Adaptation to Climate Change in Bangladesh

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Abstract

Climate change is expected to disproportionately affect agriculture; however, there is limited information on smallholder farmers ' overall vulnerability and adaptation needs. This paper estimates the impact of climatic shocks on the household agricultural income and subsequently, on farmers ' adaptation strategies. Relying on data from a survey conducted in several communities in Bangladesh in 2011 and based on an IV probit approach, the results show that a one percentage point climate induced decline in agricultural income pushes households to adapt by almost 3 percentage points. However, certain strategies are too costly and cannot be afforded in bad times. For those strategies, we provide evidence of barriers that constrain the development and deployment of adaptive measures, noticeably access to electricity and wealth.

Keywords: Adaptation, Climate Change, Vulnerability, Farmers, Bangladesh

JEL: D10, Q12, Q54, Q56, O13

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1 Introduction

Adaptation to climate change did not receive much attention in the first years of the international climate change studies, where there was more focus on mitigation and impacts [Kates, 2000], but adaptation has recently been covered more extensively due to the increasing vulnerability of some countries. In fact, it has been shown that some countries will be increasingly exposed to frequent and extreme climatic events. Long-term changes observed by scientists in recent years include widespread shifts in rainfall amounts, ocean salinity, wind patterns and extreme weather, including droughts, heavy rain/ snow, heat waves and the intensity of tropical cyclones [Smithers and Smit, 1997]. The effects of climate change pose risks for agriculture, food and water supplies. All societies consequently need to learn to cope with the changes that are predicted, especially developing countries.

The objective of this paper is to investigate the extent to which rural households engage in different strategies to cope with risks in agricultural production due to weather-related shocks in Bangladesh. Therefore, we focus our attention solely on climate change as a risk factor for the agriculture. A better understanding of the existing risk coping strategies may inform us about households ' ability to adapt to weather-related risk, and, potentially, inform the design of policy in the context of increasing climatic stress on the smallholder farmers in developing countries.

The Intergovernmental Panel on Climate Change in its Third Assessment published in 2001 has assessed the capacity of the world to cope with and adapt to the inevitable impacts that climate change will bring. This assessment finds that the impacts of climate change are not evenly distributed : the people who will be exposed to the worst of the impacts are the ones least able to cope with the associated risks [Smit et al., 2000]. But evidence suggests that inhabitant of developing nations are not passive victims [Adger et al., 2003]. Indeed, in the past they have had the greatest resilience to droughts, floods and other catastrophes. Pastoralists in the West African Sahel have adapted to cope with rainfall decreases of 25-33 % in the twentieth century [Mortimore and Adams, 2001, Cross and Barker, 1991], while resilience in the face of changing climate has been documented for smallholder farmers in Bangladesh [Huq et al., 1999, Huq, 2001] and Vietnam [Adger et al., 2012], and indigenous hunting communities in the Canadian Arctic [Berkes and Jolly, 2002].

However, much work still remains to fully understand the drivers of past adaptation efforts, the need for future adaptation, and how to mainstream climate into general development policies. We have to understand what are the adaptation strategies adopted today by rural households. The expectations are that in terms of action, adaptation may take the form of reducing dependence such as diversifying food production, seeking off farm employment or migrating, of decreasing sensitivity by avoiding building settlements and infrastructure in high-risk locations, or by strengthening existing systems so that they are less likely to be damaged by unusual events. Therefore, this paper seeks to improve upon the scarce literature on adaptation from climate change in different ways: it focuses on Bangladesh, a country where vulnerability to climate is very high and where the vast majority of people are exposed to it. This allows us to provide evidence at the household level of reactive private adaptation. In the vein of Kubik and Maurel (2015), we propose a modeling strategy in two steps, which assumes that climate impacts individuals through only agricultural income. Moreover, we consider several climatic shocks, while previous studies have been limited to one climatic shock by studying historical events. We are able to analyze the impact of climatic shocks on many adaptation options. This allows us to draw some conclusions on the type of adaptation strategy that farmers are more likely to adopt or not. Finally, we are able to distinguish the adaptation strategies according to the constraints that individuals face, which are wealth, education, households size, and access to electricity.

Bangladesh appears to be a pertinent case study for this issue. During 1991-2010, Bangladesh was one of the four countries along with Myanmar, Honduras and Nicaragua most affected by extreme weather events [IPCC, 2007] - 60% of the worldwide deaths caused by cyclones in the last 20 years occurred in Bangladesh. With an average elevation of 4 to 5 meters above mean sea level, nearly a third of the country is susceptible to tidal inundation and nearly 70% gets flooded during heavy monsoons. About 10% of the country is only 1 meter above the mean sea level, and one-third is under tidal excursions. Besides, the Bangladeshi economy is based predominantly on agriculture, forestry, and fishing. As a result, climate change is expected to decrease agricultural GDP by 3.1 % each year, a cumulative 36 billion dollars in lost value-added for the period 2005-2050.

To estimate the impact of climatic shocks on farmers' adaptation strategies, we rely upon the Bangladesh Climate Change Adaptation Survey from 2011. This initiative conducts household and community-level surveys which report the incidence of climatic shocks at the community level over the last 5 years as well as adaptation options considered by households.

We proceed with a first stage least square analysis estimating the impact of climatic shocks on agricultural income. This analysis reveals that climatic shocks have a negative effect on agricultural income. In the second stage least square estimation, we estimate the impact of agricultural income instrumented by climatic shocks on the adaptation options. We expect agricultural income to be negatively correlated with the adaptation options: the less agricultural income the households get due to climatic shocks, the more they will change their strategy. Our results confirm that climatic shocks are an important determinant of agricultural income and that Bangladeshi farmers undertake a variety of adaptation options. However, the probability of resorting to certain options is found to decrease when agricultural income decreases: opting for changing crop variety or crop type, for irrigating or irrigating more is conditional upon wealth, education, size of the household, access to electricity.

The rest of the paper is organised as follows. Section 2 reviews the literature, while section 3 introduces the database. Empirical strategy and results are presented in Sections 4 and Section 5. In section 6, we investigate the reasons why the probability of choosing certain options is positively correlated with agricultural income. We argue that it is due to non linearities, like the discriminatory effect of wealth, which implies that only rich, educated, or endowed with an access to electricity, individuals can afford certain adaptation strategies. Finally, Section 7 summarizes the results as well as highlights their policy implications.

2 Related literature

In the first years of the international climate change studies, there was more focus on impacts and mitigation [Kates, 2000]. The common view was to find any action that would allow to permanently eliminate or reduce the long-term risk and hazards of climate change to human life. However, starting in the late 1990s, a new topic for the social sciences has gained importance in climate change research: adaptation [Smithers and Smit, 1997]. It refers to the ability of natural or human systems to adjust to climate change (including climate variability and extremes) in order to cope with the inevitable consequences.

Impacts of climate change

Since the 1980s, a number of papers attempt to assess the overall economic impacts of climate change on one or several developing countries. The Stern Review [Stern, 2007] and the various DICE and RICE models [Nordhaus and Boyer, 2003, Nordhaus, 2014] are, of course, seminal references, but there have been many prior and subsequent studies as well. We will focus on extensive research that has been conducted on sectoral impacts of climate change. Stage (2010) provide a useful literature review on this subject. Apart for the studies analysing impact on agriculture, the literature on this topic is limited. Spalding-Fecher and Moodley (2002) focus on the health impacts in South Africa. Velarde et al (2005) investigate the impacts on protected areas in Africa by incorporating the effect of increasing income on the willingness to pay for a protected nature.

Due to the fact that developing countries rely mostly on agriculture, many studies have focused on the impacts on agriculture and on production values. Mendelsohn and Dinar (1999) provide a useful subdivision by methodology: agronomic/agronomic-economic studies, agro-ecological zone studies, and Ricardian studies. The agronomic and agronomic-economic approaches examine what the implications of anticipated climate change will be on the yields of crops currently being grown in various parts of the world, and on potential other varieties of those crops. Studies in this literature include Rosenzweig and Parry (1994), who assess the potential impact of climate change on world food supply by simulating global crop yields and estimating price impacts; Matthews et al (1997), who simulate impacts on rice yields in several Asian countries; Parry et al (2004), who use yield impact estimates for a range of crops to simulate price and livelihood impacts in a global economy model; Njie et al (2006), who study yield effects in the Gambia; Lobell et al (2008), who estimate crop yield impacts in 12 food-insecure regions; and Reid et al (2008), who use agricultural yield estimates for simulating economy-wide effects in Namibia. These studies reveal that developing countries are impacted negatively. More precisely, results indicate South Asia and Southern Africa as two regions that, without sufficient adaptation measures, will likely suffer negative impacts on several crops that are important to large food-insecure human populations.

Agro-ecological zone studies, on the other hand, suppose that when climate change leads to shifts in agro-ecological zones, this will lead farmers to adapt by switching from the crops that they currently grow to those crops that are currently grown in the zone that they are shifting into. This method appears not to have been widely applied in developing countries, although a recent set of World Bank studies of climate change impacts on African agriculture [Seo et al., 2008b, Seo et al., 2008a, Seo et al., 2008c] can be seen as examples. The results indicate that farmers carefully consider the climate and other conditions of their farm when making their crop and irrigation decisions.

Finally, the Ricardian method was introduced by Mendelsohn et al (1994). The assumption is that all farms choose their production portfolio so as to maximize their profits, given their characteristics including the local climate. If climate change leads to a switch from climate state A to climate state B for farms in a particular region, farms in the region will adapt by switching to the production portfolio chosen by farms elsewhere that are currently in climate state B. The economic impact of the switch from A to B can then be estimated either by studying the change in net revenue that the switch in production will entail, or by studying the difference in land values between the farms in the area and the farms that are currently experiencing climate state B. Applications of this method in developing countries include Mendelsohn and Dinar (1999), for Brazil and India; Timmins (2006), who studies a range of land uses in Brazil; Deressa et al (2005) and Gbetibouo and Hassan (2005), who study South African agriculture as well as Seo and Mendelsohn (2007a, 2007b, 2008b); and Seo et al (2008a), who study crop choice and livestock management in African countries; Kurukulasuriya and Mendelsohn (2006, 2007, 2008) and Kurukulasuriya et al (2006), who study crop patterns and irrigation in African countries; Lotsch (2007) and Maddison et al (2007), who also study African agriculture; Mendelsohn and Seo (2007) and Seo and Mendelsohn (2008), who study livestock management and crop choice in South American farms. These studies find that even though the agricultural sector is sensitive to climate, individual farmers do take local climates into account, and their ability to do so will help mitigate the impacts of global warming.

Adaptation

Given the potential risks associated with climate change, a serious effort on characterizing and understanding adaptation is therefore now underway. Tol (2005) argues that increasing developing countries ' adaptive capacity through development aid is more fruitful than climate change mitigation. Researchers have proposed numerous dimensions to adaptation. Two of these dimensions have been useful for thinking about individual behavior: proactive versus reactive adaptation, and public versus private adaptation. The first dimension refers to the form, or more specifically, to the timing of the adaptation (*ex ante / ex post*). Reactive adaptation is our immediate response to climate change. This type of adaptation is often used to regain stability. Proactive adaptation is more likely to reduce the long-term damage, risk and vulnerability due to climate change since it involves long-term decision making. The second dimension refers to the actors, and therefore to the question of who adapts (public agencies, or residents at risk). The type of adaptation matters : Public or private entities.

Studies have taken place at various spatial levels and they have two main purposes. One is to inform mitigation policy by quantifying impacts of climate change or adaptation potentials. The other purpose is to explore quantitatively who adapts, how and why. The article by Eriksen and Lind (2009) on conflict and insecurity in two areas in Kenya argues that adaptation must take place at the local level to be effective and that it is more a matter of facilitating adaptation of current practices rather than imposing nationally decided adaptation options. Several articles, also, address adaptation to climate change in specific rural settings. A study in northern Burkina Faso [Barbier et al., 2009] compares different responses of households to drought by analyzing farm decisions after years with poor and good harvests. It concludes that the households have developed strategies for income diversification as a way of reducing dependence on climate, but vulnerability is still considerable. A similar conclusion is made by Roncoli et al (2001) who analyze the responses enacted by families of the Central Plateau in Burkina Faso during the year that followed a severe drought in 1997. In Senegal, a parallel study [Mertz et al., 2009] attempts to determine the drivers of agricultural change and estimates the relative importance of climate in various adaptive strategies. Households identify wind and occasional excess rainfall as the most destructive climate factors. However, they assign economic, political, and social rather than climate factors as the main reasons for change.

Moreover, several studies also make use of household datasets to empirically examine which factors influence adaptation. For instance, in a study taking place in the Morogoro Region of Tanzania, Below et al (2012) develop an activity-based adaptation index (AAI) and explore the relationship between socio-economic variables and farmers ' adaptation behavior. They find that public investment in rural infrastructure, in the availability and technically efficient use of inputs, in a good education system that provides equal chances for women, and in the strengthening of social capital, agricultural extension and, microcredit services tend to improve the adaptation of the farmers. In a similar study taking place in South Africa and Ethiopia, Bryan et al (2009) found that the most common adaptation strategies include: use of different crops or crop varieties, planting trees, soil conservation, changing planting dates, and irrigation. However, despite having perceived changes in temperature and rainfall, a large percentage of farmers did not make any adjustments to their farming practices. The main barriers to adaptation cited by farmers were the lack of access to credit in South Africa and the lack of access to land, information, and credit in Ethiopia. Similarly, in a case study of Ghana, Fosu-Mensah et al (2012) highlighted the importance of several determinants of adaptive capacity such as land tenure, soil fertility, and access to extension service and credit. Other regions of the world are impacted as shown by Jones and Boyd (2011) explored some of the underlying features of social barriers to adaptation and drew on insights from two case studies in the Western Nepal. Other studies provide evidence of such barriers to adaptation more generally in the case of African countries [Hassan et al., 2008], or focusing on one localization: the Nile basin of Ethiopia [Deressa et al., 2009] for instance. Therefore, realizing that action is required to enhance the adaptive capacity of the most vulnerable societies and groups, an emerging research agenda aims at identifying determinants of resilience.

3 Data

As mentioned previously, the purpose of this research study is to estimate the impact of climatic shocks on household agricultural income and subsequently on farmers ' adaptation options in Bangladesh. To address this issue, we use the first round of the Bangladesh Climate Change Adaptation Survey. The BCCAS I[1] contains data on 800 farming households in Bangladesh. It provides information on demographic characteristics, agricultural production and income, incidence of climatic shocks in the last five years and adaptation options. A detailed list of the climatic shocks and adaptation options is available in Table 1. The survey was conducted from December 2010 to February 2011, covering data from the previous production year. The unit of analysis is the rural household, which operates as the ultimate decision making unit in farming and livelihood processes.

Demographic characteristics

Bangladesh is characterized by distinct agroecological conditions determining different production potentials. Therefore, Bangladesh constitutes the perfect case study. Figure

[1] https://dataverse.harvard.edu/dataset.xhtml?persistentId=doi:10.7910/DVN/27704

1 allows us to understand how Bangladesh is divided into agro-ecological zones and how different they are. Figure 2 and 3 illustrate the various risks (flood, drought) that are experienced differently by each region. Table 2 on households ' localization shows that the results can be generalized to the country level since the survey is quite representative of Bangladesh. In fact, the household survey covers 40 unions (administrative units) randomly selected, which represent the 7 broad agro-ecological zones (AEZ subsequently) as grouped by the Bangladesh Center for Advanced Studies. More unions were selected for the larger AEZs. Twenty agricultural households were randomly selected in each union, making a total sample of 800 households.

Table 3 gives information on households ' characteristics such as the *household size*, the *gender* of the household head, the *age* of the household head, his/her religion (*muslim* is a dummy equal to one if the household head is Muslim), the highest education level in the household (*education*), a dummy equal to 1 if the first (*occupation1*) or second occupation (*occupation2*) of the household head is in agriculture and whether the household has access to *electricity* or not. Information on *assets* and land holdings (*lands*) are given with the quantity of *cattle*, *goat*, *pig* and *chicken* owned by the household.

We find that about 94 percent of the households in the sample were headed by males. On average, the head of the household is forty five years old. The average household is composed of 5 members. The majority are Muslims. Education of households is fairly low, with 2 years of schooling on average. Most of them never attended school and work in the agricultural sector, which constitutes the first occupation for 77%. The majority of the households don't have access to electricity (54%). Finally, they are holding on average 3.47 lands and 6.61 assets with 1.17 cattle and 9.67 chickens.

Agricultural production

Table 4 provides information on the soil type, the crop type and the agricultural income of the households. The average household produces 6.33 different crops with more plot productions (3.73) than non plot productions (2.60). They have, in majority, cultivable lands with a clay-loam type of soil. The mean of the agricultural income is 31 426 BDT (domestic currency in Bangladesh) which is equivalent to 404 USD. According to the World Bank, the GDP per capita in Bangladesh is 841.5 USD in 2011 (65 158 BDT). The mean agricultural income of the sample is, therefore, lower than the GDP per capita measure which reflects that the agricultural sector provides employment and income to the poorest and most vulnerable members of the bangladeshi society.

Climatic shocks

The surveyed households were asked about natural hazards that adversely affected their agricultural harvest or their agricultural land. More than half of the respondents (54.65

%) reported that their agricultural plot had been affected by a natural hazard in the last five years. We construct dummy variables taking the value 1 if at least two (up to five) individuals in the community responded yes to the following question: "Did this natural disaster occur in the community in the past 5 years ?" and 0 otherwise (Table 5). These individuals were chosen according to their functions : the administrative leader of the community, the traditional leader of the community, a teacher/local elite or finally, working in farming. These dummies represent hazards that happen at the community level and no more at the household level as reported in the survey. The most commonly cited hazards were pestilence stricken (60 %), floods (55 %) and droughts (52.50 %).

From now on, we also make the distinction between two types of hazards: the first type refers to weather shocks like drought, flood, while the second refers to diseases, like pestilence stricken or livestock epidemic. In fact, weather shocks have a direct impact on the household agricultural income whereas diseases that concern livestock have an indirect impact on the household agricultural income through a reduced livestock 's productivity for instance. Due to this difference, we separate the two kinds of shocks.

Adaptation options

Households are asked whether they had made any adjustments in their farming practices. Twenty adaptation options are considered in the dataset, and they can happen simultaneously. We compute a dummy taking the value 1 if the household made at least one change (more than one) out of the twenty and 0 if not. Then, we consider twenty dummies - i varying from 1 to 20 - taking the value 1 if the household engages in the adaptation strategy i and 0 otherwise. Results (Table 6) show that a very high percentage of the households (86.25 percent) changed their farming practices due to climate change. The results also highlight the respective importance of each adaptation option : changing crop variety (64.14 %), irrigating fields (62.48 %) or intensifying irrigation (63.59 %), building a water harvesting system (23.31 %), changing crop type (19.59 %), increasing the amount of land under production (16.69 %) and seeking off farm employment (16.69 %) being the options most frequently cited.

Certain options are less frequently mentioned, which may reflect the fact that the adaptive capacities within agriculture remain low, and also that the nature of the dataset is cross-sectional, which does not allow us to make an analysis of the adaptation of the productive technology over the long run. The observed level of potential adjustments to climate change is negligible for *change and implement soil and water management techniques* (5% in both cases), *mix crop and livestock production*, *mix crop and fish farming production* (respectively 4 and 3%), *change from crop to livestock production and from livestock to crop production* (1 and 2%). Not surprisingly, households have a limited access to finance: only 1 per cent of households in our sample declare resorting to formal insurance.

Another 1% can afford setting up communal seed banks/food storage. Some strategies are more expensive and proactive than others: *change crop variety*, *change crop type*, *change soil and water management techniques*, *implement soil and water management techniques*, *build water harvesting scheme for domestic consumption*, *build water harvesting scheme for crops*, *irrigate* and *irrigate more*, *change from livestock to crop production*, and *change from crop to livestock production.* However, *changing the amount of land under production*, *changing the pattern of crop consumption*, *mixing crop and livestock production* and *mixing crop and fish farming production*, *seeking off farm employment* and *migrating to this place from another* can be implemented ex post, once the natural hazard occurred (reactive adaptations). They correspond to a more passive way of adaptation to climate change, requiring less budgetary resources.

4 Empirical strategy

Following Maurel and Tuccio (2015) and Kublik and Maurel (2015) , we assume that climate impacts agricultural income (equation 2), which in turn obliges farmers to adapt (equation 1). Households adopt economic strategies not only to maximize household earnings but also to cope with the risk, which is mainly due to natural hazards. The latter do not impact the farmers decision directly, for example through an amenity value or through the households preferences for a given climatic setting. Natural hazards affect rural behaviors solely through the decline in agricultural yields.

In our empirical strategy, weather serves as an instrument for agricultural income which appears as the main explanatory variable in the decision for a farmer i in a village j to adopt an adaptation strategy A_{ij} as expressed in equation 1:

$$A_{ij} = f(Y_{ij}, X_{ij}) + u_{ij} \tag{1}$$

where Y is the logarithm of agricultural income, and the vector of controls X refers to household characteristics such as the gender of household head (*gender*), the age of the household head (*age*), the highest level of education in the household (*education*), *muslim* taking the value one if is Muslim, *occupation1* (*occupation2*) if the first (or second occupation) of the household head is in agriculture, *electricity* taking the value one if the household has access to electricity and holdings (*assets* and *lands*).

Agricultural income is determined as a function of natural hazards $Hazard_j$ in a village j, of land units L_{ij} , soil type S_{ij} , and production type P_{ij} :

$$Y_{ij} = f(L_{ij}, S_{ij}, P_{ij}, Hazard_j) + v_{ij} \tag{2}$$

As mentioned earlier, we distinguish two types of hazards: the first type refers to weather shocks like drought, flood, while the second refers to diseases, such as pestilence stricken or livestock epidemic (see section 3).

5 Results

The agricultural equation

First, we estimate the impact of weather shocks and diseases on agricultural income as in eq. (2) in order to assess the viability of the instrument in the IV probit model. Unlike previous studies, that use temperature and rainfalls in levels (Mendelsohn et al., 1994), temperature and rainfalls shocks ([Maurel et al., 2015, Maurel et al., 2013], Feng et al (2012), Kelly et al (2005) amongst others), or temperature and temperature squared in the growing season 2008 [Schlenker and Roberts, 2008], we rely on natural hazards: drought, tidal wave, river erosion, pestilence stricken, livestock epidemic, flood and cyclone, which are related to climate change. Climatic and diseases variables display a certain level of multicollinearity, implying that we cannot consider them simultaneously in a single model. We consider therefore diseases related to livestock and plague on the one hand, and hazards related to the weather on the other hand. The diseases will allow estimating the likelihood of adopting one of the following options: mix crop and livestock production, change from crop to livestock production, and change from livestock to crop production. Those strategies are more likely to result from animal diseases than weather anomalies.

Table 7 displays the results for agricultural income. In columns 1 to 3, we take into account only the natural hazards related to the weather as predictors of the agricultural income whereas in columns 4 to 6, we take into account only the diseases. The more land household has, the more the agricultural income it gets. The plot type matters since *homestead*, *cultivable lands*, *pasture*, *bush*, *cultivable pond* and *derelict pond* have all a significant impact on agricultural income. The soil type considered here by *clay*, *loam*, *sandy*, *clay-loam* and *sandy-loam* decreases the agricultural income. The bigger the size of the land, the higher the agricultural income, as expected. Natural hazards have an impact on agricultural income, which is significant at the usual level. Floods, drought, and tidal waves on one hand (column 1), and pestilence and livestock epidemic (column 4) on the other hand, lower agricultural income. In order to account for the fact that natural hazards are aggregated at the community level, while the estimation is done at the household level, we correct standard errors by clustering (columns 2 and 5) and by applying the Moulton procedure (columns 3 and 6).

The adaptation equation

We turn now to the adaptation equation which consists in estimating the impact of agricultural income instrumented by natural hazards on farmers ' adaptation options. We consider first the farmers ' decision to adapt independently from any specific adaptation.

Then, we consider each adaptation option separately. Table 8 reports the results. The Wald test confirms the validity of the instruments. Marginal effects are reported for ease of interpretation. For the average household, a one percentage point decrease in agricultural income increases the probability to adapt by almost 3 percentage points. This result is highly significant. The number of assets significantly influences the decision to adapt : richer households are more likely to change their strategy as a response to climatic shocks. However, it is noteworthy that the gender of the household head, the age, education, religion and occupation dummies as well as having access to electricity does not affect significantly the likelihood of adaptation.

We estimate subsequently the impact of agricultural income instrumented by natural hazards on each specific adaptation option. The results are given in Table 9 panels A and B. We distinguish options that address negative shocks in a passive way, as they do not require any resource to be invested (Panel A) from proactive options that are adopted following an increase in income (Panel B). In order to adapt to climate change and especially to a decrease in the agricultural income due to climatic shocks, rural households of Bangladesh adopt the following strategies: they change the amount of land under production, change the pattern of crop consumption, change the field location, they seek off farm employment, they migrate to this place from another. The following strategies are more resource demanding and correspond to a more proactive behavior. They are chosen if they can be afforded, thanks to an increase in the agricultural income: change crop variety, change crop type, irrigate, irrigate more, change from livestock to crop production (Panel B). We do not find any significant impact of a variation of the agricultural income due to climatic shocks on the probability that the households opt for the following strategies : implement or change soil and water management techniques, build water harvesting scheme for domestic consumption, build water harvesting scheme for crops and change from crop to livestock production. In certain cases the procedure does not lead to convergence, which might be due to the too small number of observations: mix crop and livestock production, build water harvesting scheme for livestock, buy insurance, set up communal seed banks/food storage.

Panel A displays the estimates. A 1 percentage point decrease in the agricultural income increases the probability that the households change the amount of land under production by 2.46 pp, change field location by 1.98 pp, change crop consumption by 1.71 pp, migrate to this place from another by 1.43 pp and finally, seek off farm employment by 1.10 pp. As recorded in Panel B, a 1 percentage point increase in the agricultural income increases the probability that the households opt for a change of crop type by 2.93 pp, intensify irrigation by 2.66 pp, irrigate by 2.56 pp, change from livestock to crop production by 2.17 pp and change crop variety by 1.50 pp. Panel B options are more expensive as compared with the options displayed in Panel A. We argue that our results reflect the existence of constraints that restrict the access to the most resource-demanding options. We examine four candidates: wealth, education, size of the household, and finally access to electricity, that may determine the farmers ' adaptive capacity.

6 Adaptive capacity

The idea that adaptive capacity may depend on certain conditions is not out of line with the existing literature on the climate change adaptation. Whether it is expressed in terms of assets, capital resources, financial means, wealth, or poverty, the economic condition of nations and groups is a strong determinant of adaptive capacity [Kates, 2000]. It is widely accepted that wealthy nations are better prepared to bear the costs of adaptation to climate change impacts and risks than poorer nations [Goklany, 2007, Burton et al., 2002]. In this section, we add to this literature by focusing on panel B strategies. We provide support to the view that opting for those strategies is constrained by the availability of certain resources: economic wealth, education, the size of the household and finally, whether the household has access to electricity or not. Access to electricity is considered in the literature as a proxy for poverty and socio-economic status, and as a way to escape from poverty [Chaurey et al., 2004, Kanagawa and Nakata, 2007] traps through a saving of time, which can be invested in educational and health spending, or in infrastructure such as pumps for irrigating. Wealthier households might be expected to show up more flexibility in adapting to climate change due to the fact that they are more able to afford even slightly more expensive strategies [Reardon and Taylor, 1996]. Educated farmers are more able to treat the information about climate hazards and they will be more likely to opt for certain adaptation options, as compared to the least educated [Deressa et al., 2009, Bryan et al., 2009]. Bigger households have more (labor) resources, that can be invested in order to diversify the sources of income. Beyond the fact that it represents also a proxy for poverty, access to electricity is needed to resort to options, such as *irrigate*, *irrigate more*, as they require pumping water.

Testing the results for the richest of the sample

Some adaptation options cannot be afforded by the poorest households if the agricultural income diminishes because they are expensive: change crop type, change crop variety, irrigate, irrigate more and change from livestock to crop production. We generate a dummy variable "rich" equal to 1 if the household holds more assets and lands than the average (which is respectively 6 assets, 3 lands) and 0 if not. The results are provided in Table 10. In order to simplify the comparison, Panel A displays the results for the entire sample whereas Panel B incorporates only the richest of the sample. We find that richer households, as opposed to the entire sample, are able to react to a decrease in agricultural income by changing crop variety and crop type, also by changing from livestock to crop production, although the sign of the income variable is not significant. Finally, richer household do invest significantly more in order to irrigate and irrigate more when their revenue increases, as estimates in Panel B are bigger than in Panel A. Those results provide evidence that wealth matters as relatively richer households are able to react to a decline in their revenue by adopting two more farming strategies. They also invest more in improving the irrigating capacities.

Testing the results for the most educated

We turn now to the second hypothesis, namely that certain adaptation options are only considered by the most educated households because of an unequal access to information. Since the majority of the households never attended school, we generate a dummy variable "educated" equal to 1 if the highest level of education in the household is equal to one year of schooling or more and 0 if not. We pay a particular attention to the following options as before: change crop type, change crop variety, irrigate, irrigate more and change from livestock to crop production. As for wealth, Panel A displays the results for the entire sample whereas Panel C show the estimates obtained when taking into account only the most educated households. We do not find any significant difference, but for *changing crop variety*: farmers with at least one year of schooling invest more in the latter strategy than the entire sample. This can be explained by the fact that households are provided with information from other sources: the extension agents who visit/contact the households, coming from various organizations such as Government Agencies, agriculture research stations, NGOs, Community-based organizations and finally, the private sector. Of course, households can also receive information through television, radio, newsletter, neighbors or friends, shopkeepers or traders, field days, agricultural shows, etc...

Testing the results for larger households

A natural hypothesis is that the adoption of adaptation options are easier for large households that can send their members away for instance in order to diversify their income. Since the average household is composed of 5 members, we generate a dummy variable"largehh" equal to 1 if the size of the household is higher than 5 and 0 if not. The estimates of Panel D are slightly lower, suggesting that having additional household labor, such as extended family members and older children, relaxes the constraint and might facilitate changing strategy and increase the decision to adapt.

Testing the results for households that have access to electricity

Does access to electricity facilitate adaptation to a reduced agricultural income due to climate change ? We generate a dummy variable "electricity" equal to 1 if the household benefits from an electricity connection (national grid or solar system) and 0 if not. Results show that households that experience a decrease in their income and have access to electricity are coping to this decrease by changing crop variety and crop type, while those who do not have access cannot resort to those strategies. Besides, estimates of the income variable for irrigation and intensifying irrigation are much lower in Panel E compared to Panel A. Those results support the view that households that have access to electricity are less discriminated as the income matters less to cope with climate.

7 Conclusion

We estimate the impact of climatic shocks on household agricultural income and subsequently, on adaptation options in Bangladesh. The first stage least square approach consists in estimating the impact of climatic shocks reported at the community level on household agricultural income. Then, we turn to the second stage least square and estimate the impact of a decrease in the agricultural income instrumented by climatic shocks on households adaptation options. We find that a one percentage point climate induced decrease in agricultural income increases the probability to adapt by almost 3 percentage points.

This result highlights the fact that households are not passive victims of climatic shocks. They react and adjust their farming practices to cope with climate change. More specifically, they opt for risk coping mechanisms such as changing the amount of land under production, changing the pattern of crop consumption, changing the field location, seeking off farm employment and/or migrating to this place from another.

We also disentangle the existence of non linearities, that make several strategies not accessible to everybody, according to his (her) wealth and access to electricity: change crop variety, change crop type, irrigate, irrigate more and change from livestock to crop production. These options are more demanding, as they require a fixed cost to be paid. Our results show that the positive association between the most demanding options and agricultural income diminishes with wealth, size of the household, and to a lesser extent education. Noticeably, access to electricity is a powerful way of reducing the discriminatory effect of agricultural income, as agricultural income correlate with adaptive capacity but to a much lower extent. Farmers provided with such an access face therefore a wider range of options.

Poor households have a more limited access to strategies for coping with climate hazards. A proper wealth distribution along with access to electricity and education will provide poor households the capacity to adapt to climate change.

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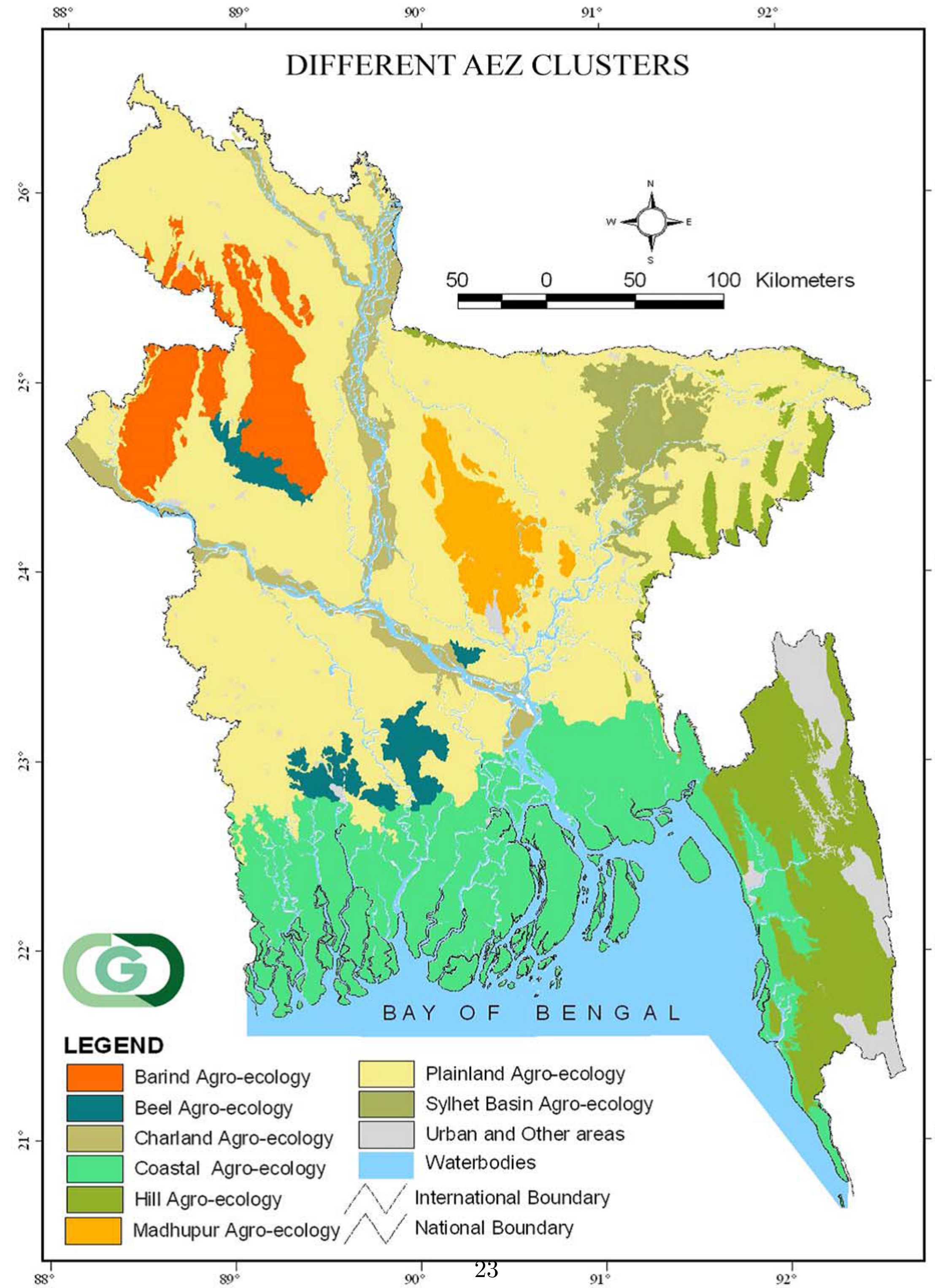

Figure 1: Differences in AEZ

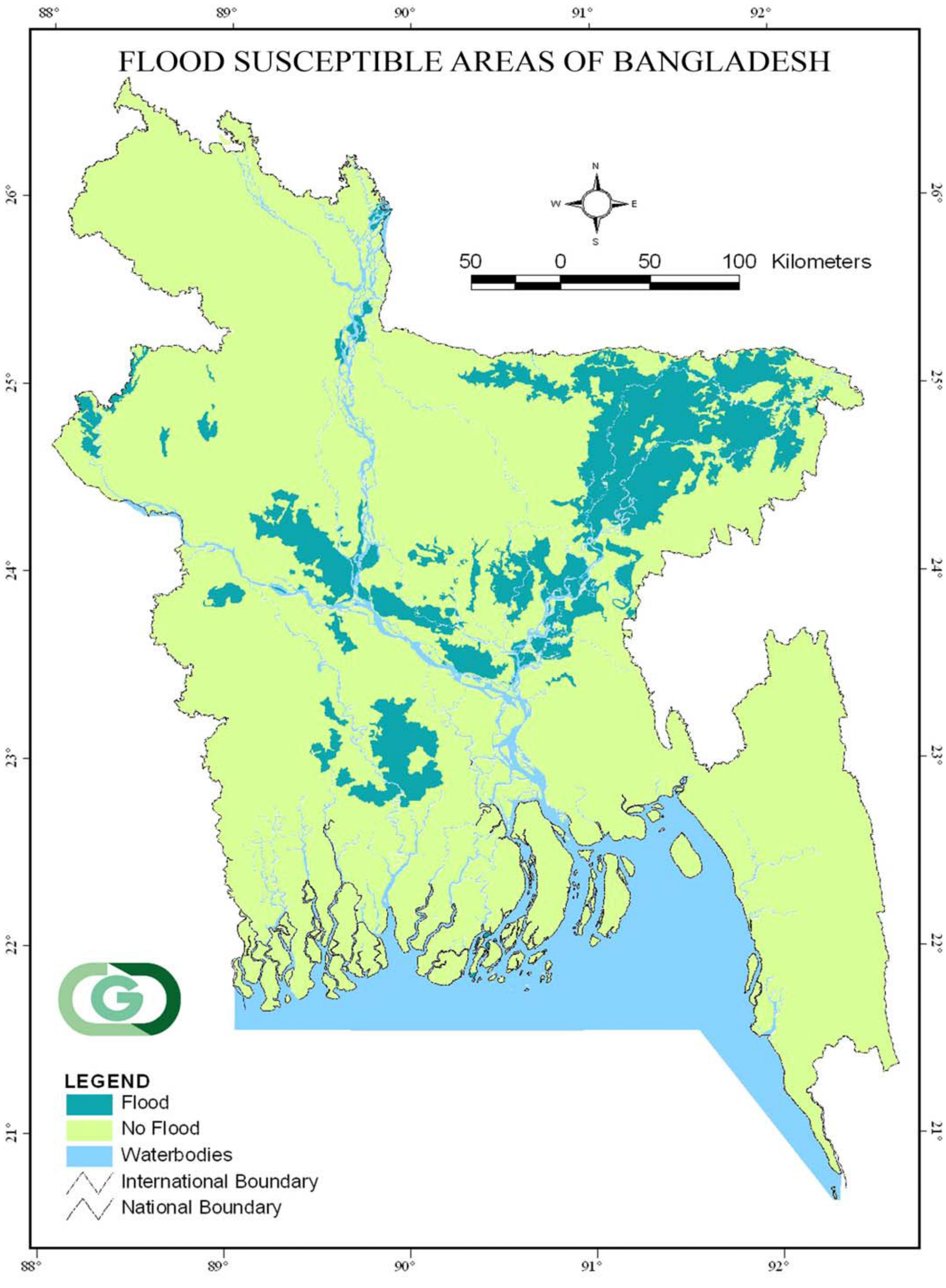

Figure 2: Flood susceptible areas of Bangladesh

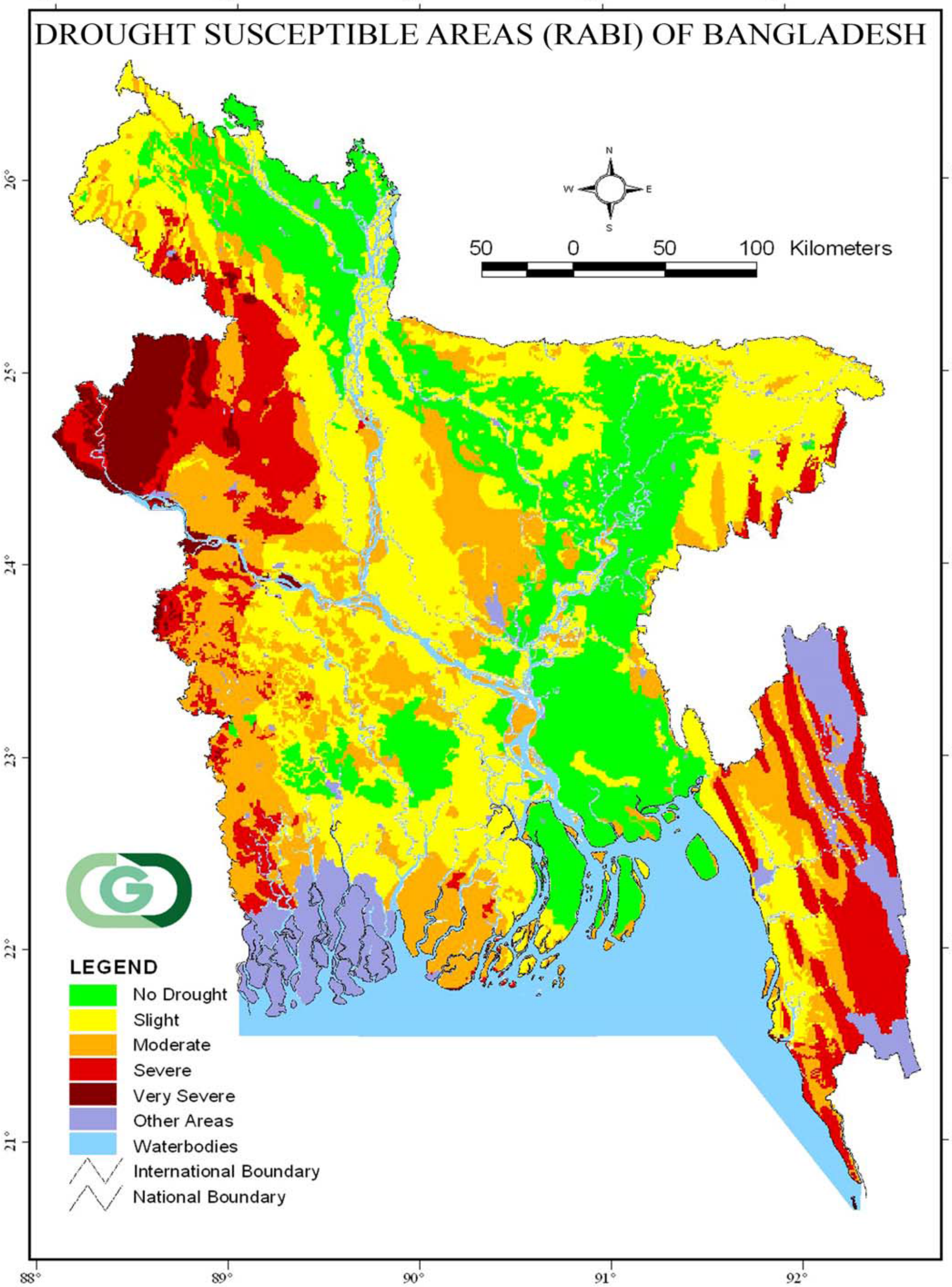

Figure 3: Drought susceptible areas of Bangladesh

Table 1: **List of variables**

Climatic shocks
Pestilence stricken
Livestock epidemic
Flood
Tidal wave
Drought
River erosion
Cyclone
Adaptation options
Decision to adapt
Change crop variety
Change crop type
Change amount of land under production
Change soil and water management techniques
Implement soil and water management techniques
Change pattern of crop consumption
Mix crop and livestock production
Mix crop and fish farming production
Change field location
Build water harvesting scheme for domestic consumption
Build water harvesting scheme for crops
Build water harvesting scheme for livestock
Irrigate
Irrigate more
Buy insurance
Change from crop to livestock production
Change from livestock to crop production
Seek off farm employment
Migrate to this place from another
Set up communal seed banks/food storage facilities

Source: Bangladesh climate change adaptation survey I

Table 2: **Households ' localization**

Variable	min	max	N
District	1	31	800
Upazila	1	39	800
Union	1	40	800
Village	1	40	800
Agro-ecological zone	1	7	800
Household id	1	800	800

Source: Bangladesh climate change adaptation survey I

Table 3: **Households ' characteristics**

Variable	mean	sd	min	max	N
Household size	4.99	2.20	1	22	800
Gender household head	0.06	0.24	0	1	800
Age household head	45.52	13.7	17	95	800
Muslim	0.89	0.31	0	1	800
Hindu	0.11	0.31	0	1	800
Christian	0.00	0.05	0	1	800
Education (years)	1.91	4.13	0	19	800
Occupation1 in agriculture	0.77	0.42	0	1	800
Occupation2 in agriculture	0.20	0.40	0	1	800
Electricity	0.46	0.5	0	1	800
Assets	6.61	2.98	1	19	796
Asset value (Taka)	356598.3	2414828	100.00	6.1e+07	796
Cattle (Qty)	1.17	1.56	0	8	800
Goat (Qty)	0.535	1.24	0	10	800
Pig (Qty)	0.01	0.13	0	2	800
Chicken (Qty)	9.67	48.22	0	1200	800
Lands	3.47	2.63	0	19	800
Land value (Taka)	759584.5	1321456	0	2.3e+07	800

Source: Bangladesh climate change adaptation survey I

Table 4: **Agricultural production**

Variable	mean	sd	N
Production	6.33	3.55	800
Plot production	3.73	2.29	800
Non plot production	2.60	2.31	800
Homestead	1.02	0.30	800
Cultivable land	3.43	2.68	800
Pasture	0.01	0.13	800
Non arable land	0.02	0.15	800
Land in river bed	0.01	0.08	800
Land in market place	0.01	0.07	800
Cultivable pond	0.25	0.47	800
Derelict pond	0.04	0.19	800
Clay	0.20	0.82	800
Loam	1.23	2.32	800
Sandy	0.18	0.82	800
Clay loam	2.29	3.04	800
Sandy loam	0.99	2.05	800
Size	163.48	306.45	800
Agric income (Taka)	31426.17	150357.5	780
Ln agric income	8.08	3.56	780

Source: Bangladesh climate change adaptation survey I

Table 5: **Climatic shocks at the community level**

Variable	mean	sd	N
Pestilence stricken	0.60	0.49	800
Livestock epidemic	0.38	0.48	800
Flood	0.55	0.50	800
Drought	0.53	0.50	800
River erosion	0.07	0.26	800
Tidal wave	0.07	0.26	800
Cyclone	0.28	0.45	800

Source: Bangladesh climate change adaptation survey I

Table 6: **Adaptation options**

Variable	**mean**	**sd**	**N**
Decision to adapt	0.86	0.34	800
Change crop variety	0.64	0.48	725
Change crop type	0.20	0.40	725
Change amount of land under prod	0.15	0.35	800
Change soil and water management techniques	0.05	0.23	800
Implement soil and water management techniques	0.05	0.22	800
Change pattern of crop consumption	0.05	0.23	725
Mix crop and livestock production	0.04	0.19	725
Mix crop and fish farming production	0.03	0.18	725
Change field location	0.07	0.26	725
Build water harvesting scheme for dom cons	0.13	0.33	725
Build water harvesting scheme for crops	0.13	0.34	725
Build water harvesting scheme for livestocks	0.01	0.10	725
Irrigated	0.62	0.48	725
Irrigate more	0.64	0.48	725
Buy insurance	0.01	0.09	725
Change from crop to livestock prod	0.01	0.10	725
Change from livestock to crop prod	0.02	0.13	725
Seek off farm employment	0.17	0.37	725
Migrate to this place from another	0.03	0.16	725
Set up communal seed banks/food storage facilities	0.01	0.10	725

Source: Bangladesh climate change adaptation survey I

Table 7: Impact of weather shocks and diseases (climate variables) on agricultural income

	(1) OLS	(2) Cluster	(3) Moulton	(4) OLS	(5) Cluster	(6) Moulton
	Impact of weather shocks			Impact of diseases		
Flood	-0.472	-0.472	-0.472			
	(-1.89)	(-0.86)	(-0.92)			
Drought	-0.861***	-0.861	-0.861			
	(-3.31)	(-1.50)	(-1.61)			
Cyclone	-1.813***	-1.813**	-1.813**			
	(-6.12)	(-2.77)	(-3.00)			
Tidal wave	-0.611	-0.611	-0.611			
	(-1.15)	(-0.52)	(-0.58)			
Pestilence stricken				-0.466	-0.466	-0.466
				(-1.72)	(-0.75)	(-0.81)
Livestock epidemic				-0.838**	-0.838	-0.838
				(-3.06)	(-1.33)	(-1.45)
Lands	0.239**	0.239**	0.239**	0.310***	0.310***	0.310***
	(3.25)	(2.65)	(2.73)	(4.26)	(3.40)	(3.53)
Homestead	3.912**	3.912**	3.912**	3.904**	3.904**	3.904**
	(3.13)	(3.13)	(3.13)	(3.06)	(3.06)	(3.06)
Cultivable land	3.381**	3.381*	3.381*	3.403**	3.403*	3.403*
	(2.86)	(2.32)	(2.41)	(2.83)	(2.25)	(2.35)
Pasture	3.937*	3.937*	3.937*	3.935*	3.935*	3.935*
	(2.53)	(2.53)	(2.53)	(2.48)	(2.48)	(2.48)
Bush	3.526**	3.526*	3.526**	3.523**	3.523*	3.523*
	(2.91)	(2.55)	(2.60)	(2.85)	(2.47)	(2.53)
Non arable land	1.941	1.941	1.941	2.029	2.029	2.029
	(1.28)	(1.28)	(1.28)	(1.31)	(1.31)	(1.31)
Cultivable pond	3.237**	3.237*	3.237*	2.958*	2.958*	2.958*
	(2.72)	(2.25)	(2.32)	(2.44)	(1.98)	(2.06)
Derelict pond	4.130**	4.130**	4.130**	3.837**	3.837**	3.837**
	(3.15)	(2.89)	(2.94)	(2.87)	(2.62)	(2.67)
Clay	-3.460**	-3.460	-3.460*	-3.621**	-3.621	-3.621*
	(-2.88)	(-1.93)	(-2.17)	(-2.96)	(-1.93)	(-2.19)
Loam	-3.282**	-3.282*	-3.282*	-3.346**	-3.346*	-3.346*
	(-2.76)	(-2.36)	(-2.44)	(-2.76)	(-2.33)	(-2.42)
Sandy	-3.232**	-3.232*	-3.232*	-3.411**	-3.411*	-3.411*
	(-2.70)	(-2.38)	(-2.43)	(-2.80)	(-2.43)	(-2.50)
Clay loam	-3.312**	-3.312*	-3.312*	-3.400**	-3.400	-3.400*
	(-2.79)	(-1.98)	(-2.09)	(-2.81)	(-1.94)	(-2.07)
Sandy loam	-3.210**	-3.210*	-3.210*	-3.312**	-3.312*	-3.312*
	(-2.70)	(-2.32)	(-2.37)	(-2.74)	(-2.32)	(-2.38)
Size	0.00107*	0.00107*	0.00107*	0.000878	0.000878	0.000878
	(2.24)	(2.04)	(2.09)	(1.80)	(1.63)	(1.68)
_cons	7.348***	7.348***	7.348***	6.944***	6.944***	6.944***
	(14.47)	(6.56)	(6.98)	(13.87)	(6.03)	(6.50)
N	780	780	780	780	780	780

t statistics in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 8: Impact of agricultural income (instrumented) on the decision to adapt

	(1)
	Decision to adapt
Ln agric income	-0.274***
	(-16.21)
Gender household head	-0.194
	(-1.03)
Age household head	0.00293
	(0.82)
Education	0.00812
	(0.75)
Muslim	0.196
	(1.33)
Occupation 1 in agriculture	0.307
	(1.17)
Occupation 2 in agriculture	-0.174
	(-0.67)
Electricity	0.124
	(1.27)
Assets	0.0868***
	(5.30)
_cons	1.605***
	(4.65)
athrho	
_cons	1.485***
	(5.31)
lnsigma	
_cons	1.206***
	(46.66)
N	776

t statistics in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Estimates are not reported for saving space. Are available upon request

Wald test of exogeneity (/athrho = 0): chi2(1) = 28.24 $Prob > chi2 = 0.0000$

Table 9: Adaptation Options

Panel A: Options more likely to be adopted after a decrease in agricultural income

	Change amount of land prod	Change crop cons	Change field location	Seek off farm employment	Migrate
Ln agric income	-0.246***	-0.171***	-0.198***	-0.110	-0.143*
	(-12.11)	(-3.56)	(-5.77)	(-1.94)	(-2.23)
Gender household head	-0.0131	0.0365	-0.259	-0.0807	-0.152
	(-0.06)	(0.12)	(-0.85)	(-0.30)	(-0.38)
Age household head	-0.00120	0.000112	0.000248	-0.000395	0.00340
	(-0.35)	(0.02)	(0.06)	(-0.09)	(0.50)
Education	0.00355	0.00875	0.0238	0.00930	0.0100
	(0.30)	(0.56)	(1.79)	(0.66)	(0.50)
Muslim	0.0858	0.334	0.425	0.0894	0.181
	(0.57)	(1.39)	(1.91)	(0.48)	(0.67)
Occupation 1	0.0379	-0.322	-0.476	-0.680*	-0.419
	(0.13)	(-0.83)	(-1.39)	(-1.99)	(-0.90)
Occupation 2	-0.337	-0.440	-0.856*	-0.433	-0.350
	(-1.13)	(-1.11)	(-2.39)	(-1.22)	(-0.72)
Electricity	0.0405	-0.0282	-0.00887	-0.273*	-0.229
	(0.40)	(-0.19)	(-0.07)	(-2.06)	(-1.14)
Assets	0.106***	0.109***	0.0918***	0.0562*	0.0615
	(6.02)	(4.38)	(4.06)	(2.19)	(1.75)
_cons	0.578	-0.606	0.00482	0.196	-0.660
	(1.33)	(-0.79)	(0.01)	(0.33)	(-0.68)
N	776	703	703	703	703

Panel B: Options more likely to be adopted after an increase in agricultural income

	Change crop variety	Change crop type	Irrigate	Irrigate more	Change livestock to crop prod
Ln agric income	0.150**	0.293***	0.256***	0.266***	0.217**
	(2.65)	(36.04)	(16.40)	(19.50)	(2.94)
Gender household head	0.457	0.341	0.118	0.182	0
	(1.90)	(1.70)	(0.55)	(0.87)	(.)
Age household head	0.00615	0.00377	0.000478	0.00117	0.00540
	(1.78)	(1.31)	(0.15)	(0.37)	(0.85)
Education	0.00616	-0.0172	-0.0172	-0.0175	-0.0378
	(0.48)	(-1.83)	(-1.67)	(-1.71)	(-1.35)
Muslim	-0.180	-0.232	0.182	0.290	-0.118
	(-1.16)	(-1.79)	(1.19)	(1.82)	(-0.36)
Occupation 1	0.870**	0.168	0.0336	0.182	-0.947
	(2.64)	(0.64)	(0.12)	(0.64)	(-1.82)
Occupation 2	0.804*	0.450	0.257	0.375	-0.716
	(2.51)	(1.68)	(0.87)	(1.29)	(-1.25)
Electricity	0.00799	-0.0627	0.0186	0.132	-0.277
	(0.08)	(-0.72)	(0.20)	(1.37)	(-1.27)
Assets	-0.0590**	-0.0596***	-0.0375*	-0.0675***	-0.0301
	(-2.92)	(-3.84)	(-2.18)	(-4.17)	(-0.75)
_cons	-1.485**	-2.219***	-1.867***	-2.071***	-2.122**
	(-3.04)	(-6.20)	(-5.13)	(-5.81)	(-3.27)
N	703	703	703	703	668

[1] t statistics in parentheses [2] * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$ [3] Estimates available upon request

Table 10: Adaptive capacity

Panel A: Entire sample

	Change crop variety	Change crop type	Irrigate	Irrigate more	Change livestock to crop prod
Ln agric income	0.150**	0.293***	0.256***	0.266***	0.217**
	(2.65)	(36.04)	(16.40)	(19.50)	(2.94)
N	703	703	703	703	668

Panel B: For the richest household

	Change crop variety	Change crop type	Irrigate	Irrigate more	Change livestock to crop prod
Ln agric income	-0.285*	-0.397***	0.320***	0.376***	-0.149
	(-2.41)	(-17.89)	(5.93)	(10.03)	(-0.60)
N	179	179	179	179	100

Panel C: For the most educated household

	Change crop variety		Irrigate	Irrigate more	Change livestock to crop prod
Ln agric income	0.265***		0.246***	0.248***	0.0253
	(5.76)		(7.06)	(6.36)	(0.08)
N	141		141	141	57

Panel D: For the largest household

	Change crop variety	Change crop type	Irrigate	Irrigate more	Change livestock to crop prod
Ln agric income	0.0196	0.266***	0.221***	0.239***	0.0468
	(0.26)	(20.70)	(8.50)	(12.44)	(0.22)
N	237	237	237	237	181

Panel E: For households that have access to electricity

	Change crop variety	Change crop type	Irrigate	Irrigate more
Ln agric income	-0.158	-0.296***	0.147**	0.174***
	(-1.86)	(-24.47)	(3.01)	(4.04)
N	334	334	334	334

[1] t statistics in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Controls : gender, age, education, muslim, occupation1, occupation2, electricity, assets.

Estimates available upon request