a fixed predetermined rate. The Land Reform Act of 1984 fixed rents for share-cropping tenants at 33 percent of the harvest for the landlords (without input sharing) or 50 percent if inputs are shared at a 50 percent rate (GoB 1984; Rahman 2010). However, in absence of proper enforcement of existing laws, most of the agricultural land rental agreements take place without any documentation through informal land rental markets.

II.B Disasters in Bangladesh: 2006-11

Geographic location and land characteristics make Bangladesh one of the most disaster-prone countries in the world: 26 percent of the population are affected by cyclones and 70 percent live in flood-prone regions (Cash *et al.* 2014). Wide-scale flooding has been the most recurrent type of disaster striking Bangladesh, and the country remains one of the worst affected by cyclones globally. Large-scale natural disasters in Bangladesh include the 1970 cyclone, 1986 flood, 1991 cyclone, 1998 flood and 2007 cyclone. Our paper focuses on the series of natural disasters in Bangladesh that occurred from 2006 to 2011. Table A1 in the appendix lists all the floods and cyclones that took place during this period, alongside the associated numbers of deaths and affected people and economic damages.

Bangladesh experienced 11 floods and 15 cyclones during 2006 to 2011 (see Table A1). These natural disasters resulted in around six thousand reported deaths, whereas more than 30 million people were affected, resulting in an estimated damages of US$ 2,648 million. However, note that the damage figures for many relatively smaller disasters are not reported in Table A1, implying that the actual economic damages from disasters over 2006-2011 are likely to be even higher.

In general, cyclonic storms primarily affected the coastal regions of Bangladesh whereas the northern regions were the primary victims of floods. Major such events during 2006-11 include the floods of 2007, the cyclone Sidr of 2007 and the cyclone Aila of 2009. Two floods in June-July and July-September of 2007 covered 46 districts and affected around 13.3 million people including 6 million children. These back-to-back floods caused more than 1,200 deaths, in addition to 1.1 million damaged or destroyed homes and 2.2 acres of damaged croplands. Damages were estimated at US$ 100 million. Next, Cyclone Sidr struck the coastal regions of Bangladesh on November 15, 2007. The 240 km per hour winds destroyed 30 districts in Barisal and Khulna divisions, resulting in more than four thousand deaths and 55 thousand injuries in addition to 1.5 million damaged or destroyed homes and 2.5 acres of damaged croplands. Economic damages were estimated at US$ 2,300 million. Finally, cyclone Aila struck 14 districts on the south-west coast of Bangladesh on May 25, 2009. Aila affected around 4 million people and caused 190 deaths, in addition to an estimated US$ 270 million worth damages in infrastructures and livelihoods.

III. DATA AND IDENTIFICATION

III.A BIHS Data

The data for our analysis is from the Bangladesh Integrated Household Survey 2011-12 (BIHS) dataset, which was collected from October 2011 to March 2012. The USAID-funded survey was designed and supervised by the International Food Policy Research Institute (IFPRI), administered by Data Analysis and Technical Assistance, Dhaka, Bangladesh, and approved for publication by the Government of Bangladesh (Ahmed 2013). BIHS has a sample size of 6,500 rural households from 325 primary sampling units. Statistically, BIHS is nationally representative of the rural areas of each of the seven administrative divisions of Bangladesh. All surveyed rural households have direct connections to agricultural production even if not directly farming household themselves.

The BIHS data includes information on household composition such as family size and employment status, age and education of the household head and other members. On average, household heads are 44.18 years old and have 3.33 years of schooling. Average household size is 4.20, with 1.71 earning members, 1.05 student members and 0.26 migrant members (Table 1).

Plot-level data includes the size (i.e., decimals), category (i.e., homestead land, cultivable land, other land, etc.), quality (e.g., soil type and current value of land) and ownership of land plots. Although the survey reports some measures of land and soil quality, they might not be reliable in absence of a properly working formal land market. Therefore, we do not employ a hedonic approach and also do not include the measures of quality in our regression analysis. On average, households own 45.95 decimals of land, rent-in 28.78 decimals and rent-out 17.20 decimals. Moreover, among the farmers simultaneously renting in and out, those figures are 11.27, 88.41 and 52.94 decimals, respectively.

The BIHS also contains data on agricultural production and cost such as area under different crops, crop yields, input use and expenditure on inputs (e.g., seeds, irrigation, fertilizers, pesticides, machineries and labor use) and farming assets (e.g., purchase price and current value of assets owned or used by the household for agricultural production). On average, the value of agricultural yields is US$ 425.44, whereas the value of agricultural assets is US$ 50.80. In addition, the survey reports household's total other income, which combines the non-agricultural incomes, transfers, savings and loan. Together, households on average earn US$ 695.15 from both agricultural and non-agricultural sources.

The survey also includes information on the number of bovine animals owned and reared by the household and the amount of land area under fish cultivation. On average, each household owns 1.51 animals such as cow, goat and sheep and cultivates fish on 5.68 decimals of land. The BIHS also reports that 6.09 percent households have access to agricultural extension services, whereas 8.68 percent have been benefited from agricultural subsidy.

The BIHS reports information on a household's exposure to any negative shock (e.g., death of main earner, loss of a regular job, loss of assets, crop loss, loss or decrease of remittances, natural calamities). We are particularly interested in household-specific reporting of exposure to natural disasters. Table 1 indicates that 14 percent of the surveyed households were affected by natural disasters over the five years of interest, 2006 to 2011. We use the self-reported household-level exposure to disaster from the BIHS in our subsequent analysis, therefore overcoming the limitations of using regional level disaster exposure data.[3]

Finally, the BIHS contains indirect data on the availability of local level infrastructure such as markets, paved roads and town. Common survey proxies of such infrastructural access include distances of nearest market and main road from the homestead. Table 1 reports that on average, households are located 2.19 and 1.75 kilometers away from the nearest main road and market.

III.B Empirical Strategy

Since farmers are the primary victims of natural disasters in rural areas, investigation into the ways of agricultural adaptation to disaster exposure is important. For example, land rentals can serve as a risk coping strategy if rental decisions are made in response to shocks resulting in income losses (Ward and Shively 2011).[4] Farmers make livelihood decisions based on their owned or operated land, and such decisions may often be motivated by exposure to extreme climatic events. The key idea behind quantity adjustment through a land rental market is that, in response to exposure to a natural disaster, larger farmers rent-out their surplus lands to smaller farmers, who rent-in to optimize their operational land.

[3] For example, note from Table A1 that most of the disasters in Bangladesh during 2006-11 affected specific regions. In addition, certain regions experience recurring natural disasters, which make it difficult to identify random treatment and control groups at the regional level. Moreover, the EM-DAT database that is the source of Table A1 only reports a disaster if one of these four criteria is fulfilled: 1) 10 or more people are reported killed, 2) 100 or more people are reported affected, 3) declaration of a state of emergency, and 4) call for international assistance. However, in many cases, this is a highly restrictive definition to identify the number of affected people, and therefore, undermines the potential effects of disaster exposure at the household level.

[4] Ward and Shively (2011) employed pooled cross-section instrumental variables probit and 3sls estimates to identify that Chinese households engage in land rentals as a response to covariate shocks, but not in response to idiosyncratic shocks. To our knowledge, this is the only previous study of the role of the land rental market in facilitating adaptation to disasters. However, the authors did not consider the land rental market as a means of indirectly adapting land operation and yields to disasters, which is a key contribution of our paper.

We develop a conceptual model similar to Deschenes and Greenstone (2007).[5] For simplicity, we assume that the land rental market always clears irrespective of whether or not a disaster takes place. We assume that all the land rental market transactions take place within the same rural community. Price is normalized to unity. Output and cost are functions of operational land, whereas land volumes are functions of disaster exposure. However, optimal amounts of rent-in and rent-out depend on whether a disaster takes place or not so that $l^i = l^i(\tau)$ and $l^o = l^o(\tau)$ denote a representative farmer's optimal amounts of rent-in and rent-out, respectively, where $\tau = 1$ represents exposure to a natural disaster, and $\tau = 0$ indicates no such exposure. The representative farmer produces a given crop (or a given mix of crops) and is unable to switch crops in response to disaster exposure. Therefore, capturing the effects of operational farm size adjustments on agricultural yield requires maximizing the following profit function:

$$(1) \qquad \pi = (1 - \alpha\tau)q\left(l + l^i - l^o\right) - c\left(l + l^i - l^o\right) + \left(l^o - l^i\right)r,$$

where q, l, c and r, respectively, denote agricultural output, amount of owned-operated land, cost of production and the equilibrium rent per-unit of land. Total operational farm size is $L = l + l^i - l^o$. $\alpha \geq 0$ indicates the loss in agricultural yield due to disaster exposure that results in lowering the productivity of operated land.

Since disaster exposure affects rent-in and rent-out amounts as well as the output, we need to disentangle the direct and indirect effects of disaster exposure. The representative farmer's profit changes with disaster exposure according to:

$$(2) \qquad \frac{\partial\pi}{\partial\tau} = -\alpha q + [(1 - \alpha\tau)q' - c' - r]\left(l^{i'} - l^{o'}\right),$$

where the first term, $-\alpha q$, accounts for the direct effect of a disaster on agricultural output; whereas the second term, $[(1 - \alpha\tau)q' - c' - r]\left(l^{i'} - l^{o'}\right)$, accounts for the indirect effect of a disaster on agricultural output through the land quantity adjustment. In general, $-\alpha q < 0$ implies that exposure to disaster lowers agricultural yield. The second term corresponds to

[5] In case of US agriculture, Deschenes and Greenstone (2007) exploited the random year-to-year variation in temperature and precipitation to estimate whether agricultural profits are higher or lower in years that are warmer and wetter. Specifically, they estimated the impacts of temperature and precipitation on agricultural profits and then multiply them by the predicted change in climate to infer the economic impact of climate change in this sector. We differ by exploiting disaster-induced variations, other than continuous measures of climatic changes.

the net effect of land quantity adjustment on agricultural yield, which includes the agricultural income from rented and operated land, money received from rent-out land and money paid for rent-in land.

Although it is evident that disaster exposure lowers income, BIHS data show that Bangladeshi farmers exposed to disaster in fact have significantly higher agricultural and total income than unexposed farmers. However, any conclusion drawn on these results may be misleading since the decomposition of the sources of yield is important to understand whether the exposed farmers did not experience any loss from disaster or they have adapted effectively to overcome those losses. We explain this situation by exploiting the variations in probabilities of agricultural land rental market participation and amounts of land traded: disaster exposed farmers have significantly higher probabilities and amounts of rent-in and rent-out of agricultural lands (Table 1 and Figure 1). Panel A in Figure 1 shows the unconditional probabilities of participation in the rental market. Clearly, disaster-affected farmers have higher probability of rent-in and lower probability of rent-out than unaffected farmers. Similarly, Panel B shows that disaster-affected farmers rent-in considerably higher amounts of land than unaffected farmers, whereas they rent-out lower amount of land.

Common adaptation practices in response to disaster exposure in Bangladesh include crop switching, migration and increased labor supply (e.g., Moniruzzaman 2015; Penning-Rowsell, Sultana, and Thompson 2013; Banerjee 2007; Mueller and Quisumbing 2011). For example, Moniruzzaman (2015) employed a multinomial logit model to identify that farmers adapt to changing temperature and rainfall by switching to more climate-resilient crops. However, climatic extremes require immediate response to overcome the immediate harms, whereas a change in cropping patterns requires longer planning horizon and is more pertinent to continuous measures of climatic changes such as longer term variations in rainfall and temperature.

Penning-Rowsell, Sultana, and Thompson (2013) found that permanent migration is an unlikely response of rural people who are less likely to migrate even in the face of extreme disasters, although they may temporarily migrate to safer places. This tendency is historically true for Bangladesh. For example, even the people affected by the 1970 great Bhola Cyclone did not migrate permanently (Sommer and Mosley 1972). Moreover, summary statistics in Table 1 reveal that both the exposed and unexposed farmers have similar probabilities and numbers of migration. In fact, unexposed farmers have insignificantly higher probability of migration and number of migrants than exposed farmers. Therefore, temporary migration does not appear to result in the effective adaptation of the exposed farmers.[6]

Banerjee (2007) identified that there can be increased supply of unskilled labor in the aftermath of floods, especially to plant agricultural lands. Mueller and Quisumbing (2011) found that the 1998 flood in Bangladesh resulted in greater short-term declines in agricultural than non-agricultural wages, and therefore, workers switching from agricultural to non-agricultural employment coped better. Table 1 shows that disaster exposed farmers actually have better access to infrastructural facilities such as marketplaces and main roads, and, therefore, might have better access to non-agricultural informal labor employment. However, both the exposed and unexposed groups of farmers have very low and similar levels of education, which is the primary determinant of non-agricultural employability.

Table 1 also compares the generic characteristics of the farmers exposed and unexposed to natural disasters. Both the groups have similar levels of education, non-agricultural household assets and access to migrants' remittances (i.e., number of migrants). Unexposed farmers experience significantly higher number of idiosyncratic shocks and have significantly better access to infrastructural facilities (e.g., lower distance from the nearest marketplace and main road) and lower number of dependent student members in the family. On the other hand, disaster-exposed farmers have significantly higher landholding, better access to agricultural extension services and subsidy, agricultural assets and number of earning members in the family. All these variables are important in determining the effects of disasters, and we include them in our econometric specifications in the following section.

IV. EMPIRICAL SPECIFICATIONS

We examine the effects of disaster exposure on agricultural yield, controlling for land quantity adjustment through farmer's participation in the land rental market. Note that, to avoid any potential bias arising from multiple use of a plot of land, we restrict our estimation to agricultural plots only. Our econometric approach accounts for both the extensive and intensive margins. First, the extensive margin of the effects of disaster involves land quantity adjustment through the rental market, which is derived by a system of equations on selectivity-corrected samples. Both the rent-in and rent-out quantities are left-censored due to farmer's participation decisions: a positive amount of land brought into rental market for either renting-in or renting-out is observed only when a farmer decides to participate in the

[6] In Appendix E, we show that migration does not work as an indirect adaptation to disasters in Bangladesh.

rental market. Thus, the participating samples are nonrandom, and are drawn from a wider population of farmers. Both choices must be modeled to avoid sample selection bias. In addition, recent evidence indicates that such rent-in and rent-out decisions can be simultaneous in case of Bangladesh (Rahman 2010).[7] According to the BIHS dataset, 9.53 percent of farmers participating in the land rental market simultaneously rent-in and rent-out different plots of agricultural land (Ahmed 2013).

Following Pfeiffer and Lin (2014), we use Lee's generalization of Amemiya's two-step estimator to a simultaneous equations model (Lee 1990), which is asymptotically more efficient than Heckman's selection model (Heckman 1978), when estimating a system of equations. At any point in time, the decision to participate in the land rental market and the optimal quantities of rented-in and rented-out land by each farmer can be estimated as a two-step process. First, a farmer i participates in the land rental market according to:

$$\begin{aligned} L_{i1} &= f(w_i, x_i, z_i, \Delta, \varepsilon_{i1}) \\ L_{i2} &= f(w_i, x_i, z_i, \Delta, \varepsilon_{i2})' \end{aligned} \quad (3)$$

where $\varepsilon_{i1} \sim (0, \sigma_1^2)$, $\varepsilon_{i2} \sim (0, \sigma_2^2)$ and $cov(\varepsilon_1, \varepsilon_2) = \rho$. Binary outcome variables representing farmer's willingness to participate in the land rental market, L_{i1} and L_{i2}, are defined as $L_{i1} = 1$ if the farmer rents in land and 0 if not and $L_{i2} = 1$ if the farmer rents out land and 0 if not. Vectors w_i, x_i and z_i, respectively, contain the infrastructural variables, conventional controls and environmental factors; whereas, Δ is the vector of district dummies to control for any unaccounted regional effects.

Our empirical approaches to estimating (3) involve specifying the components of the vectors w_i, x_i and z_i based on the information available in the BIHS dataset. First, we include the infrastructural variables in w_i, which consists of logged distances of the farmer's homestead from the nearest market and main road. Typically, distance from market measures the access to non-agricultural employment which might also have mitigating effects on the exposure to a natural disaster. For example, Kung (2002) found that Chinese households with active participation in off-farm labor markets have rented less land. On the other hand, both the distances from market and main road indirectly control for the non-agricultural and commercial use of a plot of land. Generally, better access to such infrastructural facilities lowers the dependency on agriculture, and, therefore, may affect rental market participation.

[7] Rahman (2010) adopted a multivariate tobit structure to identify the joint determinants of simultaneously made rent-in and rent-out decisions by rural Bangladeshi farmers.

Moreover, in absence of a direct measure of migration in response to disaster exposure, they also control for farmer's likeliness to migrate to unaffected or urban areas.

We follow existing literature to specify generic determinants, x_i, of agricultural land rental decisions, which commonly include household- and farm-level characteristics (e.g., Taslim and Ahmed 1992; Deininger, Zegara, and Lavadenz 2003; Teklu and Lemi 2004; Deininger and Jin 2005; Rahman 2010). A household is defined as the number of people dine-in together from the same pot. Household characteristics include the age and years of schooling of the household head, numbers of income earners and students in the family, whether the family has a migrant member, and logged per-capita values of agricultural and other household assets. It also includes diversification in farming structure and access to agricultural facilities. Diversification in farming structure is measured by the logged number of bovine animals owned and reared and logged decimals of land under fish cultivation by the household. On the other hand, agricultural facilities include agricultural extension services (defined as 1 if the household has access to agricultural extension services and 0 if not) and subsidy (defined as 1 if the household has received agricultural subsidy and 0 if not).[8,9]

Finally, z_i includes our variables of interest defining disaster exposure of a household. We define the binary measure of exposure to natural disasters, with a value equal to 1 if the household was exposed to any flood or storm in last five year and 0 if it was not exposed. In addition, since the amount of landholding influences the renting decisions in general (e.g., Rahman 2010), we interact our binary disaster variable with logged per-capita farm size. Moreover, to control for the influence of idiosyncratic shocks such as illness or death of a family member, we include the number of idiosyncratic shocks as an additional control.[10]

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[8] Bandyopadhyay and Skoufias (2015) identified ex ante occupational diversification, together with policy interventions such as access to market, credit and safety net, as an autonomous and proactive adaptation strategy in Bangladesh.

[9] In case of Bangladesh, Taslim and Ahmed (1992) found that farm size, number of workers or income earning members in the family and access to agricultural assets such as ownership of bullocks are important determinants of land rental market transactions in Bangladesh.

[10] Usually farmers sell land and other valuables, which provide immediate flow of money, in response to idiosyncratic shocks (Platteau 2000). Agricultural adaptation to natural disasters requires optimizing the operational farm size, which might be done through either the land sales market or the land rental market. However, in absence of perfectly functioning credit and insurance markets alongside low per-capita farm size, land rental markets might be right source of optimizing the operational farm size (e.g., Vranken and Swinnen 2006). Moreover, in absence of a perfect rental market, farmers engaging in land rental transaction are mainly share-croppers and the cash transactions are rare in developing countries like Bangladesh. In Appendix D, we

The purpose of the system of equations (3) is to select the sample of farmers participating in the land rental market either to rent-in or rent-out land. Employing the bivariate probit estimation method, we simultaneously calculate the inverse mills ratios IMR_1 and IMR_2. We then include IMR_1 and IMR_2 as explanatory variables when estimating the optimal land quantity adjustment to correct the sample of land rental market participants and also to control for the information contained in the cross-equation correlations. The extensive margins are estimated from a system of equations determining the optimal quantities of rent-in and rent-out land by a participating farmer i according to:

$$(4) \qquad \begin{array}{l} L_{i1}^{*} = g(x_i, z_i, \Delta, IMR_1, \xi_{i1}) \\ L_{i2}^{*} = g(x_i, z_i, \Delta, IMR_2, \xi_{i2})' \end{array}$$

where L_{i1}^{*} and L_{i2}^{*}, respectively, denote the optimal amounts of rent-in and rent-out land, which are observed when $L_{i1} > 0$ and $L_{i2} > 0$, respectively. We empirically define the outcome variables L_{i1}^{*} as natural log of one plus decimals of rent-in land by farmer i and L_{i2}^{*} as natural log of one plus decimals of rent-out land by farmer i. We exclude the vector w_i, which supposedly affect the participation decision but not the optimal quantity adjustment decision, from (4) since parameters in selection models are estimated with more precision if some regressors in the selection equation can be excluded from the outcome equation (Wooldridge 2010).

The intensive margin of the effects of disasters involves the direct effects of disasters on agricultural yield conditional on the amounts of rent-in and rent-out land. We employ following ordinary least squares model on the selectivity-corrected sample:

$$(5) \qquad Y_i = h(L_{i1}^{*}, L_{i2}^{*}, x_i', z_i, \Delta, \epsilon_i),$$

where Y_i represents agricultural income, defined as natural log of one plus the market value of total harvested crops, minus the monetary value of the payments for rent-in land and plus the monetary value of the receipts from rent-out land. We consider all harvested crops and their local market prices reported by farmers when calculating total yield. In fact, we adopt a modified Ricardian model in (5) where we use total crop revenues as our outcome variable instead of land values in order to capture the effects of disaster exposure in agriculture. The

show that exposure to idiosyncratic shocks does not result in similar variations in agricultural yields and land rental market. Therefore, land rental market does not work as a source of indirect adaptation to idiosyncratic shocks. This finding is consistent with Ward and Shively (2011), who identified that Chinese households engage in land market rentals as a response to covariate shocks, but not in response to idiosyncratic shocks.

use of revenue is particularly appropriate in this set-up since land markets are often imperfect in Bangladesh like many other developing countries (Di Falco, Veronesi, and Yesuf 2011), and the use of land values requires fully functioning land markets so that land prices reflect the present discounted value of land rents into the infinite future (Deschenes and Greenstone 2007).

We include the volumes of rent-in and rent-out land in (5), which connect the coefficients of the components of z_i in (4) with (5). The vector of controls x_i' is different than x_i, it excludes number of students, other household assets, number of animals and area under fishing which are not relevant to agricultural production; whereas includes logged labor hours spent on land preparation, planting, fertilizer, pesticide, weeding, irrigation and harvesting.

Following Moore, Gollehon, and Carey (1994), the total marginal effect of natural disaster exposure is the sum of the effect along the intensive margin from the selectivity-corrected agricultural yield in equation (5) and the effects along the extensive margin from the selectivity-corrected quantity adjustment in equation (4):

$$(6) \qquad \frac{dY}{dz} = \frac{\partial Y}{\partial z} + \frac{\partial Y}{\partial L_1^*}\frac{\partial L_1^*}{\partial z} + \frac{\partial Y}{\partial L_2^*}\frac{\partial L_2^*}{\partial z},$$

where $\frac{\partial Y}{\partial z}$ is the intensive margin, and $\frac{\partial Y}{\partial L_1^*}\frac{\partial L_1^*}{\partial z}$ and $\frac{\partial Y}{\partial L_2^*}\frac{\partial L_2^*}{\partial z}$ denote the extensive margins from rent-in and rent-out of agricultural land.

V. RESULTS AND ANALYSIS

Tables 2 and 3 report the regression results based on equations (3)–(5). We do not report the district dummies in the appended regression tables. In general, control variables show similar directions of association in all the regressions, and we confine the discussion of results only to the analysis of key parameters of interest.

Table 2 reports the bivariate probit estimation results based on equation (3), which represents the rental market participation decisions to rent-in and rent-out agricultural land. Statistically significant value of ρ justify the use of bivariate probit models rather than separate probit regressions. We find that disaster exposure increases the probability of rent-in by 55.8 percent and decreases the probability of rent-out by 86.8 percent. However, evaluated at the mean of logged per-capita farm size equal to 1.271 for the estimating sample, larger farmers exposed to disasters, on average, have 26.2 percentage points lower probability of rent-in and 63.5 percentage points higher probability of rent-out. These results are consistent with Figure 2, where Panels A–D exhibit the probabilities of rent in, rent out, simultaneously rent in and out and no rental transactions, respectively, for exposed and unexposed farmers.

However, main purpose of equation (3) is to overcome the sample selection bias. We simultaneously estimate the inverse mills ratios from bivariate probit regressions, which are then used as additional regressors in corresponding estimations of equation (4). Table 2 also reports the extensive margins from seemingly-unrelated regression estimates on selectivity-corrected samples of rental market participants. Evaluating at the mean value of logged per-capita farm size, which is equal to 1.818 for the estimating sample, we find that the farmers exposed to disasters have 16.8 percent higher amounts of land rented-in and 1.3 percent lower amounts of land rented-out. These results confirm the key idea behind quantity adjustment: larger farmers rent-out and smaller farmers rent-in to optimize their corresponding operational farm sizes.

Table 3 reports the effects of disasters on agricultural yield along the intensive margin conditional on land quantity adjustments. We find that both the rent-in and rent-out amounts increase the agricultural yield by 9.7 percent and 14.8 percent, respectively. These results are consistent with our definition of agricultural yield, which includes the monetary value of receipts from rent-out and excludes the monetary value of payments for rent-in. In addition, consistent with the results in Table 2, the coefficient of disaster exposure is negative, and that of the interaction between disaster exposure and logged per-capita farm size is positive. That is, while disasters cause harms to agricultural yield, the severity is lower for the larger farmers.

We are mainly interested in the total marginal effects of disaster-exposure on agricultural yield, which can be calculated using the equation (6). Using the regression results from Tables 2 and 3, we calculate the total intensive margin (Table 4), total extensive margin (Table 5) and total marginal effects (Table 6). All the calculations are based on the coefficients of logged rent in and rent out amounts and the interaction between logged per-capita farm size and disaster exposure, all of which are statistically significant in all the regressions. Evaluated at the mean value of logged per-capita farm size of the estimating equation (4), we estimate a total intensive margin of -1.18 percent. That is, exposure to disasters directly lowers the agricultural yield by 1.18 percent. However, farmers engaging in the land rental market can compensate themselves for these direct losses from disaster. We also identify that farmers can have a 1.63 percent increase in agricultural yield from renting in agricultural land. Although they experience a decrease in yield by 0.19 percent because of renting out, a net 1.44 percent extensive margin from land rental market transactions sufficiently covers the direct losses from exposure to disasters. In total, we identify that the farmers transacting in the land rental market to optimize their operational farm size in the wake of a disaster ultimately experience a 0.25 percent higher agricultural yield.

Our total margins estimates are consistent with the general findings of Mendelsohn (2008), who concluded that adaptation by farmers will partially offset some of the worst predicted damages to agriculture due to warming in developing countries over the next century. Our results suggest that the land rental market could enable farmers to more than overcome any agricultural yield losses from disaster exposure. Such adaptation by farmers in response to natural disasters may be more prevalent than previously thought. In related literature, for example, Banerjee (2010a) found that while severe flooding may lower agricultural yield in disaster months, they may also provide open-access irrigational input that lead to significant increases in post-flood productivity.

We also investigate the role of land rental market transactions on total household income, which is the sum of agricultural and non-agricultural incomes. Table 2 reports the extensive margins, whereas the last column in Table 3 reports the intensive margins. Consistent with our estimate of total marginal effect for agricultural yield, we find that land rental market transactions to optimize operational farm size also facilitate indirect adaptation to total household income.

Moore, Gollehon, and Carey (1994) found that the estimates of extensive margins will be similar from a multivariate tobit model. For a robustness check, we employ a multivariate tobit model instead of our original empirical specifications of extensive margins in (3) and (4). Detail specification and results are reported in Appendix B. Consistent with Moore, Gollehon, and Carey (1994), this alternative specification yields results similar to Tables 2–6. Therefore, our estimates are robust to alternative methods of estimation.

As another robustness check, we use a continuous measure of the severity of disasters defined as the natural log of immediate monetary losses from exposure to disasters in the last five years. BIHS dataset contains household-specific self-reported loss figures. Detail discussion and results are reported in Appendix F. Employing the same econometric specification, we identify that all the directions of relationship are same to those reported in Tables 2 and 3. Moreover, consistent with the results in Table 6, we identify that farmers exposed to disasters were able to reduce their losses through participation in the land rental market. In particular, we find that a 1 percent increase in the losses from disasters directly reduces the agricultural income by 0.25 percent; whereas those adjusting their operational farm size were able to reduce that harms of disaster by 0.14 percent. Similarly, a 0.03 percent direct reduction in total income is compensated by an indirect increase of 0.13 percent. Therefore, our estimates are robust to alternative definition of disaster exposure.

VI. CONCLUSIONS

We examine agricultural adaptation to disaster exposure through simultaneously made rent-in and rent-out choices in the land rental market. We employ an econometric approach based on Lee (1990) and Moore, Gollehon, and Carey (1994) and Pfeiffer and Lin (2014) that accounts for both the intensive and extensive margins. Evaluated at the mean value of (logged) per-capita farm size, we find that disaster-exposure results in 0.25 percent net increase in yield: a 1.18 percent direct decrease in yield is compensated by a 1.4 percent indirect increase through land rental market transactions. Therefore, farmers exposed to disasters appear to have successfully overcome the losses from disaster by adjusting their operational farm size through simultaneously made rent-in and rent-out decisions in the agricultural land rental market.

Accounting for the effects of disaster exposure on adjustments in quantity of operated land and its impact on agricultural yield is important since disaster exposure results in losses in income (IPCC 2012). Such a relationship may be especially relevant when farmers actively participate in land rental markets (Figure 1). Our results have important implications for Bangladesh and other low-income countries in terms of land management, economic welfare and disaster risk reduction. In general, low-income countries have high degrees of land fragmentation, severe incidences of poverty and low per-capita arable land, contributing to increasing number of farms to increasingly depend on rented lands for managing operational farm size (Deininger, Savastano, and Carletto 2012; Jin and Jayne 2013; Masterson 2007; Sklenica *et al.* 2014). Here, we find another important function of the land rental market in poor rural areas, which is to assist farmers in adapting to the adverse impacts on agricultural yield from natural disasters. Such a mechamism may become increasingly important as an adaptation response to climate change: since farmers appear to employ the land rental market to adjust the quantity of operational land to adapt to the losses of past disasters and to mitigate the potential losses of future disasters, the land rental market provides a useful mode of climate change adaptation relevant for any low-income agricultural country with recurrent disaster exposure.

As this paper suggests that access to a well-functioning land rental market might be a crucial part of the coping strategy that allows farmers to adjust their agricultural yields, improving and facilitating the functioning of such markets in rural areas should be an important component of government post-disaster relief policies. Of particular concern is that the land rental market in rural areas of Bangladesh, as well as in many other low-income countries, is an informal institution. More research needs to be conducted on how well such informal land-rental markets function in the aftermath of natural disasters, and whether more formal markets would facilitate the role of the rental market in assisting farmers to adjust to the agricultural yield impacts of disasters.

One important direction of future research is to address the effects of land quantity adjustment on the sustainability of land and soil resources in addition to the agricultural yield effect explored in this paper. However, since adaptation increases food productivity (Di Falco, Veronesi, and Yesuf 2011), it may imply that farmers actually adapt to food scarcity and not to climatic extremes. This argument justifies the short-term nature of responses to disaster exposure such as adjusting operational land quantity as outlined in this paper. However, since weather extremes are noticed much earlier than changes in mean climate (Katz and Brown 1992), adaptation practices need to be incorporated in short-term investment decisions as well (Fankhauser, Smith, and Tol 1999). Therefore, although the debate will remain whether land quantity adjustment as adaptation to disasters is good for environmental sustainability, farmer's adoption of this channel of adaptation helps them at least to overcome the immediate harms of a disaster.

FIGURES

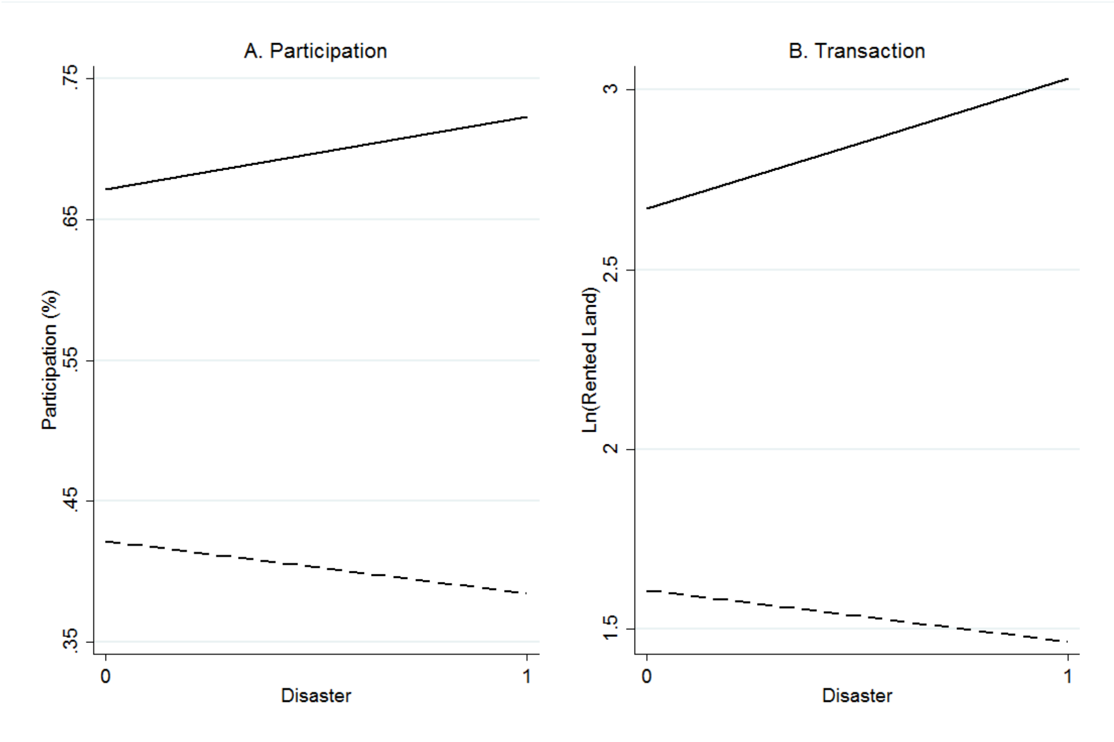

Figure 1. Land rental market participation and transaction

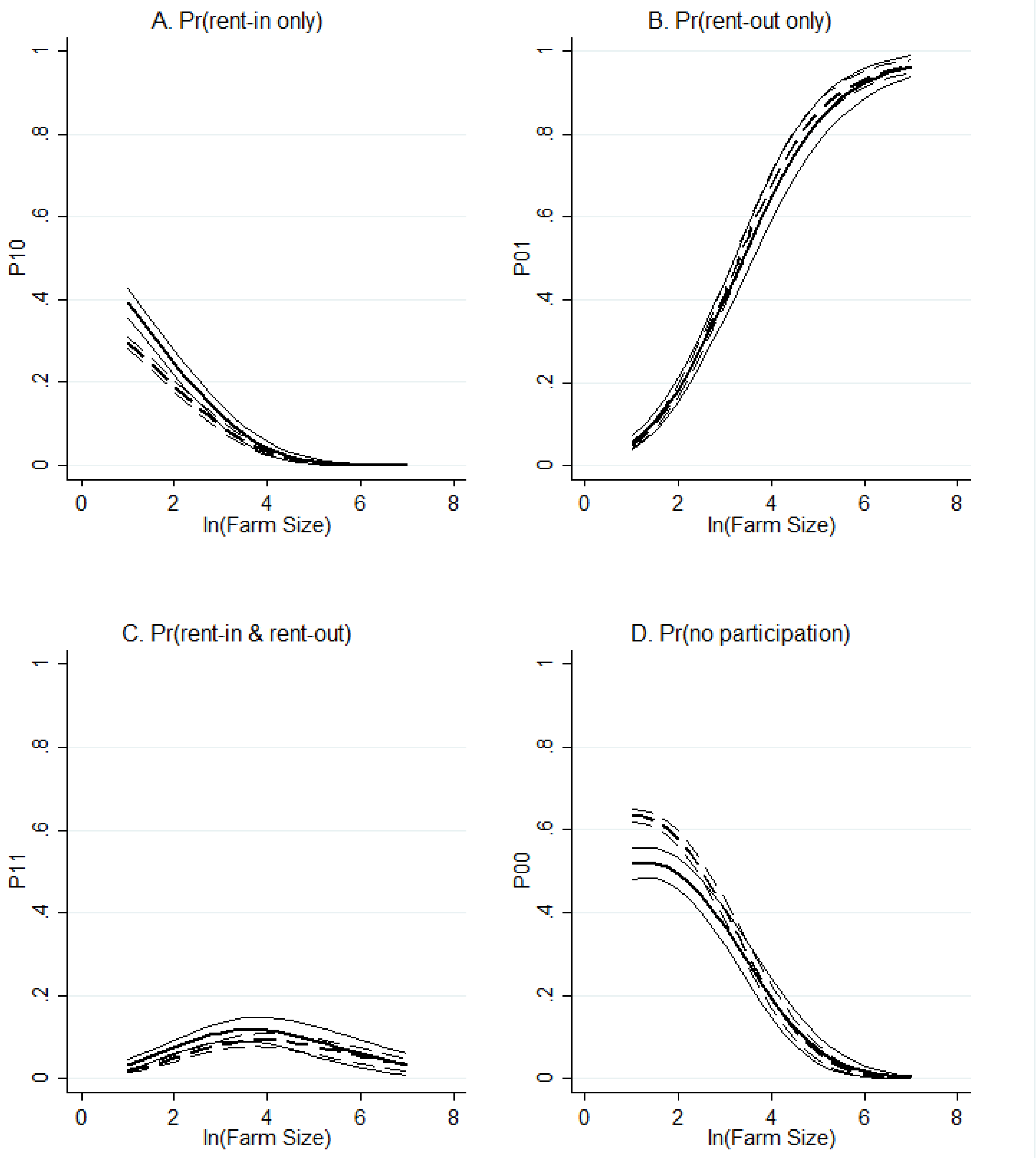

Figure 2. Probability of renting and farm size

Notes. Solid and dashed lines correspond to disaster exposure and no exposure, respectively. Thinner lines represent 95% confidence intervals.

TABLES

Table 1 – Summary Statistics by Disaster Exposure

Variables	Description	Mean by disaster exposure			
		All	Unexposed (μ_0)	Exposed (μ_1)	Mean difference ($\mu_1 - \mu_0$)
Disaster	1 if the household was exposed to any natural disaster in last 5 years, 0 if not.	0.143			
		(0.350)			
Agricultural Yield	(Logged) value of agricultural yield	9.175	9.097	9.610	0.513***
		(1.961)	(1.969)	(1.858)	(0.073)
Total income	(Logged) per-capita non-agricultural incomes and receipts in 2011 taka	9.903	9.843	10.233	0.389***
		(1.861)	(1.887)	(1.672)	(0.070)
Rent-in	1 if rented-in, 0 if not	0.340	0.320	0.457	0.138***
		(0.474)	(0.466)	(0.498)	(0.017)
Rent-out	1 if rented-out, 0 if not	0.207	0.201	0.243	0.042***
		(0.405)	(0.401)	(0.429)	(0.014)
Land-in	(Logged) volume of rented-in arable land (decimals)	1.365	1.272	1.918	0.646***
		(1.980)	(1.927)	(2.196)	(0.070)
Land-out	(Logged) volume of rented-out arable land (decimals)	0.789	0.767	0.927	0.161***
		(1.630)	(1.612)	(1.731)	(0.058)
Age	Age of the household head	44.176	43.956	45.492	1.536***
		(13.982)	(14.044)	(13.534)	(0.495)
Education	Years of schooling of the household head	3.331	3.314	3.435	0.121
		(3.937)	(3.941)	(3.909)	(0.140)
Household size	Number of dine-together family members	4.196	4.159	4.418	0.259***
		(1.628)	(1.623)	(1.641)	(0.058)
Students	Number of school-going members in the family	1.049	1.035	1.132	0.097***
		(1.046)	(1.045)	(1.049)	(0.037)
Earners	Number of income earning members in the family	1.709	1.668	1.952	0.283***
		(0.993)	(0.991)	(0.969)	(0.035)
Household assets	(Logged) value of non-agricultural assets (taka)	10.062	10.062	10.059	-0.003
		(1.455)	(1.447)	(1.501)	(0.052)
Agricultural assets	(Logged) value of agricultural assets (taka)	4.657	4.597	5.022	0.425***
		(3.215)	(3.232)	(3.088)	(0.114)
Farm Size	(Logged) per-capita landholding	1.275	1.215	1.638	0.423***
		(1.529)	(1.508)	(1.604)	(0.054)
Extension	1 if the household has access to agricultural extension services, 0 if not.	0.061	0.055	0.098	0.043***
		(0.239)	(0.228)	(0.297)	(0.008)
Subsidy	1 if the household has agriculture input subsidy card, 0 if not.	0.087	0.071	0.182	0.111***
		(0.282)	(0.257)	(0.386)	(0.010)
Animals	Number of bovine animals owned by the household	0.643	0.625	0.748	0.123***
		(0.712)	(0.708)	(0.727)	(0.025)
Fishing	Total area (pond/water-body) under fishing by the household (decimals)	0.455	0.405	0.758	0.353***
		(1.082)	(1.006)	(1.419)	(0.038)
Main road	Distance from the nearest main road (in km)	2.193	2.053	3.037	0.984***
		(4.058)	(3.561)	(6.201)	(0.145)
Market	Distance from the nearest weekly/periodic market/bazaar (in km)	1.748	1.730	1.858	0.129**
		(1.691)	(1.634)	(1.998)	(0.060)
Any migrants	1 if the household has at least one migrant member, 0 if not	0.207	0.258	0.241	-0.017
		(0.405)	(0.558)	(0.561)	(0.020)
Number of migrants	Number of migrant members in the household	0.256	0.210	0.191	-0.019
		(0.559)	(0.407)	(0.393)	(0.014)
Number of idiosyncratic shocks	Number of idiosyncratic shocks experienced by the household in last 5 years	1.062	1.134	0.629	-0.506***
		(0.508)	(0.405)	(0.775)	(0.017)
Number of observations		6,500	5,571	929	

Notes. Number of observations is 6500. In section III.A, we use US$ equivalent of the monetary figures reported in this table at the exchange rate of US$1=BDTk82.00 as of January 1, 2012.

Table 2 – Participation Choices and Extensive Margins

	Land Market Participation Choices		Indirect Effects of Disaster Exposure	
Variables	**Rent-in**	**Rent-out**	**Ln(land-in)**	**Ln(land-out)**
Disaster	0.558***	-0.868***	0.973***	-1.329***
	(0.096)	(0.131)	(0.134)	(0.201)
Ln(Farm Size)*Disaster	-0.211***	0.500***	-0.443***	0.724***
	(0.039)	(0.047)	(0.047)	(0.090)
Number of Other shocks	-0.051	0.126**	-0.024	0.170**
	(0.042)	(0.052)	(0.066)	(0.068)
Extension	0.332***	-0.144	0.593***	-0.297***
	(0.084)	(0.096)	(0.111)	(0.110)
Subsidy	0.507***	-0.109	0.507***	-0.321***
	(0.075)	(0.089)	(0.102)	(0.100)
Age	0.018*	0.015	0.022	0.005
	(0.009)	(0.010)	(0.015)	(0.014)
Squared Age	-0.000***	0.000	-0.000***	0.000*
	(0.000)	(0.000)	(0.000)	(0.000)
Education	-0.047***	0.066***	-0.108***	0.147***
	(0.006)	(0.006)	(0.008)	(0.013)
Student Members	0.038*	0.021	-0.041	0.018
	(0.020)	(0.024)	(0.030)	(0.030)
Working Members	0.184***	-0.200***	0.396***	-0.445***
	(0.027)	(0.030)	(0.038)	(0.049)
Ln(Household Assets)	-0.033*	0.223***	-0.217***	0.385***
	(0.018)	(0.023)	(0.027)	(0.044)
Ln(Agricultural Assets)	0.095***	0.009	0.101***	-0.027**
	(0.008)	(0.009)	(0.013)	(0.013)
Ln(Animal)	0.292***	-0.030	0.369***	-0.250***
	(0.035)	(0.039)	(0.049)	(0.048)
Ln(Fish)	0.018	0.105***	0.029	0.203***
	(0.026)	(0.023)	(0.030)	(0.033)
Migration	-0.109*	0.204***	-0.298***	0.452***
	(0.057)	(0.054)	(0.080)	(0.084)
Ln(Road)	0.006	0.005		
	(0.046)	(0.047)		
Ln(Market)	0.053	-0.040		
	(0.051)	(0.062)		
Constant	-1.166***	-4.014***	3.988***	-3.944***
	(0.278)	(0.319)	(0.521)	(0.969)
Observations	6,268	6,268	3,121	3,121
R-squared			0.369	0.402
Wald test of rho=0	73.88	73.88		
BP test of independence			1513	1513

Notes: Standard errors clustered at the village level are shown in parentheses. ***,** and * represent statistical significance at 1, 5 and 10 percent levels, respectively. We do not report the district dummies; however, they are available upon request. Participation choices, i.e., rent-in and rent-out, are estimated using a bivariate probit model according to specification (3), where the binary dependent variables are rent-in (i.e., 1 if the farmer rent-in land and 0 if not) and rent-out (i.e., 1 if the farmer rent-out land and 0 if not). Statistically significant Wald test validates the use of bivariate probit model instead of separate regressions. Extensive margins, i.e., indirect effects, of disaster exposure are estimated using a seemingly-unrelated regression model according to specification (4), where the dependent variables are Ln(land-in) (i.e., logged 1 plus the amount of rent-in land) and Ln(land-out) (i.e., logged 1 plus the amount of rent-out land). Statistically significant BP test of independence validates the use of SUR model (chi2(1) = 1205***).

Table 3 - Intensive Margins: Direct Effects of Disaster Exposure

Variables	(1) **Ln(Agricultural Income)**	(2) **Ln(Total Income)**
Ln(land-in)	0.097***	0.080***
	(0.013)	(0.014)
Ln(land-out)	0.148***	0.104***
	(0.012)	(0.014)
Disaster	-0.150**	-0.136*
	(0.062)	(0.071)
Ln(Farm Size)*Disaster	0.076***	0.076***
	(0.023)	(0.026)
Number of Other shocks	-0.036	-0.030
	(0.032)	(0.037)
Extension	0.140***	0.139**
	(0.049)	(0.057)
Subsidy	0.063	0.074
	(0.045)	(0.052)
Age	0.003	0.024***
	(0.007)	(0.008)
Squared Age	-0.000	-0.000***
	(0.000)	(0.000)
Education	0.025***	0.038***
	(0.004)	(0.005)
Working Members	0.046**	0.166***
	(0.019)	(0.021)
Ln(Agricultural Assets)	0.091***	0.085***
	(0.007)	(0.008)
Ln(Labor for Land Preparation)	0.036**	0.006
	(0.015)	(0.018)
Ln(Labor for Plantation)	0.202***	0.164***
	(0.020)	(0.023)
Ln(Labor for Fertilizer)	0.134***	0.100***
	(0.026)	(0.030)
Ln(Labor for Pesticide)	0.069***	0.055**
	(0.021)	(0.024)
Ln(Labor for Weed)	0.072***	0.065***
	(0.018)	(0.020)
Ln(Labor for Irrigation)	0.002	0.000
	(0.012)	(0.014)
Ln(Labor for Harvesting)	0.170***	0.087***
	(0.018)	(0.021)
Migration		-0.122***
		(0.047)
Constant	6.338***	6.954***
	(0.232)	(0.266)
Observations	2,542	2,542
R-squared	0.636	0.522

Notes: Standard errors clustered at village level are shown in parentheses. ***,** and * represent statistical significance at 1, 5 and 10 percent levels, respectively. We do not report the district dummies; however, they are available upon request.

Table 4 – Total Intensive Margin

	(1) Ln(Agricultural Income)	(2) Ln(Total Income)
Coefficient on Disaster	-0.150	-0.136
Coefficient on Ln(Farm Size)*Disaster	0.076	0.076
Mean ln(Farm Size)	1.818	1.818
Total Intensive Margin	-0.0118	0.0022

Notes. We use the mean of ln(Farm Size) from the estimating sample of equation (4). Coefficients of "Disaster" and "Ln(Farm Size)*Disaster" come from Table 3. All the coefficients of interest are statistically significant.

Table 5 – Total Extensive Margin

	(1) $\partial Y/\partial L$	(2) $\partial L/\partial z$	(3) $\partial Y/\partial L \, \partial L/\partial z$
Ln(Agricultural Income)			
ln(land-in)	0.097	0.168	0.0163
ln(land-out)	0.148	-0.013	-0.0019
Ln(Total Income)			
ln(land-in)	0.08	0.168	0.0134
ln(land-out)	0.104	-0.013	-0.0013

Notes. We use the mean of ln(Farm Size) from the estimating sample of equation (4). Coefficients of "ln(land-in)" and "ln(land-out)", i.e., $\partial Y/\partial L$, come from Table 3. We evaluated the coefficients of "Disaster" and "Ln(Farm Size)*Disaster" Table 2 at the mean of ln(Farm Size) to estimate $\partial L/\partial z$. All the coefficients of interest are statistically significant.

Table 6 – Total Marginal Effects

	(1) Ln(Agricultural Income)	(2) Ln(Total Income)
Total Intensive Margin	-0.0118	0.0022
Total Extensive Margin from rent-in	0.0163	0.0134
Total Extensive Margin from rent-out	-0.0019	-0.0013
Total marginal effect	0.0025	0.0142

Notes. Total intensive and extensive margins come from tables 4 and 5, respectively. All the coefficients of interest are statistically significant.

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APPENDICES

Appendix A. List of Disasters

Table A1 – List of Natural Disasters in Bangladesh, 2004-2011

Disaster No	Disaster Type	Date started	Totals deaths	Total affected	Total Damage ('000 US$)	Affected Regions (Districts)
2006-0146	Storm	03/04/06	4	5899		Bagerhat, Khulna
2006-0262	Flood	05/31/06		76000		Sylhet, Sunamganj, Moulvibazar, Hobiganj
2006-0502	Flood	08/24/06		135775		Jessore, Khulna, Satkhira
2006-0510	Storm	09/18/06	115	9135		Noakhali, Bagerhat, Potuakhali, Borguna
2006-0737	Storm	04/05/06	9	1465		Dhaka
2006-0738	Storm	04/08/06	22	1500		Tangail, Sirajganj
2006-0739	Storm	04/22/06	4	150		Rajshahi, Khulna, Jessore
2007-0161	Flood	06/11/07	120	80060	14000	Chittagong, Cox's Bazar
2007-0227	Storm	05/15/07	41	225		Chittagong, Cox's Bazar
2007-0311	Flood	07/21/07	1110	13771380	100000	Bandarban, Feni, Comilla, Sirajganj, Manikganj, Rangpur
2007-0556	Storm	11/15/07	4234	8978541	2300000	Khulna, Barisal, Bagerhat, Patuakhali, Barguna, Pirojpur, Jhalokathi, Bhola, Madaripur, Gopalganj, Shariatpur, Satkhira
2008-0285	Flood	06/26/08	16	20002		Chittagong, Cox's Bazar
2008-0385	Flood	08/30/08	12	615638		Bogra, Sirajganj
2008-0644	Storm	03/22/08	12	200		
2008-0648	Storm	10/27/08	15	200		Barisal, Patuakhali
2009-0157	Storm	04/19/09	7	19209		Chittagong, Cox's Bazar, Noakhali, Bhola, Thakurgaon
2009-0204	Storm	05/25/09	190	3935341	270000	Khulna, Satkhira, Patuakhali, Barisal, Barguna, Pirojpur, Jhalokathi, Laxmipur, Jessore, Bhola, Noakhali, Chittagong, Cox's Bazar, Feni, Chandpur, Pirojpur
2009-0294	Flood	07/03/09	6	500000		Habiganj
2009-0304	Flood	07/29/09	10			Dhaka, Comilla, Rajshahi, Chittagong, Barisal, Khulna, Sylhet
2010-0171	Storm	04/13/10	8	247110		Rangpur, Dinajpur, Nilphamari, Lalmonirhat, Kurigram, Gaibandha, Sirajganj, Bogra
2010-0205	Storm	04/17/10	3	10000		Lalmonirhat
2010-0269	Flood	06/24/10		75000		Sylhet, Moulvibazar, Sunamganj, Habiganj, Netrokona, Kurigram, Gaibandha, Lalmonirhat
2010-0676	Flood	10/01/10	15	500000		
2010-0686	Storm	05/01/10	15	50		Mymensingh
2011-0262	Flood	07/21/11	10	1570559		Chittagong, Cox's Bazar, Satkhira, Jessore, Narail, Bagerhat, Chuadanga, Kustia, Bogra, Sirajganj, Pabna, Lalmonirhat, Thakurgaon, Kurigram, Sherpur, Netrokona, Bandarban, Rajbari, Manikganj, Gaibandha, Naogaon
2011-0591	Storm	04/04/11	13	121		Sherpur, Mymensingh, Rangpur, Thakurgaon, Jamalpur, Netrokona, Gaibandha, Pabna

Notes. All data come from the EM-DAT database (http://www.emdat.be/database), an emergency events database collected by the Centre for Research on the Epidemiology of Disasters (CRED).

Appendix B. Alternative Method of Estimation

In this Appendix B, we employ a multivariate tobit model to estimate extensive margins. Farmers make sequential decisions; first 'whether to participate in the land rental market or not'; and then, if participating, 'how much to transact'. The first step measures farmers' willingness to participate in the land rental market either to rent-in or rent-out. Similar to (3), a farmer i participates in the land rental market according to:

$$(3') \qquad \begin{aligned} L_{i1} &= f(w_i, x_i, z_i, \Delta, \varepsilon_{i1}) \\ L_{i2} &= f(w_i, x_i, z_i, \Delta, \varepsilon_{i2}) \end{aligned},$$

where $\varepsilon_{i1} \sim (0, \sigma_1^2)$, $\varepsilon_{i2} \sim (0, \sigma_2^2)$ and $cov(\varepsilon_1, \varepsilon_2) = \rho$. All the vectors of explanatory variables are defined as before. For participant farmers, L_{1i} and L_{2i} equal the actual levels of transaction L_{1i}^* and L_{2i}^*; whereas for non-participant farmers, these are the indices reflecting their willingness to participate in the land rental market. We observe the dependent variables L_{1i}^* and L_{2i}^*, both left-censored at zero, according to:

$$(4') \qquad \begin{aligned} L_{i1}^* &= g(x_i, z_i, \Delta, IMR_1, \xi_{i1}) \\ L_{i2}^* &= g(x_i, z_i, \Delta, IMR_2, \xi_{i2}) \end{aligned}.$$

Table B1 reports extensive and intensive margins. We report only the parameters of interest; however, full regression tables are available upon request. Extensive margins are estimated using the specification (3'), where the dependent variables are Ln(land-in) and Ln(land-out). Intensive margins are estimated using the specification (4').

Table B1 – Extensive and Intensive Margins using Multivariate Tobit Models

	Extensive Margins		Intensive Margins	
Variables	**Ln(land-in)**	**Ln(land-out)**	**Ln(Agricultural Income)**	**Ln(Total Income)**
Ln(land-in)			0.097***	0.080***
			(0.013)	(0.014)
Ln(land-out)			0.148***	0.104***
			(0.012)	(0.014)
Disaster	1.978***	-3.651***	-0.150**	-0.136*
	(0.294)	(0.435)	(0.062)	(0.071)
Ln(Farm Size)*Disaster	-0.756***	1.842***	0.076***	0.076***
	(0.122)	(0.134)	(0.023)	(0.026)
Observations	6,491	6,491	2,542	2,542

Notes: Standard errors clustered at village level are shown in parentheses. ***,** and * represent statistical significance at 1, 5 and 10 percent levels, respectively.

Table B2 reports the estimated total marginal effects. For consistency, extensive margins are evaluated at the mean of ln(Farm Size) from the estimating sample of equation (4). Coefficients of ln(land-in), ln(land-out), Disaster and Ln(Farm Size)*Disaster come from Table B1. All the coefficients of interest are statistically significant.

Table B2 – Total Marginal Effects using Alternative Specification

	Ln(Agricultural Income)	**Ln(Total Income)**
Total Intensive Margin	-0.0118	0.0022
Total Extensive Margin from rent-in	0.0586	0.0483
Total Extensive Margin from rent-out	-0.0447	-0.0314
Total marginal effect	0.0020	0.0190

Notes. For consistency, extensive margins are evaluated at the mean of ln(Farm Size) from the estimating sample of equation (4).

Consistent with Moore, Gollehon, and Carey (1994), results from the alternative estimating method are similar to our main specification. Results show that while the exposure to disaster results in a 1.18 percent direct decrease in yield, those adjusting their operational farm size were able to overcome that loss due to a 1.39 percent indirect increase in yield coming from the land rental market. Results for total income are also similar.

Appendix C. Sources of Variation in yield and rental market transactions

We investigated whether exposure to natural disasters results in variations in 1) agricultural yields and 2) land rental market that works as source of indirect adaptation. In this Appendix C, we investigate 1) whether exposure to idiosyncratic shocks results in similar variations in agricultural yields and land rental market, and 2) whether access to access to migrants' remittances works as source of indirect adaptation to natural disasters.

Table C1 compares mean values of agricultural yield and rental market participation and transactions by exposure to natural disasters, exposure to idiosyncratic shocks and access to migrants' remittances. Table C2 reports the pairwise correlations of natural disasters, idiosyncratic shocks and migration with rental market participation and transactions.

Table C1 – Potential sources of variations in yield

Variables	**Mean differences (exposed and unexposed households: $\mu_1 - \mu_0$)**		
	by natural disasters	**by idiosyncratic shocks**	**by migration**
Yield	0.513***	-0.132**	0.095
Rent-in	0.138***	-0.006	-0.082***
Rent-out	0.042***	0.001	0.125***
Land-in	0.646***	-0.022	-0.332***
Land-out	0.161***	-0.015	0.504***

Table C2 – Pairwise correlation between main variables

	Yield	Rent-in	Rent-out	Land-in	Land-out	Disaster	Shocks	Migrants
Yield	1.000							
Rent-in	0.452***	1.000						
Rent-out	0.175***	-0.118***	1.000					
Land-in	0.475***	0.961***	-0.123***	1.000				
Land-out	0.199***	-0.138***	0.948***	-0.140***	1.000			
Disaster	0.094***	0.102***	0.037***	0.114***	0.035***	1.000		
Shocks	-0.034**	-0.006	0.001	-0.006	-0.004	-0.006	1.000	
Migrants	-0.020	-0.070***	0.125***	-0.068***	0.125***	-0.017	0.006	1.000

Results for natural disasters validate our use of land rental market as a source of indirect adaptation to natural disasters. However, while idiosyncratic shocks significantly lower the agricultural yield of the exposed farmers, we do not observe any significant differences in the land rental market participation and transaction of the exposed and unexposed farmers. Therefore, land rental market does not work as a source of indirect adaptation to idiosyncratic shocks. Statistically insignificant pairwise correlations of idiosyncratic shocks with rental market participation and transactions also support this inference.

On the other hand, families with migrant members have significantly lower rent-in and higher rent-out of agricultural land. However, such adjustments in operational farm size do not affect the agricultural yield. Therefore, we might infer that although migration increases land rental market transactions, it is not a source of agricultural adaptation since it does not affect agricultural yield.

Appendix D. Idiosyncratic shocks as natural experiment

In this Appendix D, we investigate whether exposure to idiosyncratic shocks results in similar variations in agricultural yields and land rental market by employing the econometric specifications (3)–(6), except for considering Shocks and Ln(Farm Size)*Shocks as our parameters of interest. Also, we controlled for the number of natural disasters experienced by a household.

Extensive and intensive margins are reported in Table D1. We report only the parameters of interest; however, full regression tables are available upon request. Extensive margins are estimated using a seemingly-unrelated regression model, where the dependent variables are Ln(land-in) and Ln(land-out). Intensive margins are estimated using the specification (5).

Table D1 – Idiosyncratic Shocks as Natural Experiment

	Extensive Margins		**Intensive Margins**	
VARIABLES	**Ln(land-in)**	**Ln(land-out)**	**Ln(Agricultural Income)**	**Ln(Total Income)**
Ln(land-in)			0.105***	0.086***
			(0.013)	(0.014)
Ln(land-out)			0.130***	0.087***
			(0.012)	(0.014)
Shocks	0.918***	-1.869***	-0.297***	-0.235***
	(0.089)	(0.162)	(0.041)	(0.047)
Ln(Farm Size)*Shocks	-0.480***	1.020***	0.134***	0.115***
	(0.043)	(0.078)	(0.016)	(0.019)
Observations	3,121	3,121	2,542	2,542

Notes: Standard errors clustered at village level are shown in parentheses. ***,** and * represent statistical significance at 1, 5 and 10 percent levels, respectively.

Table B2 reports the estimated total marginal effects of idiosyncratic shocks. Extensive and intensive margins are evaluated at the mean of ln(Farm Size) from the estimating sample. Coefficients of ln(land-in), ln(land-out), Disaster and Ln(Farm Size)*Disaster come from Table D1. All the coefficients of interest are statistically significant. All the coefficients of interest are statistically significant.

Table D2 – Total Marginal Effects of Idiosyncratic Shocks

	(1) **Ln(Agricultural Income)**	(2) **Ln(Total Income)**
Total Intensive Margin	-0.0534	-0.0259
Total Extensive Margin from rent-in	0.0048	0.0039
Total Extensive Margin from rent-out	-0.0019	-0.0013
Total marginal effect	-0.0505	-0.0233

Results show that idiosyncratic shocks result in a 5.34 percent direct decrease in yield. Farmers were able to salvage a mere 0.29 percent of those losses through adjusting their operational farm size, resulting in a net decrease in agricultural yield by 5.05 percent. That is, land rental markets do not work as a source of indirect adaptation to idiosyncratic shocks. Results for total income are also consistent with this inference.

Appendix E. Migration as Adaptation

In this Appendix E, we investigate whether migration works as a source of indirect adaptation to disasters. We employ an econometric specification similar to (3)–(6). First, probability of farmer i to have a migrant member is determined by:

(3′′) $M_i = f(w_i, x_i, z_i, \Delta, \varepsilon_i)$,

where $\varepsilon_{i1} \sim (0, \sigma_1^2)$, $\varepsilon_{i2} \sim (0, \sigma_2^2)$ and $cov(\varepsilon_1, \varepsilon_2) = \rho$. Remittances, R_i, maybe received only if $M_i > 0$. We retrieve the inverse mills ratio from (3''), which is then included in the following remittances demand function:

(4′′) $R_i^* = g(x_i, z_i, \Delta, IMR, \xi_i)$,

which provides the extensive margins on the selectivity-corrected sample. Finally, the intensive margin of the effects of disaster involves the direct effects of disaster on agricultural yield conditional on the amounts of remittances:

(5′′) $Y_i = h(R_i^*, x_i, z_i, \Delta, \epsilon_i)$.

All the vectors of explanatory variables are as defined before, except we do not include the number of migrants as a control in Appendix E.

Extensive and intensive margins are reported in Table E1. Unlike in our main results, not all the coefficients of interest are statistically significant in Table E1.

Table E1 - Migration as Adaptation

	Extensive Margin	**Intensive Margin**	
VARIABLES	**Ln(Remittances)**	**Ln(Agricultural Income)**	**Ln(Total Income)**
Ln(Remittances)		0.075***	0.055*
		(0.026)	(0.033)
Disaster	-0.204	-0.134	-0.163
	(0.186)	(0.251)	(0.342)
Ln(Farm Size)*Disaster	0.038	0.130*	0.114
	(0.072)	(0.075)	(0.105)
Observations	1,578	642	642

Notes: Standard errors clustered at village level are shown in parentheses. ***,** and * represent statistical significance at 1, 5 and 10 percent levels, respectively.

Table B2 reports the estimated total marginal effects of disaster through migration as an adaptation. Both the total extensive and intensive margins are evaluated at the mean of ln(Farm Size) from the estimating sample. Coefficients of ln(remittance), Disaster and Ln(Farm Size)*Disaster come from Table E1. Most of the coefficients of interest are statistically insignificant.

Table E2 – Total Marginal Effects of Disaster through Migration

	(1)	(2)
	Ln(Agricultural Income)	**Ln(Total Income)**
Total Intensive Margin	0.1035	0.0453
Total Extensive Margin from remittances	-0.0101	-0.0074
Total marginal effect	0.0934	0.0379

Consistent with literature (e.g., Penning-Rowsell, Sultana, and Thompson 2013; Sommer and Mosley 1972), our results confirm that Bangladeshi farmers do not necessarily use migration as a mode of adaptation to disasters. In addition, Gray and Mueller (2012) shows that natural disasters such as floods do not result in wide-scale migration of Bangladeshi rural people, although crop failures caused by non-flood related events significantly induce their migration. Therefore, migration might be an adaptation to idiosyncratic shocks, but not necessarily to natural disasters.

Appendix F. Adaptation to the Severity of Disasters

In this Appendix F, we use a continuous measure, instead of a binary measure, of disaster exposure. We define this measure as the immediate monetary losses from exposure to disasters in the last five years. BIHS dataset contains self-reported loss figures specific to households.

We employ the econometric specifications (3)–(6), expect for this new definition of disaster exposure. Table F1 reports extensive and intensive margins. We report only the parameters of interest; however, full regression tables are available upon request. Extensive margins are estimated using the specification (3), where the dependent variables are Ln(land-in) and Ln(land-out). Intensive margins are estimated using the specification (4). In all the cases, directions of relationship are same to our original results reported in Tables 2 and 3, although the magnitudes of Ln(losses from Disaster) and ln(Farm Size)*Ln(losses from Disaster) are different.

Table F1 – Extensive and Intensive Margins of the Severity of Disasters

	Extensive Margins		**Intensive Margins**	
Variables	**Ln(land-in)**	**Ln(land-out)**	**Ln(Agricultural Income)**	**Ln(Total Income)**
Ln(land-in)			0.097***	0.079***
			(0.013)	(0.014)
Ln(land-out)			0.148***	0.104***
			(0.012)	(0.014)
Ln(Losses from Disaster)	0.097***	-0.126***	-0.017***	-0.013*
	(0.014)	(0.019)	(0.006)	(0.007)
Ln(Farm Size)* Ln(Losses from Disaster)	-0.043***	0.068***	0.008***	0.007***
	(0.005)	(0.008)	(0.002)	(0.003)
Observations	3,121	3,121	2,542	2,542

Notes: Standard errors clustered at village level are shown in parentheses. ***,** and * represent statistical significance at 1, 5 and 10 percent levels, respectively.

Table F2 reports the estimated total marginal effects. For consistency, extensive margins are evaluated at the mean of ln(Farm Size) from the estimating sample of equation (4). Coefficients of ln(land-in), ln(land-out), Ln(losses from Disaster) and Ln(Farm Size)*Ln(losses from Disaster) come from Table F1. All the coefficients of interest are statistically significant.

Table F2 – Total Marginal Effects of the Severity of Disasters

	Ln(Agricultural Income)	**Ln(Total Income)**
Total Intensive Margin	-0.0025	-0.0003
Total Extensive Margin from rent-in	0.0018	0.0015
Total Extensive Margin from rent-out	-0.0004	-0.0002
Total marginal effect	-0.0010	0.0010

Notes. For consistency, extensive margins are evaluated at the mean of ln(Farm Size) from the estimating sample of equation (4).

Consistent with the results in Table 6, we identify that farmers exposed to disasters were able to reduce their losses through participation in the land rental market. In particular, we find that 1 percent increase in the losses from disaster directly reduces the agricultural income by 0.25 percent; whereas those adjusting their operational farm size were able to reduce that loss by 0.14 percent. Similarly, a 0.03 percent direct reduction in total income is compensated by an indirect increase of 0.13 percent.